Lewis Buckley Stillwell

TRANSACTIONS
OF THE
AMERICAN INSTITUTE
OF
ELECTRICAL ENGINEERS

JANUARY 1 TO MAY 16, 1910

VOL. XXIX, PART I

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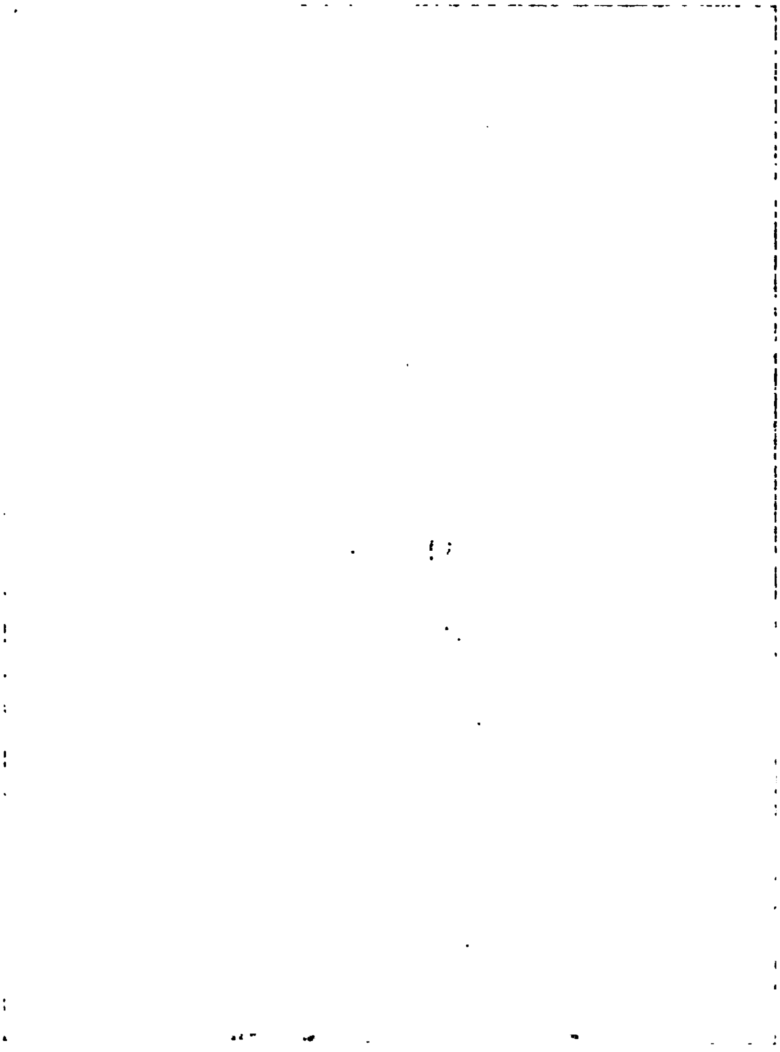

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A paper presented before the Philadelphia Section of the American Institute of Electrical Engineers, on January 10, 1910.

THE 1200-VOLT RAILROAD—A STUDY OF ITS VALUE FOR INTERURBAN RAILWAYS

BY CHARLES E. EVELETH

The various 1200-volt interurban railways have now been operating a sufficient length of time to prove that there are no material objections to the use of this voltage on passenger cars. The nature of such minor difficulties as have been experienced have been such that their correction has required only detail changes of design which have been readily made. The important items of reliability and low cost of upkeep have met all expectations.

A single statement regarding the motors may explain the reason for this successful performance. On the Pittsburg, Harmony, Butler & Newcastle line where the service is unusually severe on account of grades and curves, a considerable number of the brushes originally shipped in the motor brush holders are still in service, though many motors have now run over 150,000 car miles, and the wear on the commutators is hardly perceptible. It can be stated from the performance of the 1200-volt system that nothing is jeopardized by the adoption of this system, and such economies as are possible by its use can generally be obtained without offsetting disadvantages.

We may therefore assume that the 1200-volt system has "found itself" and a new system is thereby made available for consideration when studying the requirements of new railroads or extensions to existing systems. If desired, the cars may be run at equal efficiency and speed over tracks equipped for 600 volts.

This being the case, the question naturally arises, what gains may be expected from the use of this higher voltage?

The primary object of any railway is to pay dividends and these are limited by the amount of the receipts which must be expended for two items,—fixed charges, and operation. The most inflexible item is fixed charges. This works twenty-four hours a day whether business is good or bad and never gives up any ground once gained. Its only vulnerable point is the first cost of the railway. The 1200-volt system now offers a practical way of reducing the first cost of electrification through the material saving in substations and secondary distribution conductors. This gain becomes a permanent asset of the railroad, making a definite decrease in the fixed charges at a place which cannot be reached in any way except by raising the voltage.

INTERURBAN RAILWAY SYSTEMS.
GENERAL DESCRIPTION.
SINGLE TRACK.
LENGTH OF ROAD—100 MILES.
CARS EVERY HOUR IN EACH DIRECTION.

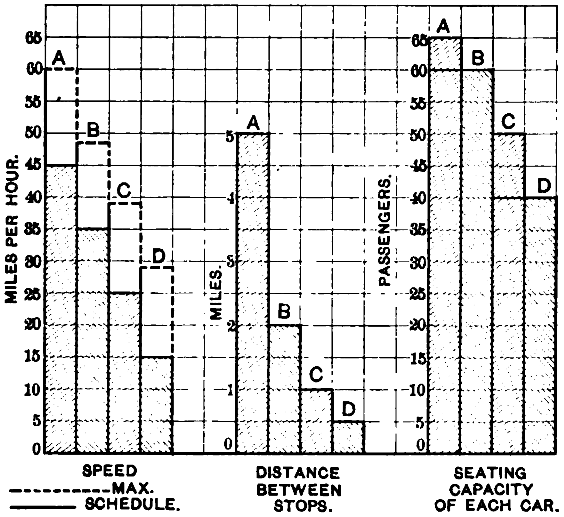

Fig. 1

The other item is cost of operation. This item may be controlled to a certain extent by the personal ability of the manager, but having once selected the type and size of cars and the voltage of the system it is practically impossible for him to materially change the cost of getting power to his cars, which depends upon the distribution efficiency of his system and the cost of substation operation. The 1200-volt system decreases the cost of getting power to the cars in two ways; first, reducing the number of substations, and second, increasing the substation efficiency by improving the load factor. This latter result may seem unreasonable at first thought until one considers upon what grounds substation units are selected. They are not selected on the basis of heating, for it is probable that there are few interurban stations in this country running with 50 per cent machine load factor, and the average is certainly below 30 per cent for ordinary interurban conditions. It is generally necessary for the station unit to commutate within its overload guarantees, the maximum starting current of at least two trains starting simultaneously. As the running current of a train is about one third of the starting current, and there are considerable periods during coasting and stops when the train is taking no current, and, furthermore, there are generally times when no trains are on the section fed by an individual substation, the low load factor can readily be accounted for. If then the units are selected for peak conditions the capacity of each station will remain constant independent of the number of stations. It is evident when decreasing the number of substations, that is, increasing the track mileage fed by each station, that the average load will be greater and the substation load factor and efficiency improved. The total substation cost and operation will be decreased practically in proportion to the reduction in the number of stations. These advantages are net advantages since they are, in the 1200-volt system, obtained without being offset by extraordinary car equipment maintenance.

Any railway is complex, but there are certain fundamental differences, namely track mileage, size of trains units, and schedule speeds, which have a definite influence on the cost of electrification. In order to obtain an idea of the advantages which may be expected with the use of 1200 volts as contrasted with 600 volts, let us consider some concrete applications to different classes of conditions from which we may be able to draw some general conclusions.

DESCRIPTION OF RAILROADS

	A.	B.	C.	D.
Length of road, miles, all single track	100	100	100	100
Time between trains each direction, minutes	60	60	60	60
Cars per train	3	1	1	1
Seating capacity per car	65	60	50	40
Distance between stops, miles	5	2	1	0.5
Schedule speed, miles per hour	45	35	25	15
Maximum speeds, miles per hour	60	48	38	28
Car-miles per day	9000	3000	3000	3000

In making these comparisons conservative values have been used, such as low substation costs, high cost of 1200-volt car maintenance, etc. so that the results will be conservative and the advantage rather less than might actually be achieved.

It will be seen that the roads vary greatly in conditions, from the heavy railroad conditions of *A*, through heavy interurban *B*, light interurban *C*, and very light traffic *D*. In fact, the cars of *D* will be no heavier than many city cars. See also Fig. 1.

Cars. Based upon the requirements, the following data may be considered reasonable for the cars.

CARS
GENERAL DATA

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Number	60	60	15	15	17	17	20	20
Cost each	$15,000	$13,000	$11,000	$10,000	$8,000	$7,000	$5,000	$4,500
Weight, tons	46.5	45	36	35	27	26	18	17
Amperes, starting	1200	2200	280	520	200	370	120	220
" running	300	574	94	174	66	124	40	74
Kw-hr. per train mile	11.16	10.8	2.88	2.80	1.89	1.82	1.08	1.02
Car-miles per day per car	150	150	200	200	176	176	150	150

It will be noticed that the power consumption which is " at the train " is slightly more for the 1200-volt cars on account of the greater weight of their equipments.

CARS
COST OF MAINTENANCE
Cents Per Car-Mile

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Mechanical	1.25	1.25	1.00	1.00	.90	.90	.75	.75
Electrical	.99	.90	.77	.70	.60	.55	.55	.50
Total	2.24	2.15	1.77	1.70	1.50	1.45	1.30	1.25
Yearly cost	$73,500	$70,500	$19,400	$18,600	$16,400	$17,000	$14,300	$13,700

In this estimate, 10 per cent greater maintenance is allowed for the up-keep of the 1200-volt electrical equipment. As a matter of fact up to the present time no noticeable increase has been observed.

Substations. In selecting the size of synchronous converter units for the stations they are in this case based on a maximum momentary demand of two cars starting simultaneously, except in the case of system *A* where the size is based on the demand of one train starting and one train running. In each case a reasonable margin is allowed for occasional additional service.

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Number of substations.....	6	14	4	9	3	6	3	5
Est. momentary demand, kw...	1,440	1,320	336	312	280	222	192	154
Number of units........	2	2	2	2	2	2	2	2
Size of each unit........	1,000	1,000	300	300	200	200	150	150
Cost of station, each...	$60,000	$56,000	$26,400	$24,000	$20,200	$18,400	$17,100	$15,600

The number of substations is dependent upon the maximum economical spacing, considered in conjunction with the cost of feeder copper and the allowable line drop with the assumed conditions of load. In each case it will be found that the addition of another substation to the number given in the data will not save its equivalent in cost of feeder copper. This brings up the question as to what may be considered equivalent feeder copper. The table below gives these equivalents.

EQUIVALANT FEEDER COPPER TO REPLACE ONE SUBSTATION

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Annual cost of labor and material........	$2,500	$2,500	$1,900	$1,900	$1,800	$1,800	$1,700	$1,700
Fixed charges........								
Interest........ 5%								
Depreciation.... 3%								
Taxes and insurance......... 3%								
Total........11%	6,600	6,160	2,904	2 640	2,222	2,024	1,881	1,716
Total....	$9,100	8,760	4,804	4,540	4,022	3,824	3,581	3,416
For feeder copper the interest, etc., will be approx. 8½ per cent								
Investment in feeder copper equivalent to each substa. will be..	$110,000	106,000	$58,300	$55,000	$38,800	$46,400	$43,400	$41,400

The acutal amount should be somewhat greater than these values, for with the addition of a substation there is a reduction in load factor on each substation, lowering the distribution efficiency. A curve is given, Fig. 2, to show the change in substation efficiency with change in the load factor on individual synchronous converters. This curve is for a station having 150-kw. to 300-kw. units. For the larger machines the curve would be about two per cent higher.

It will be seen that the investment in feeder copper which must be saved to justify an additional substation will be approximately 2½ times the cost of the substation.

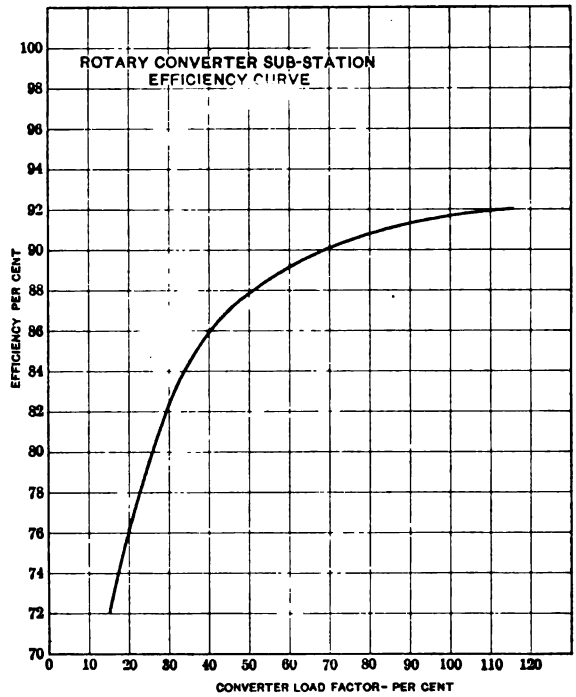

Fig. 2

An examination of the diagram, Fig. 3, showing the "location of substations" will give a fairly comprehensive view of the railroad lay out and the location of the cars at any hour.

Primary Distribution. This in each case will be the same for either system, except that the total length of the 600-volt transmission line will be slightly longer on account of the greater distance between the terminal stations. A flat price of $3,500 per mile of transmission line is taken for system *A*, and $1,000 per mile for system *B*, *C*, and *D*.

It will make practically no difference where the power is fed to the high tension system. For the sake of simplicity it is assumed that power is purchased and delivered to the power house step-up transformers at one cent per kw-hr.

Secondary Distribution. Track. For railroad *A*, 85-lb. rail is assumed. This has a resistance per mile, including bonding, of approximately 0.033 ohm. The other roads use 70-lb. rail having a resistance per mile of 0.04 ohm. A third-rail equivalent to a 1,000,000-cir-mil. feeder is assumed for *A*, and No. 0000 trolley wire for the other roads. The values used in obtaining the feeder copper necessary are based on a maximum momentary drop of 250 volts for the 600-volt systems and 500 volts for the 1200-volt systems. This will give an average secondary distribution efficiency of approximately 90 per cent.

LOCATION OF SUB-STATIONS

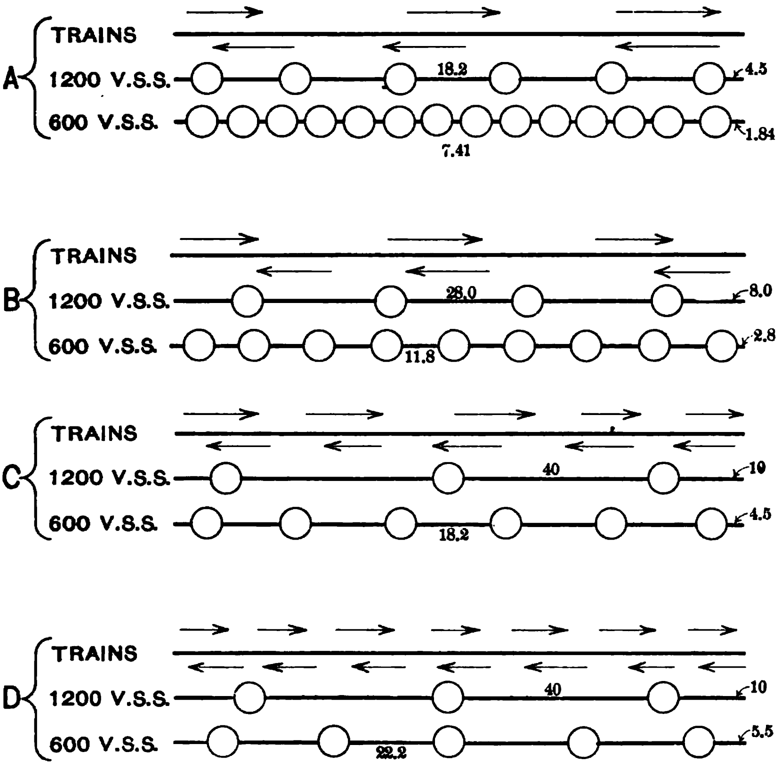

FIG. 3

FEEDER COPPER REQUIREMENTS

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Stub End Calculations:								
Trains starting and running.	1–S	1–S	1–S	1S	1S–1R	1–S	1–S	1-S
Total current, amperes	1200	2200	280	520	266	370	140	220
Length stub end miles,	4.5	1.85	8	28	10	45	10	5.5
Size copper required. .	None	1,000,000	No. 000	No. 0000	No. 00	300,000	No. 0	No. 00
Between Substations:								
Trains starting and running midway. . .	1S	1S	1S–1R	1S	1S–1R	1S	1S–1R	1S
Amperes.	1200	2200	374	520	266	370	160	220
Dist. between substations, miles.	18.2	7.41	2.08	11.8	40	18.2	40	22.2
Size copper required. .	None	1,000,000	No. 0	No. 0000	No. 00	300,000	No. 0	No. 00
Total cost of feeder installed.		290,000	53,200	80,000	60,000	100,000	50,000	60,000

FEEDER COPPER—COST PER MILE INSTALLED

Size.	No. 0	No. 00	No. 000	No. 0000	300,000	1,000,000
Cost.	$500	$600	$700	$800	$1,000	$2,900

For track bonding $450 per mile has been taken for *A* and $400 per mile for *B*, *C* and *D*.

POWER CONSUMPTION

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Kw-hr. per day at cars.	$33,500	$32,400	$8,640	$8.400	$5,670	$5,470	$3,240	$3,060
Converter load factor	0.31	0.13	0.44	0.19	0.58	0.28	0.45	0.25
Efficiency (average)								
Substation.	0.836	0.69	0.87	0.76	0.89	0.823	0.873	0.803
Secondary distribution.	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Transmission.	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Step-up transformers.	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97
Combined.	0.722	0.595	0.745	0.632	0.761	0.705	0.748	0.688
Kw-hr. per day purchased).	46,500	54,500	11,600	13,300	7,450	7,750	4,330	4,440
Cost per year at one cent per kw-hr. . .	$169,000	$199,000	$42.400	$48,600	$27,200	$28,200	$15,800	$16.200

SUMMARY OF COSTS
ELECTRIFICATION MATERIAL

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Cars	$960,000	$840,000	$172,500	$150,000	$136,000	$119,000	$100,000	$90,000
Substations	360,000	784,000	106,000	216,000	61,000	110,000	51,000	78,000
Transmission	318,000	340,000	84,000	94,000	80,000	91,000	80,000	88,000
Trolley*	625,000	600,000	160,000	160,000	160,000	150,000	160,000	150,000
Feeder	None	300,000	53,000	80,000	60,000	100,000	50,000	60,000
Bonding	43,000	43,000	40,000	40,000	40,000	40,000	40,000	40,000
	2,308,000	2,909,000	615,500	730,000	537,000	610,000	481,000	506,000
Track, roadway, etc.	2,500,000	2,500,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000
Total	$4,808,000	$5,409,000	$2,415,500	$2,530,000	$2,337,000	$2,410,000	$2,281.000	$2,506,000
Note:								
Substation buildings	45,000	105,000	20,000	45,000	14,000	29,000	14,000	23,000
Substation electric equipment	315,000	679,000	86,000	171,000	47,000	81,000	37,000	55,000
Cars and substations	1,320,000	1,624,000	278,500	386,000	197,000	229,000	151,000	69,000
Distribution materials	998,000	1,285,000	337,000	364,000	340,000	381,000	330,000	338,000

* Third rail used on *A*.

FIXED CHARGES]
ELECTRIFICATION MATERIAL

	Life years	Annuity 5 per cent	A		B		C		D	
			1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Depreciation Cars	15	46.34	$44,500	$39,000	$8,000	$7,000	$6,300	$5,500	$4,600	$4,200
Substation buildings	30	15.05	700	1,600	300	700	200	400	200	300
Substation apparatus	20	30.24	9,500	20,500	2,600	5,200	1,400	2,400	1,100	1,700
Transmission	20	30.24	9,600	10,300	2,500	2,800	2,400	2,700	2,400	2,700
Trolley	12	*62.83	18,900	18,100	10,100	9,400	10,100	9,400	10,100	9,400
Feeders	20	30.24	—	9,100	1,600	2,400	1,800	3,000	1,500	1,800
Bonding	10	79.50	3,600	3,600	3,200	3,200	3,200	3,200	3,200	3,200
			86,800	102,200	28,300	30,700	25,400	26,600	23,100	23,300
Interest: 5 per cent on total cost of electrification material			116,000	145,000	31,000	36,000	27,000	30,000	24,000	2,500
Taxes: 1½ per cent of total cost of electrification material			36,400	43,700	9,200	11,000	8,000	9,100	7,200	7,600
Insurance: 1½ per cent of cost of rolling stock and substations			19,800	24,200	4,200	5,500	2,000	3,400	2,200	2,500
Total fixed charges			259,000	315,100	72,700	83,200	62,400	69,100	56,500	58,400

* Third-rail depreciation based on 20 years life.

COST OF OPERATION AND MAINTENANCE

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
Transmission........................	$9,000	$9,500	$3,000	$3,300	$2,800	$3,200	$2,800	$3,100
Trolley and feeders..................	15,000	15,000	9,000	9,000	9,000	9,000	9,000	9,000
Rolling stock........................	73,500	70,500	19,500	18,500	16,500	17,000	14,500	15,000
Substations.........................	15,000	35,000	7,600	17,000	5,500	11,000	5,000	8,500
Cost of power.......................	169,000	199,000	42,400	48,600	27,200	28,200	15,800	16,200
	281,500	329,000	81,500	97,100	61,000	68,400	47,100	50,800
Total operation and maintenance of items listed......................	282,000	329,000	82,000	97,000	61,000	68,000	47,000	51,000
Statistics indicate that the items listed on 600-volt roads constitute approximately 44 per cent of the total operating cost. Based upon this there should be added to each of the above.	421,000	421,000	123,000	123,000	87,000	87,000	65,000	65,000
Total yearly cost of operation and maintenance of 3,285,000 car-miles per year for *A* and 1,095,000 car-miles per year for *B*, *C* and *D*....................	703,000	750,000	205,000	220,000	148,000	155,000	112,000	116,000

COMPARISON OF SYSTEMS

	A		B		C		D	
	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt	1200 volt	600 volt
I.—First Cost:								
Track, roadway, etc.	$2,500,000	$2,500,000	$1,800,000	$1,800,000	$1,800,000	$1,800,000	$1,800,000	$1,800,000
Electrification material								
Car equipments	960,000	840,000	172,500	150,000	136,000	119,000	100,000	90,000
Substations	360,000	784,000	106,000	216,000	61,000	110,000	51,000	78,000
Distribution	988,000	1,285,000	337,000	364,000	340,000	381,000	330,000	338,000
Total	$4,808,000	$5,409,000	$2,415,500	$2,530,000	$2,337,000	$2,410,000	$2,281,000	$2,303,000
In favor of 1200 volts	—	601,000	—	114,500	—	73,000	—	26,000
II.—Fixed Charges:								
Track, roadway, etc., 7 per cent	175,000	175,000	126,000	126,000	126,000	126,000	126,000	126,000
Electrification material	259,000	315,000	73,000	83,000	62,000	69,000	56,500	58,500
Total	434,000	490,000	209,000	209,000	188,000	195,000	182,500	184,500
In favor of 1200 volts	—	56,000	—	10,000	—	7,000	—	2,000
III.—Operation and Maintenance:								
Miscellaneous	421,000	421,000	123,000	123,000	87,000	87,000	65,000	65,000
Electrical	282,000	329,000	82,000	97,000	61,000	68,000	47,000	31,000
Total	703,000	750,000	205,000	220,000	148,000	155,000	112,000	116,000
In favor of 1200 volts	—	47,000	—	15,000	—	7,000	—	4,000
IV.—Annual Cost II+ III	$1,137,000	1,240,000	414,000	429,000	336,000	350,000	294,500	300,500
In favor of 1200 volts	—	103,000	—	2,500	—	14,000	—	6,000
V.—Revenue:								
Additional receipts per car-mile necessary to pay additional cost of operation, etc., for 600 volts	—	3.1c.	—	2.28c.	—	1.28c.	—	0.55c.

Note.—3,285,000 car-miles per year for *A*.
1,095,000 car-miles per year for *B*, *C*, and *D*.

COMPARISON OF SYSTEMS

	600 volt per cent	A 1200 volt per cent	B 1200 volt per cent	C 1200 volt per cent	D 1200 volt per cent
I.—First Cost:					
All electrification material..........	100	79.4	85.5	88.0	95.0
II.—Fixed Charges:					
All electrification material..........	100	82.3	87.3	90.0	96.5
III.—Operation and Maintenance:					
All electrification material..........	100	85.8	84.5	89.9	92.0
IV.—Annual Cost II+III:					
All electrification material..........	100	84.0	86.0	90.0	94.0

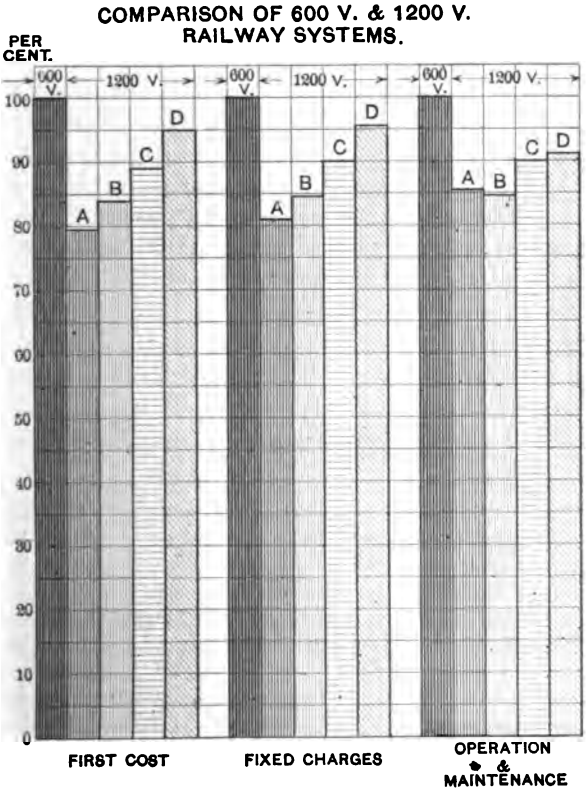

FIG. 4

In electrification material there is included under "first cost" and "fixed charges," (I and II) cars and car equipments, substations complete, transmission line, trolley or third rail, low tension feeders and track bonding.

Under "operation and maintenance" (III) of electrification material there is included rolling stock, substations, trolley, feeders and track bonding, and cost of power, *i. e.* all items which are affected by choice of system. Platform charges, general expenses, etc, common to both systems are not included.

On examination of these results, which are based on conservative figures on account of the relative newness of the 1200-volt system, it is apparent that the higher voltage effects economies at points that can only be reached by a change more fundamental than is possible with the lower voltage.

The saving of 1½ to 2 cents per car mile will permit a very material increase in dividends.

It is further clear that the relative value of the higher voltage increases as the demand for power increases, and that below a certain size of equipment there would be practically no justification for the adoption of the higher voltage. Results are shown for convenience in graphical form Fig. 4, as this indicates clearly how the economies change with the change in the system.

The place where the application of the 1200-volt system may be looked for in the immediate future is that field of interurban railroading where it has already made its successful start.

Conclusion. In conclusion it appears that a conservative estimate of the economy obtained by a 1200-volt system as compared with the 600-volt system in the elements of a railroad which are effected by the choice of system, that is, all of the electrification material, would place these savings approximately as follows:

1. First cost	10 to 20 per cent
2. Fixed charges	10 to 18 per cent
3. Operation and maintenance	10 to 15 per cent

Furthermore, experience has shown that

4. The 1200-volt system is just as reliable as the 600-volt system.

5. Substations may be operated from a system of any commercial frequency.

6. In specific cases the saving has been found materially greater than indicated in conclusions 1, 2 and 3, notably where the length of road is such that no substations are required for the 1200-volt system while substations are required for the 600-volt system. In some insatnces the savings have been as great as 25 or 30 per cent in the electrification material.

DISCUSSION ON "THE TWELVE HUNDRED-VOLT DIRECT-CURRENT RAILWAY SYSTEM." PHILADELPHIA, JANUARY 10, 1910

W. S. Murray: I want to speak of the New York New Haven and Hartford system, because in reviewing the paper tonight, I find that Mr. Eveleth has not mentioned, throughout all of his interesting lines, the single-phase system.

It is to be noted that the discussion is strictly direct current vs. direct current, and not direct current vs. alternating current. I believe there is a zone which is a function of traffic or distance, not the combination of both, but the one or the other, which requires the use of a system as brought out in Mr. Eveleth's paper.

I should have been very much interested, if, in the classification that Mr. Eveleth has used (*A*, *B*, *C*, and *D*), a third system, the single-phase, had been introduced for comparison.

I want to try to acquaint you with the conditions that exist on the New Haven road in comparison with the conditions cited. For example in *A* the heaviest conditions are used. Let us assume the cars weigh 60 tons apiece, or say 80 tons. Three of them will total between 180 and 240 tons for the train. Now with the New Haven, our trains run up to a maximum of 800 tons. Our minimum weight of trains is over the maximum *A* conditions.

I cannot pay too high a compliment to Mr. Eveleth for the earnest effort his paper indicates. I would like to say this, however, that I think it is slightly more academic than would be the case if he had actual field data from which to make the compilations. The 1200-volt system, of course, has not been sufficiently long in operation to afford comparison, but the framework and the synopsis of the whole scheme is so well arranged that the highest tribute is due Mr. Eveleth for the manner in which he has put it together; and in the future, when electrical engineers are collecting such data, I can think of no better arrangement than the one which Mr. Eveleth has laid before us.

One thing that struck me as important is the question of motor slip on the 1200-volt system. It is quite evident that eventually this system will include the 1200-volt motor itself, but it is the combination of the 600-volt motor and 1200-volt line that is included in the paper tonight. Thus, in the event of the motor slipping it does not eliminate the bad effect that would result in the collection of the full voltage across the terminals of the motor, and while low motor speed would take care of mechanical difficulties, the slip would inevitably lead to commutator flash-overs of a serious nature.

Reference is made to the conditions of a 250-volt drop in a 500-volt line, or a 500-volt drop in a 1200-volt line. Some electrical engineer has paraphrased an old saying, which now reads: "It is voltage that makes the mare go." In order to find out the drop in the New Haven system during the rush hours of the morning and afternoon, voltmeter readings were taken at Woodlawn, 18 miles from the power station. The voltage never fell below 9,800.

Another point in this paper is that the calculations are based on theoretical assumptions of trains taking current in the vicinity of substations. Upon the basis of this assumption many of the financial considerations of the paper are involved, and one can see in an instant that this is the crux of the whole situation. If I had attempted to write the paper, I should have made the same assumption. While it seems perfectly reasonable to make these assumptions, at the same time this brings out the academic feature to which I have referred, and emphasizes the fact that we lack the data of actual 1200-volt practice.

One point I want to make tonight, more than anything else, is that electricity can certainly wear a great many different suits of clothes. I think the 1200-volt system has come to stay, and that it is applicable to certain classes of interurban service. The first reason, to me, for its adaptability to these conditions is, that it does away with something that has been a nightmare to us, particularly on the New Haven road. In nearly every city there is and will be direct current. One of the earliest mistakes made with the single-phase was the attempt to combine it with direct current. I would like nothing more than to be able to eliminate direct current from our system. I think the best reasons for the existence of the 1200-volt system are the excellent opportunity it affords for the reduction or elimination of substations in rural territory, and the facility with which motors operating on lines of this voltage can be made to accommodate themselves to equally efficient operation on 600-volt city lines, bringing into sharp contrast the obnoxious arrangement of the combined alternating and direct current equipment.

Dr. Hutchinson has recently given us an interesting paper in which he has cited the true conditions for the application of a three-phase system. Just as the 1200-volt system will be applicable to interurban roads, conditions will likewise be met in another case, where the three-phase must step in as the preferred system. That system which figures the least first cost and operating expense must rule. That is one thing I think we ought to realize, namely, that, if we make a success of something, it does not necessarily follow that it applies to everything else.

Now I want to acquaint you a little more thoroughly with the New York, New Haven & Hartford conditions. First, it is a trunk line proposition; 60 miles of four-track road. This mileage covered the primary consideration, with its possible extension to Boston, the total distance of which would then be 220 miles. As I have stated before, our passenger train weights reach a maximum of 800 tons, and the service between New Haven and New York would require as many as 175 trains daily. On the freight side of the schedule, trains of 1500 tons are common;

the average being in the neighborhood of 1200 tons, and as many as 80 of these trains are in daily operation between New Haven and New York. In reviewing these conditions it is clear that nothing under the classification of *A*, *B*, *C* and *D* even approximates them.

The history of alternating current shows that it has steadily replaced direct current wherever power and distance are involved. What greater field for the application of this agency exists, than an 800-ton Pullman train which may be seen standing in the Grand Central station, with sign boards marked " Boston." As an electrical engineer, is not your first mental conception of this train associated with power and distance?

One of the points in Mr. Eveleth's paper that has particularly interested me, is the gradual betterment in first cost and operating expenses by the use of a 1200-volt system in preference to the 600-volt, as it passes from the conditions imposed by city requirements to light interurban traffic, and finally to those conditions required in heavy interurban traffic. This suggests to me the system that comes into play after the 1200-volt system has done its best. It is fair to assume that 1200 volts on the direct-current motor will not be exceeded. Thus, with the motors in series it is possible to establish a 2400-volt line. This may widen the field of application of the 1200-volt system for interurban work, but its competition under trunk line conditions, such as obtain on the New Haven road, disappears when compared with single-phase current with 11,000 volts overhead. There is nothing to prevent a higher voltage than 11,000. It is not impossible to conceive of 22,000-volt transcontinental lines for the future. The increase of voltage by direct-current system is limited on account of the impossible condition imposed of increasing the voltage of the motor to an impracticable point, while in the case of the single-phase system the very antithesis of this condition holds, in that it is perfectly possible to raise the line voltage and reduce the motor voltage even lower than that at present used.

In connection with a single-phase system, I wish to say that I thoroughly believe its principal application is relegated to just one thing, trunk line traffic. I do not think, except for isolated branch or interurban lines that come within the zone of power supply from a trunk line system, that it is applicable to interurban or city lines, but I believe it is the only system today which can produce the economies that a railroad president and his board of directors would listen to, in the matter of steam road electrification.

Now a word as to why I believe this. One of the greatest and most unproductive mileages of steam lines in the eastern territory consists of yards, sidings and branch lines. In such territory as is involved by our Atlantic coast lines, let us say between Boston, and, for the present, Washington, think of the innumerable yards that must be electrified in order to handle freight by electricity. The greatest economy can only be obtained by using high voltage power. Mr. Stillwell compiled some very interesting figures in regard to the efficiency of electricity for steam railroad traction. Using some twenty steam locomotives over a long period of test we have been able to corroborate these figures, and establish the ratio of 1 to 2, for coal burned in electric vs. steam traction, with the density of traffic, for instance, such as exists on the New Haven road. It is unquestionably true that if these large areas are to be electrified it will be impossible on a direct-current basis to put up a sufficient amount of copper to handle with proper economy the requirements in the yards for switch and road engine work. We must go to the high-voltage low-priced conductor. The use of the third-rail is prohibitive, for two reasons; first, it is dangerous; and second, the costs involved are on a lineal basis; that is to say, it may be feasible to lay down a main line third rail, but in the case of yards it fails in comparison with the economies that can be effected by the overhead conductor. The cost of the overhead system in yards has been reduced to about one half, or perhaps 35 per cent, of the cost of main line electrification, and in this way these large unproductive areas may be taken care of.

L. B. Stillwell: I should like to point out briefly certain general considerations which engineers should keep in mind when they have occasion to deal with this problem of selecting a system for the electrical equipment of interurban or other railway lines.

While the problem presents itself in each instance as a question of selection of a system to meet certain definite requirements, a correct solution must take into account certain general considerations which at first sight are not obviously included in the local problem.

We have in the United States something like 220,000 miles of railway lines operated by steam. We have in our cities and towns many thousands of miles of track used by electrically-driven equipment and practically all of this equipment is operated by direct current at a potential of from 500 to 600 volts.

Outside our cities, great progress has been made in supplementing transportation facilities by what are generally called interurban railways. In Illinois, Indiana and Ohio, approximately 25 per cent of the aggregate steam railroad mileage is today paralleled by these interurban electric lines. These for the most part are operated by the direct-current system at 600 volts, but a few are using the single-phase alternating-current system and a few others recently have been equipped with 1200-volt direct-current apparatus.

Several of the great steam railroad companies recently have expended large sums of money in equipping certain of their terminals in large cities with electric power and at least one (the Great Northern Railroad) is using electricity to operate its trains on a short section of a mountain division where special difficulties imposed by tunnel and grade had to be met.

It requires no argument to prove that the time has arrived in the application of electric motive power to transportation when special solutions adapted to specific local problems should be avoided unless they are in line with general tendencies; in other words, engineers investing millions of other peoples' money are bound to direct these expenditures, so far as practicable, along lines which recognize the natural and inevitable tendency in railroad work to standardize everything essential to interchange of traffic.

Mr. Eveleth's paper admirably compares the 1200-volt and the 600-volt direct-current systems in the field of interurban transportation and, within the limits of the problem which he considers, the advantages of the 1200-volt system are manifest. Broadly speaking, his paper presents figures which show that the higher voltage possesses advantages which in certain kinds of service are more than an offset to its disadvantages.

It is an obvious and fair deduction that the possibilities and limitations of voltages still higher must be carefully considered. A comparison of the 1200-volt direct-current system with a 10,000-volt single-phase or three-phase alternating-current system, as applied to the operation of heavy passenger and freight trains such as are operated by the steam railroads of the country, would show advantages for the latter analagous to those which the 1200-volt system possesses when compared with the 600-volt system in the class of service which Mr. Eveleth considers.

There are two methods by which electric railway service outside the zone of natural application of the 600-volt system can be standardized with respect to those things which are essential to interchange of rolling stock. One is the method which Germany has adopted. Essentially it consists in (1) careful study by a competent commission of the broad problem of railway electrification; (2) selection of that system which present knowledge points to as best adapted to a general solution; and (3) concentration of effort in perfecting the details of a system selected.

The other is the method which thus far we are trusting to in America. This method assumes that each specific problem of electrification is to be considered independently of present or future relations. It ignores the obvious fact that the horizon of present " zones of electrification " is sure to expand in the near future and that these horizons in many instances are certain to overlap before the expiration of a proper period of amortization of the capital invested in the apparatus selected. It trusts to the future to find a method of writing off whatever capital may be wasted by reason of short-sighted special solutions, secure apparently in the conviction that the owners of the property will find a method, and also equally secure in the belief that the premature scrap heap is not a source of loss to the manufacturer of electrical apparatus whatever it may represent to the purchaser.

One question which engineers should keep carefully in mind is this: What part is the 1200-volt system destined to play in the future extension of the application of electric motive power to transportation.

Germany has adopted the single-phase system at 15 cycles and 10,000 volts.

In America, opinion is divided. We are using as substitutes for steam locomotives the single-phase alternating-current system at 25 cycles and 11,000 volts, the three-phase alternating-current system at 25 cycles and 6600 volts, the direct-current system at 600 volts; and in each case electric locomotives more powerful than the heavy steam locomotives which they displaced are in effective and satisfactory service. The consensus of opinion now is in favor of 15 cycles rather than 25 cycles for single-phase working and, as Mr. Eveleth has shown, the 1200-volt direct-current system possesses substantial advantages as compared with the 600 volt direct-current system for work outside city boundaries. The difficulty which electricity faces, therefore, in challenging the superiority of steam in the field of transportation is not poverty of resources but embarrassment of riches.

Two years ago, Mr. H. St. Clair Putnam and the speaker presented a paper before the Institute in which we advocated the early standardization of those things essential to interchange of traffic, *e. g.*, the location of third rail, the frequency used in alternating-current systems, and the height of the overhead trolley. The cross fire under which we found ourselves was unusually animated and vigorous. Since that time, however, some progress has been made. The engineers of both the leading American companies manufacturing electrical apparatus for traction purposes agree that where single-phase apparatus is used the frequency should be 15 cycles per second. Probably it is safe to assume also that the height of the trolley wire above track in the case of single-phase equipment has been practically agreed upon; at any rate, the New Haven engineers have selected a height which appears to meet all requirements and any engineer who may adopt in future a different location will find it necessary to justify his choice by very strong reasons.

In the cities we have the 600-volt direct-current system. Few will dispute that if we were today called upon to electrify any very large proportion of the existing steam railroads of the United States the 15-cycle single-phase alternating-current system would be chosen. Undoubtedly the use of other systems, such as the 1200-volt direct-current system, under conditions and for certain kinds of service intermediate between the trolley service of the city and trunk line service on our great railways, is justified in certain cases, but the engineer who recognizes tendencies and recalls the rapidity with which the use of electricity has expanded hitherto in the fields which it has entered, will be reluctant to adopt an intermediate system except in cases where his decision rests upon reasons unquestionably controlling.

C .E. Eveleth: You may expect to hear me express an opinion as to whether or not the 1200-volt system would be adequate for the New Haven situation. I do not consider myself in a position to express an opinion at this time. I am not sufficiently familiar with the conditions and have not studied the problem in detail to analyze the various requirements. Without a thorough study of the situation, a guess as to whether 1200-volts would or would not be applicable would be meaningless.

I agree with Mr. Murray's objections to the complications of the combined single-phase and direct-current systems. I heartily agree with Mr. Stillwell in his expression of opinion that we should go slowly about adopting any system that will add complication to a situation already very complicated. Both of these conditions were borne in mind and it was to meet both of these broad and very important considerations that the particular potential of 1200-volts has been selected instead of 1500, 1800 and 2000, any of which would have been applicable for interurban practice. By the use of 1200 volts direct current on the trolley, and motors wound for 600 volts, the car may be operated at the same speed on either 600- or 1200-volt trolleys by connecting the motors all in parallel for 600-volt operation and two in series and two groups in parallel on a 1200-volt section. By exactly doubling the voltage we thus take advantage of the economy of higher voltage with minimum complication of equipment.

One road is now successfully running with motors wound directly for 1200 volts on each commutator. The choice of individual motor voltage is one of the questions which must be considered in any particular case, as they may be wound for either 600 or 1200 volts.

The reason I have gone no further in the comparisons than conditions assumed under *A* is merely that the 1200-volt system is a new arrival and I do not know into what field it may extend. In this connection I am reminded of the answer that Benjamin Franklin gave to some inquirer who had seen the first baloon ascension. The man asked what good it was and Franklin said: " What good is a new born baby?" We cannot tell and we do not know where these things are going to end.

The trend of the future will depend on the operation of what we have, to a very large extent. What has been done in electrification of steam roads is comparatively small. Even in the case of the N. Y. N. H. & H. R. R. it is my understanding that the total cost of electrification is only about 3 per cent of the investment which the New Haven road has made for improvements in its system in the last seven years. Looking at the matter broadly, for the sake of unification we could afford to discard the millions of the present investments in steam road electrification if a commission along the lines that Mr. Stillwell mentioned were sufficiently competent and foresighted to decide on exactly the right system for future development.

Conditions in this country are vastly different from the conditions abroad. The Government here has practically no control over the equipment of railroads. The principal influence there, which is unknown to us, is the question of military transportation which, for flexibility, necessitates a uniform equipment for an entire country.

The choice of a system for heavy traction is quite a different problem from the choice for interurban service. Just as one tool fits one class of work, and another tool fits another class of work so there seems to be at the present time no one system best for all classes of service. I would regret very much to be considered an advocate of any one system. I hope to see the single-phase system ultimately make good because it has been the most promising from its inception on account of the apparent advantages in distribution, simplicity and cost.

A paper presented at the 242d meeting of the American Institute of Electrical Engineers, New York, January 14, 1910.

ON THE SPACE ECONOMY OF THE SINGLE-PHASE SERIES MOTOR

BY WM. S. FRANKLIN AND STANLEY S. SEYFERT

It is not the object of this paper to argue for single-phase alternating-current electrification versus direct-current electrification, nor to argue for the locomotive versus the multiple-unit system of electric propulsion, nor to argue in favor of the axle motor as against the detached motor with side-bar or gear connections. The sole object of the paper is to discuss the question as to the maximum single-phase series motor rating that can be placed within a given space, and indeed the authors approach this question, not on an absolute basis, but on a basis of comparison. Given a well-designed single-phase alternating-current series motor of the usual construction, as represented, for example, by the motors of the present locomotives of the New York, New Haven & Hartford Railroad (and every one who has seen these motors in operation must admit that they represent a splendid achievement on the part of their designer) the question is how great an increase of rating can be realized by certain alterations in the design and by the use of certain new auxiliary devices. As will appear in the sequel, this question admits of a qualitative answer in every particular and of a quantitative answer in several important particulars.

A single-phase series motor differs from a direct-current motor:

1. Because its power-factor is less than unity.
2. Because of greater core losses and because of power loss due to short-circuit currents.
3. Because of a great tendency to spark at the commutator.

From the view-point of the operating engineer, however, these differences may present themselves as a single difference as follows:

(*a*) For a given frequency and rating, satisfactory operation may necessitate a very bulky and expensive motor; or

(*b*) For a given size and rating, satisfactory operation may require the use of a very low frequency; or

(*c*) For a given size, given frequency, and given rating, it may be impossible to realize satisfactory commutation.

Thus it may be said that the disadvantage of the single-phase series motor lies either in its excessive size, or in the necessity of using extremely low frequency, or in the unsatisfactory character of commutation. If, however, we choose a frequency of 25 cycles and set ourselves to meet the condition of satisfactory commutation—and we must meet this condition in any case—then the disadvantages of the single-phase motor reduce themselves solely to the question of size and weight. It is from this point of view that the authors approach the discussion of the single-phase series motor in this paper.

In a recent paper by Messrs. L. B. Stillwell and H. St. Clair Putnam,[*] the single-phase series motor problem was reduced to a question of frequency, and from this point of view they reached the following conclusions:

> * * * * * consideration of the facts now available lead us to conclude that notwithstanding the number and force of the arguments in favor of 25 cycles, a frequency of 15 cycles is preferable and should be adopted for heavy electric traction. The fundamental and, as it would appear, controlling reason which leads to this conclusion is the fact that within given dimensions a materially more powerful, efficient, and generally effective single-phase motor can be constructed for 15-cycle operation than is possible if 25 cycles be selected.
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> In the case of multiple-unit equipment of passenger cars where locomotives are dispensed with and motors carried upon the car trucks, it is very important that the dimensions of motors be reduced to a minimum.
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> * * * * *
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> In the application of single-phase commutating motors to locomotives in general railway service, the minimizing of motor dimensions is perhaps still more important, although in this instance the limitations imposed by the space available are less obvious.

In the following discussion of the possibilities of space economy of the single-phase series motor, frequent reference will be made

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[*] *Transactions of American Institute of Electrical Engineers*, 1907, Vol. XXVI, Part I, pages 31–101.

to the present electrical equipment of the New York, New Haven and Hartford Railroad, and the authors take occasion at this point to express their conviction that the equipment as it stands meets all of the conditions originally specified by the railroad company. This conviction is based in part upon a somewhat intimate personal association of the authors with the engineers of the New York, New Haven and Hartford Railroad, and in part upon the published records of the construction and operation of the equipment. No one claims, however, that the New Haven electrification represents a complete and satisfactory solution of the problem of heavy trunk-line electric traction. Indeed the authors have been assured by the New Haven engineers that the present equipment leaves much to be desired in the way of increase of motor-rating for a given weight of locomotive, especially an increase of tractive effort at starting. Mr. E. H. McHenry, for example, has not hesitated to state his opinion that greater and longer continued tractive effort, especially at starting, must be made possible without increase of weight.

Inasmuch as this paper refers almost wholly to matters of design, it is desirable to give a statement of the conditions which determine the design of a single-phase series motor.

(*a*) To produce a moderately large power-factor, and

(*b*) To reduce the tendency to spark at the brushes.

CONSIDERATION OF POWER-FACTOR

Fig. 1 is the well-known clock diagram in which I represents the current flowing through the motor, E the voltage acting across the motor terminals, $X_f I$ and $R_f I$ the reactance and resistance drops respectively in the field winding, $X_a I$ and $R_a I$ the reactance and resistance drops respectively in the armature and neutralizing windings combined, and E_c the induced counter electromotive force in the armature due to rotation. It is evident from this Fig. that a large power-factor (small value of the angle θ) depends upon a large value of E_c in comparison with $X_f I$ and $X_a I$. Of course $R_f I$ and $R_a I$ should both be as small as possible because they represent energy losses in the windings.

(*a*) In the first place the reactance $X_a I$ of the armature winding may be reduced nearly to zero by the use of the neutralizing winding.

(*b*) In the second place, consider the reactance drop $X_f I$ in the field winding. For a given frequency this is proportional to the product of the number of field turns and the maximum value of the alternating field-flux, exactly as in the case of the primary coil of a transformer. Assuming that we have a motor in which a specified maximum flux is to be produced, then to make the reactance voltage $X_f I$ a minimum, the machine must be designed so that the desired field flux may be produced by the least possible number of field turns. That is to say, the reluctance of the magnetic circuit must be small; or, in other words, the gap-space between the pole faces and the armature core must be short, and the iron of the field magnet and armature core must be operated at a low degree of magnetic saturation.

In the third place, the value of E_c may be increased for a given value of speed and given value of field flux by increasing the number of armature conductors. Therefore the use of a large amount of armature copper is an important feature of the single-phase series motor.

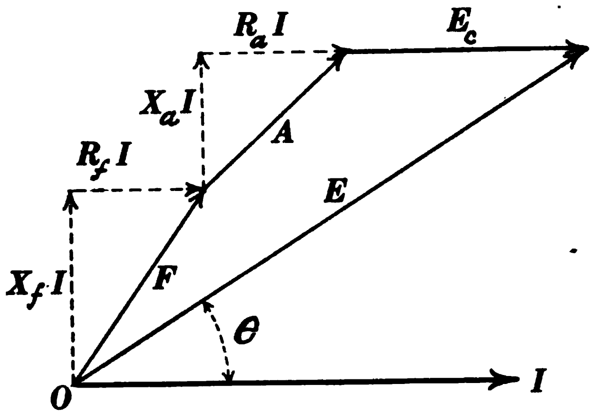

Fig. 1

In the fourth place, suppose we have a single-phase series motor running at given speed with given value (effective) of current and given value (effective or maximum) of field flux. Under these conditions E_c is definite in value (effective), the mechanical power $E_c I$ is definite, and a reduction of the frequency produces a proportional reduction of the reactance voltages $X_f I$ and $X_a I$ without affecting the value of E_c; that is, a reduction of frequency increases the power-factor of the motor. Therefore it is important to use low-frequency alternating current for a single-phase series motor.

CONSIDERATION OF SPARKING

A number of undesirable effects are included in the general term of sparking, as follows:

(*a*) The effects that are present in a direct-current machine and which are due to the necessity of a quick reversal of the current in a given armature section as the terminal bars (commutator bars) of the section pass under a brush; and

(*b*) The effects that are present in the alternating-current machine due to the excessive current which is produced in each short-circuited armature section by the pulsations of the field flux.

The first effect is quite familiar to designing engineers and need not be discussed here.*

The effects of excessive short-circuit currents due to pulsations of field flux are: to heat the armature winding; to heat the commutator; to heat the brushes; and to roughen the commutator by sparking. The remedy for these undesirable effects is of course to prevent excessive short-circuit currents and to shorten their duration as much as possible.

The electromotive force induced in a short-circuited armature section by the pulsating field flux is proportional to the number of turns of wire in the section, proportional to the maximum value reached by the pulsating field flux, and proportional to the frequency. Therefore the short-circuit current may be reduced by reducing the number of turns of wire per armature section—the resistance of the short-circuit not being reduced in proportion to the turns because of the relatively large resistance at the brush contacts—by reducing the maximum value of the pulsating field flux, and by reducing the frequency. It is essential, therefore, in the design of the single-phase series motor to provide for few turns of wire per armature section (many commutator bars); to provide for small field flux per pole (many field poles); and to use alternating current of low frequency.

The duration of short-circuit of an armature section by a brush is proportional to the thickness of the brush, and therefore it is desirable to use thin brushes. If the armature winding is of the simplex type, the necessary thickness of the brushes is determined solely by the necessary area of brush-contact to

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* A good discussion of this subject is given in a paper by W. L. Waters, *Transactions American Institute of Electrical Engineers*, 1904, Vol. XXIII, pages 365-378.

collect the given current. If the winding is of the multiplex type, a brush must never touch fewer than *n* commutator bars, where *n* is the number of constituent windings in the multiplex winding. In the multiplex winding, however, adjacent commutator bars do not form terminals of an armature section, and therefore the mere touching of two bars by a brush does not short circuit an armature section of a multiplex winding.*

SPECIAL DEVICES FOR THE PREVENTION OF SPARKING

The foregoing discussion refers to those general features of design which tend to reduce short-circuit currents in the armature sections of a single-phase series motor. It does not seem to be possible, however, to produce a single-phase series motor that will operate satisfactorily, without the use of special devices for the prevention of excessive short-circuit currents. The simplest device for this purpose is the insertion of a moderate amount of resistance in each commutator lead. This device is well known and need not be further discussed. A number of special inductive devices have also been proposed, and perhaps

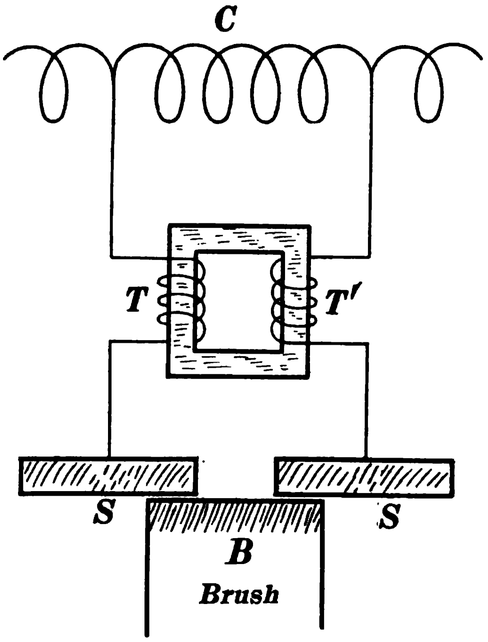

FIG. 2

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* It would be out of place here to discuss in detail the short-circuits which occur in a multiplex winding.

the best of these is the balanced choke-coil arrangement of S. S. Seyfert.

The essential features of the Seyfert arrangement may be seen in Fig. 2 in which C is a section of the armature winding, $S\,S$ are two commutator bars and T and T' are two coils on a small iron core. The two coils T and T' are so connected that their magnetizing actions on the iron core are equal and opposite when equal currents flow into (or out of) the armature winding through both coils; whereas their magnetizing actions work together when current tends to flow out of the armature winding through one coil and into the armature winding through the other coil. The resultant effect is that current can flow into or out of the armature through both coils T and T' without being choked, whereas opposite currents in the coils T and T' (due to the short-circuit current in the section) are greatly choked.

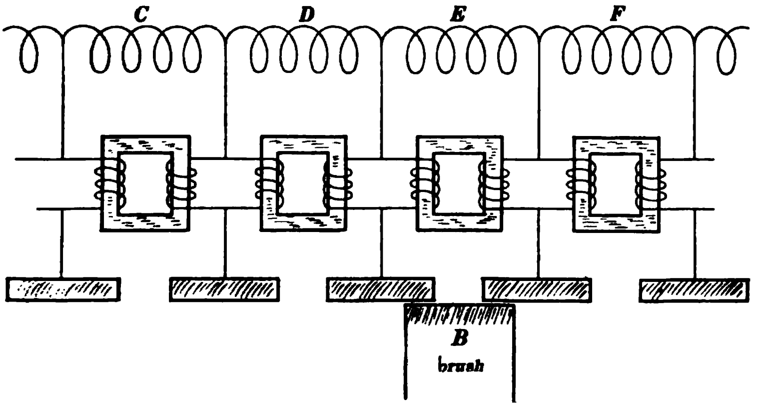

Fig. 3

Complete arrangement of the balanced choke-coils for a simplex armature winding are shown in Figs. 3 and 4. Fig.3 shows what the authors call the single-span connection which requires the use of narrow brushes, and Fig. 4 shows the double-span connection,* which permits of the use of a broad brush.

In order to test the efficacy of the balanced choke-coil arrangement, it was applied to a single-phase series motor which

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* Several distinct arrangements of the double-span connection are possible with a simplex winding, and a greater number of arrangements are possible with a multiplex winding. Ssome of these arrangements are much better than others.

was constructed and tested by Messrs. J. H. Wily and Geo. S. Mervine in 1905.† For the armature of this motor an old 25-h.p., 500-volt, Walker, direct-current, railway motor armature was used without any alterations except the addition of the system of choke-coils. The armature winding was a four-pole simplex wave, and it had three turns per armature section; that is, six turns between adjacent commutator bars. The commutator contained 97 segments. The armature core was 12.5 in. in diameter and 8.5 in. long. Two identical armatures were purchased, one to be used with and the other without balanced choke-coils. Fig. 5 shows the rosette of choke-coils nearly completed, and Fig. 6 exhibits the dimensions of the iron core structure. Each coil contained eight turns of No. 18 B. & S. copper wire. A general view of the completed armature is shown in Fig. 7. The field structure of this experimental motor was made* in the approved form with compensating windings placed in slots in the pole faces.

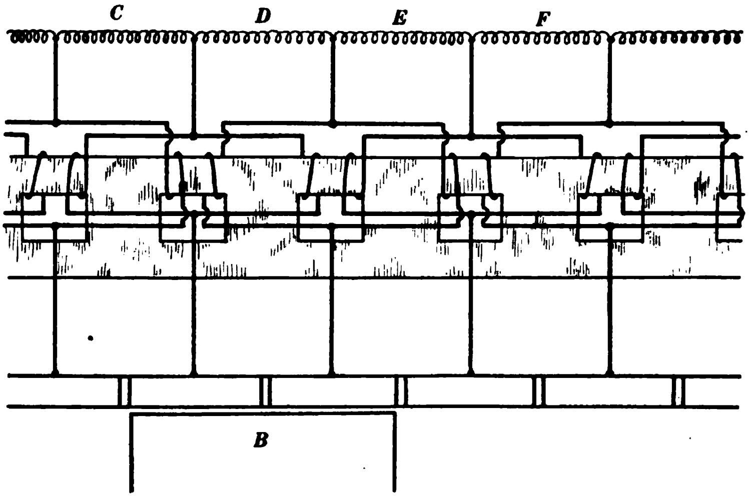

Fig. 4

The ordinary speed, torque, and power-factor curves were determined for this motor as shown in Fig. 8. These tests were made with 30-cycle current from an old style high-fre-

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† See graduating thesis in Department of Electrical Engineering of Lehigh University.

* All of the sheet-iron stampings were made by Messrs. Wily and Mervine, dies being especially constructed for the purpose.

quency alternator driven at about one-quarter speed. It was found impossible to maintain full voltage throughout the test; in fact the pressure ranged from 275 volts when the current input was 23.2 amperes to 260 volts when the current input was 35.2 amperes.

The pressure between adjacent commutator bars near the brushes was 19 volts effective when the motor current was 31.8 amperes, and yet the commutation was entirely satisfactory; even with a motor current of 35.2 amperes no more sparking was in evidence than is usual on a direct-current motor of the same size. Indeed the commutator was in perfect condition after a long series of test runs. A single and momentary trial of the armature without the choke-coils exhibited a superlative degree of sparking, as was to be expected.

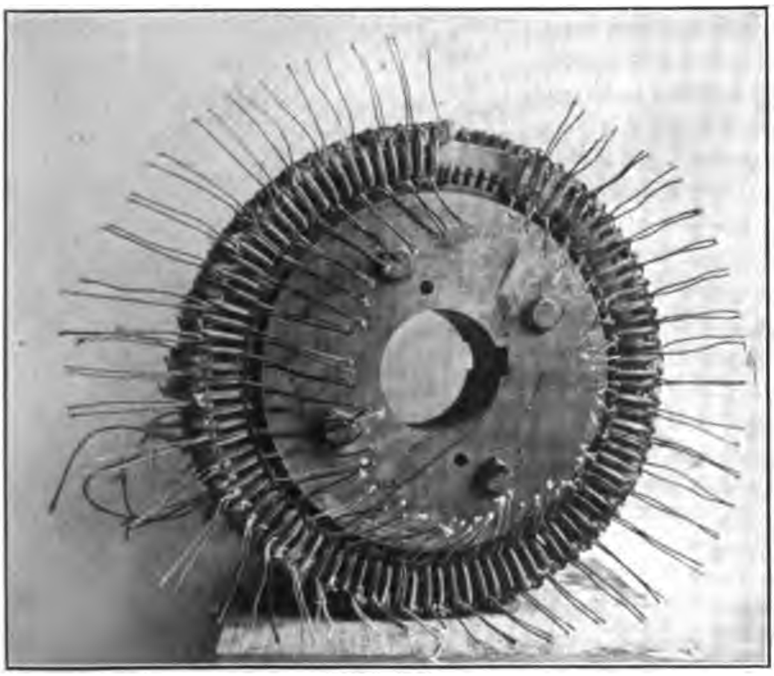

FIG. 5

THE INVERSION OF FIELD AND ARMATURE IN THE SINGLE-PHASE SERIES MOTOR

In the direct-current motor the field should be much stronger magnetically than the armature and it should, therefore, be the external member to give room for the field windings; in the alternating-current commutator motor, however, the armature must be the preponderating member and it should, therefore, be the external member to give room for the armature windings. An internal-rotating-field external-stationary-armature type of direct-current dynamo was brought out a number of years ago in England, but this type of direct-current machine is now entirely discredited both practically and theoretically. The internal-field external-armature type of single-phase series motor, however, presents very great advantages as follows:

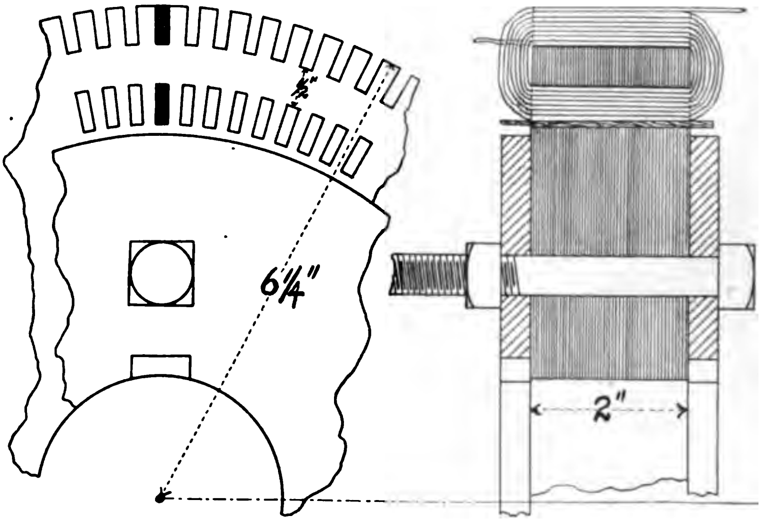

Fig. 6

(*a*) It presents more available space for the windings.

(*b*) It makes possible a material shortening of the end-connections of the compensating windings without lengthening the end-connections of the armature windings.

(*c*) It makes possible the removal of all non-sparking devices from the motor region proper, relieving the designer of every limitation in the use of resistance leads or other non-sparking devices except the limitation of cost and weight; and

(*d*) It makes possible the detaching of the commutator and the utilizating of the large amount of space ordinarily occupied by the commutator for motor iron and motor copper.

What may at first sight appear to be a disadvantage in the detaching of the commutator is the necessity of driving the brush mechanism by gearing, but the transmission of the power required for this purpose does not present a serious problem; indeed, it would seem that the advantage of having the commutator and brushes always in view and always easily accessible would counterbalance any mechanical disadvantage involved in the detaching of the commutator.

Figs. 9 and 10 represent sectional views of two single-phase series motors having the same external and internal dimensions. Fig. 9 represents the ordinary design with internal armature and external field, and Fig. 10 represents the new design with internal field and external armature. The following table exhibits the details of dimensions, weights, losses, and efficiencies of these two machines according to the designs of S. S. Seyfert, and according to the independent calculations of Comfort A. Adams of Harvard University, and of A. S. McAllister. The core loss in the armature is calculated in each case as if it were due to the full-load flux density at normal primary frequency. In fact, armature core losses are somewhat larger than this.

FIG. 7

These calculations are substantially in agreement, and they show a remarkable difference in rating of the two types of machine. The internal-field external-armature type of machine has a rating which is approximately 20 per cent in excess of the rating of the external-field internal-armature type of machine.

TABLE I

COMPARISON OF INTERNAL AND EXTERNAL FIELD SINGLE-PHASE MOTORS OF SAME SIZE

	Adams		McAllister		Seyfert	
	New type	Old type	New type	Old type	New type	Old type
Outside diameter, inches	30	30	30	30	30	30
Inside diameter, inches	10.75	10.75	10.75	10.75	10.75	10.75
Net length of iron	15.3	15.3	15.3	15.3	15.3	15.3
Full-load speed, rev. per min	550	583	550	576	550	576
Horse power at above speed	156.7	130.7	157.1	129.1	160.5	131.5
Efficiency at full load, per cent	88.4	89.5	89.9	89.5	91.1	89.8
Power-factor at full load, per cent	81.3	77.2	78.2	77.8	76.9	73.
Full-load current	432	432	432	432	432	432
Terminal electromotive force	372	327	387	318.5	386	330
Electromotive force between adjacent segments of commutator at brush	10	10	10	10	10	10
Weight of copper, total	894	824	888	850	881	846
Weight of copper per h.p	5.7	6.3	5.65	6.59	5.5	6.45
Weight of iron, total	1767	1781	1737	1659	1757	1742
Weight of iron per h.p	11.3	13.6	11.1	12.8	10.9	13.2
Total weight of active material	2661	2605	2626	2510	2639	2589
Total weight of active material per h.p	17	20	16.7	19.4	16.5	19.7

REMOVAL OF NON-SPARKING DEVICES FROM THE MOTOR REGION PROPER

After having been led to the external-armature internal-field type of construction for the single-phase series motor, the authors realized the very great advantage to be obtained by removing the resistance leads, or other non-sparking devices, from the motor region proper. These advantages are:

1. That resistance leads and balanced choke-coils, for example, can be used regardless of the amount of space they occupy so that the advantages to be gained by the use of such devices may be pushed to the limit, thus enabling the designer to produce a machine which commutates satisfactorily with a higher short-circuit voltage than would otherwise be possible.

2. The power losses in the non-sparking devices take place outside of the motor region proper and do not therefore have to be taken care of by ventilation.

3 Repairs to resistance leads, or other devices for preventing sparking, may be made with the greatest of ease and without opening up the motor in any way; and

4 Arrangements can be provided for the short-circuiting of any portion of the resistance leads or the disconnecting of the choke-coils at any prescribed motor speed, thus enabling the designer to treat the problem of starting and the problem of steady running independently of each other.

REMOVAL OF COMMUTATOR FROM MOTOR REGION PROPER

Another great advantage secured by the adoption of the external-armature internal-field type of construction is the possibility of removing the commutator from the motor region proper and the consequent possibility of utilizing the motor region solely for motor iron and motor copper. This change alone represents a possible increase of about 60 per cent in the motor rating that can be placed in the region occupied by the motors of the New York, New Haven and Hartford locomotives, and it has the further advantage that the commutator losses occur outside of the motor region proper, thus simplifying the problem of ventilation.

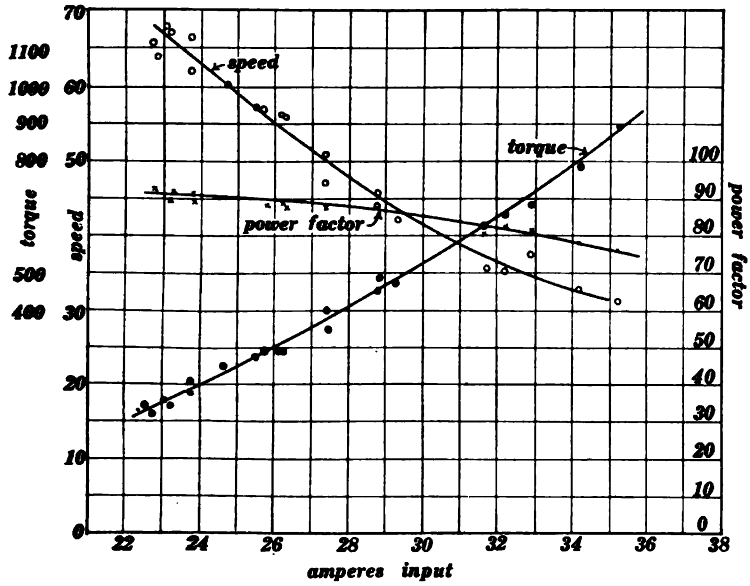

FIG. 8

A 500-H.P. DIRECT-CONNECTED, 25-CYCLE, SINGLE-PHASE SERIES MOTOR BETWEEN 62-INCH DRIVERS

The authors have worked out in succession the more important details of design of five single-phase series motors in their application to the principles set forth in this paper. The last of these studies in design related to a 25-cycle motor to be placed between 62-in. drivers on a standard gauge locomotive. This

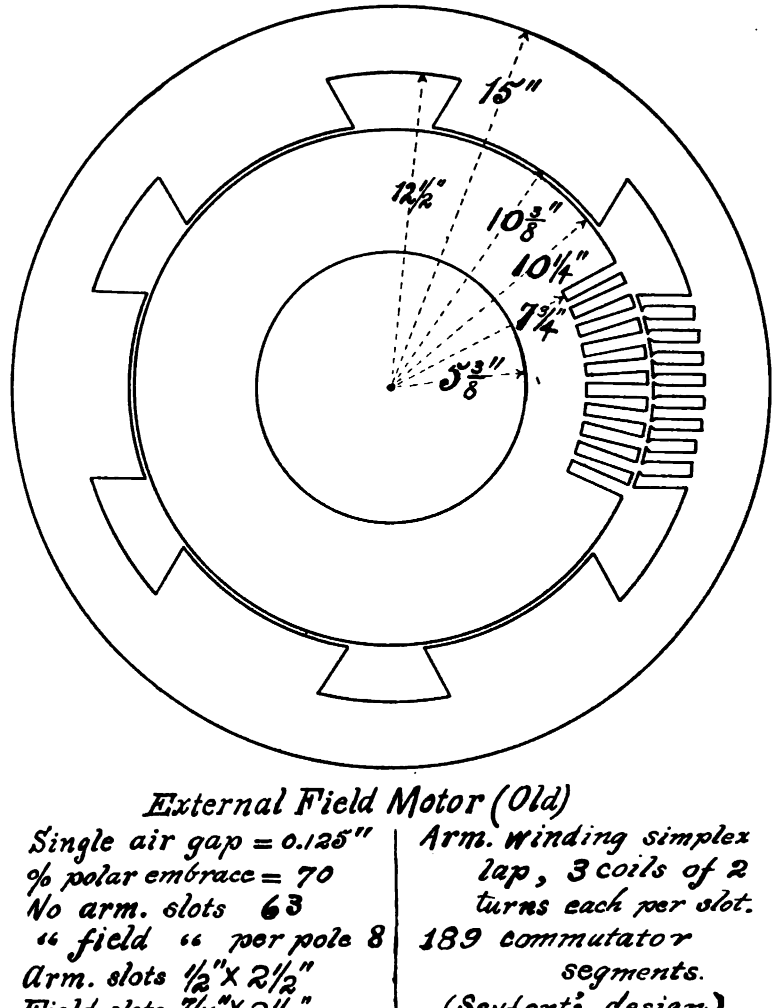

FIG. 9

motor is referred to as motor No. 5. Fig. 11 is an outline sketch of this motor; *F F* is the internal rotating field and *R R* the collector rings for leading current into and out of the field and compensating windings; *Z Z* are the end-connections of the compensating windings, *A A* is the external stationary armature, *C C* the detached commutator, *S S* the rotating-brush arms which carry the brushes *B B*, and *R′ R′* the collector rings for supplying current to the rotating brushes. The axis of the com-

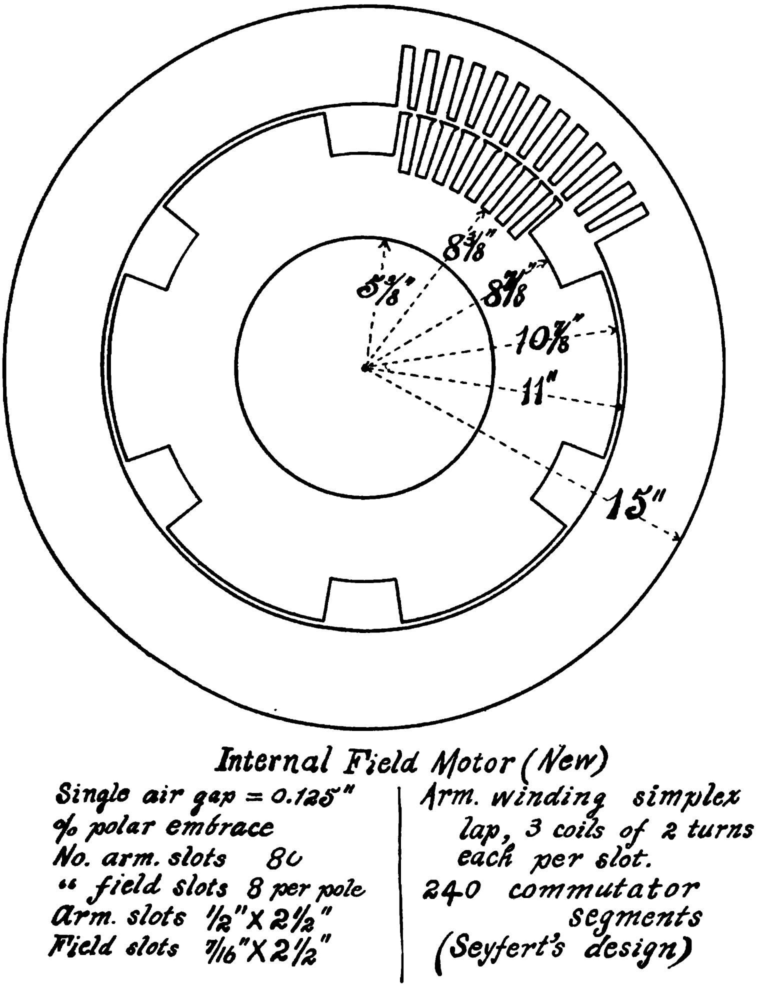

Fig. 10

mutator is vertical, and the commutator is represented as being a hollow cylinder with the commutating surface on its interior. The brush shaft is supposed to be supported by arms which project forwards and backwards in the Fig. to the front and back parts of the motor casing; these supports are not shown in Fig. 11. The stamping dimensions of armature and field are shown in Fig. 12. Immediately above the commutator and surrounding the commutator lugs *L L* a set of terminal bars are to be provided to which the armature leads are to be connected, and the resistance leads and balanced choke-coils are to be connected between these terminal bars and the armature lugs and placed in any convenient position in the locomotive cab.

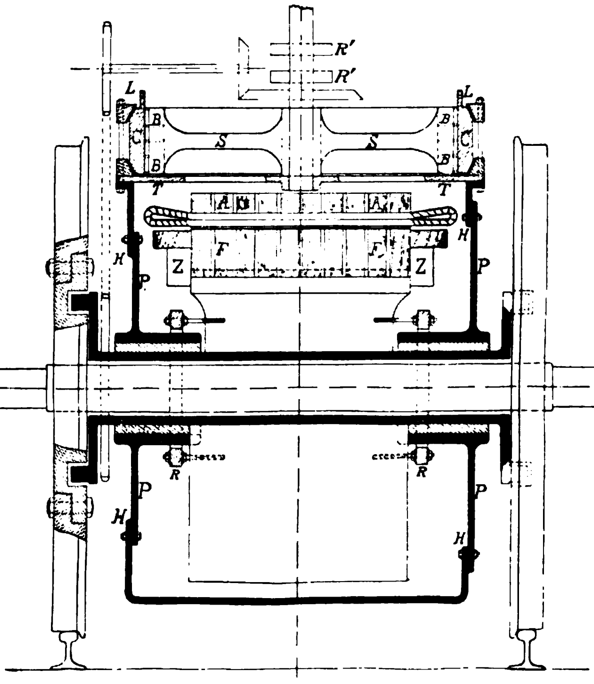

Fig. 11

Provision is made for removing the internal field for repairs by sliding it out endwise. The details of this arrangement are shown with sufficient clearness by the holes *H* in the two ends of the motor casing, and the plates *P* which cover these holes; the left-hand driver in Fig. 11, being provided with a detachable

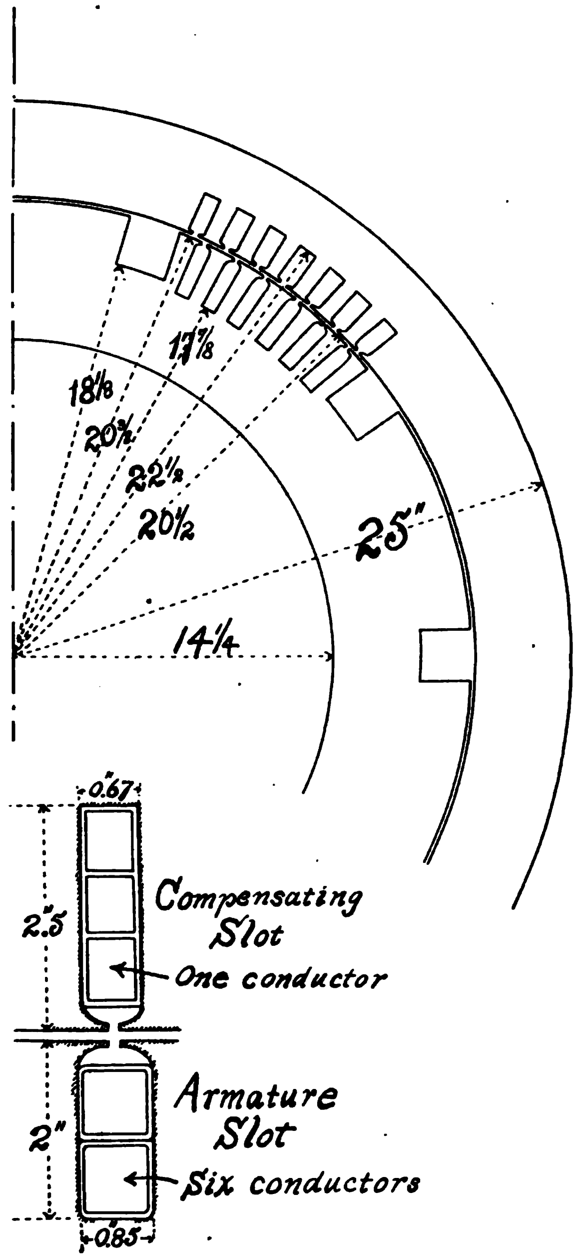
18⅛
20¾
17⅞
22½
20½
14¼
25"
0.67"
2.5"
Compensating Slot
One conductor
2"
Armature Slot
Six conductors
0.85"

FIG 12

rim so that what remains of the driver when the rim is detached can pass through the armature of the motor.

It was decided to adopt a 10-pole field instead of a 12-pole field as in the present New Haven motors. This decision was reached on the basis of a conviction that satisfactory commutation can be accomplished with 12 volts between commutator bars at the brushes by the free use of non-sparking devices which is permitted by the internal-field external-armature type of construction.

The more important items of design of motor No. 5 are here collected to give a better idea of the machine.

TABLE II

Gross motor length, $39\frac{3}{16}$ in.
Net length of iron, 21.46 in., which leaves 12 in. for end-connections and for 9 ventilating ducts each $\frac{3}{8}$-in. wide.
Outside diameter of motor, 50 in.
Terminal voltage of motor at full load and 45 miles per hour, 216.7 volts.
Full-load current, 2400 amperes.
Counter electromotive force at full load and 45 miles per hour, 154.8 volts.
Mechanical power developed in armature at full load, 380 kw. or 509 h.p.
Power-factor at full load, 76.8 for air-gaps of $\frac{1}{4}$-in. total.
Power-factor at full load, 83.1 for air-gaps of $\frac{3}{16}$ in. total.
Armature copper loss, 6010 watts.
Field copper loss, 1655 watts.
Compensating copper loss, 5140 watts.
Field core loss, 5940 watts.
Armature core loss, 7746 watts (calculated for full frequency and full-load density).
Total stator loss, 13,756 watts.
Total rotor loss, 12,735 watts.
Total power dissipated in motor space, 26,491 watts.
Electrical efficiency, neglecting commutator losses, 0.937.
Voltage between commutator bars near brushes, 12 volts effective.
Commutation constant corresponding to effective value of full-load current, 0.947 (equals reaction electromotive force per armature section during reversal of current at commutation).
Armature winding duplex lap with 1008 inductors.

DISCUSSION ON "ON THE SPACE ECONOMY OF THE SINGLE-PHASE SERIES MOTOR." NEW YORK, JANUARY 14, 1910

S. M. Kintner: The topic of space economy of single-phase motors is a most timely one and merits a very complete discussion. In the paper presented this subject is dealt with in a very heroic manner, and the methods proposed for increased output are certainly radical in the extreme.

In the discussion of a paper presented by the theorist, with admittedly no practical experience, there is always the danger of too much stress being laid upon the fact that these are the ideal conditions, and that matters of detail in carrying out such a proposal are entirely subordinate and not worthy of serious discussion at such a time. In this paper, however, there are a number of details which deserve special attention, as it is largely upon these details that the success of the plan for increased output depends. A comparison of the output of the proposed 500-h. p. motor, that the authors submit as one that could be operated within the space limits of the present New York, New Haven and Hartford Ry. Co's. locomotive motors with one of those motors, shows that there is no gain in output per unit weight of active material, that is copper and laminated iron. The attempt to gain, has been made by dividing the motor up into two parts, one of which is made up of the magnetic circuit and inductors which occupies all of the available space at present used by the entire motor on the New Haven locomotives, and the other part, made up of the commutating device with its necessary choke coils for keeping down the short circuit currents, which the authors propose to place in some convenient location outside the motor frame, and which has its own additional space requirement.

With the proposition then that an increased output can be effected in direct proportion to the increase in active materials, such as copper and laminated iron, that can be placed in the available space, the discussion hinges on:

1. The feasibility of the external commutator with revolving brush holders, and,
2. The value of balanced choke coils for limiting the short circuit currents.

In passing, it may be well to note that, estimating the dimensions of the copper conductors from published I^2R losses, the insulation allowances in the proposed 500-h. p. motor are much too small, there being but one-half that allowed in the armature slots of standard machines, which allowance the experience of years has indicated as the minimum that is safe. Further, it should be noted that the method of getting the windings in place with the proposed slot, copper and insulation dimensions, is by no means evident. Again, the number of commutator bars selected is such as to cause some difficulty in connecting the equalizers.

There is also some question as to how successful the commutation would be.

My understanding of Prof. Franklin's duplex winding is, two independent parallel windings, in which there are 12 volts between alternating commutator bars, with one bar of the other winding intervening—am I correct in that?

W. S. Franklin: Yes, 12 volts with one turn of wire around the field flux.

S. M. Kintner: In my statement here, I have assumed that it was alternating commutator bars that were subjected to these 12 volts difference, and I am not clear just as to the type of windings proposed, if that is not the case. However, the same condition of total weights of metal, copper, iron, etc., holds as regards output, flux densities, etc.

I do not believe an external commutator with revolving brush-holders can be built for this class of service which will be a commercial success. The difficulties involved are:

1. The construction of the commutator with its 504 flexible connections from the motor windings, through the choke coils mounted on the locomotive cab, as proposed by the authors, down to the commutator bars.
2. The mechanical arrangement necessary for driving the brush-holders synchronously. This forms a problem in construction that has no feasible solution.

It seems to be well nigh impossible to devise a satisfactory arrangement of this kind when viewed from the standpoint of reliability, accessibility for inspection and repairs, freedom from mechanical injury during overhauling other parts of the locomotive, first cost, etc. Again the increased complication, cost and maintainance expense of the two sets of collector systems for supplying current to the brush-holders and to the rotating field, is another serious feature of this type of motor. While the authors' statement that but little power would be required to drive the rotating brush-holders is probably true, it does not necessarily follow that no serious difficulty is involved in the construction of such a drive. On the other hand, I believe it would be very difficult to construct a drive which would be absolutely positive and not liable to any interruption, and which would maintain accurately for long periods of time the correct brush-setting on the commutator. It is a well-known fact that single-phase commutator motors are very sensitive as regards brush-setting and great care is taken to insure a correct setting on the present types of such motors to within less than 1/16 in. as measured on the commutator face.

It is not at all likely that anything near this accuracy could be maintained with the proposed system. Fortunately, a limited amount of lost motion would be beneficial, as it would tend to rock the brushes backward for more favorable commutation. All the brush-holders if rotated at motor speeds would need to be carefully balanced and the carbon springs would require some form of compensator on account of centrifugal forces which would otherwise cause unequal brush pressures. Many other difficulties suggest themselves, but the foregoing are sufficient to indicate the character of trouble that would be encountered.

On considering the question of balanced choke-coils for limiting the magnitude of the short-circuit currents, one is surprised to find how large these coils become. It is worthy of note in connection with the 500-h. p. motor proposed by the authors, that the voltage between consecutive commutator bars is not as great as that on the New Haven motors. The magnetic density in the various parts of the proposed motor is also somewhat less than in the New Haven motor.

From this it may reasonably be argued that the size of the choke-coils and the motor power-factor proved to be the limiting conditions which prevented an increase in output per unit mass of material.

There are two other points that should be considered in connection with the choke-coils, as determining factors of their value:

1. Their ability to withstand without injury heavy momentary overloads, such as they might be subjected to in the event of the motor not turning over at once when current is applied at starting, and

2. The character of their construction combined with an adaptability for ready assembling in a suitable manner and at a reasonable cost.

In considering the first point, an examination of the choke-coil for the small machine shown in the paper, indicates that there is approximately as much resistance in the copper of the choke-coil as would ordinarily be used in a regular resistance lead, and that this alone would have been sufficient to limit the short-circuit current without the inductive effect. This then indicates a serious sacrifice in sturdiness and overload capacity in order to keep down the size to such proportions as would allow the choke-coils to be mounted inside the armature. In this case there has been increased complications, equal or greater loss, an inferior arrangement to withstand heavy overloads, and when compared wth the resistance lead properly installed, it seems to be less desirable than the latter.

The authors state " It does not seem possible, however, to produce a single-phase motor that will operate satisfactorily without the use of special devices for the prevention of excessive short-circuit currents."

I wish to take exception to this statement, as it *is* perfectly feasible to build motors without any special devices of this nature, provided the induction per pole is kept low enough. There are a great number of motors of this kind in operation giving satisfactory service. The contact resistance of the carbon brush is sufficient to limit the current to a safe value provided the short-circuit voltage does not exceed 3½ to 4 volts. The employment of preventive leads, however, allows the use of higher inductions per pole, and in general results in a somewhat smaller motor for the same rating.

Considering the second point, that of cost and adaptability for assembling, I have found on calculating suitable coils for the proposed 500-h. p. motor mentioned in the paper, that the sizes are rather startling, and one is inclined to the belief that the authors were so glad to find a place large enough to accommodate the choke-coils that the mechanical difficulties involved in the use of the external commutator looked small.

Space economy. The space available for the motor of a locomotive depends so much on the type of motor-mounting and drive, that comparisons on the basis of output of the motor designs of different types are misleading. It is of course allowable and proper, to compare locomotive performances provided they have been designed for the same class of service.

For motors mounted concentric with the locomotive axle similar to the New Haven motors, the desired freedom and standard wheel-flange-spacing fix the maximum length of motor, while the motor diameter allowable, depends upon the wheel size and the permissible clearance below the motor.

If a particular locomotive speed condition is assumed, the end clearances will be practically the same, and the size of motor that can be put in the space will increase with the increase in the driver size. For a particular case of this type of mounting, in which the same locomotive speeds are assumed for various sizes of drivers, the increase in horse power output, which can be put in the available space, will be approximately along a straight line, which indicates a 250-h. p. motor on 62-in. drivers and a 500-h. p. motor on 94-in. drivers.

The increase in motor weights will be somewhat more rapid than their increase in diameters, owing to the fact that the active electrical and magnetic parts will increase almost directly with the diameters, while the weight of most of the mechanical parts will increase more nearly as the square of the motor diameter.

Motors mounted horizontally, with one side supported rigidly on the axle, similar to the ordinary method of mounting motors on car trucks, gradually lose end-room as their sizes increase, on account of mechanical requirements of increasing space for larger gears, and their outputs do not work out on so simple a curve as the motors mounted concentric with the axles. This loss in end-room results in a double loss as it makes it necessary, for a given rating, to use a larger motor diameter. This increase in motor diameter requires a reduction in motor revolutions, on account of mechanical limitations, which in itself makes a larger diameter necessary. This increase in armature diameter, forces the gear centers further apart and increases the size of gears. A final balance is reached, above which, it is not feasible to mount motors in this manner on account of the gear sizes and dead motor weight on the axle. This dead weight can be relieved by the use of quills which afford a spring support for the motor, and this makes it possible to increase the size of motor. The use of a quill, however, increases the gear centers, and this causes the limit due to the size of gear, to be reached sooner. Here it should be noted that the required range of locomotive speed plays an important part. The motor, for mechanical and insulation reasons, is designed for a certain limiting speed above which it must not be operated. If the continuous rating speed is chosen near or at the maximum speed, the smallest motor possible for the locomotive rating is obtained. As the continuous rating speed is decreased, the motor size increases. It follows, therefore, that from the standpoint of the motor design alone, the less the requirements of range in locomotive speed between continuous and maximum, the cheaper the motor will be. It is largely on this account, coupled with the mechanical requirements of locomotive riding qualities at high speeds, that locomotive costs are increased so much, for conditions where it is expected to operate in both freight and passenger service at quite different speeds. In general for this type of mounting, there is little or no gain in motor size by reducing the continuous rating locomotive speed below about 12 miles per hour.

Motors mounted directly above the axles and geared thereto through quills, are but one division of this general class of direct-gear drive and are subject to the same limiting conditions. The quill is, however, necessary in all cases with this type of mounting in order to relieve the axles, wheels and track, of the otherwise excessive dead weight.

When use is made of the combination drive employing gears and side rods, there is a distinct gain in the end-room space available for the motor, as in this type of drive, the entire space between the locomotive side-frames, which are generally plate-frames inside the wheel-flanges, can be utilized for the motor. The gears can be placed outside the wheels and there is not very much difficulty in making them any desired size. The driver sizes, wheel-base limits, and crank-throw are, in most cases, the determining factors. This increase in end-room makes a smaller diameter and higher speed motor possible, and hence a cheaper motor. This type of mounting gives almost as much end-room as that employing the straight side-rod drive. The latter has a slight advantage as it is possible with it to extend the motor up to the wheel-flanges and in fact to cut away part of the motor housing for a still further slight gain.

With both of these types of drive the diameter of the motor is limited by cab clearances. These last mentioned types of mounting, allow space that makes possible the largest sizes of motors desirable.

The combination drive is much more flexible and gives a better selection of motor speeds and driver sizes, as the gears can be selected to get the desired locomotive speed. It is impossible with these last mentioned types of drive, to state the sizes of motor in terms of the ordinary methods of rating, without a definite limiting speed range, and so I will not attempt to state more than the preceding indications of the general limits.

E. H. Anderson: The paper brings out very clearly the difficulties of designing a single-phase commutator motor. The scheme of placing reactances in such connection as to theoretically reduce sparking is ingenious, to say the least. The criticism of the scheme is, that it does not make for simplicity. The simplest form of apparatus is more often the most enduring.

It appears from the text that the leads of the stationary winding are connected into the stationary commutator, although space and detail of construction are not shown. In order to take the motor apart for repairs, it is necessary to pull off a driving-wheel, or separate the stationary member, and in this case it becomes necessary to disconnect the winding and all the commutator leads coming from the lower half. The driving mechanism for the revolving brush-holders must be positive and rigid. No slack or looseness can be allowed, for the exact position of the brushes on a single-phase commutator motor is very essential for proper operation and speed. Such a motor as described, usually has about an 8-in. commutator and 18 in. of core iron between heads.

The power of a motor is dependent largely upon the length of core, and if all of the commutator length could be put into core, that is, by adding 8 in. to 18 in., it becomes possible to increase the power about 45 per cent. However, all the commutator length cannot be added to the core, for the reason that there must be a circular conduit at each end to allow the leads of the lower portion of the stationary member to be brought up to the stationary commutator. This will require approximately 3 in. on each end thus leaving 2 in. to be added to the core-length, giving 20 in. instead of 18 in., or an increase of 11 per cent. After the leads leave the conduit they must be spread around the commutator and held firmly, as well as properly ventilated. Usually from a given space, a certain amount of heat can be blown out, so that with a given efficiency only a given amount of work can be done in that space. The driving device for the revolving brush-holder rigging must take up some space on the axle. This will no doubt use up the spare 2 in. with the result that the iron core between heads is not increased.

The question naturally arises, is the taking away the commutator from the rotary member, and placing the same on the stator worth the complication? It appears from the paper that this scheme is best suited for single-phase axle motors for locomotives, and is limited to the construction shown, of mounting the stationary member on a quill and using quill-drive. It appears that there is difficulty in building within the limited space between wheels, a motor large enough to slip the wheels and do the work usually required on the usual axle weight of 50,000 lb. The above refers to a single-phase commutator motor and this scheme with its complication is an effort to increase the size of motor.

The serious question about the construction, to my mind, is that it is not the simplest. A prominent railway company built and installed a motor on a single-truck car, which should act as a counterweight to the real motor. The motor was a chunk of cast-iron, with armature bearings on it, mounted outward on a single-truck car, and over-balanced the effect of the real motor, which was outwardly-hung on a single-truck car. This was put on as it was thought the real motor might tip up end wise and block the system. These motors were used for a long time, and gave no trouble, probably on account of their simplicity.

E. F. W. Alexanderson: The title of the paper opens a broad subject. There may be as many ways to look at it, as there are designers who have worked on the development of single-phase railway motors. I prefer to look at the subject in a somewhat different light rather than discuss the schemes presented in the paper.

In the design of any electrical apparatus, there is usually one requirement that is more severe than any of the rest, or one weakness in the type of apparatus considered to which most of the attention must be given, so that all the other features must be subordinate to that particular consideration. Most electrical machines are sold on the basis of a standardized commercial rating, and this rating is in most cases based upon the temperature rise during a certain test. Other features, like regulation, power-factor, efficiency, and overload capacity, are given as supplementary descriptions of the apparatus. The commercial rating of railway motors is based upon heating, usually upon the one-hour test at 75 degrees rise, and the adaptability of a railway motor to any specific requirement is usually judged by the heating of the motor. This generally accepted method for determining the service capacity of railway motors has been developed with reference to the motor of the wholly enclosed type.

The three principal limitations in the design of an alternating-current railway motor are heating, commutation, and starting torque; of these three, the starting torque is, however, the most important.

The first attempts to design the alternating-current railway motors were naturally along the same lines as those of the direct-current motors. The motors were completely enclosed, and the service capacity was determined from the heating characteristics. It was soon found, however, that owing to the lower efficiency of the single-phase motor, the temperature has a tendency to become considerably higher than in the direct-current motor. An increase in the size of the motor, in order to reduce the temperature, led to an increase in the weight of the trucks, car-body, and the control, so that the motors had to do more work than was contemplated in the first place, and the desired reduction in heating was not obtained. At present it is accepted as a necessity by all manufacturers of alternating-current railway apparatus, that the motors must be cooled, either by natural or forced ventilation. As soon as forced ventilation is adopted in an alternating-current motor, the whole basis of the design is changed. The cooling that can be accomplished in this way is so effective, that heating is no longer the limiting feature of the design. Commutation difficulties can be entirely overcome at any normal operating speed, by application of a commutating field of suitable phase and strength. They can also be counteracted, to a great extent by the use of so-called resistance or preventive leads. The ruling feature is therefore the starting torque. This applies to the three-phase railway motor, as well as to the single-phase railway motor, although for entirely different reasons.

In the discussion of Dr. Hutchinson's paper on the Great Northern electrification, I explained that the reason why the three-phase motors exceeded their guaranteed capacity on the basis of temperature rise, with forced ventilation was not an accident. The starting torque was the most severe requirement, and as a matter of fact, the motors are able to slip the wheels of the locomotive, only with a necessarily small margin.

In the single-phase railway motor, the starting torque is limited by local heating on the brushes, commutator bars, and certain parts of the winding. Various methods have been devised to increase the starting torque of the single-phase commutator motors as much as possible. Although there may be a disagreement as to what methods are the most practical it seems to be a general agreement that some special methods must be used.

The starting torque of the single-phase commutator motor is limited by the voltage per bar on the commutator, and the current per bar in the winding. Generally speaking, it can therefore be said that the starting torque is proportional to the size of the commutator. The special methods that are used to increase the starting torque consist in providing means for either raising the voltage per bar or by means for raising the current per bar. In other words, both systems require space in the motor which could otherwise be usefully employed if the motor was intended for direct current.

The scheme presented by the authors of the paper is the first of the two mentioned principles for increasing the starting torque, carried to the extreme. The system is, according to the authors, very effective, but there is also every indication that it takes room in proportion to its effectiveness, and there is no convincing evidence in the paper that the space occupied by the motor with its elaborate non-sparking devices, will not be quite as large as the space of a motor of more familiar design.

This refers to the motor of the Seyfert type with rotating commutator shown in the illustration. The scheme of the detached commutator, apart from its complication, does not solve the problem of space factor as it is worked out in the design shown in the paper, because no provisions have been made for materially increasing the diameter of the commutator, which after all is a measurement of the starting torque. A natural solution is however given by the use of side rods which allows the commutator as well as the rest of the motor to assume its necessary dimensions as well as its natural proportions.

It is interesting to observe that the results obtained by the four or five manufacturers of single-phase railway motors in America and in Europe, agree closely in regard to weight and space per horse power. In order to give some more concrete figures, as to the space and weight factor of moderate size single-phase motors, the following data may be mentioned. A 25-cycle motor of the series repulsion type designed for 36-in. wheels, has a weight of 5900 lb., and delivers 150 h. p. at 600 rev. per min. in accordance with standard rating. This is, as far as I can see, in close agreement with recent developments of motors of several other types and makes.

The various schemes employed for overcoming commutation difficulties cannot, therefore, be judged by the space factor or the weight per horse power. The nearest to a practical comparison is undoubtedly a test that has been embodied in the specifications for locomotives in connection with the contemplated electrification of two of the large western railroads, that the motor should be able to develop full torque at stand still for a specified time, one minute or five minutes. If the motors are compared on a basis like this, the type will undoubtedly be most favored, which offers the greatest simplicity of structure, and the easiest work for the repair man.

S. S. Seyfert: The discussion that has taken place, following this paper, has amply repaid us for going to the trouble of presenting a few ideas in the line of motor design. Perhaps the best reason for bringing up a subject like this is to find out what the chief workers are doing.

I would like to mention a few points, however, because it seemed to me during the discussion, that the non-sparking devices that are proposed were assumed to be a necessary part of the inversion of the relative positions of field and armature. It is not necessary to use these choke-coils in the case of a motor with external armature, and as a matter of fact I have often thought that it might be desirable to use resistance leads, only under certain circumstances, especially if the short-circuit volts are reasonably small. We have found it is extremely difficult to design a motor of so large size, with a reasonable short-circuit voltage per turn, for with a reasonable number of poles, say 12, the flux per pole on a 500-h.p. motor becomes so large as to produce 12 volts or more per turn on the armature circuit, and if we wish to reduce this voltage we would either have to tap into the half-turns or increase the number of poles.

In order to build a large single-phase motor, it is absolutely necessary to use a large number of poles, or use a high short-circuit voltage per turn. I think however, that motors could be built on the resistance-lead principle, that would commutate well enough, and in that case the stationary character of the armature, with the available space for placing the leads, would enable us to design the leads somewhat more generously, and therefore their liability to burn out at starting would be less, which would mean a lessening in the cost of repairs and an increase in the reliability of service. I think it is plain, that with the ordinary construction of armature, in which the resistance leads are doubled upon themselves in the bottoms of the armature slots, they consume a large amount of valuable space, real motor space, and they add their heating to the total heating of the armature. In case of burn-outs, which are liable to occur at starting, the armature windings have to be undone to repair the leads. In this case, I can easily imagine an arrangement of the leads so that they might be replaced at short notice separately and in fact a lead might be replaced while the motor was running, if the winding of the armature was of the proper type. On the basis of resistance leads alone, dropping entirely the question of choke-coils, it would seem an advantage to have the leads so located, that they can be easily and separately repaired. This would compensate for a great deal of the otherwise complicated arrangement.

I would say another word about the length of commutator. One of the members who discussed the paper mentioned that the length of the commutator on the present New Haven motor was about seven or eight inches, and in case of the removal of this commutator we would gain that space. I find, if we attempt to build a 500-h. p. motor, that the commutator would be about a foot long. In this case, assuming the commutator on the motor concentric with the axle, we would gain a foot of space by removing the commutator. Should we decide to make the commutator concentric with the armature—this one foot of space needed would force us to a greater driving-wheel diameter. It should be plain, therefore, that the increase in gross length of useful iron made possible by the removal of the commutator would be 12 inches instead of the seven or eight inches, as would be the case in changing a 250-h. p. motor. We were driven to that construction to get the necessary rating on a direct-connected motor for 62-in. drivers.

As to design, the inverted motor has among others, the following advantages:

1. The long external yoke or armature core has to carry the effective armature flux only, whereas, in the old type of motor, the corresponding core has to carry the total field flux.

2. The placing of the armature externally allows the use of a wider and shallower armature slot, resulting in a better commutation constant and a slightly better power-factor. The compensating slots through the poles must be deeper in this case, which condition may be easily met. Because of the comparatively low voltages at which single-phase motors must operate, it has

been found somewhat difficult to satisfy the direct-current commutating condition on a motor of large size with such a small number of poles.

3. The air-gap periphery is somewhat increased in the case of the external armature motor mainly because the armature requires less radical depth than the field.

4. The end-windings of the compensating-coils are very much shorter, as was mentioned in the paper.

We made some experiments on core losses in field and armature,

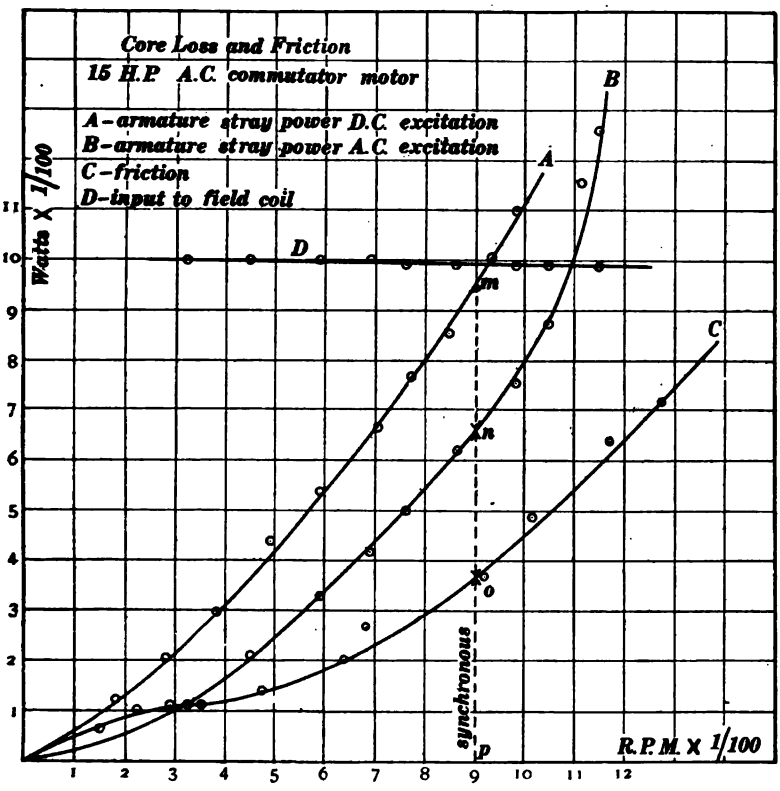

Fig. 13

which might be interesting at this juncture. For some time Dr. Franklin and myself were under the impression that the core losses per unit of volume in the armature of the alternating-current motor should diminish as synchronous speed is reached. Upon going into the theory of the matter this seems to be so, but for some reason, the core losses actually increase somewhat with speed. The experiment was performed on a single-phase motor of the ordinary type, and the results are shown in Fig. 13.

In the first place, a constant direct current of 30 amperes was supplied to the field. The armature was rotated at a series of speeds up to and beyond synchronous speed.

Curve *A* gives the total input to the rotating armature from the driving motor; curve *C* gives friction loss in the motor tested so that $m\ o$ represents the core loss in the armature.

In the second place a constant alternating current of 30 amperes effective value was supplied to the field. Curve *B* gives the corresponding core loss as measured by the driving motor. Curve *D* shows the watts input to the field-coil throughout the test. These curves show that the armature core losses in the aternating-current motor are not as great as they would be for the same effective values of induction on direct current. It is shown, however, that the core loss, in both cases, increases with speed, growing very rapidly above synchronous speed. This may be due to the fact that the losses caused by the bunching of flux by the teeth are such a large percentage of the armature core loss.

In the paper it is stated that we selected the 10-pole type of motor; we found later that 12 poles would have been better for it is well known that the larger the number of poles on the motor, the less its weight per horse power, because the individual magnetic circuits are less bulky, and the cross-sections of the core, both field and armature, are less. By going to 12 poles we could make a better machine, one that would commutate better and have a smaller short-circuit voltage.

President Stillwell: I am sure the Institute owes its thanks to Dr. Franklin and Professor Seyfert for the very interesting and suggestive paper which they have presented. It is always an advantage to look at a subject from another point of view, and I am sure that the engineers who are accustomed to the designing of motors of these types for commercial service will be glad to agree with me, and in a judicial spirit examine their own work very carefully to see if there be anything in this suggestion which might be utilized. I do not propose to enter into the discussion, but one or two points have occurred to me which might be mentioned to advantage, and one is that the argument in favor of the increase in output in proportion to dimensions are greatest in the case of multiple unit equipment, and in which case I think the paper makes no suggestion as to the location of the commutator and its leads.

In the case of the electric locomotive, taking the state of the art as it existed when the New Haven locomotives were designed, the designers were undoubtedly cramped for room in attempting to place the motors underneath the floor of the locomotive, but the tendency is now, I understand, rather towards raising the motors and gearing to a shaft, in which case the argument in favor of separate commutator and its leads from the field armature is somewhat minimized. I will now call upon Dr. Franklin to close the discussion.

W. S. Franklin: In regard to the location of the detached commutator in the multiple-unit car I may say that Professor

Seyfert and I have considered that matter in some detail after a consultation with Messrs. Gibbs and Hill, and we came to the conclusion that a very great advantage would be realized by placing the motor on one side of the axle, and the commutator on the other side of the same axle, taking the commutator leads across through a covered passageway over or under the axle.

In regard to the general question of detaching a commutator, I wish you to consider what a commutator really is. A commutator is a switchboard, and it is proper to detach a switchboard from the machine which it controls. I never saw a power house with a switchboard placed inside of the dynamo! I only make use of this evidently exaggerated statement in order to emphasize the fact that we have perhaps become too much accustomed to a certain point of view. Perhaps, after all, the detached commutator is the rational and practical thing, and yet I have enough respect for practical engineering to know that the question must ultimately be answered in practice. I do not know for certain whether the detached commutator is the best thing, and neither does anybody else know. It is a question which can be decided only by an actual and long-continued trial under practical conditions.

In regard to the importance of simplicity which has been emphasized by Mr. Anderson, I wish to point out that the motor which Professor Seyfert and I have designed is about the nearest approximation that I know of to a " piece of cast-iron."

In answer to Professor Kintner's question concerning the short-circuit voltage I would say that the short-circuit voltage of our No. 5 (500-h.p.) motor is 12 volts per turn, that is, 12 volts in a single turn around the field-pole.

The question was raised as to the necessary size or carrying capacity of the individual choke-coils. Concerning this point, it is stated in the paper that a short-circuiting arrangement can be provided so that choke-coils or resistance leads can be cut out or in at pleasure. The frequency of commutation is low at starting, and under these conditions one needs high resistance in the leads, whereas the inductive choking is rather small. At high speed, on the other hand, the choke-coils are extremely effective without any resistance. Therefore at starting, very high resistances might be inserted in the leads and these resistances might be cut out with increase of speed after starting.

I wish particularly to emphasize a point which is brought out in the paper, namely, that one of the most important features in the suggested design is, that you can treat the problem of starting and the problem of running as two distinct and separate problems; you can put large resistance in your leads at starting, and when the machine reaches a certain definite speed you can cut out as much resistance as you please by a ring which is made to drop between terminal bars in a manner which will at once occur to any designer.

A paper presented at the 243d meeting of the American Institute of Electrical Engineers, New York, February 11, 1910.

A MODERN AUTOMATIC TELEPHONE APPARATUS

BY W. LEE CAMPBELL

The writer presented a paper before the annual convention of the Institute in 1908, dealing with automatic telephone equipment from an economic viewpoint.* The present paper will therefore be principally devoted to a description of the apparatus used and its method of operation in modern plants. Although there are several different types of automatic telephone equipment upon the market or being developed, practically all of the working plants use apparatus of the " Strowger " type with or without the addition of Keith line switches. Since this paper must be confined to one system, only the one which is extensively used will be discussed. The description will begin with a short reference to the subscriber's station equipment.

Prior to the year 1896, an automatic telephone subscriber called any number which he might desire by pressing push-buttons on his telephone. There were generally three push-buttons arranged and labeled as shown in Fig. 1. If the subscriber wished to call No. **143**, for example, he would first push the " hundreds " button once, then the " tens " button four times, and finally the " units " button three times. While this arrangement gave passable service, the subscribers made many mistakes in counting the pushes and sometimes did not press a button in far enough or hold it in long enough. Consequently, in 1896, a button-pushing machine or a " calling device ", as it is commonly named, was substituted for the push-buttons. A modern wall telephone equipped with a calling device is shown in Fig. 2 and a modern desk telephone in Fig. 3.

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* A Study of Multioffice Automatic Switchboard Telephone Systems, TRANSACTIONS A. I. E. E., 1908, p. 503.

As shown in these Figs. the visible portion of the calling device consists of a dial pivoted at its center so that it may be turned in a clockwise direction. For convenience in turning it has finger holes eleven in number around its outer edge. Through each finger hole, except the eleventh one, a number is seen. These numbers are consecutive from **1** to **9** and back of the tenth finger hole **0** appears. In automatic practice **0** always represents 10.

To call **143**, for example, a subscriber will first put his finger into the hole through which number **1** is seen and pull the dial around until his finger strikes the stop. He will then take out his finger and place it in the hole through which **4** is seen and again pull the dial around until his finger strikes the stop. Finally he will place his finger in the hole through which number **3** is visible and turn the dial till his finger again strikes the stop. He then places the receiver to his ear and awaits the answer of the party called. Each turn of the dial requires approximately one second, and by the time he has placed the receiver to his ear the automatic machines at central office will have completed the connection to the desired line and will be automatically ringing the bells of the desired telephone. When through talking, he hangs the receiver on the switchhook and the break in the talking circuit thus made causes the central office apparatus to return to normal condition.

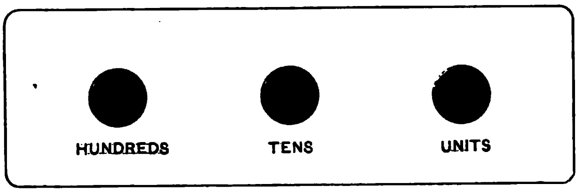

FIG. 1

There is contained within the calling device, but not seen, a revolving cam arranged to make and break the contact between a pair of springs. An escapement geared to a small governor controls the speed at which the cam revolves. The power is furnished by a clock-spring which is rewound each time the subscriber turns the dial. The cam does its work after the subscriber's finger strikes the stop and while he is placing his finger in the next hole. If he tries to turn the dial before the cam rotation is finished, he finds it locked. It stays locked until the cam rotation is completed.

The principles involved in the operation of the dial are carefully worked out and are essential to rapid and accurate calling; the finger is each time placed in a stationary hole in front of a stationary number and is then moved until its strikes a stop. Every movement is positive and accurate, regardless of the speed at which it is made. Any one who has experienced the slow and painstaking care required to manipulate the dial on an ordinary office safe to bring each successive number opposite the stopping point without first passing it, will readily appreciate that any calling device which would require the subscriber to stop each number opposite a pointer or, vice-versa, to stop a pointer opposite each number, would be very slow and inaccurate in comparison with a calling device like that shown in the illustrations.

FIG. 2

If the number called by a subscriber is " busy ", his receiver will give forth an intermittent buzzing sound, the same as that used for a busy signal in large manual systems.

If the number he calls is that of a former subscriber, or of a subscriber whose number has been changed, he will be automatically switched to the information operator, who will give him the information most suitable under the circumstances.

If a " long-distance " connection is desired, the subscriber turns his dial once from the 0 finger hole, which is labeled " Long-Distance " also. He is thereby connected directly to the recording operator of the long-distance board, who takes his order just as in manual practice and then informs him that she will call him when she has his party. When the long-distance connection has been put up, the operator calls the subscriber and the conversation proceeds in the usual way.

Each automatic system is generally equipped with an information and a complaint desk, each of which is presided over by an operator who supplies needed information to inquiring patrons, or records their complaints.

Extension telephones, coin-in-the-slot telephones, party lines, inter-communicating systems, and private branch-exchanges are all worked satisfactorily at the subscriber's stations.

FIG. 3

A subscriber's private branch switchboard may be either of the well known manual type presided over by an operator—who makes the local connections and who supervises all of the calls to and from the public exchange—or it may be automatic with all subscribers' stations equipped with automatic telephones so that they may call each other or call public exchange patrons by means of their automatic calling devices without the aid of an operator, or it may be a combination of the two with the local calls automatic and those to and from the public exchange supervised.

It is perhaps needless to say that the transmitter, receiver, ringer, and hook-switch for an automatic telephone may be of any standard type. The only part of the instrument that is peculiar to the automatic system is the calling device. In fact an ordinary common-battery manual telephone may readily be adapted for automatic service by mounting the calling device upon it as shown in Fig. 4.

Turning from the discussion of the subscriber's station to the central office equipment, the machines which make the connections between subscribers' lines are divided into the following classes:

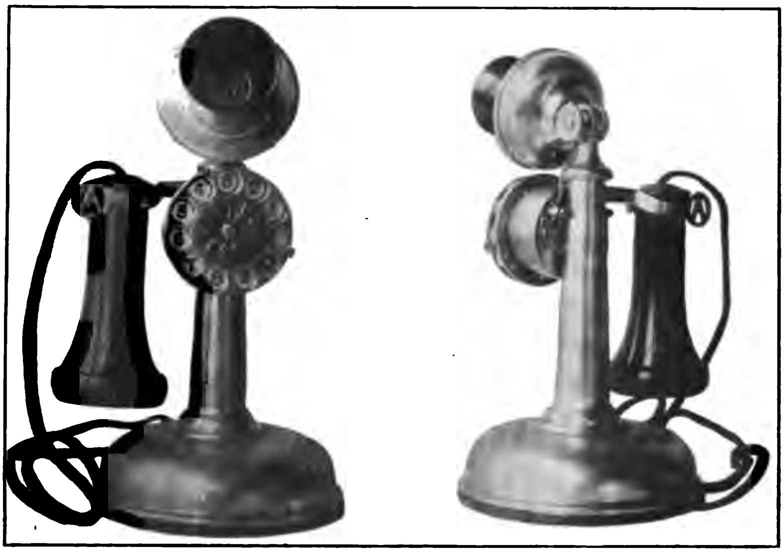

FIG. 4

1. Line switches.
2. Selector switches.
3. Connector switches.

A connector switch commonly called a " connector ", is the last one operated in completing each connection; but as its functions correspond most closely to those of an operator on a manual switchboard it will be considered first.

There are two principal differences between the work of an operator on a multiple switchboard and that of an automatic connector. The first lies in the difference in the number of lines to which they have access. The operator has within her reach a multiple jack for every line in the switchboard, be the number of lines 1000 or 10,000. She may therefore make a connection *to* any line entering the office, but a connector switch has access to but 100 lines. Secondly, a subscriber's operator takes the orders of and makes connections *for* certain predetermined subscribers only. The number she serves seldom exceeds 200 and is often less than 100, but a connector switch is, when idle, ready

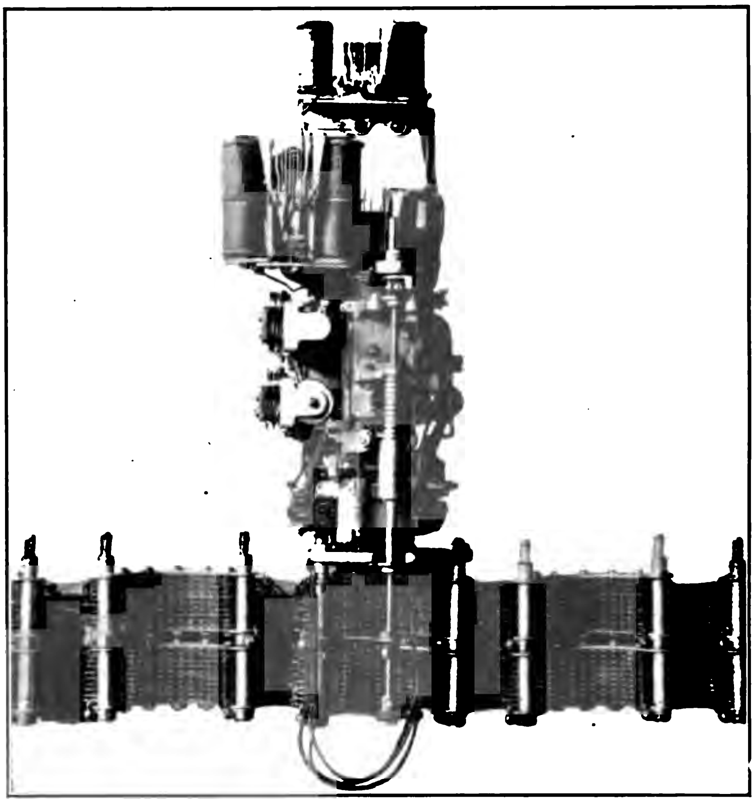

Fig. 5

to handle the order of any subscriber who may wish to connect to any one of the 100 lines to which it has access.

A picture of a connector switch is shown in Fig. 5. The lower part of the machine supports two curved banks of contact plates or strips. The under bank, called the line bank, contains 100 pairs of these contact plates arranged in 10 horizontal rows, 10 pairs to the row. See left hand bank, Fig. 6. These pairs of bank contacts correspond to the line springs in the multiple jacks of a manual board, and, as pictured in Fig. 5, may be multipled before any desired number of connector switches. The upper bank contains 100 single contacts which correspond to the sleeves of multiple jacks. This is the busy-test bank, commonly called the "private" bank. The cord and plug of the manual board are represented by the " wipers " on the shaft of the machine. The lower or line wiper consists, as shown more clearly in Fig. 7, of a pair of long flexible springs insulated from each other and each soldered to a flexible cord, while the upper or private wiper is a pair of springs connected together to a third cord. The movements of the wipers, corresponding to those of an operator raising a plug and inserting it into the proper multiple jack, are performed by the shaft which has a step-by-step vertical movement and a step-by-step rotary movement.

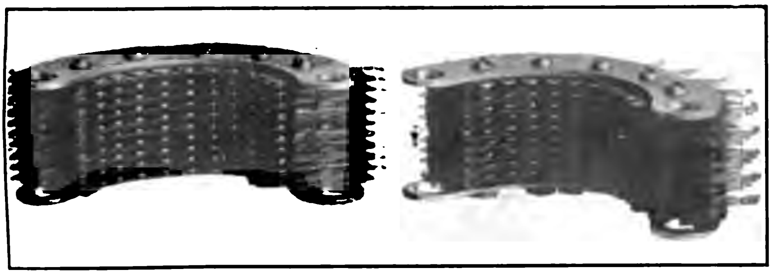

FIG. 6

These movements are actuated by pawls and ratchets operated by electromagnets controlled by the subscriber from the calling device on his telephone, and are always in accordance with the last two digits of the number he calls. For example, if he calls a number ending in **43**, the shaft is raised four steps and then rotated three steps, thus raising each wiper opposite the fourth row of contacts from the bottom of its respective bank and then sliding it over to the third contact in the row. The machine is then ready to close the circuit of the calling subscriber through to the circuit of the called party, but before doing this it first closes the private wiper-circuit only and thus makes an automatic busy test. If it finds the desired line busy, it keeps the connection open and immediately transmits the busy signal back to the calling subscriber. If the desired line is not engaged, the connector switch immediately begins to ring the called party's telephone bell automatically and intermittently. When he answers, the ringing stops and the two subscribers lines are closed together for conversation. Talking current is supplied to the transmitters of both telephones from the central office battery through the relay coils of this connector switch, just as in manual practice it is supplied through the relay coils of the cord circuit. The talking circuit includes nothing but these coils and the subscribers' stations. Its simplicity and perfect balance are shown by the circuit in Fig. 8.

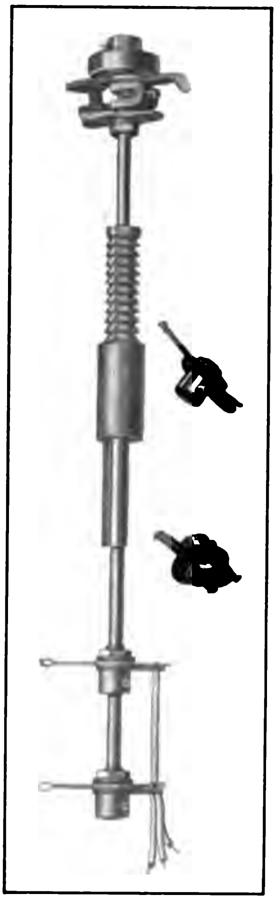

FIG. 7

When the subscriber's conversation is completed and the calling party restores his receiver to the switch-hook, the shaft of this connector switch is " released " and is immediately returned to normal position by means of a clock-spring and gravity. It is now ready to handle another connection for any subscriber in the plant.

One such switch cannot, of course, handle all calls to the 100 lines to which it has access. In the average plant, 10 connectors are sufficient, however, for each 100 lines, because ordinarily not more than 10 subscribers in any hundred are ever receiving calls simultaneously. Consequently a system of 10,000 lines, for example, is divided into 100 groups of 100 lines each, the calls to the subscribers in each group being completed by a set or multiple of 10 connector switches. Where it is found necessary, more than 10 connectors may be put in a multiple; where expedient, economy is attained by putting in less than 10. Uniformity is desirable, however, and it is therefore good practice—although it is not general practice—to exercise some care in arranging the subscribers' numbers, so that each group of 100 will contain approximately the same proportion of frequently used lines to lines that are used less often. The grouping of lines is strictly according to number; that is, all lines numbered from 2100 to 2199 are put into one group and connected to by one set of connectors, while all lines from 2200 to 2299 are put into another group, etc. It will now be understood that a calling party, to complete a connection to a desired line, must first obtain connection to an idle connector switch belonging to the group or multiple in which the desired line terminates. In other words, processes of group selection and of idle switch selection are performed by other switches which do their work before the connector switch is operated.

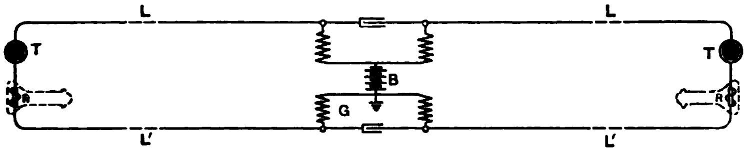

Fig. 8

These switches, which are called selector switches, have already been mentioned. A picture of a selector switch is shown in Fig. 9. It looks, and is, very much like a connector switch; in fact the mechanism and banks are the same. The differences are in the circuits and relays only. In a system of 10,000 lines, these selectors are divided into two classes; namely, first selectors and second selectors. While there is a group of connector switches for each 100 lines to which connections are to be made, there is a group or multiple of second selectors for each 1000 lines to which connections are to be made, and a group or multiple of first selectors for each 10,000 lines to which connections are to be made. The bank contacts of the selector switches are terminals of trunk lines instead of subscribers' lines. The first or lower row of first-selector bank contacts constitutes the terminals for a group of 10 trunk lines leading to second-selector switches in the **1000** section of the plant. The second row represents another group of 10 trunk lines to second selectors in the **2000** section of the plant, the third row represents a group of trunks leading to second selectors in the **3000** section of the plant, etc., so that through the 10 rows of bank contacts the first selector has access to 10 second se-

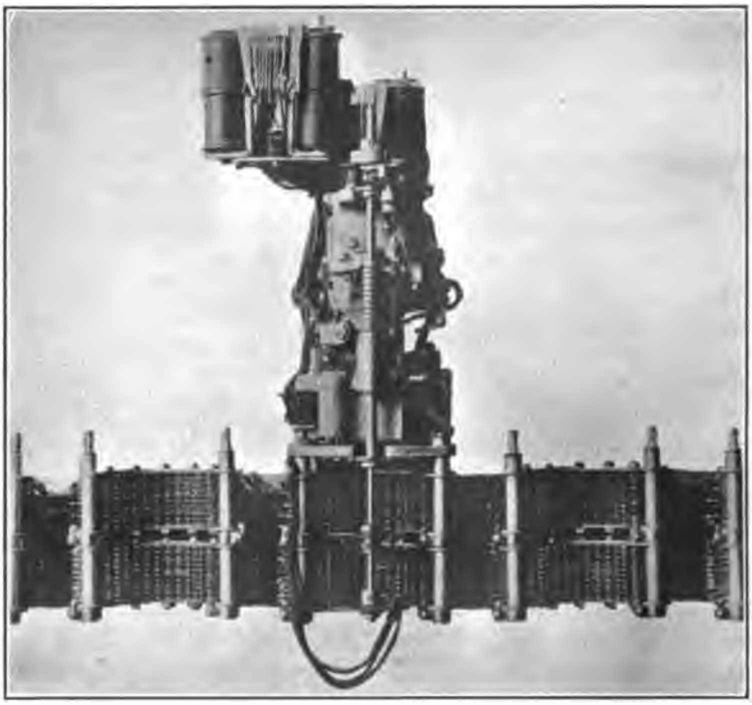

Fig. 9

lectors in each of the 10 sections of 1000 lines which make up a 10,000-line office. The first selector switch used by a calling subscriber is operated in accordance with the first digit of the number he calls. Suppose, for example, he is calling the number **2543**. The impulses sent in by the first movement of his calling device will raise the shaft, and accordingly the wipers of the first selector switch two steps, placing each wiper opposite the row of bank contacts second from the bottom in its respective bank. Now the selector switch unlike a connector switch, does not wait for the subscriber to make another turn of his dial before rotating its shaft, but the rotation is automatic and beyond the subscriber's control.

The rotation starts the instant the vertical movement is completed, and, in the particular case which is here used as an example, sweeps the wipers step-by-step over the row of bank contacts connected to trunks leading to the **2000** section. At each step of the rotation the bank contacts on which the wipers then rest are given the busy test, and as soon as a disengaged trunk line is found the rotary movement stops and the connection is completed to an idle second selector. This is all accomplished in a fraction of a second, so that the second selector is operated by the subscriber's calling device impulses corresponding to the second digit, **5**, of the number **2543** which he is calling. The wipers of the second selector are accordingly raised five steps and are then automatically rotated just as the first selector wipers were. The bank contacts of this second selector are the terminals of the trunks to the 10 sets of connectors which complete the connections to the line groups making up the **2000** section of the plant. Consequently when the second selector wipers stop on an idle trunk in the fifth multiple, the calling subscriber is placed in connection with an idle connector in the 2500 groups; that is, a connector which has access to the desired subscriber's line No. **2543**. This connector is then operated by the last two movements of the subscriber's calling device, and performs the functions of an operator in the manner already described at some length.

Fig. 10 is an endeavor to illustrate this grouping arrangement and shows the connection just described from the calling telephone to a first selector, then from the second row of first-selector bank contacts to a second selector in the **2000** section of the exchange, then from the fifth level of this second selector's bank contacts to a connector switch in the **500** group of the **2000** section, and then through the fourth row of the bank contacts of this connector to the called telephone.

It is readily understood that by thus using a first selector to pick out a trunk to any one of ten different **1000** sections, second selectors in each section to pick out trunks to any **100** group in each **1000**, and then by using the connectors to complete calls to individual lines in each **100**, that connection may be made by the use of three switches from any calling tele-

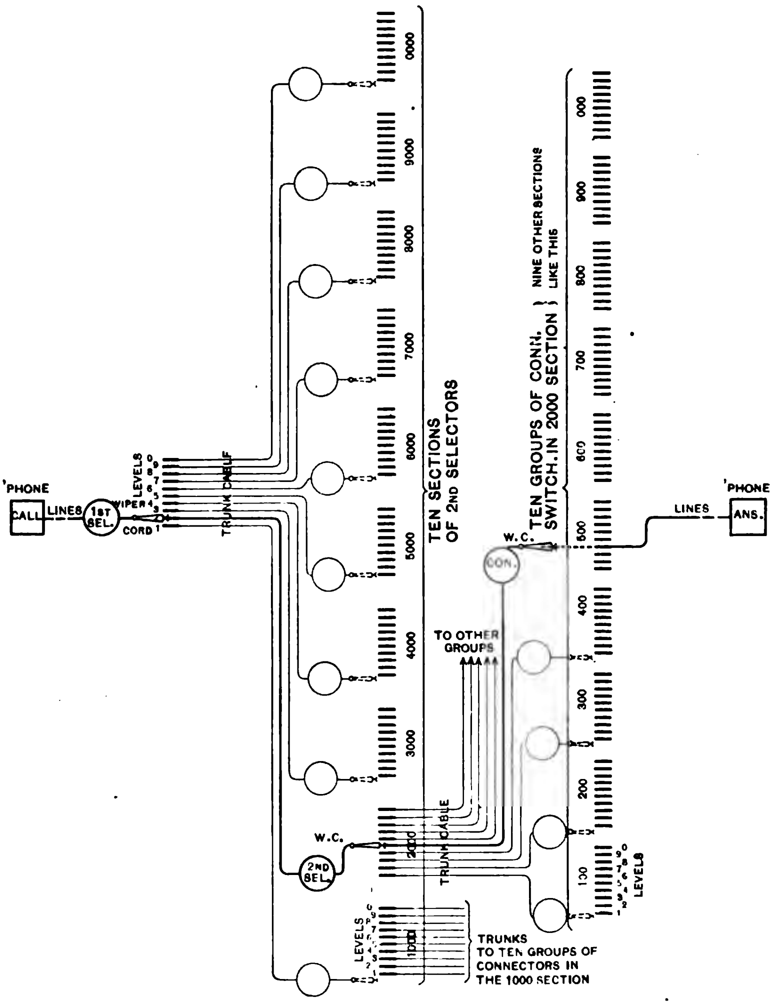

FIG. 10

phone to any number from **0000** to **9999** or in other words to **10,000** different numbers. It will also be readily understood that by using a fourth switch, called a third-selector switch, and using numbers with five digits instead of four, that the capacity of the system will be multiplied by ten and will be 100,000 lines instead of 10,000. In a system of 100,000 lines, **10,000** numbers are generally set aside for each main central office. Consequently on each call the first selector picks a trunk to the desired office, the second selector picks a trunk to the desired **1000** in that office, the third selector picks a trunk to the desired **100** and the connector completes the connection to the desired line.

Systems of 100,000 lines' capacity have been installed in a number of different cities. One of the most notable is that in Los Angeles.. This system is illustrated in Fig. 11. As shown, there are six main offices, each with an ultimate capacity of 10,000 lines.

The Olive Street main office is now equipped for 10,000 lines, West for 4000 lines, Adams for 2500 lines, South for 5000 lines, Boyles for 800 lines, and East for 1000 lines. The numbers in the South Office all commence with **20,000**. Those in Olive Street Office all commence with **60,000** etc.

South office has a branch office called Vernon; West office has two branches which are called Prospect Park and Hollywood; East office has a branch called Highland Park. The numbers in each branch office commence with the same digit as the numbers in the main office to which it connects. That is; one of the sections of **1000** numbers are taken from the main office and are set aside for use in the branch. For example: the lines now equipped in South office are numbered from **21,000** to **25,000** and the numbers in its branch Vernon, run from **29,000** to **29,999**. It is, of course, unnecessary for a calling subscriber to know to which office he is connected or to which office the party he desires to call is connected.

The trunking between offices is all automatic. A subscriber, for instance, in the South office, who, on the first move of his dial turns it from the number **2**, will automatically select a local trunk line to a second-selector in South office. If he makes the first turn from the number **3**, a first selector at South office will automatically connect him to a trunk line terminating in a second selector at East office. Or, if he makes the first turn from the number **6**, the first selector at South Office will automatically select an idle trunk to Olive Street office, etc.

Suppose, a subscriber connected to the South office wishes to call **62,127**, which is an Olive Street office number. The first movement of the dial operates a first selector at South office, and extends the connection over an idle trunk to a second selector switch in the Olive Street office. The second digit **2** will operate the second selector at Olive Street office, and extend the connection to a third selector in the **2000** section of the Olive Street switchboard. The third digit **1** will extend the connection to an idle connector switch in the **100** group of the **2000** section. The last two digits will operate this connector switch and complete the connection to **27** in this particular **100**.

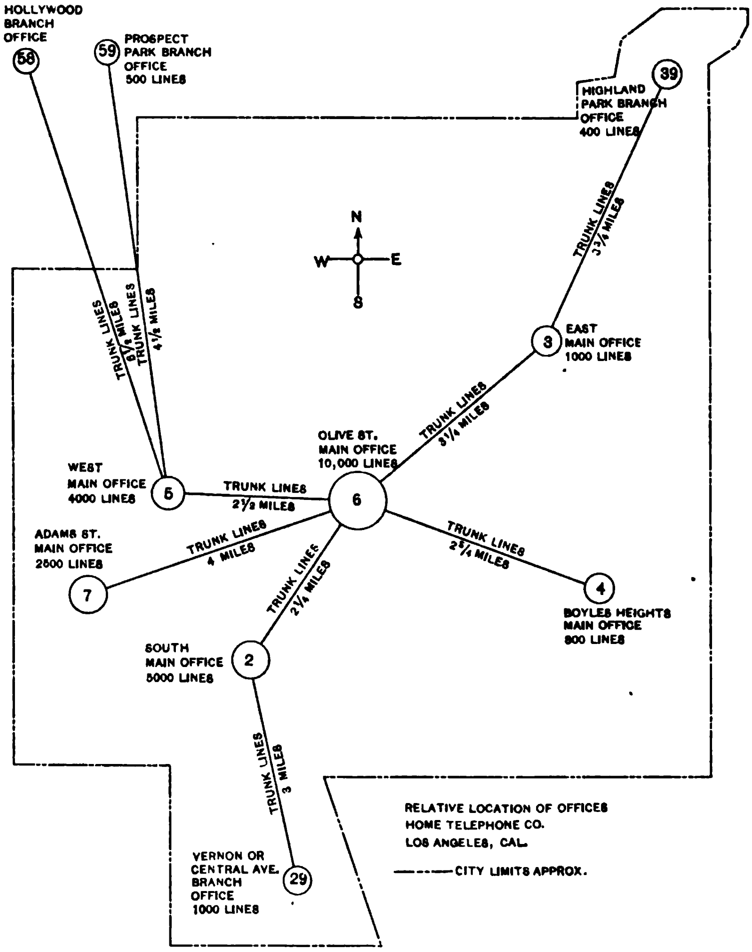

FIG. 11

Suppose, again, that a South office subscriber is calling **39,143** which is in the Highland Park branch office. The first movement of the dial operates a first selector in the South office and selects a trunk to a second selector in the East Main office. The second movement of the dial raises the shaft of this second selector nine steps, and selects an idle trunk to a third selector in the Highland Park branch office. The third movement extends the connection through a local trunk in the Highland Park branch office, to an idle connector in the **100** group, and the last two motions of the dial result in the completion of the connection to **43** in that particular hundred.

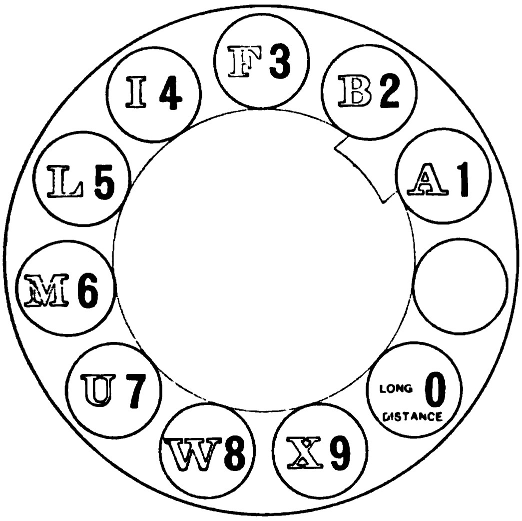

FIG. 12

It is interesting to note that the distance from Vernon office to Highland Park office is over 12 miles, and that the distances between the other offices are quite long. It is therefore apparent that the trunks between switches may be of almost any desired length. It is also to be noted that the time required to complete a connection and the number of machines used is independent of the number of offices through which a connection may be trunked.

It should be said here that in all 100,000-line systems the numbers are made up of a letter and four figures instead of five figures.

Fig. 12 shows a calling-device number disc for a system of this size. Using this arrangement **26,187**, for example, would appear in the telephone directory as B-**6187**. When operating the calling device many subscribers will remember a letter and four figures more clearly than they will five figures.

It might be inferred from the foregoing portion of this paper that there is one first-selector switch permanently connected to every subscriber's line. Formerly this was the case, but in a modern plant each line terminates in a much smaller and a cheaper device called a line switch. The line switch is not under the control of the subscriber, but connects him automatically to an idle first-selector switch the instant he removes his receiver from his switch-hook preparatory to making a call. The first-selector is, therefore, operated by the first impulses transmitted from the subscriber's calling device just as in the older systems. When the line switches are used, 10 first-selectors for each 100 lines are generally sufficient to handle the traffic.

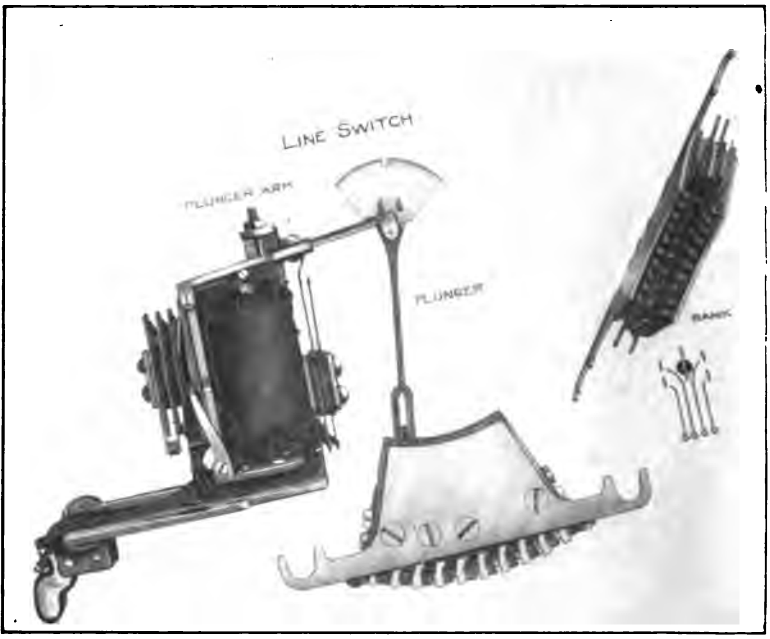

FIG. 13

Each line switch, see Fig. 13, includes the line and cut-off relays with which each line is equipped just as in manual practice. It also includes a moveable plunger arm at the end of which a plunger is so pivoted that it may be swung back and forth over the line-switch bank. The bank consists of 10 sets of springs

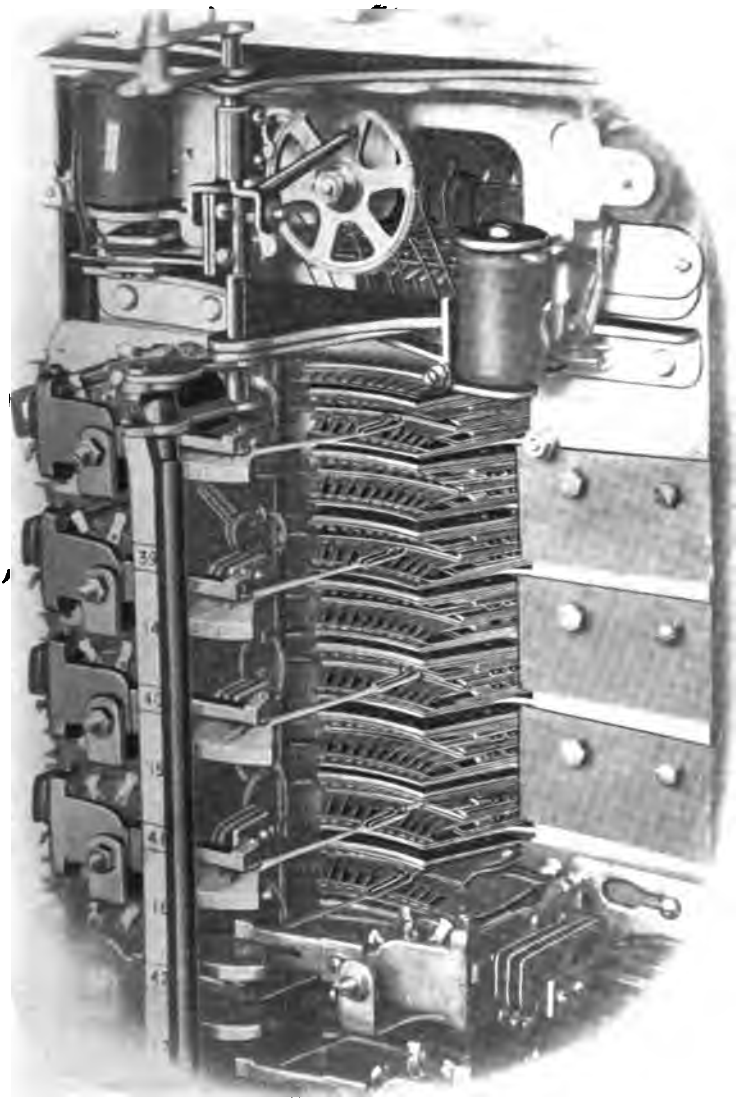

FIG. 14

and represents a multiple of 10 trunks to first-selector switches. The line switches are mounted in groups of 25 each on the face of an upright in such a manner that the plungers are in alignment. See Figs. 14 and 15. The notch in the head of each plunger meshes with a rocking bar or " master shaft " as it is called. A step-by-step device called a master switch (seen in the upper part of Fig. 14) is connected to each pair or to each four master-shafts and by means of them can swing the plungers back and forth, step-by-step over the banks of contact springs. Normally the plungers are at rest poised over bank contacts multipled to an idle trunk.

When a subscriber removes his receiver from his telephone switch-hook preparatory to making a call, a circuit is thereby

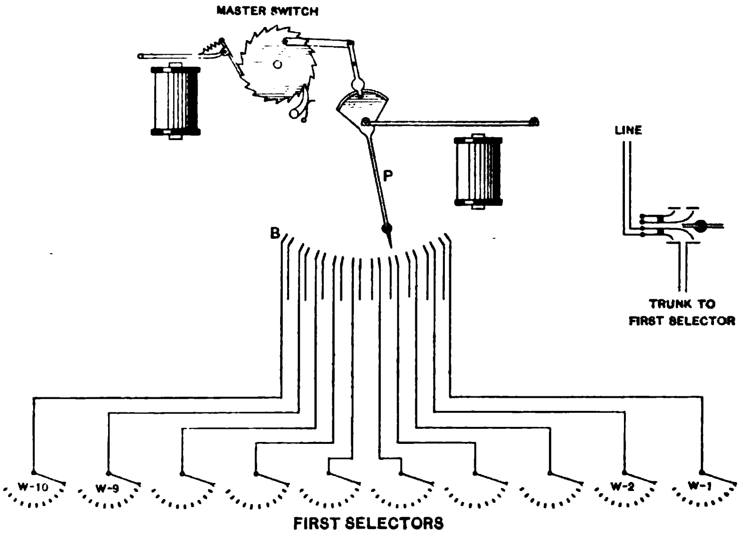

Fig. 15

closed which causes the plunger arm of his line switch to be instantly pulled down, carrying its plunger out of engagement with the master-shaft and thrusting it into the bank. The effect of this is to connect the subscriber's line to a trunk leading to an idle first-selector switch, as shown diagrammatically in the right-hand portion of Fig. 15.

The instant that one line switch thrusts its plunger into the bank, thus occupying the trunk over whose multiple all idle plungers have been poised, the master-switch operates and swings the remaining idle plungers forward over the next multiple of bank contacts. If this trunk should be busy, the movement pro-

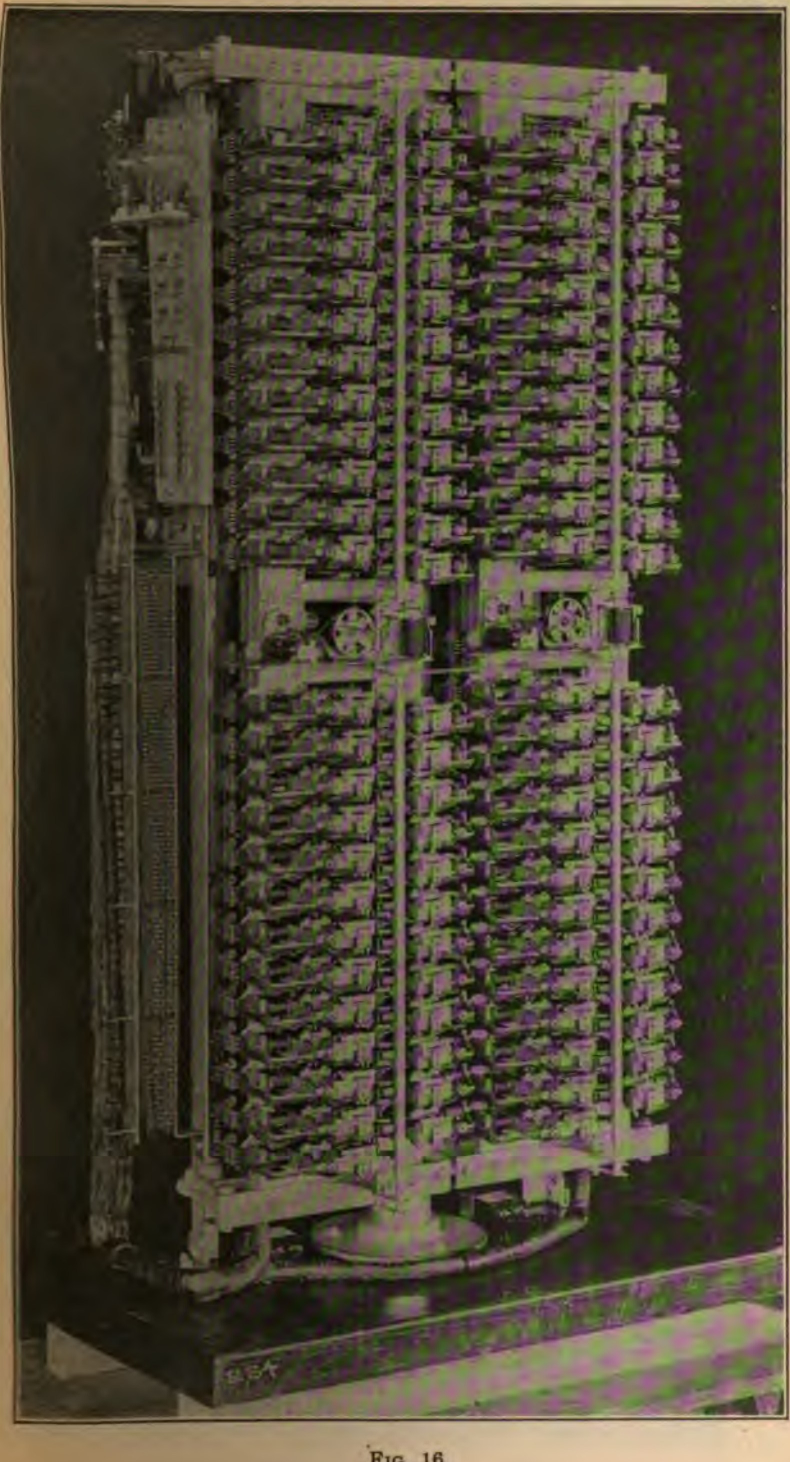

FIG 16

ceeds until an idle trunk is found. It is to be noted that a line switch always uses a pre-selected idle trunk instead of making a selection after a subscriber starts to call as the Strowger selector switches do. This is quite an important feature and saves considerable time in establishing a connection.

Ordinarily the banks of 100 line switches are multipled together and connected to 10 first-selector trunks, but for four-party line service or extra heavy traffic, the number in one multiple is often reduced to fifty. Fig. 16 shows a front view of a complete line-switch unit with 100 line switches and two master-switches mounted. Only one master-switch is used at a time, the other being held in reserve. Fig. 17 is a rear view of the same unit showing how the 10 connector switches used for handling calls incoming to any 100 lines are mounted on the same upright as the line switches handling their outgoing calls.

While the primary object of the line switches was to reduce the cost of the switchboard by eliminating 90 per cent of the comparatively expensive first-selector switches, they have also simplified the central office equipment and have reduced the space required for it. Further, they have resulted in several new and somewhat radical departures in the art of building automatic telephone systems. The most important of these is the line-switch district station which enables very considerable savings to be made in underground and aerial cable.

A district station is installed by placing one or more line-switch units complete with connector switches in a small building at the telephonic center of a district, generally a mile or more distant from the nearest central office. The lines of all telephones in the district are brought to the district station and are there connected to the line switches. The first selectors to which these line switches are trunked remain at the nearest large central office, consequently when a district station subscriber removes his receiver from his switch-hook preparatory to making a call, his line switch instantly puts him into connection by means of a trunk with a first-selector switch at central office. The connector switches for handling the calls to the district station telephones are mounted in their usual places on the back of the line-switch units, and are connected by trunks to the banks of second selectors, also located at the nearest central office. Thus all calls from and to the district are handled over trunks instead of over subscribers' lines.

Since, as already stated, there are usually but 10 first

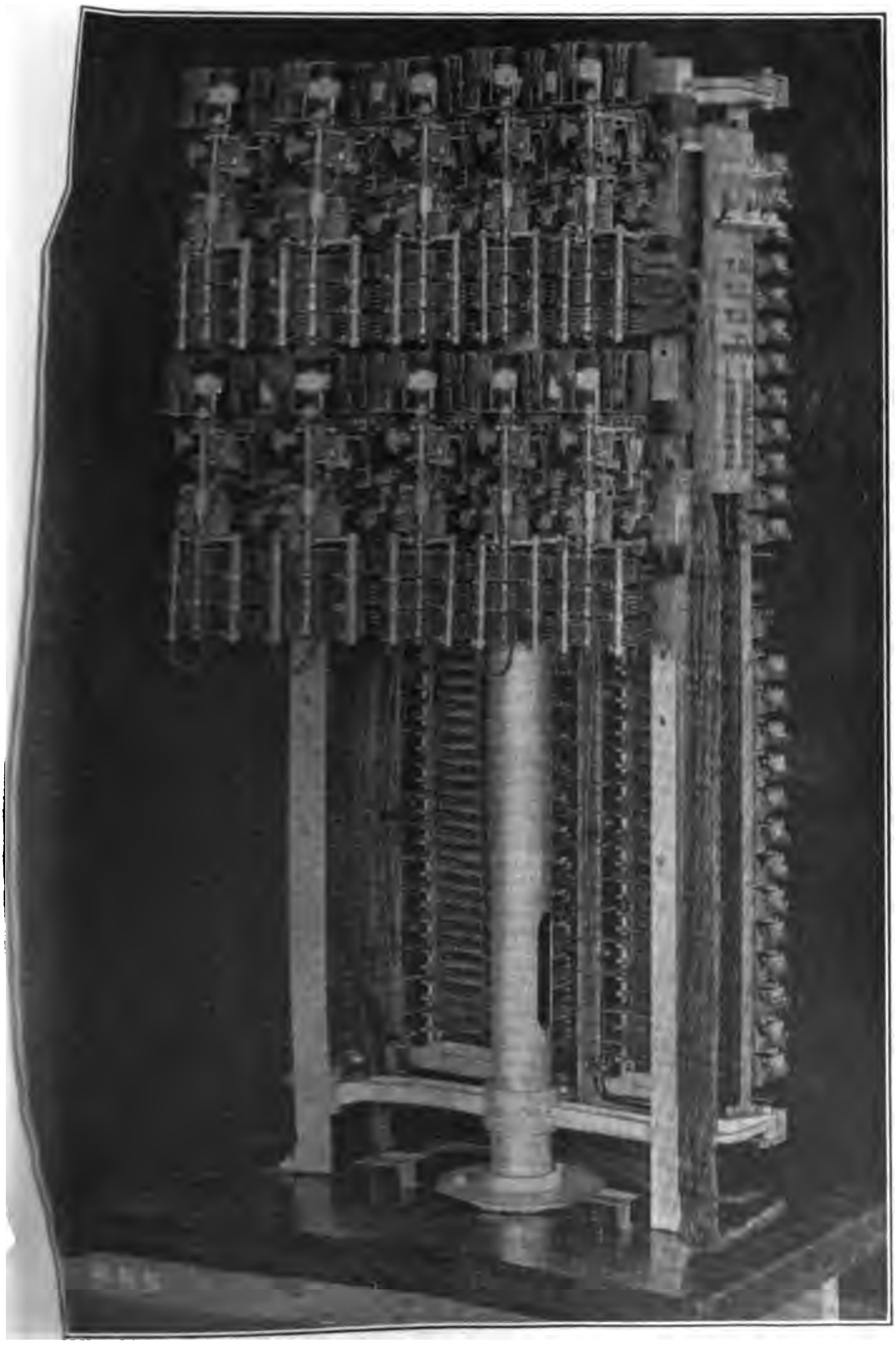

FIG. 17

selectors and 10 connectors for each 100 lines, and since but three pairs are needed for testing and supervisory circuits to the district station, a total of 23 trunk pairs is sufficient between the station and the central office. This leaves a net saving of 77 pairs of wires per 100 lines. In district-station practice stations of less than 500 subscribers are generally unattended and supervised entirely from the central office to which they connect. This is so thoroughly worked out that the wire-chief can test every line entering each district station without leaving his desk at central. Stations of 500 lines or more are generally put into a combination residence and office building so that one attendant living in the building gives the equipment all the attention that it may require at any time.

FIG. 18

Fig. 18 shows the exterior of a typical line-switch district station building 15 ft. by 16 ft. with a capacity of 700 lines. Fig. 19 shows the interior of one equipped for 200 lines.

Fig. 20 is a sketch of a notable system in Columbus, Ohio, using one large central office of approximately 10,000 lines, surrounded by 9 district stations, varying in size from 100 to 600 lines. One of these 100-line units in Columbus was installed as an experiment in an underground vault about the size of an ordinary underground manhole, and has now been so operating for about two years.

One can readily imagine that the trunking scheme of this system would be very complicated if each of the small offices shown in the illustration had trunks to each of the other offices. Furthermore the cost of trunks divided into such small groups would be so much greater, that the saving in line wires would be much reduced and in some instances almost wiped out. But using the district stations each having trunks to no office except the central office (placed near the business center of the city) the trunking plan is a very simple and economical one, and the conditions for centralized supervision of the system are practically ideal.

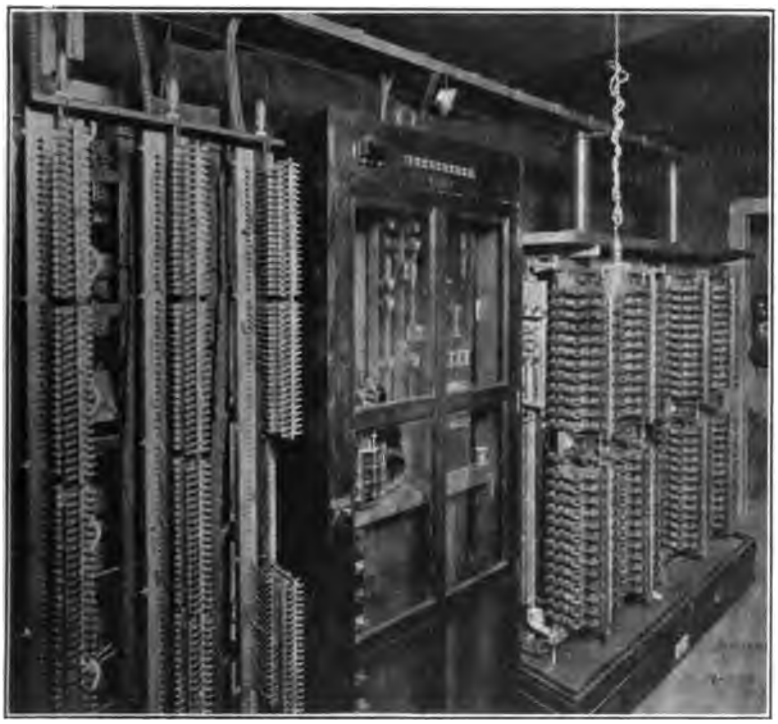

FIG. 19

A new feature called a secondary line-switch has very recently been introduced into the automatic system. The mechanical construction of this switch and of its bank is the same as that of the regular or primary line-switch, and it is mounted and controlled by a master-switch in the same manner. The purpose of the switch is to reduce still further the required number of first-selector switches, and their trunks. As explained, it has been the general practice to install a number of first selectors equal to 10 per cent of the number of subscribers' lines. Observations made in numerous plants at the busiest hour of the day, however, show that at the peak of the load not more than from 1.5 to 5 per cent of the subscribers are using first selectors. The percentage is smaller in the larger plants and greater in the smaller plants, being about 5 per cent for a plant of 1000 lines and not over 2 per cent for a plant of 10,000 lines. This reduction in the percentage of trunks required as the number of subscribers' lines increases, follows a law well known among telephone engineers. The secondary line-switch takes advantage

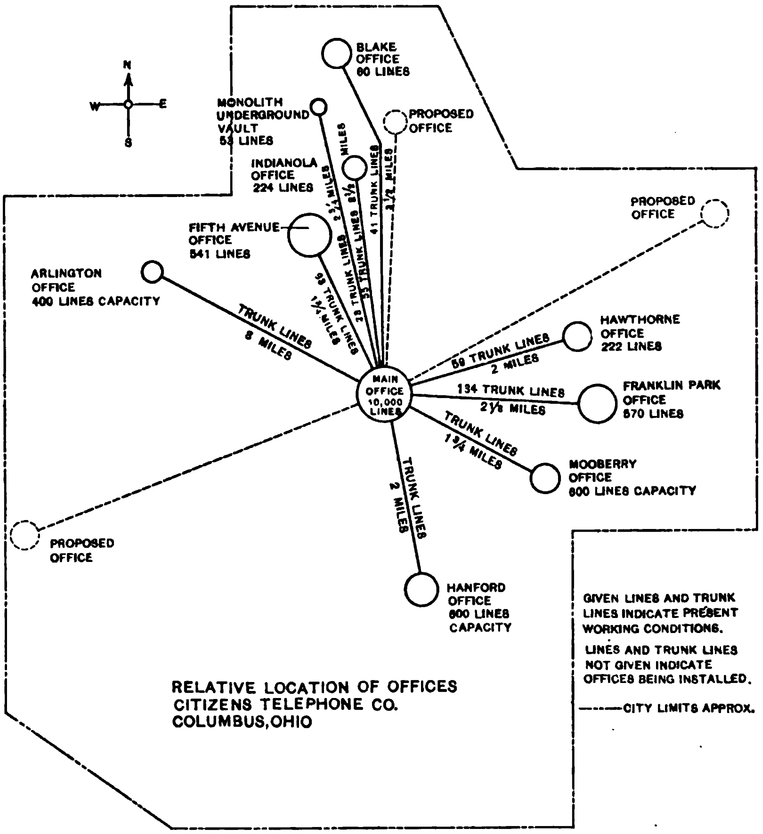

FIG. 20

of this principle by making it practicable to give 2000 or 2500 subscribers' lines access to one group of 100 first selectors. The secondary switches are inserted between the line-switches and the first selectors in such a way that the primary line-switches pre-select idle secondaries and the secondaries pre-select idle first selectors. Therefore, when a subscriber lifts his receiver from the switch-hook preparatory to making a call, his line-switch and the secondary to which it connects him operate almost in unison. This re-selection of trunks, combined with a rather complex system of cross-multipling, accomplishes the desired result of giving a large number of subscribers access to one group of trunks, and thereby reduces the number of trunks and first selectors. It is obvious that if the first selectors are at a considerable distance from the line-switches, for example, in a central office while the primary and secondary line-switches are in a district station, that these secondary switches will save materially in the cost of trunks to the first selectors.

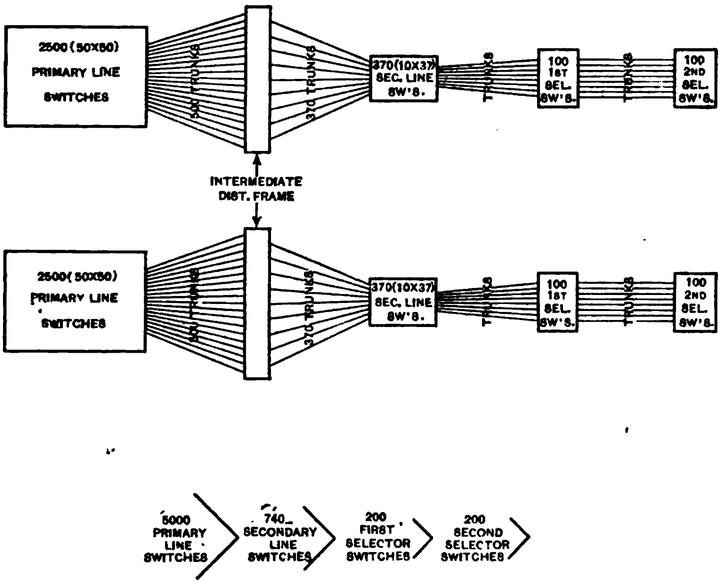

FIG. 21

Fig. 21 shows the use of secondary line-switches in the general trunking equipment scheme for one of the automatic offices now being installed in Havana, Cuba. This office is equipped for 5000 lines. The line-switches are divided into two large groups each of 2500 lines, and each consisting of 50 small groups or multiples of 50 lines each. The trunks from a 2500-line group pass through an intermediate distributing frame to 370 secondary line-switches, arranged in 10 sets of 37 each. Each of the 10 sets has trunks to 10 first-selector switches. Thus, all calls from 2500 lines will be handled by 100 first selectors.

An automatic system equipped for 15,000 lines divided among four offices, was installed in San Francisco last year. Secondary line-switches are there used between the line-switches and the first selectors and are also used to reduce the trunks between offices. In former practice each inter-office trunk terminated in first-selector banks at the calling office, and in a second-selector switch at the called office, but in San Francisco each trunk between offices terminates in secondary line-switch banks at the calling office. Then, short local trunks connect the secondary line-switches to the first-selector banks. Fig. 22, illustrates the trunks outgoing from Main office to Howard, West, and South offices, indicating that the secondary line-switches reduce the trunks to Howard office from 120 to 60, the trunks to West office from 70 to 35, and the trunks to South office from 70 to 35, by combining the trunks coming from the first-selector banks in groups of 10 each, into one group to each office.

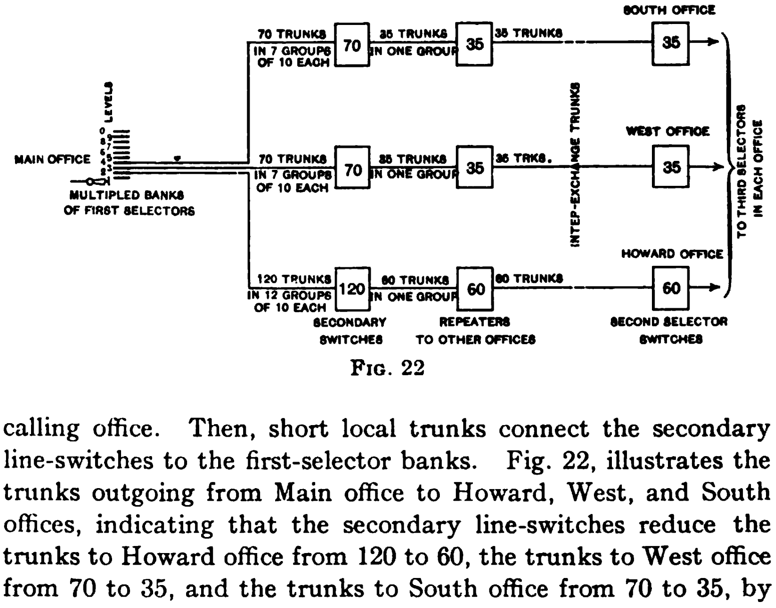

FIG. 22

Inter-office trunks in automatic systems are equipped with another piece of apparatus which is also indicated in this sketch and which is called a repeater. This is simply a set of relays, and derives its name from the fact that it repeats the calling-device impulses from the subscriber's line to the trunk. It serves another important purpose, for through its relay coils, talking current is supplied to the transmitter of the calling subscriber.

Talking current is always supplied to the called subscriber's telephone through the connector switch used in calling him. Such an inter-office talking circuit is shown diagrammatically in Fig. 23. Each subscriber always receives talking current from the office in which his line terminates. This is in conformity with the best practice which requires that the subscriber's " loops " shall be as short as possible, and as nearly alike in resistance as conditions will allow. This makes it practicable to supply all transmitters with sufficient current through small and economical line wires, and to supply them all with comparatively the same amount of current.

The length of this paper precludes a discussion of the mechanical details and circuits of the machines and their accessories, even if it were thought that a considerable number of the members of the Institute would be interested in such a discussion.

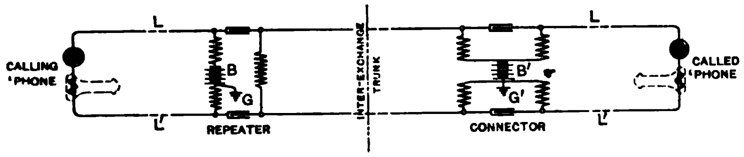

FIG. 23

There are just two measures of permanent success for any telephone apparatus. One is its popularity with its users and the other is the profits it affords the owners. Numerous investigations, some of them made on a very large scale have, to the best of the writer's knowledge, always resulted in the verdict that automatic telephone service is preferred to manual service by the large majority of telephone users, and while the first cost of the equipment is greater than that of manual equipment, the elimination of operators' wages, the saving in building space, and the savings in cable and conduit (discussed at length in the writer's Atlantic City convention paper) have generally made automatic equipment a more profitable investment than manual equipment.

While a considerable number of small private automatic plants are in use, public automatic systems are generally confined to cities and the larger towns. For where a manual switchboard is so small that during a considerable portion of the day one operator can make all local connections and, in addition, handle all rural and long-distance calls, it is very difficult and generally impossible for an automatic switchboard to compete with it. The larger the system the more economical automatic apparatus becomes. It is a matter of common engineering knowledge that automatic machinery is not warranted in any class of work until the output desired becomes sufficiently large.

STATING THE CASE DIFFERENTLY

When automatic machinery is substituted for manual labor it is generally for three purposes.

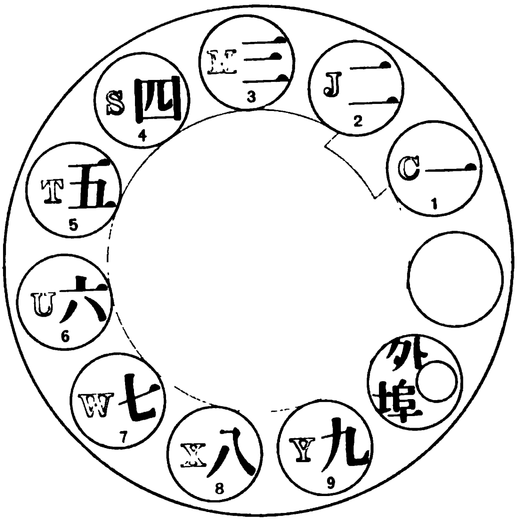

FIG. 24

1. To increase and quicken production.
2. To reduce the cost of the product.
3. To secure uniformity both in the quality or form of the product and in the time required to make it.

These results have been generally attained by automatic machine telephone switchboards.

Among the reasons for the popularity of the service it may be noted that almost every one likes to feel that the making and breaking of each connection is entirely in his own control. The quickness with which connections are obtained appeals to the subscribers, and in relation to this it may be said that while connections are generally obtained more quickly than in manual service, the difference in time seems much greater to the subscriber than it really is, for two reasons: first, he is occupied in turning his dial while the connection is being put up, and the time, therefore, passes more quickly than it would were he waiting for an operator. Secondly, subscribers generally answer calls received through automatic telephones more quickly than those received through manual telephones. This can readily be explained by an example: For instance, a grocer will answer his automatic telephone more promptly, because he knows that the customer calling him will hold him directly responsible for any delay; otherwise the switchboard operator would probably get the blame.

The instantaneous disconnection is another good feature which is appreciated by any one who has occasion to call several numbers in rapid succession.

Bankers, doctors, and others, who have private matters to discuss over the telephone wire appreciate the comparative secrecy of the system.

The uniformity of the service at all hours of the day or night, holidays and Sundays included, is attractive to many.

A foreigner or a person who does not speak plainly often has considerable difficulty in getting an operator to understand correctly the number of the subscriber with whom he wishes to be connected. This is even a common cause of complaint among telephone users who move from the southern part of our own country to the northern part. Fig. 24 shows a calling-device number disc such as used in the Chinese quarter of San Francisco. This disc is equipped with Chinese characters, and up to this time the section of the automatic switchboard which serves "Chinatown" is one of the busiest in the exchange.

A WORD WITH REFERENCE TO THE FUTURE

Although inventors have been giving attention to automatic switchboards as long as to manual switchboards, and although automatic equipment has passed through as many stages of development, and in many instances through stages of development similar to those through which the manual apparatus has passed, yet the former has not by any means reached the dead level of "no more beyond" that the latter has. From one view point this is discouraging, but on the whole it is inspiring, for while those who are most familiar with automatic equipment are most painfully aware that it has not yet been brought to its highest possible state of development, they are, at the same time, its most enthusiastic admirers, and they hope, by further development, simplification, and reductions in first cost, that many families who cannot now afford telephone service of any kind will have it offered to them at a price which they can pay and that the telephone will thus eventually become a universal household necessity. They also hope that the automatic operation of many long-distance lines will greatly increase their capacity and consequent efficiency. This has been tried on a small scale between Columbus and Dayton, Ohio, with very encouraging results. Inasmuch as both of these cities are equipped with automatic switchboards for local service, it was only necessary to have a toll line terminate in the automatic switchboard in one city and in a calling device before a long-distance operator in the other city to make a trial. It was found that connections could be put up much quicker than in the ordinary way. This plan is used very satisfactorily by several automatic companies for handling their own short local toll lines, by giving the operator at each suburban town a calling-device, and allowing her to call all parties in the city automatically without any supervision at the city end of the line. While the opportunity for an operator cheating the company by not reporting all fees earned and collected is greater than with double checking, this has not been found to be a serious drawback. In fact, it is possible to bridge an ordinary stock ticker across the line in such a way that it records every call the operator makes and the length of every conversation. It has been found, however, that the knowledge that this could be done, and might be secretly done at any time, has been sufficient to prevent any tendency toward dishonesty. Careful tests and comparisons made by one company using a considerable number of these short automatic toll lines showed that sufficiently busy lines handled three times the number of conversations that was possible with the former arrangement.

DISCUSSION ON "MODERN AUTOMATIC TELEPHONE APPARATUS," NEW YORK, FEBRUARY 11, 1910

Chairman Maver: It may be of interest to note that in telegraphy two general systems are employed, namely, manual telegraphy, and automatic telegraphy. The first relates to the hand transmission of messages and the second to the machine transmission of messages. In telephony we also have manual and automatic systems, so called, but these relate to the manner in which subscribers' circuits are coupled into one metallic circuit at the exchange and have nothing to do with the transmission per se of communications, which is of course effected by the subscribers' voice. It is of course well known that in the present day practice of telephony each subscriber in a given district is connected with central by two wires, the terminals of which, in the manual system, are led into a switch board in the exchange and normally end there. There is in the circuit of these wires a relay which closes a circuit containing a small incandescent lamp which lights up when the subscriber lifts his telephone receiver from the hook, thereby indicating to the attendant operator in the exchange that a connection is desired. Upon listening in and ascertaining the number of the desired subscriber the operator by means of jacks and cords performs the operation of placing the lines of these subscribers in a through metallic circuit, ready for intercommunication. In a large exchange one operator can attend to the calls of about two hundred subscribers. In automatic telephony on the other hand the operation of coupling up the circuit of a calling subscriber with any other subscriber is performed automatically in the exchange by selecting and connecting apparatus controlled by impulses of electric current established primarily by the calling subscriber.

The question of automatic telephony is perhaps not a very active issue with us in the East at present, but it is decidedly so in the western part of this country, where it is in quite extensive operation, and also to a smaller extent in the eastern part. For instance, New Bedford and Fall River, Massachusetts have automatic telephone exchanges that have been in successful operation for the past eight or ten years.

I am sure, that we all feel under obligations to Mr. Campbell and to the company with which he is associated, for their courtesy, in not only presenting the paper, but also in bringing before us this model working exhibit of the apparatus, and on behalf of the Telegraphy and Telephony Committee, I desire to express our hearty appreciation of this courtesy.

Before calling for discussion, I will ask Mr. Campbell to kindly show us the manner in which the ringer arrangement acts in this apparatus and also to point out the location of the Keith line switch.

(Mr. Campbell then briefly described the apparatus and gave further demonstrations.)

Ralph W. Pope: A discussion of a system of this kind naturally brings up a comparison with other systems. We have been through various discussions of that kind in this room, that have sometimes raised the temperature appreciably. This is a case, however, where we are not called upon to discuss the question of whether or not the apparatus works, because we know that it does work. I think that our vision can be cleared sometimes by taking a reverse view of the conditions. There is always some doubt as to whether an automobile is better than a horse, but if we always had had automobiles, would we use horses to supersede them? So, if we had always had the automatic telephone system in use, would we be talking about introducing the manual system as an improvement.

I have been much gratified, in reading over the paper, to see the modest claims made by the author, and to note that he has refrained from saying that the automatic system will answer in every place and under all conditions. In a certain sense, I am quite familiar with it, so far as lapse of time is concerned. I was Chairman of the Committee on Telegraphy and Signalling at the World's Fair in Chicago in 1893, when we examined the Strowger system which was at that time on exhibition. I believe that it did not receive an award, because of its crude construction, and it was felt that it did not appear equal to the claims made for it; and I think I am safe in saying that it was not then in use to any great extent. Rather curiously, we considered at that time the question whether it was really adapted to large cities, and it seemed to be the opinion that it was better adapted for the smaller cities and the question of its suitability for the larger cities had not been proved. Since 1893 its utility has been proved, and here in New York, where we are supposed to be able to get the best of everything there is, and to see everything that is worth seeing, it remained for the American Institute of Electrical Engineers to have a working exhibit of this automatic telephone system for the public to come and examine.

Last summer I visited the Pacific coast, and there, for the first time since my experience in Chicago some seventeen years ago, I had the opportunity of examining the automatic system in operation in Portland, Oregon. It was rather a novel experience to be in that exchange of about eight thousand lines, and to see the connections, or rather hear them, being made throughout the room, with practically no one in attendance at all; and another thing I learned there in Portland, from our own members, who were simply subscribers to the automatic system, was that from their experience they preferred the automatic system to the manual system, on account of its certainty of conveying the signals, and not giving the wrong numbers. Another point, which was new to me, and which was first made known to me by a subscriber who was an electrical man and had an automatic exchange system connected with his residence, was that occasionally a lineman came looking for trouble on the circuit before the subscriber knew that there was any trouble. It appears that in the exchange, instead of waiting for trouble to be reported from the outside, they can locate the trouble on the line from the exchange and remove it promptly before the subscriber is aware that there is any trouble.

Another interesting device connected with the system, which was called to my attention, was the meter for registering the calls. It appears that in some of the cities on the coast the franchise requires that the telephone exchange system must be on a meter basis, that is, that the subscriber must pay by the number of calls. The result is that the companies are obliged to meter the system, and the meter not only registers completed calls, but it discards " service " calls and discards calls that are not completed, so that the meter actually registers only the calls that are to be paid for.

From Portland, Oregon, I went to San Francisco, and there the Home Telephone Company's system was in process of construction. I visited the main exchange and several of the branches, and it is quite certain and evident that the people who are building that system have faith in the automatic telephone exchange, for the reason that it is one of the best and most expensively constructed systems that I have ever visited—all the exchanges are fire-proof, the wires are underground, led up in lead-covered cables, and as far as I could see no expense has been spared to make the installation first-class in every particular.

It must be remembered that the manual system may be properly divided into two classes, so far as the subscriber is concerned—the subscriber may work direct with the exchange or he may work through a private branch exchange. In the course of my experience I have found that the perfection of the manual system depends very largely on the disposition, the voice and the attention of the particular operator that has charge of the section with which one is connected. I feel that with the introduction of a private branch, while the operator usually has less on her mind, that we do not receive the short and petulant answers, and the impression that we are trespassing on the time of somebody, and we had better be quick about it, that we get when we are connected with the main exchange. Right here, while this has no bearing particularly on the paper, I think it is well for all of us to remember, and I presume we have criticised it—that when the operator at the exchange repeats back the number wanted, we can rarely understand what the number is, and if you wish to correct it, the operator has gone, so that that time is practically lost, and I understand that the practice has been abandoned in some of the exchanges for that reason. It may have been due to Mr. Campbell's Chicago voice that he brought with him to-day, but when he undertook to make a telephone connection from my office, he succeeded twice in getting the wrong number, and we began to think that the number was wrong in the book, but I believe he finally succeeded in getting connection with the subscriber. I am free to confess that this was a rather bad exhibit to make of the manual system to a gentleman who came here with this exhibit we see to-night.

Chairman Maver: I will make some additional remarks, and read one or two communicated discussions, to one of which Mr. Pope has referred. As Mr. Pope has said, Mr. Campbell is quite modest in his claims, and therefore, even if one were disposed to be critical, not much opportunity is afforded. Mr. Campbell presents his apparatus almost as though it were on trial, whereas it is in actual operation on a large scale in over fifty cities and towns in this country, embracing a total of 250,000 subscribers.

Mr. Campbell refers to the somewhat crude apparatus first employed in the system which he has described in his paper, in which the calling subscriber pushed buttons corresponding to the call number of the called subscriber. There were, however, more cumbersome ways than this employed in some of the early automatic telephone systems, to one of which (the Callendar automatic telephone) I may refer, as it may help to show the manner in which our predecessors sometimes groped about to reach a desired point; just as our successors will no doubt observe that we of 1910 have only been groping in many things, where we imagine we have reached the acme of perfection. The Callendar automatic telephone was, I believe, in limited use for some time in this country. By reason of its awful and wonderful design it is worthy of passing mention. Each subscriber's wire was led into the central exchange in such a manner and so arranged with regard to certain mechanism that when a subscriber called he was first connected with a "numerical receiver." This numerical receiver had a movable grooved arm, in the form of a rail, which was adapted to make contact with certain other rails as required. In a suitable receptacle were kept a number of metallic balls, which were allowed at the proper moment to roll into the traveling rail from which they were delivered to the subscriber's rail. The subscribers' rails were placed across certain conductors normally not touching. At each point on a rail, where it crossed a conductor, a trap was placed in the rail. When any one of these traps was opened a metallic ball coming down the rail fell through the trap and made contact with the conductor below. Each subscriber was allotted a rail and a cross conductor. When, then, a certain subscriber desired a certain other subscriber, he would give the necessary impulses of current which would bring the traveling rails into position with the rails of the desired subscriber, and the metallic ball would then pass from this receptacle on to the subscribers rail up to the point where a trap was found open, when the ball fell through and made connection with the subscriber's cross-connected conductor. In short, by the mechanism employed in this system, the subscribers, by a process of selection, were finally automatically connected and they were isolated from other subscribers while thus connected. When through, one or other of the subscribers pressed a release button; the traps were closed and the balls were returned automatically to their receptacle, ready for other calls.

It is to be feared that if automatic telephony depended on a system involving contact by movable rails and rolling balls it would be within bounds to predict that hopes of its ever attaining commercial usefulness would be meagre.

One of the most frequent objections that was offered to automatic telephony in its early days was that the multiplicity of contacts necessarily employed would prevent its successful operation, and it used to be pointed out that whereas in a manual exchange for 5,000 subscribers there are, for instance, something like 133,000 pairs of contacts, in an automatic exchange for 5000 subscribers there might be 1,000,000 pairs of contact in the first selectors alone. The introduction of the Keith line switch, however, has reduced the number of such contacts in the automatic exchange by perhaps eighty per cent. Even, however, before the introduction of the Keith switch, comparatively little trouble was experienced by the great multiplicity of contacts in the automatic exchange; and from actual observation it is my experience that such troubles are quickly indicated by supervisory signals.

Another point that may be mentioned is that the wear and tear on the automatic apparatus is inconsiderable. This is partly due to the fact that much of the apparatus is not in operation more than 2 to 5 per cent of the time. Apart from this fact, actual experiments with certain automatic apparatus, where the mechanism was operated by machinery over 1,000,000 times, shows that the wear of the parts was not perceptible.

There is no doubt that the large amount of apparatus and the multiplicity of contacts employed in the automatic coupling of subscribers circuits tends to the occurrence of troubles that are unknown in the manual systems. An instance of these troubles of comparatively frequent occurrence is the " off normal " troubles, due to a failure of some part of the apparatus to complete its full function or to return to normal position. This for example may be due to sticking of the wipers in the bank contacts, to imperfect contacts, etc. In the common battery system of the manually operated exchange there are numerous delicately adjusted relays operated automatically, and in the multiple switchboard of the same system there are countless contacts, jacks and cords, subject to handling in no delicate manner, and all conducing more or less to the production of defects, but it may fairly be assumed that the occurrence of contact and apparatus troubles in the manual system is less frequent than in the automatic system.

It is, however, a fact that while the occurrence of such troubles is comparatively frequent in the automatic system, nevertheless the methods adopted to promptly announce or indicate the occurrence of defective operation to the attendants, by supervisory lamps and other signals, are so efficient that in the large majority of cases the defects are discovered and rectified before the subscribers concerned are aware that such troubles have existed. Further, the attendants become so accustomed to the rhythmic sounds of the apparatus in the process of making normal connections that their ear detects any abnormal operation of a piece of apparatus almost before the supervisory signal can indicate the defect. By reason of this ability of the attendants to recognize non-completed calls they are frequently able to assist in completing a call. This is done by cutting in on the calling subscriber's line to inquire the number of the called subscriber, on learning which the attendant rotates the various parts of the apparatus manually as required for the proper connection. I believe that a daily average of about 16 such " assist " calls has been noted in one large automatic exchange. In consequence also of this ability of the attendants to forestall and to quickly rectify apparatus troubles in the exchange, the disadvantage of the occurrence of such troubles loses much of the weight it might otherwise possess. Obviously, in this as in many other systems, electrical and mechanical, constant vigilance is the price of good service.

The advantages rightly claimed for automatic telephony are numerous. Of course the most important one is that of dispensing with the need of operators at the exchange, not only in effecting a large saving in operating expenses, but also by solving the " girl " problems in the exchanges, which involve training the girls, their leaving the service abruptly when trained, the necessity for resting rooms in the exchanges, etc. These problems, together with the difficulty in obtaining operators suitable for the work in certain localities, have frequently been the deciding factors in determining the adoption of an automatic exchange. There is also the further important advantage that, in the aggregate, much time is saved in the automatic method of connecting, and more especially of disconnecting, subscribers, which admits, among other things of the use of a lower percentage basis of apparatus and of trunking circuits.

It is also evident that the percentage of " wrong number " calls is, in the nature of things, much higher in manual than in automatic exchanges, the difficulty in hearing numerals by telephone, and the repetition from voice to voice accounting for much of this confusion. There is perhaps no greater single cause of annoyance to subscribers, and of loss of valuable time in effecting connections to a telephone company, than this matter of " wrong number " calls. The claim for secrecy in the automatic system does not have much weight with me although it appears to do so with the general public. It is my experience that the operator in a busy manual exchange has little time and less inclination to listen to the subscribers conversation.

As the result of a wide investigation of automatic telephony in the United States and Canada, I can confirm the claims made for automatic telephony by its advocates as to its popularity with the general public where it is established, especially that basic feature of the art which enables the subscriber to make his own calls without the intervention of an operator.

E. A. Mellinger: A field for further development of the automatic system is suggested by Mr. Campbell's reference to small exchanges. Since a very large proportion of the telephones in use in the country are in exchanges of 500 lines or less, the development of a simple inexpensive switchboard designed especially for use in the small town exchange would go far toward making the telephone universal.

Aside from the economic consideration pointed out by Mr. Campbell, the chief problems which present themselves as affecting the practical operation of small automatic exchanges using the present type of equipment are the maintenance of the battery supply and the care of the apparatus. These problems are successfully solved in the case of private installations, as is indicated by the number of these exchanges in use in government and state institutions, industrial plants, mines, etc.; but in these instances ample facilities exist for charging storage batteries and a competent electrician is usually at hand to attend to trouble which might arise, or to make needed adjustments or changes. The average town exchange of one hundred lines or thereabouts is at a serious disadvantage with respect to these items, which it would appear might be at least partially overcome by the use of simple equipment constructed especially for this kind of service.

Concerning the economic disadvantages of small automatic exchanges, it would be of interest to some to know how large an exchange must be to justify the use of automatic equipment as now installed, and what factors are to be considered in making a comparison. A consideration of the data available from a number of both manual and automatic exchanges indicates that the automatic begins to show an economy at about 500 lines. In a typical modern manual plant of this size there are employed eight operators at an annual expense of $2,160. As against this, an automatic plant of 500 lines has one operator or clerk and a switchman, totaling $1,100.00 per annum, thus showing a net average in operation over the manual exchange of $1,060.00.

Assuming that the automatic equipment, telephone and switchboards, will cost $8,500.00 in excess of the manual equipment, and allowing on this excess investment six per cent interest and six per cent for depreciation, we find that these annual charges amounting to $1,020.00 are just about equivalent to the saving effected in maintenance and operation. The other factors entering into consideration total about the same in each case, and would not appreciably affect the result, except that the smaller floor space required for the automatic switchboard would be an item in its favor.

Local conditions in small exchanges vary so greatly that this figure of 500 lines cannot, of course, be taken as authoritative. Public automatic exchanges of fewer than 200 lines have been operated satisfactorily and economically, but it is probable that under present conditions the average exchange of less than four or five hundred lines cannot afford to install automatic equipment except that the greater popularity of automatic service might be considered as an economic advantage as it undoubtedly is in most instances where competition exists.

E. L. Lehman: Mr. Campbell's description of the working of the automatic telephone appears to be well set forth, but what about the apparatus that does not work or cannot report when out of order? After all, it is the efficiency of repairs and cost of maintenance that satisfies the subscriber and lowers the rental charge. The fundamental requirements of operation to be met in maintaining both the manual and the automatic systems may be briefly summed up as follows: The " busy " and " trouble back " signals, " don't answer," " receivers off," and line and trunk troubles. In the manual switchboard any trouble occurring with the "busy" or "trouble back" signals would be noticed instantly a connection was put up. " Don't answer " reports are given to the calling subscriber if the called subscriber does not answer. In the case of a business subscriber or the calling subscriber insisting that the called subscriber is within hearing of his telephone a report of " can't raise " is given to the wire chief who makes a test on the line and quite often finds the line in trouble, in which case repairs may be quickly made.

Another important item in maintaining telephones is the loss of incoming calls to subscribers who have left their receivers off the hook. In a manual exchange of about 6,000 stations, a percentage of about 1.5 per day is comparatively small, and the percentage to total calls outgoing and incoming would amount to one-quarter of one per cent. Yet if these stations had their receivers off all day the loss in outgoing and incoming calls would amount to the considerable sum of 1,200, or three per cent of the total calls for the day. It is safe to say that, with the present system of plugging out on the manual system, very few calls are lost, as the subscriber is reminded to hang up his receiver by a high frequency tone thrown on the line.

Relative to lines in trouble; operators are quick to report swinging grounds, receiver circuits open due to tips out, etc., poor transmission, etc., while the plugging-out system takes care of a large percentage of instrument, line, cable and office trouble, such as shunts, grounds and open circuits. Trouble on trunk lines, office to office, may be intermittent yet are quickly noticed by an operator.

One more comparison occurs to me, namely, the calling of private branch exchange numbers or any subscriber that has two or more lines, generally numbered in consecutive order. In the manual operation, if such a subscriber is called, and the number called is busy, the connection will be put upon the next available trunk line, while the automatic subscriber would probably have to look up the number and call until a trunk line not busy was found.

Query: Can the automatic system be controlled to such an extent that a subscriber's station may not be out of order over a period of two or three hours before the fact is known by the switchman?

H. W. Pope: Some fourteen years ago I met Mr. Campbell at Augusta, Georgia. One of the first systems of automatic telephony was introduced in that city, with one selector, as I recall it, to each line. It was a very crude affair, and the wonder to me was that it worked at all, and I presume it was very largely due to the care of the man in charge of it that it did work.

There are some things that this paper hardly touches upon—in fact, you would hardly expect it to—and these are the questions of maintenance and of depreciation. Now, I have an idea that the cost of maintenance is a very large item in connection with the automatic system. I am laboring under the impression that it requires a skilled man for every thousand telephones, which would be quite an item in a large exchange, for skilled men do not work for nothing, and this system is particularly applicable to large exchanges. Of the matter of depreciation, I have no reliable knowledge. I understand there has been a system in operation in Fall River for something like ten years, which has shown a depreciation not to exceed, I think that of the manual board. Mr. Campbell has refrained from saying anything in this connection that would lead to any argument or criticism.

Another thing which occurs to me is this; a good system, whether manual or automatic, should be one that is available for all people, for the illiterate and for the blind, or for any person that can speak the language of the country in which the telephone system is operated. Now, the automatic system especially as regards the requirements for the placing or transmitting of the call, does not meet these conditions as easily or as simply as the mere act, in the manual system, of lifting the telephone from the hook. I do not know how you could handle this automatic system in the dark, unless you were very familiar with the transmitting apparatus, and that is quite an essential thing, so far as its use in residences is concerned. In case of danger, fire, burglary, or anything of that kind, the mere fact that if, in the manual system, you take the telephone off the hook, attention is called to the fact that something is the matter, is of very great advantage. I read only yesterday or the day before of a case of suicide, where the information was gained from the telephone; the woman who committed suicide left the telephone off the hook and they heard her groan. That is a newspaper story, but I can imagine cases where emergencies might arise whereby attention would be called in this manner. Of course, it is a small thing, but it is worth considering in connection with automatic systems. A blind man is certainly prevented from using the automatic telephone, and we have many blind people who use the telephone.

I do not think there is much in the contention as to the rapidity of the signalling to the central office. Of course, the subscriber in working the automatic system is busily engaged in whirling around the transmitting devise to the proper point, and he does not realize the time he is consuming. While he is doing that, in the City of New York you put in a call and get an answer. That may not apply everywhere, but it applies here. Mr. Campbell says in his paper that "generally speaking" it is more profitable than the manual system. I infer from that that sometimes it is not, and I think that is quite a question. From what I have learned and seen, and I have seen quite a good deal of it, I have always considered it an expensive system to maintain; but I do find that it gives great satisfaction to the subscribers and it eliminates a good deal of difficulty in connection with the wrong number. Of course, with the automatic system, the wrong number comes right back to the customer every time. In the manually operated system the subscriber looks in the book and finds 3700 and gives 3800; he does not realize that he is making the mistake and is prone to blame it on the operator; but the fact is that the customers probably make more mistakes than the operators do.

Charles A. LeQuesne, Jr.: I ask Mr. Campbell to explain if this system can be adapted to the use of private branch exchanges in connection with city exchanges; and also, what provisions is made for handling pay station calls, and whether in using a pay station telephone, it is necessary to first deposit your coin before being able to operate the calling mechanism, and, having done so, is the coin returned if you do not get the connection?

A. R. Sawyer: In 1904 when I became connected with the Michigan Agricultural College I found a campus of 25 acres or more with about 18 buildings scattered over it and no method of communication between them. I recommended to the Board of Control the adoption of a system of communication that would facilitate intercourse between the heads of the departments and save much time, the arguments for which need not be repeated. I saw that what we needed was a telephone system which would be intercommunicating for every office on the grounds and would be cheap enough in maintenance cost so that everybody could have one. I also soon realized that most of the offices should have connection with one or both of the Lansing exchanges.

After studying the matter I decided to recommend the automatic system, which was adopted by the Board of Control after due investigation. The outcome was that we put in an automatic telephone system sufficient to accommodate one hundred telephones, with three trunk lines connected to the city exchange in Lansing. The automatic system was selected because, once installed, the management would hear virtually nothing more of it in the way of running expenses. A manual system would necessitate adding to the college pay roll at least three operators as well as at least part of a man's time to keep the exchange in order, whereas the automatic system would need only part of a man's time to keep it in shape and we would have good service twenty-four hours a day and seven days in the week. At that time neither of the exchanges in Lansing gave us satisfactory service and it was my desire if we were going to put in a system that the outcome should be satisfactory telephone service. As a result, we shortly found ourselves in possession of an automatic system with three trunk lines to Lansing and a telephone in every office on the grounds as well as in the residences of those who wished to pay the college a small fee for the privilege.

The Lansing Citizens' exchange was under the management of the Grand Rapids Telephone Company which employed an automatic system and an up-to-date automatic exchange was shortly afterward installed in Lansing. At that time the automatic company did not claim that its system was best for a small exchange, but in the light of the experience we have had, we are satisfied that by all odds the automatic exchange was the best for us.

The college electrician calls up the Lansing exchange every morning over the trunk lines to make sure that they are working satisfactorily, and spends perhaps a half hour in looking over the system; the rest of the day he is free for other duties. This test over the trunk lines is necessary because of line troubles that may have occurred and not because of defective apparatus.

I will say that some of the lines to the residences outside of the campus run through a district where wires are numerous and consequently we have had much trouble with those lines, due to imperfect insulation, crosses, etc., and at times the electrician has had to spend a good deal of time on line work. That condition, however, would exist with any system. All our campus phones are connected by means of lead covered cables in tunnels so that we have no line troubles except those mentioned above.

In my recommendation to the Board I predicted that the automatic system would require less attention than any other system, but I was not prepared for the freedom from trouble which we found in the switch room. This system calls for better line work and really puts telephone work on a higher plane.

L. C. Tomlinson: It is very interesting to note the rapid advances that have been made in the past few years in automatic telephony. The large inartistic telephone, in use a few years ago, has been displaced by the small, neat and compact telephone of the present day.

At the same time the central office equipment has passed through a series of changes. By making the units compact, the central office floor space required per 1000 lines, has been greatly reduced. The apparatus has been simplified and improved with every change. A few years ago an automatic telephone system was considered so complicated, that many telephone engineers considered it quite impracticable and were unwilling to recommend it to their clients, but the ease with which it has adapted itself to all conditions has won the hearty support of most of the progressive telephone engineers.

By the multi-office arrangement of the automatic system a telephone company may reach out and serve the sparsely settled territory, that if served by the manual system, would cause an annual loss to the operating company. Not only do these subscribers receive the same class and quality of service as subscribers whose lines enter the main office direct, but their rates are generally the same, although they are at a greater distance from the main office.

H. A. Robbins: In 1905 an automatic telephone system was installed in the main office building of the Brooklyn Rapid Transit Company, the system being designed for an ultimate capacity of 1,000 lines, but to date only 110 lines have been put in service. The purpose of this installation was

1. To secure quick communication between departments, and the several offices of the departments.

2. To relieve the general switchboard, in order to obtain better service on outside calls.

The results anticipated from the installation have been very satisfactorily realized, and a large proportion of the inter-office communication is handled over the automatic system tests having shown from 80 to 120 calls per hour over this system.

As to the operation of the system, probably 90 per cent of reported troubles, although few in number, have been in the instruments. The selectors and connectors in the exchange which might be expected to give the most trouble being almost free from trouble of any kind.

While we anticipated some trouble from cross talk due to low insulation in the exchange, the system has been free from this trouble, and the talking qualities have at all times been equal to those of our manual system. The maintenance of the system is in charge of the building electrician, and requires not more than 15 to 30 minutes of his time each day, the maintenance being almost entirely labor costs. While this system, consisting of the straight Strowger type of apparatus, has given very satisfactory results, the improvements which have been brought out in the last few years, especially the Keith primary and secondary line switches, should increase materially the possibilities of the system in large installations. I believe that the combination of the present manual system and the automatic system will be the ultimate solution of the telephone problem in our large cities.

W. Lee Campbell: The point has been made that if the "busy back" should get out of order, it would probably not be noticed, for a considerable length of time in the automatic system. The method of taking care of an automatic system is somewhat different from that usually pursued in taking care of a manually operated switchboard. I can best illustrate, I think, the method of taking care of an automatic system by referring to the method which the locomotive engineer uses in taking care of his engine. He does not sit on the engine and keep going until something breaks or something that has worked loose comes off and wrecks the train. He goes out at the stations where he stops long enough, and goes over the parts that he knows from experience are liable to work loose, or to get too tight, or to get out of order in some way, and cause trouble, and with an experienced touch here and there he keeps all the mechanism in working order. Any good mechanician having the care of a machine pursues that same policy, and any successfully operated automatic switchboard must be run on that plan. The "trouble" reports that are commonly used for recording trouble with automatic telephone switchboards divide the trouble into two classes—detected troubles and reported troubles. If the switchboard attendant does not put down more detected troubles than reported troubles, it is generally taken for granted by his supervisor that he is not giving very close attention to his duty. An automatic switchboard is provided with supervisory signals for the use of the attendant, but many of the disorders he notices simply by the sound of the machines. As you know, an experienced locomotive engineer can tell by the sound of his engine whether it is running properly or not, and an experienced automatic switchboard man, who is anywhere within hearing of an automatic switchboard, can tell instantly if there is a machine which is not working properly. If he should fail to notice it, there is always a complaint clerk, an information operator, or somebody at the office, to which the subscriber can report his trouble, just as it is sometimes necessary to do with a manual plant. If a subscriber leaves his receiver off the hook, his attention is called to it in the same way that it is in the case of the manual plant; there is a device called a " howler " connected to his line, which sends an alternating circuit of high frequency and considerable voltage through his receiver, that causes it to give forth a tone called a " howl " and calls the subscribers attention to the fact that his receiver is left off the hook.

In regard to trunk lines and private branch exchange switchboards, these are handled in a manner similar to that in use in manual practice. For instance, suppose there is a private branch exchange subscriber who has a half dozen trunk lines, for handling calls to and from his place of business; they are all given the same number, just as in manual practice, and any subscriber desiring that private branch exchange simply calls the number shown in the directory. If the first trunk is busy, he is automatically switched to the second trunk, and so on until he finds an idle trunk. The apparatus does automatically what the operator does on the manual switchboard. Of course, if all the trunks are busy, the calling party gets the " busy signal " just as he does in manual practice.

In regard to the cost of maintenance, the maintenance labor for the automatic system is undoubtedly higher than for the manual system. The cost of maintenance material, however, for the automatic system is considerably less than for the manual system. I am not prepared to say, offhand, that the following is positively true, but my recollection is that the cost of new cords alone on the manual system will more than pay for the cost of all the maintenance materials on an automatic switchboard of the same size. The additional cost of maintenance labor on the automatic system is considerably more than offset by the elimination of the operators' wages, and the elimination of these wages takes care of the higher charges on the automatic system, due to the greater first cost.

With reference to depreciation, the oldest automatic system that I know of in operation to-day is the one at Fall River, Mass., which was installed in 1901, and has accordingly been in operation about nine years. I had a letter from the manager of that system very recently and he says that it is working better now than it worked nine years ago, and that the switchboards and telephones both show very little wear. So far as its wearing qualities are concerned, he sees no reason why the system should not be good for a number of years to come. Of course, the system is considerably out of date and it may be advisable to replace it, before it wears out, with a system more modern, although no plans are on foot to do so yet.

With regard to the method of reporting fires with the automatic system, nearly every automatic system in operation is arranged so that a subscriber by making one turn of his dial can report a fire to the attendant at the central office. This attendant throws a key and simultaneously rings all of the fire alarm stations, or as many as the authorities desire to have rung, and reports the fire. The method is very similar to that in use in manual practice, with the exception that the calling subscriber has to know the number to call, in order to give the alarm. It is very common in cities where the automatic systems are in use to have fire alarms sent in through the automatic switchboards. It may be that the party on whose premises the fire occurs is sometimes too excited to be able to report it, but I have never heard of such a case.

With reference to pay stations, there are very few pay stations in operation in connection with the automatic system, and in fact there are very few pay stations in operation in any independent telephone system. The pay station with an automatic system is operated in this way: The subscriber removes his receiver from the switch hook and calls the party he wants, in the usual manner. If the party answers he then drops his coin. Until he drops the coin he cannot talk to the called party, but he can hear the called party answer him. As soon as he drops the coin, his transmitter circuit is closed and he proceeds with the conversation. If he wants "long distance," or "trouble operator" or some one to whom he should have free service, the apparatus is arranged so that it is not necessary for him to drop a coin in order to close the talking circuit.

Frank F. Fowle (by letter): Mr. Campbell's paper gives a very good perspective of the principal features of a full automatic system, up to 100,000 subscribers. This limit meets the conditions at present in all but the largest cities, so that it is fair to draw general comparisons with manual systems.

The general question of manual versus automatic systems is a many-sided, complex subject, to which full justice cannot be done in a brief discussion. It is one of those questions which can never perhaps be settled for all persons under all conditions, and for all time. On the whole, the recognition accorded to automatic systems and service is increasing, and they are coming into greater use.

There are to-day three basic systems of telephone operation; the first and earliest of these was the full manual, the next was the full automatic, and the last the semi-automatic or auto-manual. A comparison of these systems should embrace all questions relating to service, economics and rates, along somewhat the following lines:

- 1. Service
    - Transmission.
    - Reliability.
    - Accuracy.
    - Speed.
- 2. Economics
    - Operating. Expenses.
        - General.
        - Operation.
        - Maintenance.
    - Fixed charges.
        - Taxes.
        - Insurance.
        - Depreciation.
        - Interest.
- 3. Rates
    - Exchange.
        - Business.
        - Residence.
        - Special.
    - Toll.

The manual system is much the oldest of the three, dating back to the origin of the business. The oldest automatic system in service has been in use about 10 years, only. The auto-manual system is comparatively recent, and the only installation in the writer's knowledge is at Ashtabula, O.

Full automatic and full manual systems are generally well understood as to their principal features. The auto-manual system is a compromise between the other two. The subscriber's station equipment and the method of calling the central office are similar to the manual system; after the arrival of the calling signal at the central office the procedure is different. The subscribers' lines do not terminate in front of an operator, but any incoming call is automatically switched to the first idle operator. The operator's equipment consists of a keyboard equipped with numbered plungers or keys much in appearance like the keyboard of an adding machine; there are also lamp signals and selecting keys. There is no multiple of lines before the operator and none of the equipment used in the manual keyboard. The first idle operator receives the calling signal, takes the subscriber's order, sets up on her keyboard the number called for and presses a key which causes that number to be automatically selected. The ringing is automatic and the operator is automatically cut out of the connection, so that full privacy is insured. When the subscribers hang up their receivers, the connection is automatically cleared.

This system avoids the complicated and expensive multiple switchboard, but retains a human agency in its operation. It seems to be especially adapted to the extension of manual systems where a conversion to the full automatic is not desired. A comparison of some of the individual features of these systems will now be taken up.

SERVICE

Transmission. Efficiency of transmission is a matter of electrical design and the selection of equipment. There is fundamentally no reason why the three systems cannot be designed to have equal efficiency in this respect, but both the full automatic and the semi-automatic have an advantage over the full manual system, in avoiding the electrostatic capacity and the resistance of the multiple, including the cable and the jacks. The effect of a large multiple on transmission is an important factor, and the loss occasioned in this way can only be compensated for by selecting more efficient equipment and increasing the size of the talking conductors.

The circuits shown in Figs. 8 and 23 of Mr. Campbell's paper differ somewhat from the common repeating-coil circuit and are probably no more efficient; under some circumstances they may be less efficient; as when ordinary solid-core relay magnets are used for impedances, in place of the more efficient repeating coil or impedance coil, constructed with a properly sub-divided iron core. The effect of such core construction is to increase the apparent resistance and diminish the apparent inductance, due to the energy losses in the core.

Reliability. Full automatic service tends toward greater reliability than manual or semi-automatic service, because it depends on no human agency in its operation; it is equally ready at all times of day or night. On the other hand, it possesses some disadvantage in that it is composed of such complex apparatus and has such a multiplicity of parts and contacts.

It is conceivable, also, that in some of the most recent automatic systems, which employ line switches and substations, a sudden peak in the traffic load might exceed the capacity of the available lines and switches. Insofar as such a condition might exist, it would tend to create a public sentiment against the service. But any such condition should be only temporary, as one of the traffic problems peculiar to automatic systems is that of eliminating the danger of busy line switches and trunks. Reasonably alert supervision should disclose all such faults.

Automatic systems are of course free from interruptions due to strikes of the operators, such as have occurred with manual systems in Chicago and San Francisco. They are also less likely to suffer interruption from neighboring fires, so close as to make it impossible for operators in a manual system to remain at work; instances have occurred where smoke drove the operators from their positions.

The manner in which the upkeep of a plant is taken care of is, of course, a basic factor in the service which it gives. This is particularly true where there are so many moving parts and contacts. It would be very instructive to have a comparison of these systems on the basis of the number of contacts in a complete connection between any two subscribers in the same exchange territory.

The liability of service interruptions increases in some measure with the complexity and multiplication of contacts. This tendency can be offset in part, at any rate, by proper maintenance methods, and in particular by the adoption of the policy of frequent periodic inspections to detect the approach of troubles and faults before they cause actual interruptions. Particularly in large plants, this policy is almost indispensable to good service.

Accuracy. This is one of the important qualities of good service, but rarely attained in perfect degree in manual systems. In fact, the writer has not, in the course of visiting most of the large cities in the country, found manual service that was above criticism. The human element seems to preclude the possibility of 100 per cent of accuracy in service. Under the general head of inaccuracies we should include the following:

1. Wrong numbers.
2. False busy reports.
3. False don't answer reports.
4. False rings.
5. Disconnects, or cut-offs.

All large telephone companies maintain a force to supervise and test the quality of the service. On account of the expense, it has never been the custom to verify more than a very small percentage of the total traffic; the ordinary practice in service testing or supervising does not cover more than one per cent of the whole traffic, and it is usually but a fraction of that figure. When the tests are sufficiently numerous, however, they furnish some index of the general quality of the service. Some results recently given for Chicago are as follows:

	Per cent
Calls completed without trouble	78.5
Reported " busy "	13.0
Reported " don't-answer "	3.0
Cut-offs, double connections etc	1.0
Wrong numbers, fault of operators	3.0
Wrong number given by subscriber	1.5
	100.0

These figures show that nearly one call out of every four is interfered with for some cause, or more than one in five. About one in eight is held up because of busy lines, and one in twelve is interfered with for other reasons. The " don't answer " reports, amounting to three per cent, undoubtedly include some wrong numbers. The writer finds it safe always to verify a " don't answer " by calling a second time, as in some cases the party called responds on the second call, and usually advises that the first call did not reach him. The writer has also experienced the following service: " don't answer " report on first call, " busy " report on second call, party answers on third call and advises that line was not busy and no previous call or signal had been received.

Incoming wrong number calls are also annoying to the party wrongly called. The writer's telephone number is 6,033 and he has always been annoyed with calls for 6,433; this arises in part from the difficulty of distinguishing 0 from 4, when pronounced O instead of naught. There are many other instances of confusion of vowel sounds. The remedy of course is adequately loud and clear transmission and clear enunciation of numbers. But there is also the element of operator's errors, including the misunderstanding and mis-giving of orders and misplugging in the multiple. The writer has noticed that bad service at individual telephones, particularly in the way of incoming wrong number calls, seems to vary greatly and is no doubt traceable to inefficient operators on the incoming trunk or B positions, at certain hours or on certain days.

Among the prominent causes of poor manual service are over-loaded operators, especially in the " busy hour " or peak load period; inexperienced operators; over-loaded order-wires or calling circuits; poor transmission, especially on order wires, which results in misunderstanding of orders and assignments; and lack of adequate traffic supervision and analysis.

The problem of procuring, training and maintaining an efficient force of operators is one of the important and sometimes difficult problems in manual service. In large cities it is necessary to maintain a training school and in consequence there is an ever-present percentage of non-productive labor. The operating force is usually somewhat unstable and the average length of service is not high.

The auto-manual system tends to eliminate many of these difficulties, because the opportunities for error are greatly diminished. The work of the operator is concentrated upon fewer functions. The limited experience with it thus far, shows that an experienced operator can handle more than double the number of calls per hour than in a full manual system.

The full automatic system eliminates the operators' errors altogether, and in this respect should give superior service. On the other hand, it places an increased burden on the subscribers, due to the manipulation of the calling device. This burden does not appear, however, to be serious, and seems warranted if it eliminates the operators' errors in the manual system.

Both the semi-automatic and the full automatic eliminate the cut-offs due to errors in manual operation, but they tend to increase the cut-offs caused by accidental manipulation of the switch-hook by the subscriber. In these systems one depression of the hook disconnects the line, and if there is no element of time lag in the apparatus, this is likely to be annoying. A slow-acting disconnect feature seems very desirable.

Speed. Speed in operation is directly a factor in operating labor costs of manual and semi-automatic systems. The sacrifice of accuracy for speed, which is sometimes the result in manual systems when high operator loads are over-emphasized, can hardly fail to create a public sentiment of both inaccuracy and unreliability in the service. The semi-automatic system has a large advantage over manual systems in this respect, and the full automatic probably has an advantage over both, all things considered.

Rapid disconnection, especially on trunk circuits, is one of the important advantages of both forms of automatic operation. Slow disconnects reduce the circuit loads in the busy hour and generally slow up the service. The circuit loads in the busy hour are directly of prime importance in determining the investment in the trunking plant, and in toll lines.

It sometimes occurs in manual operation, that the disconnect signals fail, and in consequence a subscribers' line as well as the trunk line is sometimes tied up for considerable periods. It is conceivable of course that this may happen, with automatic operation, but is seems much less likely, owing to the positive character of the disconnect function.

Other Considerations. Coin-in-the-slot telephones and pay stations require manual operation, and in a full automatic system there is no feasible way to handle this class of service, except by introducing manual operation. This objection does not exist in semi-automatic systems.

Toll service cannot, of course, be handled on a full automatic basis. The experiments which Mr. Campbell describes in substituting automatic selection at the " inward " end of toll circuits, in place of manual operation, are very interesting. The increased circuit load in the busy hour thereby made possible, will have a very important bearing on the toll line investment and should result finally in cheaper rates. It should be noted, however, that where double checking is dispensed with, an increased amount of supervision is essential to detect and prevent fraud, either by operators or subscribers. The fact which should be made plain to the operating force is not that supervision is possible, but that it exists without cessation.

One of the objections often advanced by advocates of manual systems against automatic operation has been the seeming difficulty of joining automatic with manual operation in the same plant. This difficulty exists to some degree, but manual operation in toll service will always be necessary and in toll boards designed for operation with automatic local service exclusively the objection seems more imaginary than real. It has not at least proved an insuperable objection in some of the instances where it has been tried.

OPERATING EXPENSES AND CHARGES

Operation. The cost of operation, including operating labor, supervision, rent, light, heat, etc., would seem to decrease in the following order: manual, auto-manual, automatic. Labor is the largest item in this account and the saving in labor costs is of basic importance.

Maintenance. The cost of maintenance may vary considerably even in similar plants equally situated. The efficiency of maintenance is directly a factor in the quality of service, and comparisons are therefore difficult to draw. The character of equipment to be maintained in the respective systems is quite unlike. It has been urged against automatic systems that the cost of maintenance would prove excessive, but given well built and properly installed equipment it is not apparent why this should be so. In fact a comparison between automatic and manual systems does not appear to the writer to offer a very decided choice either way.

Fixed Charges. On the general question of fixed charges, the first consideration is the investment. This in a large measure fixes taxes, insurance and interest. Automatic office equipment costs more than manual, but the distribution system less. Approximately 75 per cent of the investment in a manual system is in the outside plant or distribution system. The saving which results from the use of substations, placed at about 75 per cent in residence territory, is almost certain to prove a substantial ultimate economy in favor of automatic operation. There will be further economies in the trunking plant, brought about through higher circuit loads, with automatic operation and secondary line switches.

The insurance risk on a well engineered telephone plant is low, and the rate should not differ materially in any of the systems. If it varies at all it should probably be slightly higher on manual equipment; the steel cords which are now in wide use have sometimes started fires. This, however, has led to the practice of introducing lateral and transverse fire bulkheads in manual boards to reduce the hazard.

The annual charges for a depreciation reserve fund are determined by the investment and the useful life of the plant. More properly it is the cost of reconstruction instead of the investment, labor and materials costing the same. Automatic and auto-manual plants have not been long enough in service to determine their useful life with reasonable accuracy. The oldest automatic plant in service is about 10 years old, but there are few manual plants that are much older, counting from the date of construction or last reconstruction. The effects of obsolescence and inadequacy have been prominent in the depreciation of telephone properties, because of the very rapid expansion of the business and the frequent advances in the art. For the same reasons depreciation will probably continue to be high, in the case of automatic plants at least. However, there is a growing recognition of the necessity of sound engineering, and plants to-day are more intelligently planned and better constructed than they were formerly. The results of this will inevitably diminish the rate of depreciation, as time goes on. The useful physical life of a well engineered plant ought to be very much in excess of 10 years, with the exception perhaps of some rural systems.

RATES

It seems pretty clear that, aside from any unforseen contingencies, a modern automatic plant should be able to offer lower rates than a manual system, and should in consequence produce a greater development. The important advances in the automatic art are comparatively recent however, and rates do not seem to have been materially affected as yet.

The history of telephone rates shows that in the early days there was no scientific basis of rate making, but rates were fixed at what it was thought the traffic would bear. In many instances they were exhorbitantly high, and consequently suppressed development and stimulated competition. The competitive movement placed rates in many instances too low again, because there was no scientific analysis of cost.

To-day, the generally accepted theory, or the theory toward which we are tending as a whole, is the cost-of-service-plus-a-fair-profit. The rates of public utility companies generally are undergoing revision, mainly downward. But this is only partly true of telephone rates; many companies after ten or fifteen years of operation have found it absolutely necessary to raise them in order to earn no more than the legal interest rate. The failure to provide at all for depreciation and the lack of intelligent planning of the original systems and their extensions have been responsible in part for this state of affairs.

It has frequently been stated that the cost of operating a telephone system increases per unit as the system enlarges. This statement has been advanced in support of high rates in some cities. It is of course true that the unit cost of construction is higher in cities than in towns and country districts, but the greater density of development to some extent compensates for it. The aforementioned statement is somewhat misleading. The facts in the case are that the cost of a manual multiple switchboard increases in faster ratio than the number of lines, and the cost of distribution increases as the average mileage of wire per line increases. The investment in the distribution system exercises the largest single influence on the amount of the fixed charges. The average wire mileage per line increases with the area of the zone which comprises the exchange territory and within which the schedule of local rates applies exclusively to all traffic; it decreases with the density of development within this area. In large exchange areas more than one central office is a necessity, in manual systems, and where there are two or more offices there is necessarily an investment in a trunking plant. As a whole rates are higher in large exchange districts—higher in cities than in small towns. If the exchange district should be increased without limit, the cost of the trunking plant would make the rates prohibitive. Low exchange rates can be obtained by restricting the exchange area, and this principle has been recognized in at least one large city. Traffic between different exchange districts must bear a toll charge.

What effect the introduction of automatic operation will have upon this phase of the rate problem is not yet decided by any actual experience in very large cities, but in general it should result in lower rates, or, with present rates, in larger exchange areas. But as development will be increased by lower exchange rates, it appears to be desirable to reduce the rates rather than increase the size of the exchange district. The full automatic system as described in Mr. Campbell's paper is not worked out for more than 100,000 stations. This limit is already exceeded in the largest cities and further development of automatic equipment is necessary to fit such conditions. The competition between manual, semi-automatic and full automatic systems is certain to have a healthy result upon the telephone art and it is to be hoped that automatic equipment will soon be adapted for use in the largest cities, with ample margin for growth.

A paper presented at a joint meeting of the American Institute of Electrical Engineers and the American Society of Mechanical Engineers, Boston, Mass., February 16, 1910.

THE APPLICABILITY OF ELECTRICAL POWER TO INDUSTRIAL ESTABLISHMENTS

BY DUGALD C. JACKSON

In two papers on electrical power for factory purposes which were published 14 years ago in the Journal of the Western Society of Engineers and the Transactions of the American Society of Mechanical Engineers, respectively, I set forth the status of the then rather new practice of utilizing electrical power distribution in manufacturing establishments. In this paper, I propose to describe the present status of electrical power in factories, and will point out certain remarkable changes which have arisen on account of improvements in methods of using electrical power and improvements in prime movers adapted to driving electrical generators.

A great change has arisen in the attitude of mill and works' owners toward electrical power, following the demonstration of certain of its qualities—especially those qualities which have contributed convenience in the arrangement of machinery so as to save floor space and to accelerate output, quicker speeds for machines or closer adaptation of speeds to the needs of high-grade manufacture, cleanliness in work rooms, and safety to employees. First creeping into use in manufacturing establishments as an auxiliary readily added in connection with electric crane service or to operate isolated or special features, electric power has now come to an established place, and it is needless to discuss its advantages in factory service compared with mechanically distributed power.

Whenever water power is available, but not contiguous to the most convenient factory site, electrical power is essential to the highest success of a manufacturing project, because by it the power of the water may be conveniently and reliably delivered for use in the most effective manner at the most desirable site. The power of several waterfalls may in the same manner be converged upon a single factory site, which may either be contiguous to or distant from the stream providing the power These advantages are effectively utilized by many successful manufacturing establishments; and they lie at the root of the success of the great power transmission plants constructed for the purpose of providing a general power supply. Even when water power in large quantities is available directly alongside suitable factory sites, the electrical distribution of the power may play a part of sufficient importance to enable it to supplant mechanical methods on account of its flexibility, which leaves the mill architect free to arrange his factory buildings to suit the requirements of manufacturing product, substantially untrammeled by those difficulties that always surround the transmission and distribution of power by mechanical means.

Also, in these days of perfected electrical power distribution for factory purposes, a multiple of boiler and engine rooms (or water-wheel rooms) located at various points on the premises has become not only unnecessary, but is recognized in most instances as wasteful. A single power house where electrical power is generated for distribution to all parts of the establishment provides a more convenient and economical arrangement. The recognition of this truth is to be observed in the power arrangements of manufacturing establishments in industrial communities from the Atlantic Coast to the Rocky Mountains, wherein each more important of the recent establishments has its individual electric power house built with a comprehensive eye to economy, conveniently located on the property, and therein are located the only prime movers of the establishment. Steam-driven power houses of this character may be located on the most favorable part of the property for the receipt of coal and supplies and the disposal of ashes, and with a proper eye to prevent inconvenience in the manufacturing processes from the smoke and dirt that ordinarily accompany the processes of generating steam power.

In a similar manner the old and ineffective plan of dividing water-wheels amongst several power houses along a canal, where large amounts of power are to be used in an establishment, and adapting the factory buildings to the locations of these power houses—a plan characteristic of many of the older textile mills of New England—may now be replaced by the much more effective arrangement with a single water-driven electric power-house located at the most advantageous hydraulic position on the canal. The factory buildings may then be grouped and arranged as best suits the requirements of economical manufacturing, without limitations caused by inflexible mechanical means for distributing the power. By the electrical distribution, the power may be put wherever it is needed with convenience, economy, cleanliness and safety, and to any amount needed.

Advantages are thus derived from both the manufacturing aspect and the aspect of power generation *per se* from utilizing electrical power distribution in connection with important industrial plants. Steel works, with their valuable by-product of gas-power from blast-furnace gases, make striking instances of the use of comprehensive, unitary, works' power-generating plants under conditions which formerly would have required at least several power plants scattered about the works. These are striking instances illustrating the present tendency, but many similar illustrations are to be found amongst the factories in nearly every important branch of industry.

The centering of power generation into a single generating plant for any large establishment is accompanied by economies in power generation that are of themselves appreciable, besides contributing to reliability. The question that I wish particularly to bring to your attention is: how far should such concentration proceed?

Without the electrical distribution of the power, such concentration could not be adequately carried out at all. Moreover, whatever limitations still exist toward improving the economy by completely concentrating the power generation in any industrial establishment, exist with respect to the prime movers and not with respect to the electrical distribution of the power. Where hydraulic prime movers are to be considered, the concentration may ordinarily be made as complete as the conditions of the water supply will permit, since the charges on account of first cost of installation and the labor cost of operating practically dominate the cost of the power developed, and these may ordinarily be expected to decrease per unit of output as the capacity of the plant is increased, under conditions of equal or improved load-factor.

An equivalent condition has not heretofore existed where steam prime movers have been used. Since neither labor cost nor steam economy are much improved by increasing a steam-electric generating plant over a size of a few thousand kilowatts capacity when reciprocating engines are used, the need of extreme concentration of individual plants has not heretofore been acutely felt. But the advent of large steam turbines has altered the conditions. Plants equipped with these machines installed in association with boilers provided with adequate labor-saving appliances may be operated with labor costs that vie with the labor costs pertaining to hydraulic generating plants equipped with machines of equal size; and the steam economies derived from the newer steam turbines are remarkably satisfactory. As this paper is limited by the program-makers to an introduction to the more specific papers on electrical power for industrial establishments, I cannot here enter upon a discussion of steam-turbine economies and their influence on the generation of electrical power for manufacturing establishments; but my purpose is fulfilled by emphasizing the fact that the operating economies of large steam-turbine plants, either in respect to the use of labor or the use of fuel, do not seem to be exhausted within the limits of capacity yet attained in even the largest generating plants now in commission. Moreover, the first cost per kilowatt of capacity of plant, including land, buildings, and machinery, falls off in an important degree for the larger steam-turbine plants, until such a plant may nearly rival a hydroelectric plant in the gross cost per kilowatt-hour of energy delivered at the switchboard, through the fact that the fuel cost pertaining to the steam-turbine plant has an offset in the charges caused by larger first cost per kilowatt of capacity of hydraulic plant. Mr. Stott's curves* illustrate this point clearly.

These considerations indicate that concentration of steam-electric generating plants will afford considerable economies when the concentration is carried much further than heretofore, provided large steam turbines are utilized as prime movers. The ultimate economy cannot be reached in a single factory plant, even when it comprises several thousand horse power; and logical development leads beyond the present practice of concentrating the power units of each manufacturing establishment into an individual power plant. Economy and reliability in power service are both to be obtained by further concentrating such individual power plants located in a compact

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* PROCEEDINGS Amer. Inst. of Elect. Eng., Apr. 1909, p. 283.

industrial center into one or more great central stations each of which provides power for a number of establishments.

The usual round estimate of the cost of power in machine-shops and the like is $60 per horse power per year—taking the average power during working hours, perhaps 9 hours a day on the average. The cost is probably fully that large, as the power in machine-shops seldom exceeds a couple of hundred horse power and often does not exceed one hundred horse power. The load-factor is also rather low. Under more favorable conditions, large reductions may be made compared with this figure. In the case of a mill using an average of substantially 2000 h.p., for 24 hours per day, 313 days in the year, the cost per indicated horse power per hour may be reduced to the following figures in case a good compound condensing Corliss engine is used and the boiler firing is intelligently supervised. The cost of coal is put at $4 per ton on the cars at the purchaser's siding, and it is supposed to cost 25 cents per ton of fuel to put the coal in the power-house bunkers and to dispose of the ashes. As my experience with power plants located in New England is limited, I refer to conditions in parts of the country with which I am more familiar; but the data apparently apply equally well to New England conditions.

Under the conditions referred to, the costs are substantially as follows, per indicated horse power per hour in a well-run plant:

	Cents
Fuel, oil, waste and repairs	.42
Labor	.08
Insurance (boiler, liability and fire), interest (at 8%), depreciation and taxes on power plant including building and land	.15
	0.65

This is based on horse power measured by steam-engine indicators on the engine cylinders, and (on account of power losses and other expenses) the cost may be increased 50 per cent or more for the power mechanically delivered to the centres of use in the mill; in which case the cost would correspond to a central station charge of as much as 1¼ cents per kilowatt-hour for electrical power delivered to motors of large size carefully located in the mill. When running the same plant ten hours per day instead of twenty-four, the cost would come to substantially one cent per indicated horse power per hour, and when mechanically delivered to the centers of use, the cost of the power may reach a rate corresponding to a central-station charge of as much as two cents per kilowatt-hour. In small plants and plants with a less favorable load-factor, the cost is ordinarily much higher; the illustration which I have taken relates to power generated under conditions particularly favoring a low cost per horse-power-hour for an individual industrial plant.

The mill using 10 per cent more power at the maximum than is required on the average, and operating 313 days of 24 hours each in the year, gives substantially 78 per cent annual load-factor based on an installation of a rated capacity equal to the maximum load. If the 10 per cent by which the maximum load exceeds the average is expected to be carried by the margin in the capacity of the machinery over regular rating, as it properly may be in cases where the extra load only occurs for brief periods when the mill is cold after having been shut down, or for some similar reason, the annual load-factor of the machinery is substantially 86 per cent. With a load-factor like this, a large steam turbine station can generate electrical power at a remarkably economical rate. It is three times the load-factor ordinarily pertaining to electric lighting stations.

Putting this mill on a 9-hour regime for 313 days in the year, would bring its annual load-factor down to little over 30 per cent and would increase the cost of the kilowatt-hour. The load-factors of the run of manufacturing establishments rule less than this, as the power consumption is generally subject to more variations than in the mill that I have chosen for illustration.

Even with the conditions named in my illustration, a large properly designed and built steam turbine station delivering power to a considerable number of factories ought to be able to improve a little on the power costs and add something to reliability. The requirements for heating mills and the use of steam in various manufacturing processes often make it impossible to remove the means for generating steam from the factory site, but the generation of steam for power purposes is often accomplished separately on account of the different pressures needed for the two purposes, and the separation is then a matter to be dealt with as of manufacturing convenience rather than as controlled by economy of steam generation.

It therefore seems that we have before us a certain definite character of development in the power generation for our industrial cities. Electrical distribution of power has made its way in factories of all kinds of product, on account of its adaptability to diverse requirements; that is, on account of what we commonly refer to as its flexibility. It has proved particularly advantageous on account of its ready adaptation to delivering power wherever and in whatever position the best interests of getting out product demands; on account of its joint properties of steadiness of speed and controllability of speed, which have contributed to increasing both the quantity and quality of product; on account of cleanliness, reliability and safety, which have also strongly commended its use. Its use has also ordinarily proved economical from the standpoint of cost of horse power applied to the machine shafts. The advantages of flexibility and speed-control are being constantly widened by wiser designing of motors and their appurtenances, as experience extends. Economy and reliability are being additionally provided in the improved designs and more substantial construction of new power houses. But one of the important possibilities for densely crowded industrial cities is still almost untouched. For instance, in the city of Philadelphia many tens of thousands of horse power are used for manufacturing in establishments crowded together in city blocks, and the power is developed in separate large and small power plants located, as physical conditions warrant, in each establishment and with a minimum consideration given to economy. Several (perhaps three) large steam-turbine electric power houses, located on tide water aside from the densely occupied areas and constructed with a careful eye to minimizing the cost of the kilowatt-hour, could profitably supply this power at figures corresponding with its existing cost, and at the same time release for productive purposes large parts of the very valuable space now occupied by individual factory power plants. This would also relieve the thickly occupied parts of the city from the smoke and dirt that have become seriously objectionable, and would also remove the inconveniences now relating to providing the fuel supply and discarding the refuse. Some of the advantages of concentrating the power supply for large cities were urged in the address of President Ferguson at the Frontenac Convention of the American Institute of Electrical Engineers and by President Stillwell at a meeting in New York City.* It is unnecessary for me to discuss them further here.

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* PROCEEDINGS Amer. Inst. of Elect. Eng., August, 1909, p. 1055 and May, 1909, p. 317.

Much is now being said of "city planning." Some of the proposals seem to be founded on pure altruism, but others are obviously founded on economy. The city planners of crowded industrial cities have an opportunity which joins economy with altruism in studying the applicability of electrical power from centralized generating stations to large and small industrial establishments. There is here an opportunity for the betterment of crowded larger industrial cities that ought not to be overlooked. It has its possibilities also in the smaller industrial cities. The possibilities are larger and more real than appear at first view, but the limits of the program will not permit me to enlarge upon them by illustrations and argument. I lay this before you as one of the most important and desirable ways in which the proved applicability of electrical power to industrial establishments may be utilized for the betterment of crowded factory areas.

A paper presented at a joint meeting of the American Institute of Electrical Engineers and the American Society of Mechanical Engineers, Boston, Mass., February 16, 1910.

CENTRAL STATIONS VERSUS ISOLATED PLANTS FOR TEXTILE MILLS

BY CHARLES T. MAIN

Textile mills are in the business of manufacturing tops, yarns, cloth, carpets, or some other product for the market. The production of power required is an incident or detail, and usually the cost of power does not exceed 5 per cent of the value of the product. In selecting a location for a new mill it is important carefully to consider the source and cost of power—and in estimating the value of a mill already existing—but the power is only one item for consideration and it should not be allowed to play too important a part in the decision.

The chief items of cost entering into the product of a textile mill are usually materials and labor. It is therefore more important to locate in some place where skilled operatives in the particular kind of business to be carried on can be obtained at reasonable wages, or where there can be obtained help who can be trained, and where the cost of transportation of raw materials and finished products is relatively a small amount, than it is to seek a location where cheap power can be obtained but where the other items are lacking. A saving of 10 per cent in the cost of power would represent a saving of not over one-half of one per cent in the cost of the product. The relative importance of locating a plant with reference to cheap power increases as the ratio of the cost of power to the value of the product increases.

Most of the earlier mills were located on rivers, and it was due to such water powers as were developed on the Merrimac, Connecticut, Blackstone and other rivers that the manufacturing cities were begun along their banks.

Most of these powers within reasonable reach in New England have been outgrown, and now there is found in some of the manufacturing centres a great preponderance of steam power over water power. New centers of manufacturing on tidewater have grown up which have little or no water power, but which can obtain cheap coal and low rates for transportation, and some of the most prosperous mills are driven by steam power.

In recent years the transmission of power by electricity has made it possible to locate the mills more advantageously for construction, light, railroad facilities, etc., and has made valuable water powers which on account of their location were hitherto valueless, and has enabled the construction of central steam plants to be located at the mouth of the mines or at tidewater where cheap fuel can be obtained.

ITEMS IN COST OF POWER

It can be said generally that the cost of producing power may be divided into two parts:

1. *Independent charges*, or the part which is independent of the output, embracing fixed charges on the plant—as interest, depreciation, insurance, and taxes, and, to a certain extent, repairs.

2. *Proportional charges*, or the part which is proportional to the output, including such charges as coal, labor, supplies, etc.

In general, steam plants may be said to have low independent charges, and high proportional or operating costs.

Water-power plants are usually the reverse, with high fixed charge accounts and low operating costs.

Another item which should be mentioned as affecting the cost of power is what Dr. Steinmetz calls the "reliability-factor," which takes into consideration the spare machinery needed to insure continuous service. The charges on this spare equipment are apt to have quite a bearing on the cost of power in a central station supplying power for sale, where reliability must be one of the chief considerations, and more spare or duplicate plant is usually maintained than in a private plant.

FACTORS AFFECTING THE COST OF POWER

The chief conditions which affect the cost of steam power, are as follows:

1. Cost of fuel delivered to the furnaces.
2. Amount of power produced.
3. The load-factor in its relation to fixed charges, whether the power is continuous and uniform, or intermittent and variable.

4. The net cost of power is reduced considerably in some concerns where the waste heat of the power plant can be used in the manufacturing processes in the form of low-pressure steam or warm water.

The chief conditions which affect the cost of water power are as follows:

1. Fixed charges on the development.
2. Amount of power produced in its relation to fixed charges.
3. The load-factor in its relation to efficiency of wheels, pondage, and reservoir capacity.
4. The cost of supplementary power necessary to make up for the fluctuations of the water power, if required.

VARIATION IN COST OF STEAM POWER

Steam power costs the most per unit of power when produced in small amounts. The cost is increased for fluctuating loads, and when used for purposes where the load-factor is small. By load-factor in this instance is meant the average output in per cent of the full capacity of the plant.

Steam power costs the least per unit of power for comparatively steady continuous loads, as for paper mills and other similar industries; and the cost may be still further reduced where there is use for exhaust steam or other by-products from the plant. Such conditions as the last are found in color textile mills. Power costs the most in plants having a low load-factor with a variable load, and where there is no use for the by-products of the plant, as in a lighting or street railway plant.

Textile mills usually run about 10 hours a day, and have a comparatively low load-factor, but while the load is on, it is usually fairly steady. Public service plants usually have a load-factor somewhat lower than that in textile mills but the load is variable, which is not so favorable to economical operation as the textile load would be.

So far as we know, the net cost of steam power is the least, and the net value of water power also the least, for color textile mills of any of the important industries. This is due to the usually steady load and to the fact that the waste products from the steam plant are valuable for manufacturing purposes to those industries.

The net cost of steam power for textile mills gradually increases from the cost to the mill which can use all of the waste products which will have the lowest cost, to the case of mills making white goods where only exhaust steam for warming the building and drying the yarn in the slashers can be used. In order to give a general idea of the usual costs of power under ordinary conditions in this section of the country, an analysis of the cost of power for a station of 2,000 kw, capacity is given below. This station is similar to some which have been constructed within the last few years.

As electric drive is becoming so common in textile mills, we will assume for the basis of these costs that the stations considered below will be electric, and of 2,000 kw. capacity, composed of two 1000-kw. units. Usually there is no spare apparatus in these plants. This may be considered as fair average practice at present for textile plants, but would not be tolerated for public service plants where reliability is necessary.

In making up the cost of power, all charges have been considered except the interest charges and taxes on the cost of land. These are usually not large items in textile mills, and are variable. The cost of land for the station has also been omitted from the cost per kilowatt of the station.

In making up these costs, interest has been taken at five per cent, depreciation and repairs on the apparatus for 10-hour power at 5 per cent and on the building at 2.5 per cent, insurance and taxes at 1 per cent, making a total of 11 per cent on the apparatus, and 8.5 per cent on the building. For 24-hour power, the depreciation and repairs on apparatus is increased 2 per cent, thus making the total charge 13 per cent instead of 11 per cent. A small amount is added in both cases for incidentals.

These rates of depreciation would not be proper for a station where the manufacture of current was the main product, as for a public service plant, for newer and more efficient types of apparatus would make it necessary to discard apparatus which was mechanically good. This course would not be so necessary in a manufacturing plant where the saving of a small percentage of the cost of power is not of such vital importance as are some other considerations.

With a steam engine plant, with direct-connected generators, the cost of the plant per kilowatt of capacity is about $125.00.

The cost of power from this station with coal at about $4.25 a long ton, in the pocket, would be about $33.00 per kilowatt per year of 3000 hours, as a straight power proposition. This is equivalent to about $24.60 per electrical horse power per year, and about $21.50 per indicated horse power per year. This would be a cost of 1.1 cents per kilowatt-hour.

If steam turbines are used instead of steam engines, the cost of the station will be reduced to about $105.00 per kilowatt capacity.

The cost of power produced on steam turbines would also be reduced to about $29.50 per kilowatt-year against $33.00 for the engine plant. A part of this difference is made up from the reduced cost of the station and apparatus, and a part from the better economy of the turbines which we have assumed are using the superheated steam and high vacuum which is common practice.

If steam power were to be generated for 24 hours a day for 6 days in a week, or say 300 days a year, as for a paper mill and a few of the textile mills, the cost of power would be about $57.50 per kilowatt per year for the engine plant and about $53.00 per kilowatt per year for the turbine plant. These costs reduce to 0.80c per kilowatt-hour, and 0.735c per kilowatt-hour, respectively.

The difference in the cost for the two kinds of power is due to the fact that practically the same amount of fixed charges is spread over a much greater number of kilowatt hours. There is also some saving in coal due to the elimination of banking of fires for a large portion of the time.

For industrial plants, under consideration, the load is nearly constant throughout the operating time, which means good operating conditions.

PUBLIC SERVICE PLANTS

In a public service plant, even with the same load-factor as for the 10-hour textile mill, which would be high for most of these plants, the operating conditions would not be so favorable as in a textile mill as about the same amount of banking would have to be done, and the prime movers would have to operate at variable loads. This latter undesirable feature would not be so serious in a large station as in a smaller one, so far as the efficiency is concerned, as the variation could be more nearly cared for by varying the number of units and thus operating all of them at advantageous points.

The cost of power for this type of plant is more, other things being equal, than for a plant of the same size for a textile mill having the same load-factor. This is due to the effect of variable load towards a reduction in efficiency, and because of the greater cost of plant and consequent greater fixed charges per unit of output.

It should be borne in mind, however, that these public service plants are usually of very large size, and that their output delivered has to compete in price with the cost of power from very small stations. This would give the advantage all to the central station as far as the actual cost of making power is concerned. To the cost of making the power, the central station must add the cost of transmitting, distributing, and selling it.

These additional costs probably form a very large part of the total cost to the purchaser of the power. The distribution of power in a city is expensive, meters must be read, accounts kept, bills collected, etc. So that while a central station may deliver a kilowatt-hour at the switchboard for less than one cent, it can hardly afford to sell it for that.

Some years ago, the manager of some large public service properties, testified that the cost of power to a plant of this type could not be more than one-quarter of the gross income. A representative of another company made the statement recently that it cost his company more to meter the current for their smallest customers than it did to generate it.

EFFECT OF USE OF WASTE PRODUCTS FROM POWER PLANT FOR MANUFACTURING PURPOSES

It has been common practice for many years to use the by-products, such as exhaust steam and warm water from the steam plant, for manufacturing purposes, and for heating buildings, etc. It has been also very common practice to take steam out of the receiver, between the cylinders of a compound engine, for these purposes. In many mills all of the exhaust of simple non-condensing engines is used for manufacturing purposes.

The saving from using the exhaust of a non-condensing engine, which would otherwise go to waste, is large, because there is no additional steam required for the engine, unless the back pressure is increased. Any use of the steam is nearly all clear profit, and if all of it is used the only part left to charge to power is the difference in B. t. u. due to the difference in pressure, and the condensation in the engine cylinder and jackets.

There seems to be no good reason why in time the practice of bleeding turbines should not become as common as bleeding engine receivers.

RECEIVER STEAM

Table I shows the amount of coal chargeable to power when certain percentages of the steam entering the high pressure cylinder are taken out of the receiver. This table takes into consideration the effects on the economy of the engine of not passing all of the steam into the low-pressure cylinder, cylinder condensation, etc. The percentages in the first column are the percentages of the steam passing the high-pressure cylinder which is taken out of the receiver for manufacturing purposes. The second column is the total coal burned and the third is the coal chargeable to power after deducting the coal chargeable to manufacturing.

TABLE I

Per cent of exhaust steam used for heating purposes	Pounds of coal per one horse power per hour. All coal charged to power	Net pounds of coal per one horse power per hour after deducting for exhaust steam used
0	1.75	1.75
25	2.06	1.50
50	2.38	1.25
75	2.69	1.00
100	3.00	0.75

If the mill did not obtain its power from steam, so that it could use the low pressure steam of the plant for manufacturing, it would have to maintain a boiler plant of sufficient size to produce an amount of steam equivalent to that bled out of the receiver. The amount of B. t. u. or its equivalent in coal chargeable to power is represented by the amount of work done by the engine, and the losses due to the presence of the engine. The cost of generating the rest of the steam is chargeable to the manufacturing processes.

Examples of Manufacturing Plants

A few examples of the reduction in cost of power due to the uses of the by-products from the steam engine plant, and the bleeding of steam from the receiver may be of interest.

In one colored cotton and silk mill, the power to run the mill was about 1800 indicated horse power and for manufacturing purposes about 25 per cent of the steam for this was required in the form of steam from the receiver.

Assuming the cost of power $33.00 per kilowatt year with no bleeding, the cost chargeable to power with 25 per cent bled continuously is $29.75. The saving is $3.23 per kilowatt-year. This was for the use of low-pressure steam alone. Probably another material saving could be made by using the overflow from the condenser for water for dyeing purposes.

In another mill where much more dyeing was done, requiring a large quantity of hot water, also a large amount of exhaust steam for manufacturing and heating, the cost of power if no steam and waste products had been used, would have been about $34.00 per kilowatt year, but when the proper credits had been allowed for items chargeable to manufacturing purposes, the cost was reduced to about $26.00 per kilowatt-year, or a reduction of about $8.00 per kilowatt-year.

In a plain or white goods mill, where no steam would be required for manufacturing, other than warming the building and slashing, the saving to be effected by using receiver steam for those purposes, would be about $2.00 per kilowatt.

About three-fifths of this, or $1.20 is for heating, and the rest for slashing: so about $1.20 per kilowatt is the amount of the reduction which could be made in heating the buildings of an industry similar to a textile mill.

There are a few plants run by simple non-condensing engines exhausting into the dye-house and if the dye-house is running full there is very little change in the boiler room whether the engine is running or not.

There is one plant run by a simple non-condensing and a cross-compound engine. The exhaust from the simple engine and the condensing water from the compound engine are all used in the dyeing, finishing, and heating. The net cost of coal for power under the two last conditions is small.

In one mill which is run wholly by water power about 12,000 tons of coal are burned annually for dyeing, finishing, and heating the buildings. If a portion, or all of this mill had been run by steam power, the waste products of the steam plant would have furnished a portion of the heat required for manufacturing purposes.

The above are fair examples of the requirements in textile mills.

The Cost of Water Power

The cost of water power depends upon a great variety of factors, but the essential feature is usually the fact as to whether the combined result of all these factors is such as to make the cost of the development per horse power delivered, a reasonably small amount, so that the fixed charges shall not be excessive. In other words, the allowable cost of water power cannot be materially more than the net cost of producing the same amount of power for the same purpose in some other satisfactory manner, usually by steam.

The cost of maintaining and operating a supplementary steam plant to make up for the shortage of power during low-water, flood periods, etc., must be carefully considered as it affects the actual cost of power delivered from the hydraulic plant.

For the reason that water powers usually have high independent charges they are more valuable for use on loads with high load-factors than with low load-factors, and hence are more valuable for 24-hour power than for 10-hour power.

Many of the modern developments are of very large size and the cost per horse power of the plant is in some cases small. In the determination of the cost of power, the cost per horse power of development should not be allowed to confuse or cause misrepresentation of the actual cost of power delivered. Usually the larger the development installed, the smaller is the cost per horse power of development, but it does not follow in all cases that the cost of delivered power will be smaller per horse power.

There are usually more elements of chance and more unknown factors in a hydraulic development than in a steam plant, and these facts should be taken into consideration and properly cared for. It is the lack of consideration of some of these items that has caused some of the water power developments to get into disrepute.

On the other hand a development properly made and at a reasonable cost is a valuable asset and one which bids fair to increase in value if the price of coal increases in the future as in the past.

VARIATION IN VALUE OF WATER POWER

The value of a hydroelectric power to various industries will vary in approximately the same ratio as the cost of producing power in some other way, if considered as power, pure and simple, without taking into consideration other important items affecting the business, which are sometimes more vital than the cost of the power itself.

To illustrate the value and cost of power under different conditions, it may be well to mention the two following cases:

A price for hydroelectric power was submitted to a color textile mill, of 1.2c per kilowatt-hour. After due consideration, it was decided that the mill could not afford to accept the offer, the principal reasons being:

1. On account of the use of steam for manufacturing purposes and of the water of condensation for dyeing, the net cost of steam power would be less than the price of hydroelectric power.

2. It was considered better for the textile company to own and control its own plant, if it had the capital to build it, than to purchase current brought over many miles of pole line, and be tied up to some foreign company.

The cost of power per kilowatt at the switchboard from the hydroelectric company for the operating time of the mill was about $36.00 per kilowatt-year; and for the steam plant which the mill was proposing to install this cost was estimated at about $34.00 per kilowatt-year, but if the power had been bought from the hydroelectric company, the mill would have had to install and operate a boiler plant nearly as large as the one required for both power and manufacturing.

It was estimated that the use of the waste products from the steam plant would reduce the net cost of the power at least $8.00 per kilowatt.

In another case an offer from a hydroelectric company was made to furnish power at 1.2c per kilowatt-hour, the same price that was refused by the color textile mill. For a plain cotton mill it was decided proper to accept the offer.

The principal reasons for accepting it were:

1. 1.2c per kilowatt-hour—about $36.00 a kilowatt-year, or $27.00 an electric horse power delivered. This reduced back to one horse power equals about $23.50 per year, which was very near the estimated cost of steam power for the quantity required and at the price of coal for this particular industry.

2. The mill desired to postpone the expenditure necessary for a steam plant if it could be done without serious loss.

Central Station Built by Mills

Steam central-station plants for the distribution of power to textile mills are being built and operated by the mills themselves to considerable extent, because it is acknowledged that a central station of large capacity can be run at less expense than several isolated plants, if considered for power only, without considering the other uses for steam and warm water. It is doubtful, however, if a central plant located at such a distance from the manufacturing processes as to make it necessary to forego the saving which can be made by the use of the waste product of the steam plant can be run as economically as several scattered plants from which low pressure steam and condenser water can be made of use. In some plants, it becomes a necessity to abandon this advantage owing to the growth of the plant and the necessity of separating the power plant from the mill.

Other advantages may be derived by the concentration of plants which warrant the change.

Nearly all of the recently built concentrated plants are for electrical transmission.

HYDROELECTRIC STATION

There are comparatively few hydroelectric plants owned by other corporations which are supplying textile mills in the North with a portion or all the power required by them.

The reasons for this are as follows:

Power costs more and can be sold at a greater price.

The power plants of textile mills are usually of a sufficient size to make them fairly efficient in fuel economy and fairly cheap to run in other respects.

There is usually no large amount of reserve machinery as the service is not severe, and as it is owned and controlled by the company itself, it can take some chances which could not be taken by a power company furnishing power to the mill.

The power plant is one of the items that goes to make up the whole plant, and is so considered. It is usually of very little trouble or care to the manager, and requires no additional salaries outside of the ordinary engineers.

The item of depreciation is not so great as it is in a central power station, for in the mill the cost of power is a small percentage of the value of the product and there is not the necessity of change so frequently in order to get the utmost economy that there is in a power station whose product is power only.

With the mill plant, there are no large charges to be made to transmission costs and losses, to selling and metering the power, to franchises, administration and other charges which are necessary and common to central power stations.

The most favorably situated and least expensive hydroelectric developments can make power and distribute it and sell it to plain textile mills at prices which will be attractive, but it will be quite difficult to sell at prices low enough to compete with the net cost of power to the color textile mills which use their steam power to the greatest advantage for power and manufacturing processes.

Surplus power which can be furnished for less than the whole year must be sold at low prices as the mill must maintain its steam plant for emergency use and run it when necessary, thus adding to the cost of purchased power the fixed charges on the steam plant, and such operating costs as may be met from time to time.

In this section of the country but few of the textile mills have purchased power from any central station either steam or hydroelectric, but in the South, it is not uncommon practice for the mill to purchase hydroelectric power.

Some of the reasons for this are as follows:

Most of the mills in the North are older than those in the South and were built previously to the time of electrical transmission of power. They were, therefore, equipped with their own power plant, either water or steam, or both, and having made the investment there is not the incentive to change, whereas a new plant might save considerable investment in power plant by the purchase of power.

Most of the Southern mills are plain white mills, requiring no large amount of steam for dyeing and finishing, and requiring also less steam for heating the mills.

The mills of the North average larger in size than those in the South, and the larger the plant, the less the cost of power per horse power other things being equal.

As a rule the northern manufacturers are more accustomed to the supervision of their power plants.

CENTRAL STEAM-POWER PLANTS OWNED BY OTHER INTERESTS

There are still fewer textile mills purchasing current from central steam plants, and the reasons for this are the same as stated for the hydroelectric stations.

The central station men claim that the mills do not know how much steam power is costing them. This may be true, in many instances, but not in all. The larger mills know the cost pretty closely.

ADVANTAGES TO PURCHASERS OF ELECTRIC POWER

Some of the advantages to the purchaser are as follows:

In a new enterprise, in which the power plant has not already been constructed, there will be required less investment for the power plant with the purchase of current, than if the power is produced by the company itself, and the manufacturing company will have more capital for other uses in its business.

Less space will be required on account of the omission of the power plant and perhaps a better arrangement of buildings can be made on that account.

There will be less care to the managers of the mill if the power is purchased than if it is produced by the mill, but in a textile mill this does not usually seem to be very serious.

The company is enabled to postpone the introduction of a power plant until some later date, and in that way is able to take advantage of any improvements in power plant equipment which might be brought about during the time that current was purchased.

For the above reasons, I should expect that a mill would be willing to pay something more than the bare cost of power if the power were purchased from outside, but the mill should determine what the net cost would be from its own power plant, taking into consideration not only the cost of power, but also the saving due to the use of low pressure steam and warm water for manufacturing purposes.

If power is purchased, there must usually be added the cost of running a boiler plant at the mill for heating and manufacturing purposes in making the comparison with the combined plant at the mill for power, heating and manufacturing purposes.

For the above reasons, the central station will have difficulty in contracting with large textile mills for power except under the most advantageous conditions for the central station and the most disadvantageous conditions for the textile mill.

A paper presented at a joint meeting of the American Institute of Electrical Engineers and the American Society of Mechanical Engineers, Boston, Mass., February 16, 1910.

THE SUPPLY OF ELECTRICAL POWER FOR INDUSTRIAL ESTABLISHMENTS FROM CENTRAL STATIONS

BY R. S. HALE

We have heard an account of electric power plants planned for each mill to have its own plant. Now, even if the 2000-h.p. plant is of a size greater than the majority of electric central stations, nevertheless the question at once arises why should we not have a central station larger than most of those of to-day and then let the very large station supply the comparatively small plants with all the possible advantages due to size and combination. This is the question on which I shall dwell.

I am interested in a great central station and this is a very immediate and almost personal question, but the form in which the question comes to a sales manager is always whether some particular owner of a mill or factory can be persuaded to buy electricity, while the American Institute of Electrical Engineers is interested in principles rather than in particular contracts.

The general question of whether a large station can supply power more cheaply than several small ones is, however, one that hardly admits of argument. Still, in order to satisfy myself as to whether 1000- or 2000-h.p. isolated power plants for mills diverge, except in detail, from the general principles that have produced our existing central station, I asked the engineers of the construction bureau of the company with which I am associated, these questions:

1. What would be the cost of power in a station that you would build to-day to supply about 2000 h.p.

2. Suppose you had to supply the same at each of ten scattered points within a territory 100 square miles, what would the power cost from a big central station?

The point of asking for both figures from one office was to be sure that both were on the same basis: that if the cost of turbines, for instance, should be taken too low, or too high, or if the cost of labor were taken too high or too low, nevertheless the same basis would be used on both sized plants and would produce no error when comparing the two propositions.

There are, of course, two kinds of errors that we are subject to. If one man makes an estimate for both sets of conditions, then even if there are errors or omissions, as, for instance, if we have figured the price per ton of coal too high or too low, or if we have figured 10 per cent depreciation against an actual 3 per cent, or have omitted taxes altogether, still the comparison is, on the whole, correct even if both sets of figures themselves are a good deal out of the way, since they would be out of the way by the same proportion in each case.

On the other hand, if instead of comparative estimates we take actual results in plants that have run long enough to give results, we find that the comparison is never on the same basis. One man has bought turbines when the manufacturer was willing to cut prices; the other has run into quicksand in his foundations or unusual labor troubles; and although the individual figures in each actual case must be much more correct than in the estimates, yet there is no question but what accidental items affect tremendously the actual costs in individual cases, so that the comparisons based on actual correct figures are often very erroneous comparisons.

For instance, published cost figures are sometimes what would be called the engineering costs, omitting several items that should be included in the real commercial costs before dividends would be declared, but if omitted items apply to both sets of figures, the comparisons are not seriously wrong. On the other hand, we know of hundreds of 2,000- horse power plants when the actual figures over a term of years show results much higher than in Mr. Main's plants, and higher than in some 1,000- horse power or even 500- horse power plants. We cannot use such actual figures for comparison, no matter how correct each set of figures may be, because they are not on the same basis and we cannot take figures for a few well-designed plants as representing real average conditions any more than the average central station can feel sure of operating at as low costs as the best central station.

Our engineers' figures, however, are on the same basis for both small and large plants. I will not take time to present their figures in detail but they figured that ten plants of 2000 horse power each cost $980,790. per year to deliver their power, and one large plant to deliver the same power, including distribution expenses, $739,580. per year—a saving of 25 per cent.

No one should expect any other comparative results. When the Edison Electric Illuminating Co. of Boston owned plants of from 100- to 2,000- horse power capacity each in Somerville, Dedham, Milton, Newton, etc. it found it paid to abandon them and establish one big generating plant at L Street in Boston and distribute the power to outlying districts.

When the Pacific Mills in Lowell, or Swift & Company in Chicago, concentrate all power in one large power house instead of one plant for each building, it is because central station power is cheaper than small scattered plants.

It is safe to say that a good engineer who has a chance to make a saving for his clients would seldom advise a dozen small plants as against one large one.

Apparently, there can be but one answer to the question as to whether a central station or scattered plants are cheapest and yet plants such as Mr. Main has installed in his practice and even smaller ones, are still being put in occasionally instead of the user buying power from existing central stations.

The real question is not whether large stations are cheaper than small ones, but the question is: Why do not the present central stations take all the present business when it can so surely be supplied at a less cost to the community if supplied from a central station?

The question is: Why are any small plants left? The real question is not as to the facts, but as to the reasons why we do not take advantage of the facts.

Now the figures usually assumed as the cost of supplying power to a small plant are somewhat different from the prices the central stations will actually quote. The question is, therefore, not whether central station power is cheaper than power of a private plant, but whose fault is it that there should be so much difference of opinion as to the actual cost in particular cases? In my opinion, both sides are to blame. The central station has, to a large extent, failed to realize its opportunity. Also, the builders, or rather promoters, of the small plants usually figure much too low for the real commercial cost, and all of us, even when we have thought clearly ourselves, have failed to get the exact knowledge sent home to the general public.

Now why should the central stations, who are not making fabulous profits, insist on such high prices instead of giving the customer at least part of the advantage of the reductions in cost that everyone agrees ought to come with central supply.

The first thing is to analyze the actual central station figures and find where the money is going. We find on taking published figures of central stations certain large items that are nearly or entirely omitted by private plants. Billing and collecting is, for instance, a large item in central station costs.

The size of these items is obviously due to the number of small customers. On the other hand, with twenty large customers, or even one such customer, it would amount to something, yet it is practically negligible in comparison with the bills rendered. Again, for a few large plants we have figured 10 per cent loss from the central station while the actual central station of to-day reports 30 per cent. For a few large customers 10 per cent is correct and again the high figure for the existing central station is due to the number of small customers who use transformers at a poor load-factor. For a few large plants, we figure only a small distribution expense, while the actual central station spends far more for distribution than for manufacturing, and as before stated, this is because the existing central station has a lot of small customers.

The combination of big with little does not necessarily add to the cost of either and more usually saves on both. The wholesale department of Jordan, Marsh & Co., dry good merchants, is not handicapped by the retail store of the same company but the wholesale and retail departments complement each other. If a central station for a few large wholesale customers should add retail net-work and get enough income from the retail to pay all the additional costs, it would not add to the cost of supplying the wholesale, although the average cost per horse power delivered to all the customers might and would go up.

Up to within a very few years, central stations have had only a retail business, and have not realized that they did not increase distribution expenses proportionately by adding a few big customers. Up to within a few years central stations figured on their average costs of retail business and thought that the big business was a loss because it would not bring as much per kilowatt-hour as their average costs. To-day, they are beginning to realize that it is per cent on investment and not cents per kilowatt-hour that means profit; but business of to-day is the result of prices of three years ago; it takes time to develop. Even to-day, however, few central stations realize the field that they should cover. Unjust critics are to a certain extent responsible for this, as central stations depend on popularity. A central station making 5 per cent on its investment from the proceeds of retail business, seeing that a low kilowatt hour price to a big mill means a 6 per cent return on the investment for that customer and an accompanying later reduction in price to its small customers, hesitates to make the price necessary to secure the large customer because the big differential furnishes an apparent argument to those who claim that central stations are favoring large customers against the small, and 5 per cent with popularity is better than 6 per cent with unpopularity, even if in the latter case the small customer is getting his price actually lower.

Central stations have been weak in not analyzing their expenses properly, but the owners of small plants have likewise failed to analyze their expenses as between their plants and the rest of their business.

When a central station figures that doubling its kilowatt hours by selling ten million more to a single customer will add to its distribution expenses as much as if it sold them to ten thousand customers, it makes a very serious error. On the other hand, it is sure that every additional piece of business added adds something to the expenses all along the line; in some cases more, in some cases less. There are a great many expenses of a business that must be paid but cannot be said to be part of the cost of any particular portion. These are what are sometimes called the general expenses, but they often have other names. For instance, the salary of the president's office boy is not obviously part of the cost of unloading coal, and yet we know pretty well that if we should unload five times as much coal as we do now, the expenses of the president's office would go up.

The cotton mill seldom figures any of the interest on its floating debt against cost of power, and yet the money tied up in the coal pile must be drawn from somewhere and must earn its interest somehow.

Each item is in itself usually small, but in some isolated cases there are often extra expenses that run into big figures.

Once I prepared some estimates for one of the best engineers we have, one of the men who is now doing things rather than engineering them. He said to me, " Hale, your estimated figures are all right so far as they go, but remember that the expenses that really count in business are those that you don't figure on." In my own department I am always tempted to figure that when I add another salesman at $100 a month, I am adding only $1200 a year to my expenses. I have, however, taught myself to remember that he will need a desk, part of the office, rent, part time of a stenographer, office boy, etc., and these all cost money. A stock exchange broker once told me that when he hired a salesman, the commissions on the business the salesman brought in must be four times his salary, otherwise the salesman was really a loss.

Now, just as central stations have figured the costs of adding large customers to their retail business too high, so the mill in its analysis has failed to remember that its power plant involved other expenses besides those it figured on.

I am perfectly willing to agree that the figures which are presented in Mr. Main's paper are correct as far as they go. We have in Massachusetts 100 to 1,000 such plants as those of which Mr. Main has given an account. What has been the cost in others? The cost in a central station we *know*, and know for large stations and small stations. We have had bed-rock experiences for 20 years with no chance to draw on the general expenses of the rest of a mill. Any expenses which we forget to figure on come out of profits; but do you not suppose that if you got at a mill whose treasurer took a pride in his weaving-room and cared little about the expense of his engine-room that you would find a good deal more charged against cost of power than Mr. Main has given as the cost in the best plants?

To bring this out, take some of these estimates of cost and consider what a promotor says if he is asked to put in a plant and sell power at his estimates. Suppose he figured 6 per cent on the money; 6 per cent is a good return year in and year out and if the promotor's figures are for the actual costs, they should show profits that would give more than 6 per cent just as often as they would show losses. But we all know what the promotor says: he is not in the business of selling power and would not want to risk his money. He knows that before the work is done there will be all sorts of extra expenses of the kind he has not figured on. He knows that if the plant is run in connection with a mill, or hotel, by anyone that is not in the power business, that all these extra expenses will come out of the general profits of the other business, while if the plant is run independently and on its own basis, it would have to stand its share. Still these other expenses must be paid before the dividends. The owner of the business usually realizes this, though not in full degree. He always says, " I am perfectly willing to pay 10, 15 or 25 per cent more for central station power than it would cost me to make it myself ". If the costs he is thinking of were his real costs, this would be foolish, but what he really means is, " In addition to the costs that my engineer or bookkeeper figures for me, I must add 10, 15 or 25 per cent for what they do not figure on ".

Now, if the engineer has included all the items, *viz.*, interest at the same rate of profit the owner wants on all his busines depreciation figured not on the time the plant might last but on the date when he will scrap it, taxes, insurance, coal, water, labor, repairs, rent, removal of ashes, loss due to noise, loss due to vibration, loss due to dirt, loss due to non-flexibility, loss due to extra cost of running overtime, extra cost for superintendence including the time spent in hiring and discharging engineers, purchasing coal and supplies, checking records, etc., etc. (these all should be added), and if after *all* the expenses are included the plant shows a less cost than purchased power, it should be put in. When an owner says he will pay 20 per cent more for purchased power than it would cost him to generate it for himself, he is really saying, " My engineer is sure to omit 20 per cent of the real costs;" and just as the actual central station of to-day has a tendency to figure costs of supplying big power too high, the actual isolated plant of to-day figures its costs too low.

The projectors of isolated plants often lay stress on the special advantages of a separate plant for some particular case. This is usually in connection with the use of exhaust steam. One of the isolated plant advocates told his client that he could use his steam three times; first, for power; second, for heating by exhaust steam; and get a third supply of heat for evaporating sugar or in chemical processes.

There is no question about the theoretical advantage of using the exhaust steam for heating, but if the practical advantage followed the theoretical then the central stations should be putting down small plants in the centres of cities and selling steam heat in local blocks. If the central stations find this does not pay, and practically every one of them has tried it at some time or other, then the chances are that it usually does not pay. The same idea applies to many of the other special cases.

A further difference between a small plant and a central station is that there is an actual difference in the thing supplied in two very important ways. One is quality of service. Theoretically, a small plant can often give as good service as a large one. Practically, the large one gives wool against cotton in many ways. The steadiness and reliability of the power in every way is, as a matter of fact, much greater for central station power. This costs more and is worth more and often the central station has not any poor service to sell at a low price. This is a special condition that is really more frequent than the question of steam heating. A business that is fully satisfied with cheap and irregular power at a low price can often make that quality of power itself better than to buy a good quality of power from the central station.

A second is that the isolated plant supply is inflexible but the central station supply is flexible. An isolated plant, if figured on depreciation of 3 per cent, must be used a quarter of a century. Even at 10 per cent, it must be used a long time; and, more than this, no plant is like the one-horse shay, it can *never* be discontinued without a loss. On the other hand, central station supply in many cases can be discontinued at the will of a purchaser on a moment's notice. In other words, with central station supply, the purchaser is free; with a plant he is tied like a serf to the investment he has put in.

It is true that this freedom for the purchaser can only be given at an expense to the central station. When the central station must be prepared to lose a customer at a moment's notice, or a month's notice, it cannot make its arrangments as economically as if it counted on running along exactly the same year in, year out, as the mill that has its own plant must do in order to make the plant pay. Part of this condition can be and is taken care of by long-time contracts. If a central station can figure that its investment for a particular customer will be used for all time and will not be discontinued at some definite or indefinite date, it can supply power more cheaply. On very large business, it must get this assurance by long-time contracts; on small business by its own judgment of the future; but even with the longest and strongest contracts made with the central station, the mill is freer when purchasing power than with its own plant, since at the end of the contract it discontinues without loss, while with a plant of its own it can never discontinue without loss. Perhaps in special cases this freedom may not be worth anything, yet it is safe to say that in general the central station sells better power and allows more freedom than the isolated plant can give.

To summarize:

1. Central station power can, except in very unusual and special cases, be supplied more cheaply than when a man in another business attempts to make power as well as to carry on his own business.
2. Central station power is practically always better and gives the private owner more freedom and flexibility than when he ties himself to his plan.
3. The existing central stations have in the past figured the cost of their power supply in large lots too high, and have unconsciously hurt themselves and the public by attempting to charge large customers too much.
4. When central stations have made proper prices, the people who do other kinds of business have hurt themselves and the public by figuring their own costs of power too low and not charging their own time and general expense against the added business responsibility of the plant.

In future, the central stations will come closer to the other businesses; all will get together and pull together, and an isolated power plant will, before many years, be just as scarce as an isolated plant for making gas is to-day.

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ILLUMINATION FOR INDUSTRIAL PLANTS

BY G. H. STICKNEY

The problems of industrial illumination include the lighting of offices, yards, elevators, stairways, and other accessories, but it is the purpose of this paper to treat principally of artificial illumination for the actual processes of manufacture.

Electric light is being adopted generally as the standard of the best practice, furnishing the safest, most convenient, and usually the most economical illuminant available, therefore this paper will treat of electric lighting only.

Value of good artificial illumination. All industrial processes are subjected to a close cost-scrutiny. Pressure is placed wherever it seems possible to reduce cost. The lighting bill, holding as it does an indirect relation to the resulting product, is often discriminated against. Although it is seldom practicable to estimate accurately the relative values of different degrees of illumination, it is well known, however, that an average workman can do more work and better work with an illumination of suitable intensity than with a weaker light. Figures have been published which show the relative rate of production by daylight and by artificial light in particular installations. In every case the superiority of daylight has been startingly demonstrated. Unquestionably in the majority of manufacturing plants to-day, raising the standard of illumination would justify its cost, in the improved quantity and quality of production. Many factories are operating by old and inefficient methods, where the use of modern apparatus and methods would actually show a reduced operating cost with improved illumination.

In revising the lighting of plants to take advantage of new developments, the manufacturers have in a number of instances expressed surprise at the marked improvement in production due to the better illumination.

The workman. The operative is an important factor for consideration in any lighting proposition. Since the light is provided primarily for his use, in order that he may perform his work advantageously, it follows that it should be suited to his needs. To be satisfactory the illumination should enable the workman to perform his work quickly and well, without excessive eye-strain. The illumination can further increase his efficiency by making him at ease with his surroundings, or it can render him dissatisfied.

It is seldom practicable to equal daylight, and therefore it is usually advantageous to call as little attention as possible to the artificial lighting. One of the serious objections to placing a small portable light under the control of the workman is that he is inclined to experiment with it, not only wasting his time, but often placing the light so as to produce a glare in the eyes of his fellow, workman or himself. Such an arrangement is soon followed by eye-strain, and the workman feels a desire for more light. An increased light only makes matters worse, and at the same time calls for a higher current consumption. We have revised such installations when it was possible, cutting the current consumption in two, by going to general illumination and still providing ample working illuminations.

Such a change is usually resisted at first by the workman, partly because the strained condition of the eye makes it require more light for clear vision, and partly because the workman thinks an inherent right is being taken from him. If the change can be made diplomatically, perhaps providing additional intensity for the first few days, it is not unusual that a considerable reduction can be made, and at the same time a light furnished which is really better for the employe. In making such a change the operator should understand that the new system is an accepted success elsewhere. If it is treated as an experiment and the workman's opinion asked, he is apt to become over-critical.

The building. The lighting system in any building or room should be arranged so as to fit the conditions. Likewise the building should conform as far as possible to the requirements of good lighting. The finish of a room affects the efficiency of a lighting installation considerably. A dark finish is rich and pleasing to the eye, but in a workroom it is often extravagant. Whitening the walls, pillars and ceilings of a room will produce a remarkable increase in the effectiveness of the light.

A high-studded room sometimes requires more power to light than a lower room, but it permits the use of larger units with wider spacing. This is desirable from an installation and maintenance standpoint. It is common practice to space lamps one and one-half to two times as far a part as the height above the work.

Especially in large rooms the use of low glaring lights should be carefully avoided, as the lamps brought together by perspective are distressing to the eye. The higher the lamps are hung the less the necessary precaution to avoid glare. Modern factory buildings have as large window areas as possible. While this construction increases the effectiveness of daylight, it requires a higher intensity of artificial illumination. This is partly because operators accustomed to strong day illumination require relatively strong artificial illumination, and partly because of the loss of the artificial light through windows. Where conditions permit the use of white curtains, much light can be reflected back and retained in the room.

It is well in arranging lamps in a room to favor those parts which have the best daylight, because in arranging the work the processes requiring the most light are located near windows.

General and local illumination. There are two principal ways of lighting a room; namely, by local illumination and by general illumination. Where the former method is followed, a small lighting unit is placed at each point where particular illumination is required, the remaining parts of the room depending on stray light or a low general illumination. For general illumination, the room or section is lighted by systematically placed units so arranged that all parts receive approximately the same illumination.

Relatively large lighting units are used, depending in size upon the dimensions of the room and degree of illumination required.

With general illumination the arrangement of lamps, being independent of the detail location of machinery, does not require change with rearrangement of the work. General illumination does away with temporary construction and unsightly drop-cords, and the accompanying high depreciation, and, in many cases fire-risk.

The use of drop-cords among stock shelves is especially to be deprecated, on account of the tendency to put the lamp down where there is danger of causing fire. With properly labeled shelves, a permanently installed lamp above the aisle will provide necessary illumination. When it is necessary to look under the shelves, a hand mirror can be used.

When lighting processes in an open room, general illumination can be used economically where work is concentrated, but where there are just a few widely separated points that require light the method of local illumination will be the cheaper. The choice between the two methods often depends upon the process. General illumination gives a softer and better diffused light, but will not furnish light in a deep boring as readily as a specially placed local lamp. General illumination permits the use of the most efficient illuminants, with least wiring and maintenance expense.

Processes. In order that a process may be properly illuminated it is necessary that it should be understood by the illuminating engineer. He must know how the light is to be used, in order to determine intelligently the most desirable intensity, degree of diffusion, direction, and color of light.

In a textile mill, for example, the weave room is more exacting in lighting requirements than the spinning and carding rooms. Colored goods require more light than white goods. Different types of looms have different requirements as to direction of light. In high-grade work where there is shading of colors, white light is demanded.

A very exacting problem in color lighting was for the process of shading of buttons in a large button factory. The manufacturer who had built up his reputation on careful workmanship, was sorting buttons in from 14 to 17 shades, when the ordinary observer could readily detect only 5 or 6 different shades. After experimenting with various so-called white lights, he had practically given up the possibility of illuminating this process by artificial light. With high amperage direct-current arc lamps, equipped with inverted diffusers and large opal outer globes, specially placed over the work table, satisfactory results were finally obtained. The problem was complicated by the glossy surfaces of some styles of buttons, which demanded extreme diffusion and rifted surfaces of other buttons which demanded suitably directed light.

An interesting intensity problem was presented by a leading rifle manufacturer, who was unable to obtain suitable artificial illumination on the targets of a 220-yard testing range. Measurements showed that the marksman required 25 to 30 foot-candles for satisfactory work. Daylight intenstities were running as high as 60 or 70 foot-candles, but the artificial illuminants as installed were giving only about 6 or 8 foot-candles. An equipment which gave about 30 foot-candles was installed and gave immediate satisfaction. Later they decided to eliminate daylight altogether, as the steadier artificial light gave more uniform results.

In machine shops, general illumination can ordinarily be used to good advantage, although some special operations require local lighting. Such local lighting is sometimes provided by loaning extension lamps to the workmen on check, after the practice followed with tools. This practice is often used for automatic machinery, where special light is required for setting up, though a low general illumination is suitable for regular operation. Ordinary machine-shop work requires about 3 foot-candles, though for rough work 1 foot-candle is often satisfactory, while for fine work 6 or more foot-candles may be required.

The presence of many overhead belts makes the elimination of shadows with general illumination more difficult, and also is apt to be destructive to drop-lights. Modern shops use as few overhead belts as practicable.

In a large clothing factory recently completed remarkably satisfactory results are being obtained by general illumination from tungsten economy diffusers. This suited all processes, the number and size of lamps in each diffuser being varied to meet the intensity requirements of the different departments. Some difficulty was found in seeing the seam at the middle point of a sewing machine when working on black cloth. This ordinarily would require a local lamp. Preliminary experiments with a local reflector for casting a special beam of light at this middle point indicate that this form of local lighting can be satisfactorily applied.

In drafting rooms at least 6 foot-candles should be provided on the drawing board. The selection between general and local illumination depends upon arrangement of the room and other conditions. Where local lighting is used lamps should be shaded to cut off glare, and if possible located out of the draftsman's reach over the table a little to his left.

Circuits. The circuits for feeding factory lighting are usually determined by the central station current available, or the requirements of the electric motors in the plant. Either direct or alternating current can be used to equally good advantage for lighting, except that arc lamps do not give a steady light on 25-cycle circuits. Wherever possible the voltage of the lighting circuit should be between 100 and 125, as the most efficient lamps are more readily applied to these voltages. A 220-volt, 3-wire circuit is commonly used to good advantage.

Where motor service is intermittent, affecting the voltage regulation of a local circuit, it is desirable to separate the lighting and power circuits as far as possible. In some of the largest textile mills in New England, where the supply is alternating current, the general illumination is provided by means of series direct-current arc lamps. This furnishes a white light with remarkable economy of current consumption and maintenance. Series circuits in general, however, should be avoided except when they can be safeguarded.

Careful study is usually warranted in dividing up circuits and locating switches to accommodate requirements of particular processes.

Lamps. The lamps available for industrial illumination may be considered under two classes; namely, incandescent and arc lamps.

The principle types are as follows:

INCANDESCENT	ARC
Carbon.	Enclosed carbon.
Glower.	Intensified carbon.
Tantalum.	Mercury.
Tungsten.	Luminous, magnetite.
	Flame carbon.

None of these lamps is suitable for all conditions of lighting. It is often desirable to use several types in different parts of the same plant.

Incandescent lamps are usually made up as small units, but may be combined or grouped so as to form larger units.

The carbon incandescent lamp has a high specific consumption and is economical only with very low price of power, or in small portable units. As it will stand rougher handling than any of the other forms, the carbon lamp is ordinarily used with extension cords.

Tantalum lamps are finding a considerable use in manufacturing plants, especially where direct current is available.

The tungsten lamp has practically revolutionized commercial lighting and is now being extensively adopted in industrial lighting, especially in textile mills. It is by far the most efficient of the incandescent class, and while the maintenance seems high in some cases, it is being rapidly reduced with the progress of development. Where lamps are protected from excessive vibration or shock, the tungsten is giving an exceedingly long burning life. In choosing between tungsten and tantalum, the cost of current and the size of unit desired are usually determining factors. Tungsten lamps are used singly or in groups with metal diffusers or prism glass reflectors. Where there is considerable building vibration, they are provided with spring suspensions. In equipping and arranging lamps thought should be given to determining where the light is wanted and what degree of diffusion is required. Where there are dark ceilings, all upward light is wasted, as far as lighting the process is concerned.

Enclosed-carbon arcs, both direct and alternating current, are used to a large extent in industrial lighting. They are efficient as large units and have a very low maintenance cost. For the higher grades of lighting they are often equipped with diffusers to soften the light and direct it downward at desirable angles.

The intensified enclosed arc lamp is now available for direct-current multiple circuits. It is more efficient than the corresponding capacity of the enclosed arc lamp. This lamp and the high current enclosed arc lamp are superior to all others for color selection.

The flaming arc lamp, using the so-called yellow carbons, after several years use principally as an advertizing light, is now being used to a considerable extent for the lighting of foundries, machine shops etc., where the rooms are high, and where it is desirable to hang lamps above the crane.

The characteristic distribution of this lamp as now built is particularly adapted to high buildings since the maximum light is thrown directly downward. The light is very powerful, and suited for lighting large areas when hung high. When placed too low the light would be glaring and inefficiently distributed.

Future progress. The remarkable developments of the last few years, and the remoteness of ideal efficiency, give promise of further development and improvement in illuminants. The importance of these developments in cheapening and at the same time improving the artificial illumination of industrial processes behooves the manufacturer to keep abreast of the times. It should be borne in mind that the first cost of almost every type of electric lamp is relatively small, as compared with the cost of a year's operation, so that the user can afford to take advantage of the developments, even to the extent of throwing out his old lamps and putting in new ones at reasonable intervals.

An estimate recently made in store lighting showed, that by capitalizing the saving of the next seven years the storekeeper could afford to throw away his present lamps and install a more modern type, even if he had to pay about 10 times the market price for the new lamps. There are many similar conditions existing in the field of industrial illumination.

A paper presented at a joint meeting of the American Institute of Electrical Engineers and the American Society of Mechanical Engineers, Boston, Mass., February 16, 1910.

THE REQUIREMENTS FOR AN INDUCTION MOTOR FROM THE USER'S POINT OF VIEW

BY WALTER B. NYE

In attempting to discuss this problem I have a natural hesitation, owing to my lack of technical knowledge, but I nevertheless appreciate that possibly the point of view of that large class which pays the bills, and to which the motor is but a means to an end, may be of some interest to the designing and constructing engineers.

My experience with induction motors has been mainly in sizes ranging from 50 to 500 h. p., running 24 hours a day six days a week, and the prime requisite from a manufacturer's point of vew is *continuity of operation*. I will not say that to this everything else must be subordinated, but in any industrial plant continuous operation must be maintained. To insure this the motor must be of a rugged mechanical design, with ample bearings; capable of withstanding reasonable overloads for a considerable period without undue heating; accessible so that it can be easily cleaned, and, in case of trouble, be easily and quickly repaired; and must be able to hang on and not "pull out," even under great variations in voltage. Efficiency, power-factor, and starting torque are all worthy of consideration, but are not, to my mind, as important as the points above mentioned.

To secure continuity of operation and ease of repair, form-wound impregnated coils should be used. Impregnation of coils is suggested because in many industries motors are subjected to moisture, steam, fumes, either acid or alkaline, and dust, which may be organic and which by its decomposition affects the insulation. Impregnation renders the coils much more immune to these conditions.

However good the motor may be, sooner or later repairs will be necessary, and in that case a form-wound coil is much more easily put in place than any other type. Coils should be made accurately to size, so there may be no difficulty in placing them in the slots, and there should be good mechanical connection between coils, as lack of this often leads to open-circuiting. It is also desirable to have a good terminal board, and preferably flat, flexible copper leads, so as to do away with soldered or screwed terminal connections. It would also be well to use particular care in the quality of the insulation on the copper bars in the rotor where they pass through the slots, as this would reduce the amount of labor in repairs. It is to be hoped that some better scheme may be devised for connecting the conductors to the outside rings, as bolts corrode, and it is seldom possible to remove them without twisting them off, which again occasions delay.

Bearings should be long, well designed, and filled with the best quality of babbitt. Great care should be given in designing the channels for the oil-rings to travel in, so there may be no chance for the rings to catch; and the sight-feed or overflow pipe should be piped away from the bearings, so that inspection may be given it regularly.

Shafts should be stiff, and the motor so designed as to permit of considerable overhang of the driving pulley. There is a tendency on the part of designers to increase the diameter of the driving pulley, narrowing the face in order to reduce the overhang; but at the speed at which most motors run, these large driving pulleys occasion difficulty in getting down to such speeds as are common in mill practice. In fact, the motors which so far have come under my notice have practically all had to be equipped with smaller, wider pulleys than those sent with them. This condition might as well be realized, and the motor designed for this service.

My experience has been mainly with a group drive, hence there is a chance of continual slow growth in the power requirements, and for that reason the motor should be capable of standing up to the load, even if in excess of its name-plate rating. A motor, therefore, should be designed to stand at least 25 per cent continuous overload wthout undue heating, and should be so designed as to permit of good ventilation and a ready access of the air jet in cleaning out.

Controllers, and particularly switches, should be of the oil-immersed type, doing away with fuses, thus meeting the requirements both as to fire hazard and to life, by avoiding the exposed live parts of the average jaw switch. Experience shows that autotransformers for use in connnection with the induction motors furnished have almost invariably been too small, and after considerable trouble in endeavoring to start the motor, it has been necessary to secure larger ones. Designers may well consider this point and be more generous in their provision of capacity in these most necessary appurtenances.

In view of the various suggestions which have been made, the motor manufacturer may well say that to meet these conditions he will be obliged to increase the price of his motor. I believe to-day that motors have been re-designed to a point where there is almost no margin for the user, and as the motor is but a means to secure a desired result, the user can well afford to pay a little more for a well designed motor containing some reserve in capacity and ability to stand hard usage, and it will be found to be a paying investment in the long run.

A few words may not be amiss here as to the method of application of induction motors to the work in hand. In the business in which I am interested (paper manufacturing), we have not thought it wise to take up the application of the individual motor to the individual machine, although this has been developed quite fully by the electrical engineers. We have so far made use of group-drives, so arranging the groups as to make use of but a few standard sizes of motors, of which we always keep one or two in reserve for use in case of emergency. The standard group might be said to be that driven by a 100 h. p. motor, of which we have twenty, and for which we constantly hold two extra motors in reserve, one of them on trucks ready to be hurried to any point required. In this way, should anything occur to a motor, it can be removed and a new one slipped in its place with the loss of but a few moments, and the repairs may be made at the shop at leisure. This same practice holds good for all sizes up to 150 h.p., above which this scheme is not practicable.

DISCUSSION ON "THE APPLICABILITY OF ELECTRICAL POWER TO INDUSTRIAL ESTABLISHMENTS", "CENTRAL STATIONS *vs.* ISOLATED PLANTS FOR TEXTILE MILLS", "THE SUPPLY OF ELECTRICAL POWER FOR INDUSTRIAL ESTABLISHMENTS FROM CENTRAL STATIONS", "ILLUMINATION FOR INDUSTRIAL PLANTS" AND "THE REQUIREMENTS FOR AN INDUCTION MOTOR FROM THE USER'S POINT OF VIEW", BOSTON, FEBRUARY 16, 1910.

J. C. Parker: The first three of the five papers, *viz.*, those by Messrs. Jackson, Main and Hale, concern themselves with the question of the advantage and disadvantage of concentration in the generation of power for industrial establishments. Mr. Jackson indicates some of the advantages of concentration without, of necessity, indicating the desirability of carrying it quite so far as would Mr. Hale's recommendations which point to the generation of power by public utility enterprises exclusively. Mr. Main seems to pursue a middle course indicating that there are limitations to the concentration of power generation, while by inference, indicating that in many cases the process of concentration may be desirable. While, were the wish father to the thought, I should incline to agree with Mr. Hale, I believe that, as in all matters of human experience, the middle course comes nearer to hitting the facts.

For extreme concentration there are numerous arguments. I do not find that any of the gentlemen have emphasized one feature of the concentration, *viz.*, that of the possibility of securing expert skill and refined supervision to insure the maximum advantage from the refinements in design, which are possible in plants whether large or small. Operating refinements, on the other hand, are possible only in larger plants. Extreme refinement in engine and boiler efficiencies may be offset ten times over by the lack of attention to the loading of the equipment, the boiler drafts, etc. A plant of 25,000 or 30,000 h.p., can not only employ a higher type of operators but can readily carry the burden of a skilled engineer to supervise the operators and to systematically investigate the plant economies.

In the matter of flexibility, I incline to sympathize more with Mr. Hale's view than with that of Mr. Main, as I have had considerable experience negotiating with private plant owners and in attempting to indicate to them how they would improve their utilization of power with substantial savings. In many such cases I have found that the isolated plant is a veritable old man of the sea. Public service enterprises nowadays must, without exception, dispose of their power on a system which in some form or other is a variant of the Doherty system, of a fixed charge per kilowatt of maximum demand plus a unit charge per kilowatt-hour of energy consumption. The customer of a public service plant may, at any time, make improvements in his factory operation or motive power, whereby his maximum demand may be kept down or materially reduced, and, therefore, the fixed cost for the maximum demand is eliminated from his power bills. With a private plant on his hands this could not be done nor would it be defensible, since the investment is already made and the labor must be paid anyway, and therefore the reduction in maximum demand will not throw off anything from the fixed costs. Where on the other hand, power is purchased, the customer essentially has the advantage of a flexible and variable investment charge carried for him by a public service enterprise. It may be said that it is to the interest of the owner of a private plant in a growing concern to do everything in his power to improve his load factor by keeping down the maximum demand so as to prevent the necessity for additional investment in the power plant as the business grows. This condition, however, does not obtain in practice. Seldom in the early stages of a business development is it apparent that some little trouble in load factor improvement is justifiable, and conditions continue to follow their unrestricted bent, until the capacity of the power plant is reached. Then the cost of making changes which would improve the load factor has accumulated to such o large sum as to be quite prohibitive. The result is that the awner is compelled to extend his plant and to again mortgage himself to a bad load factor.

The same considerations apply in the matter of efficiency as in the matter of load factor already referred to. A private plant owner has, as an inducement to improve the efficiency of his power-utilizing machinery or motors, only the coal pile saving, which is probably not more than 10 per cent of the actual cost of power. If, on the other hand, he were purchasing his power under a satisfactory form of contract from an outside company, every per cent of reduction in his bills means reducing his maximum demand and his kilowatt-hour consumption alike, thereby enabling him to make the cost economy equal to the power economy.

One other phase of the matter of flexibility in the use of purchased power is that the owner of a private plant is unable to take advantage of the progress in the development of power plant equipment as distinguished from power-utilizing apparatus. Improvements have gone on at a rapid rate during the past 20 years and seem to show no abatement at present. It seems to the speaker that were he a power user he would prefer to have the opportunity to benefit by all the improvements in the art as they come along rather, than to install to-day a plant which five years from now would be of an obsolete type. These improvements can be made by the public service companies since with their multiplicity of units, some of which are always ready to be retired from commission, they can make their improvements in line with the latest development of the art.

These considerations would indicate that the manufacturer contracting for his power supply, so far from being " tied up " to some foreign company, as Mr. Main expresses it, is relieved from being tied up to what may be a bad investment, and is in a position to utilize every advance in the machinery peculiar to his own process, in motors, and, through the supply company, in generating apparatus.

The speaker does not seem able to reconcile Mr. Main's statement that "the isolated plant does not need to carry a large amount of reserve machinery, as it can take chances," with his earlier and more nearly defensible statement that "economy in power costs is not vital where power represents only five or ten per cent of the cost of running an enterprise." Surely for the same quality and dependability of service rendered, the isolated plant must carry a much larger percentage of stand-by equipment than the public service enterprise with its multiplicity of units; and economy on this score would hardly accord with the cost of a partial shut down of the manufactory.

With one other of Mr. Main's suggestions the speaker has an economic quarrel and that is with reference to the item of depreciation. The fact that the cost of power is, in a manufacturing enterprise, so small a percentage of the value of the product, is no reason why every effort should not be expended to secure the utmost economy in the power station. Pursuit of this philosophy to the logical conclusion would be to multiply by twenty each one of the 5-per cent elements entering into the value of the finished product and to thereby conclude that the manufacturing efficiency was a matter of more or less indifference altogether. A thousand dollars a year saved in the power plant is just as good as one thousand dollars a year saved in an office, a drafting room, in by-products, or any other way, and should be considered on its own merits absolutely irrespective of the percentage which it is of the whole. It is true that many owners of private plants do view the matter of plant economy as Mr. Main suggests, and this is doubtless a result of the fact that they are non-expert in the matter of power production and probably do not realize the importance of power plant economies. This fact constitutes another argument for the use of purchased as against privately generated power and also substantiates the alleged flexibility of power purchased.

The speaker's personal experience indicates very strongly the necessity for stopping centralization much short of what has obtained in the past. There is as pointed out by Mr. Main a certain class of business which a public service enterprise can not possibly hope to secure. Consider for a moment a condition which obtains in the centers of our large cities. Hotels have an all year and an all day demand for heat. Office buildings have an all day demand for heat during at least eight months of the year. If supplied with power by a public service company they must not only pay for the fuel burned in the central station, for the labor and supplies in a central station and for the power and boiler equipment charge, but they must in addition pay for the extra investment to take care of from 10 to 20 per cent drop in the feeders, for the power lost in these feeders, for the use of expensive underground mains with franchise taxes thereon, but over and above they must themselves maintain a nearly identical boiler equipment and pay for a nearly identical fuel, water, boiler room labor and boiler room supply expense, which effectually puts the public service enterprise without the pale.

There is a commercial feature involved also, and that is the fact that the man contemplating a private plant for such a service always under-estimates his coal consumption whereas, the central station company knows what its coal consumption is. If then we are to talk power purchase to a man who estimates that he can develop a kilowatt-hour on one and a half to two pounds of coal at his switchboard and supply his by-product heat thereby, and if we have to tell him that under a power purchase arrangement he will have to pay for, in addition to his coal for heating, three and a half to four pounds of coal delivered in his building in the form of electrical energy, we are practically tripling his fuel bill. Of course this is a fallacy on the part of the man talked to, but it is a condition nevertheless which all sorts of missionary effort fails to eradicate.

Some of these considerations have led the concern with which the speaker is associated to do the very thing which Mr. Hale finds by a process of *reductio ad absurdum* to be an argument against the theoretical advantage of exhaust steam for heating. The Rochester Railway & Light Company is at the present time laying plans for the establishment of decentralized plants throughout the business and industrial districts of our town. These plants will consist of comparatively small and inexpensive steam turbine plants interconnected on the exhaust side and electrically feeding into our electric net work. This class of plants has one signal advantage over the central power plant, *viz.*, that they cannot possibly demand any expensive condensing equipment—that, by their very nature, these plants must be cheap and simple. One thousand kilowatts of apparatus so installed will replace 1,200 kw. of central station equipment and even irrespective of the electric feeders which they obviate will cost less than 50 per cent of what the same capacity cost in our latest and best extension of the central steam plant.

While thoroughly appreciating the experience obtained heretofore and cited by Mr. Hale, we cannot fail to recognize the principal of logic that any number of failures to prove a certain proposition do not actually disprove it. The trouble in the past has been that the decentralized plants have gone at the thing in a half-hearted way and without one tremendous advantage, *viz.*, interconnection on both the steam and electric ends, whereby, the element of diversity factor may be called into play.

Mr. Main's suggestion of the possibility of bleeding the turbines for live low-pressure steam is a most interesting one and is illuminated by a suggestion made at the Briar Cliff meeting of the Association of Edison Electric Illuminating Companies last fall, *viz.*, that turbines should be so bled for the purpose of securing the necessary pre-heating of the boiler feed. This the speaker understands has been done in some few instances and very successfully. The advantage of carrying out this suggestion is much greater in the case of a turbine plant than in the case of a reciprocating engine plant, since it permits utilizing, in the lower stages of the turbine, steam not needed for heating. In the turbine this steam is very effective in the production of power, whereas in the reciprocating engine the steam so used is operating in the least effective part of the engine cycle, owing to the disproportionate friction and engine capacity needed for extorting the last few foot-pounds of work from the steam.

In handling, during the last two years, something like 180 industrial propositions, involving the examination of many private plant schemes, the speaker has found ample confirmation for Mr. Hale's statement as to the habitual under-estimating of the cost of isolated plant power. Almost every detail is viewed in the light of an unjustifiable optimism. Investment costs such as those cited by Mr. Main are seldom recognized by the man getting up the figures for such plants. Repairs, fuel cost and depreciation rate are sadly under-estimated. It is to be hoped that some day we will have a much larger group of competent engineers undertaking consultation work in connection with small plant development—men whose experience is broad enough to lead to analyses like those by Mr. Main, which while not colored by central station prejudice, on the one hand, will be free from the predisposition to habitually advise isolated plants in preference to purchased power, as a consequence of lack of experience to correct a too optimistic system of estimating.

In closing, the speaker would like to say a few words about the besetting desire of the central station companies to secure the big business. This business is very attractive sentimentally, and for advertising purposes it is very excellent, but it is questionable whether the effort so expended is so profitable as the effort used to get the smaller business. It is true that central station companies have not done enough toward making their rate systems logical and favorable to the big plant work, but it is questionable whether the big plant is per se cheaper to supply than a number of comparatively small plants since a group of large customers will have a very small diversity factor while all other expenses of serving them with the exception of the service taps, meters and clerical work are practically identical, therefore it ensues that the large customers demand, for the same individual load factor, a greater equipment per kilowatt-hour than do the small ones, whose diversity factor may be much larger.

Charles B. Burleigh: I am inclined to feel that Mr. Jackson has touched the key-note of the present power conditions when he calls to your attention the effect of the large steam turbine on industrial development.

It has not been until within the last few years that those having in hand the establishment of manufacturing plants requiring the use of any considerable amount of power would not have sacrificed many other desirable manufacturing advantages to secure a location where water-power was available.

As notable examples of this, one has only to call to mind the immense manufacturing establishments located along the banks of the Merrimac, Connecticut, Kennebec and other power-supplying waterways of the country.

Had power in suitable quantity on an equally attractive basis been as readily available in the (at that time) large commercial centers located on tide-water or near large railroad centers, these locations would have undoubtedly been chosen instead of such locations as Lawrence, Lowell, Manchester, Holyoke, Lewiston, Augusta and many other inland cities so located as to necessitate the receipt of raw material and the shipment of their finished product over lines where freedom from competition, to say the least, did not tend to decrease transportation charges or facilitate the immediate movement of goods.

The last few years, however, have produced marked changes in these conditions, as stated by Mr. Jackson. The large steam turbine plant " may nearly rival the hydraulic plant in gross cost per kilowatt hour of energy delivered at the switchboard." In other words, Boston, New York, Chicago, St. Louis and hundreds of other large cities throughout the country are to-day occupying the same relation to the power consumer as though an unlimited, never failing, never varying water supply for power were at all times available, and its use for manufacturing purposes was not hampered by any abnormal developmental charge, or subject to any excessive depreciation or climatic uncertainties in order to make it available for his purpose.

These conditions, together with the comparatively recent advancement in the design and operation of high-voltage electric machinery have not only vastly increased the economical radius of both steam and hydraulic developments, but are making valuable, water privileges for power purposes which have heretofore been considered not worth developing, as well as making desirable for manufacturing purposes locations which could not previously be considered.

Due in a large measure to the foregoing conditions, the time is fast approaching, if it has not already arrived, when few if any manufacturers having use for power, in large or small quantities, within a radius of 10 or even 20 miles of a large power distributing plant, can afford to devote the necessary time, energy and capital to the production of their own power.

It is with extreme hesitancy that I limit the present radius in the above statement to twenty miles. I am not sure it should not be extended to at least 50 miles, and I have no doubt that the developments of the next few years will result in lower production and transmission costs, which will permit of even further economical extension.

Consider for a moment what these conditions are capable of doing for Fall River, where all of the many thousands of tons of coal burned per annum in her immense textile establishments have to be carted up hill at an expense of from 30 to 75 cents per ton; and also at New Bedford, where notwithstanding the fact that it is located on tide-water, over 80 per cent of all the fuel burned in the city for power purposes is teamed at an average cost of some 30 cents per ton; and at Lawrence, Lowell and Holyoke, where in each case, a central electric power plant ideally located with reference to the most economical utilization of their water-powers would not only serve their present available market, but would more than double it, and the land now occupied by canals would be made available for the location of additional manufacturing industries, while the land values and saving in canal and water-wheel upkeep would very nearly, if not quite, pay for the development, to say nothing of the immense benefit that would accrue to the several communities.

While to-day the power producer and the power consumer are practically the only ones actually interested in these conditions it will be but a comparatively short time when they will realize that a percentage of their public tax is chargeable to the street wear and traffic congestion in large cities, incident in a measure to the delivery of fuel and removal of ashes, and when the tax payer not primarily interested in the production or consumption of power begins to realize that he is obliged to contribute for the upkeep of conditions no longer necessary to the prosperity of the community, I am inclined to feel that you will see the enactment of laws, pertaining to large cities at least, which will make the so-called isolated plant less desirable and the central station even more attractive.

Mr. Main in the opening of his paper calls attention to one of the most important points in connection with the consideration of the isolated plant versus the central station and I can most heartily endorse his statements that "the cost of power in a textile mill, as well as in many other classes of manufactures, is but an incident to the ultimate result," and that "a saving of 10 per cent in the cost of power would represent a saving of not over one-half of one per cent in the cost of the product."

This being an undisputed fact, it is obvious that there are other features in connection with the production of power of vastly more importance than the cost, and we may dismiss this item of the comparison with the statement that power is available from the large steam turbine or hydraulic central station or isolated plant at costs so nearly comparable, and having so little bearing on the ultimate results as to be worthy of little or no consideration.

What then should we consider as the deciding factors?

Reliability should without question be considered of prime importance as the fixed charges in an industrial plant are continuous and any interruption to, or impairment of production represents the widest and most important variable with regard to the earnings on a given investment.

What, then, may be considered the reliability of operation of a manufacturing establishment furnishing its own power as compared with one receiving its energy from a central power plant?

Let us consider first the producing machinery; here there is no material difference in either case, and I feel that those interested will concede that motors and the interior wires and fittings are as reliable as belts and shafting, which brings us to the prime mover in the isolated plant, and the entrance to the service from the central station.

Considering the isolated plants prime mover, I feel that I am correct in the statement that no 10 per cent of the manufacturing establishments, large or small, have duplicate prime movers, while central power distributing plants have many similar units, the overload capacity of a small number of which would be equal to the full capacity of any single unit.

The average isolated power plant being but an incident to the main object of the business, is given less attention by the management than is similar apparatus in the central plant, where, on the uninterrupted economical production of power, wholly depends the success of the object of the investment made, for which reason there can be no question in regard to reliability up to this point.

But, you say, the transmission line from the central station to the point of delivery is an item of unreliability not necessary to consider in connection with the isolated plant. Let us therefore consider the central station location.

In order to equitably do this, we must give some consideration to the items of difference between the water and the steam station.

With regard to the reliability of output from the station there should be no material difference because if there be any source of anticipated unreliability from the water-power, such as high or low water, anchor ice, or any interruption to the efficiency, we may consider that in order to make it commercial it has been provided with a steam relay of such capacity as will meet any possible contingency.

The steam station is or should be so located that its source of fuel and water supply can under no conditions be interfered with, while the hydraulic station must of necessity be located with reference to water supply to which the source of fuel supply is secondary, in fact the location of the hydraulic station is comparable to the old water-operated manufacturing plant in which all other considerations in regard to location are subservient to the hydraulic conditions.

The location of the steam operated isolated manufacturing plant is selected in accordance with its market, source of supply of raw material, ease of shipment, availability of suitable help, and in some industries, on account of climatic conditions, or in other words, its source of fuel supply is of minor importance.

I feel that you will agree with me that the transmission of energy by electricity over wires permanently and substantially installed, and not liable to be affected by strikes, hold-ups, wash-outs, snow-storms, floods and other natural causes to nearly the extent that the transmission of fuel is, demonstrates this last item to be fully as, if not more, reliable than the other.

While there are many other items of minor importance emphasizing the added reliability of the central station over the isolated plant, I feel confident that in view of the foregoing you will agree with me that the item of reliability is better conserved by the central station than by the isolated plant.

Flexibility is another item worthy of consideration. This item is one of admitted superiority of the electrical drive over the mechanical drive, and as the central station drive must of necessity be electrical, the comparison of this feature can only be between the electrically operated isolated plant and the central station, and a comparison on this basis is all in favor of the central station.

If a manufacturer wished to operate say 25 per cent of his plant over time from an isolated plant, he would do so at extremely poor efficiency while if supplied from the station, power is used at maximum efficiency so far as the consumer is concerned.

Additions and alterations can be made, without in anyway interfering with the continuity of operation, and changes in product and capacity have no effect on operating efficiency.

Less financing for a given output is required, and to revert for a moment to the cost item, I can perhaps best illustrate the point which I wish to bring to your attention by detailing a recent investigation I was privileged to make in this connection.

A 100,000-spindle print cloth mill was projected and the question arose with regard to the source of power. It had been considered advisable to equip the property for the electrical operation of the producing machinery and the scheme had been financed to the extent of some $1,800,000.

Carefully prepared estimates demonstrated the fact that the necessary power plant would require the expenditure of some $225,000 thus leaving $1,575,000 available for the mill and its equipment of producing machinery.

It was further estimated that 100,000 spindles should produce sufficient yarn to operate 2,400 looms, each producing 90 yards of cloth per day, having a sale value of 3½ cents per yard, resulting in a yearly production of $2,260,000 worth of finished goods at a manufacturing cost of $1,810,000 when operated from its own power plant, showing a profit of $450,000, or 25 per cent profit on the invested capital.

The operating costs on the power plant included coal at $3.50 per ton delivered in the coal pocket; 5 per cent depreciation on the machinery and 3 per cent on the buildings. The cost also included 5 per cent interest on the power plant investment and on this basis it was estimated that the power cost at the switchboard would be $22 per h.p. per 300 ten-hour days per year, or a total of $66,000 per year for power.

Figures were obtained from the local steam turbine equipped central station, located on tide water and using fuel at a cost of $3.20 per ton delivered into the boilers, of 1.5 cents per kw-hr.

The acceptance of the above proposition permits of the investment of the $225,000 allotted to the power plant in producing machinery, and it will be noted from the foregoing figures that but 5 per cent was charged against the power plant, while 25 per cent was shown as the profit on the total invested capital; therefore that proportion of the capital invested in producing machinery shows much better returns, which is a strong incentive for investing the money where it will show the greatest profit.

Contracting with the central station for power and increasing the producing machinery incident to the investment of $225,000 increases the yearly output of the mill 14½ per cent and the sales price of the finished goods becomes $2,583,933.

We would anticipate that our power cost had also increased, first due to the fact that we feel that it is costing us more and second that we are using more power, due to the fact that we have enlarged our mill.

In the first case we used some 3,000 h.p. and in the second case we have apparently used some 3,500 h.p. This is not the case, however, as I will attempt to explain. It is a fact that for the sake of argument we have increased our producing machinery to the extent that 500 h.p. additional capacity is required to operate it.

The textile manufacturer will tell you that his mill shows a 90 per cent load factor on the basis of ten hours operation and for the sake of argument we will take this as a basis, for when operated from his own plant, it does.

When operating at a 90 per cent load factor and paying for current by meter, however, the meter records the current consumption each instant of operation. In other words, a machine stopped and started 60 times a minute, under such conditions that the intervals of stoppage just equal the intervals of full load, would record on the meter as operating one-half minute at full load.

Tests made with curve-drawing electric meters, show that the power consumption of textile manufacturing processes, with the exception of ring spinning, average about one-half of maximum, and that the spinning averages about two-thirds of maximum. Spinning consumes about 60 per cent of the power required in a mill. The central station customer obtains advantage from these conditions, which he would not if operating his own power plant, because his investment, depreciation, coal-pile and labor are not so sensitive as his meter.

First, if all the machinery in the mill stroked together we would have a load factor when operating by meter of one half of forty per cent of 0.90 plus two-thirds of sixty per cent of 0.90, or 54 per cent, for the entire mill. But all the machinery does not stroke together, nor does it break joints (so to speak) entirely, and this feature is the result of a disputed point between the central station operator and the textile manufacturer, the former claiming that from his meter readings the textile mill seldom if ever shows a better ten hour load factor than 75 per cent while the manufacturer insists that an experience of many years has shown him a 90 per cent load factor. Again for the sake of argument we will admit that they are both right.

The central station man's tell-tale (his meter) permits no lost motion but records actual conditions, while the manufacturer's tell-tale (his coal pile) is less sensitive in taking advantage of these conditions and fails to record them. It is therefore equitable to figure on the basis of experience.

As 3,500 h.p. for 3,000 hours equals 7,835,700 kw-hr., and 75 per cent of this equals 5,876,775 kw-hr., which gives at 1.5 cents, $88,151. as our total power bill.

Now what has it cost us to do this?

1. It has cost us $22,151 per year.
2. We have sacrificed our independence.

What have we gained by this sacrifice?

1. We have increased our production $323,933 per year.
2. We have a more reliable power supply.
3. We can devote all our time and energy to our legitimate business.
4. We have no need to worry about the fuel market.
5. We can make alterations without regard to the power plant.
6. We can run any department overtime at maximum efficiency.
7. We can change the style of goods without change in our power plant.
8. We can select a location ideal to manufacture without regard to power.
9. We have made $51,809 additional net profit on our investment.
10. We have earned 27.8 per cent on $1,800,000 invested instead of earning 25 per cent as would have been the case had we installed our own power plant.

If you are disposed, however, to question the position I have taken on the load factor, pending more careful investigation of the subject, if we use the same load factor of 90 per cent we have still increased our profits by $22,405 over the use of the isolated plant on the given investment of $1,800,000.

Second, consider for a moment the mill using exhaust steam and hot water in preparation work and heating. With regard to heating, I believe I am correct in the statement that about 80 per cent of the heating of textile mills is done when the machinery is not in operation and this is the case in many other classes of manufacture, for which reason the heating can be practically eliminated from the consideration so far as the power plant is concerned.

In the most extreme case, named by Mr. Main, of saving to be effected by the use of steam as a by-product, the saving is $8.00 per kw-yr. or some 23.5 per cent. Let us add 23.5 per cent to the cost of the power in the mill I have taken as an example, under the worst conditions for comparison of 90 per cent ten hour load factor where our additional profit due to the use of central station power was $22,405 and our power cost was $88,151 per year. Our increased profit is reduced by $10,715 but we still have a profit over our isolated plant operation of $11,690.

I feel that the foregoing figures demonstrate that maximum production is the item of paramount importance to the manufacturer, which is to a large extent subservient to and dependent on reliability and flexibility, all of which are best conserved by the central station at costs at least commensurate with the results obtained.

Norman T. Wilcox: In most cases the advantages of using exhaust steam where there is a steady use for it the year around cannot be successfully questioned, although it should not be forgotten that there are some disadvantages in distributing low pressure steam over considerable areas, such as might be present in the case of the larger mill plants.

The whole trend of modern development the world over is towards centralization. The laws underlying this development are peculiarly applicable to the generation and distribution of electric energy for power and other purposes. This must ultimately result in the greater portion of power being generated in great, modern central stations. These stations can take advantage of the larger load factor and greater economy resulting from the great diversity of use for power, lighting and other purposes.

When we consider that the larger central stations are already growing into wholesale power plants, that with distributing systems complete can be installed for approximately one-third the cost per unit of a lighting system only, and that the total cost of such a complete system will be as low, probably lower, than the average mill plant of even 2,000 to 5,000 kw. capacity, we may well pause before spending money for a lot of small plants with their relatively much poorer economies.

On the other hand, it should be clearly borne in mind that investment as well as distributing losses for a wholesale modern power system will not be more than one-third of those of a lighting system only. Then again, the great advances made in the art of insulation, manufacture of cables, transformers, etc., make it possible for a modern plant of this character to generate and distribute current to mill plants with even greater reliability than that afforded by the isolated plant. In addition to this, the big central station has the practical advantage of vastly greater economy in the cost of generating current, this due to its more efficient equipment, better load factor and ability at all times to benefit from a highly skilled operating force capable of applying refinements and checks which are necessary to the attainment of the best economies.

RELAY

There are several conclusions in Mr. Main's paper with which I cannot agree. The logic of assuming that no less relay is necessary for the 2,000 kw. isolated plant than for the central station is very much open to question, as the central station will have a much larger plant and more competent force; therefore, less chance of interruption to service. The central station will require less relay equipment to furnish the same reliability of service. Modern central station distributing systems, with a 13,000-volt underground system, are as reliable as belt drives.

As most of our mills are not dead, but are progressing and growing, and some of them quite rapidly at that, is it not reasonable to assume that by a second year at least, the 2,000-kw. plant outlined in the paper will be called upon to put in a third 1,000-kw. unit, necessitating 25 per cent to 50 per cent additional investment per kilowatt of capacity? This would make the total cost per kilowatt, instead of $105, as in the case of the turbine station, $130, or possibly $150 per kilowatt of capacity.

DEPRECIATION, ETC.

When it comes to the matter of depreciation and cost for equivalent service, I fail to see why more depreciation should be charged against the better cared for central station equipment than would be allowed in the case of the mill plant. If anything, rather more depreciation should be charged for the isolated plant than for the central station equipment. This tends to increase the cost of isolated plant supply. In order to meet the competition of the central station, due to the introduction of modern apparatus, the isolated plant must also replace its machinery and accept the same or greater depreciation than the central station.

CHECKS ON PLANT, ETC.

As steam is used from a common boiler at all points in the mill yard, it is not practical to obtain such operating checks as to enable the isolated plant to even approach the net economies obtained by the central station with its larger and more economical equipment. The superior economies of the modern central station are due to constant and close hourly and daily checking, a practical impossibility with the mill plant. Omit this checking for ten days and the result is a loss of 10 per cent in the plant efficiency. A longer period will materially increase this loss. This being the result of experience in the best central stations, what must be the relative efficiency in the mill plant where these checks may not be obtained?

COST PER KILOWATT-YEAR AND KILOWATT-HOUR, AND EFFECT OF LOAD FACTOR ON PRICE

Results obtained by a large central station serving textile and other industries, this station having several power feeders varying from 500 to 1800 kw. capacity in daily use, show on a 3,000-hour-year basis an average 10-hour load of not to exceed 85 per cent, and this with all the advantages of diversity factor. As this station meters its energy to the customer *at the motor* in comparing services, the 5 per cent or more loss from customer's generator through switchboard and distributing system to the motor terminals should be deducted, making the real load factor 80 per cent.

In many plants, this annual 10-hour load factor is not over 70 per cent or 75 per cent. Taking the case of the color mill, an application of the 80 per cent load factor would result in the use of 2,400 kw., making the rate slightly more than 1.4 cents per kw. as compared with the impossible 100 per cent load factor assumed with 3,000 kw. annual use and estimated kilowatt-hour price of 1.1 cents. This would be approximately correct, as the only variable in the kilowatt-year cost would be the slight difference in cost of fuel for less number of kilowatt-hours, other expenses remaining the same. Likewise if the hydraulic power at $0.012 per kw-hr. had been figured on a 2,400-kw-hr. per year use, instead of 3,000, the kilowatt-year cost for the hydraulic power would be $28.80 instead of $36, and the horse power-year reduced to $21.60. Similarly, the kilowatt-year cost of $36 is reduced to 2,400 kw-hr. × $0.012, = $28.80, and the $27 per horse power is reduced to $21.60. These examples illustrate the danger of not clearly distinguishing between terms of capacity and actual work done and to be paid for by the customer.

Central station power at a definite price per kilowatt hour is a known quantity, not an estimate, and is easily checked from day to day, and for each department if desired; but cost of power to the isolated plant is an unknown quantity with cost depending largely on the varying personnel of the mill staff, as well as relatively poorer attainable efficiencies and other factors.

In order to obtain the insurance of service and price incident to the supply obtained from a big central station, the mill man can well afford to pay 10 per cent more than his estimated cost in order to obtain the central station supply.

In considering the price of the isolated plant and cost per kilowatt-year and per kilowatt-hour, load factors should not be predicted upon estimates based upon intermittent daily observations or special tests. If we would avoid disappointment and loss we should make the basis of comparison actual yearly operating conditions and costs, with their inevitable contingencies, including competent supervision. A few careful and consistent checks of this kind, if they were possible, would reveal that 80 per cent is a remarkably high yearly load factor, although it may appear from intermittent observation that the load factor is apparently higher. Consequently the kilowatt-hour cost of the isolated plant will prove much higher than anticipated and generally believed.

Incidentally, I believe that in the majority of cases our mill friends will ultimately realize that the central station will be able to furnish current and service which the mill men will be warranted in accepting.

H. B. Emerson: It is conceded to-day, by practically all who have studied into the matter, that the flexibility of electric power, places it as the foremost of all operating forces; and the points brought out by Professor Jackson's paper only tend to confirm this conclusion.

The matter of concentration of the generating plant, however, I believe must be decided by individual conditions. If the question involves only the laying out and building of a strictly new plant, then I most heartily favor a single generating station, with modern prime movers; also the placing of the manufacturing buildings so that the greatest economy can be obtained outside as well as inside the station. This, however, can not always be accomplished in old plants; for example, I know of a case where the plant has outgrown the original distributing potential of its station, where steam was needed in the process of manufacture too far away to economically transmit it from the station, and where both of these difficulties could be overcome more economically by building a second generating station than by adding step up transformers and a new steam plant for generating only steam for the manufacturing processes. Such cases are undoubtedly special, but engineers are destined to encounter such special cases, and they require even greater study and care in planning for the still further development of the plant, than would an entirely new plant, if the owners are to obtain the greatest return for the money they expend.

CENTRAL STATIONS *vs.* ISOLATED PLANTS

Regarding the question of whether the power should be obtained from a central station or an isolated plant for industrial purposes, I believe here, again, we can only decide after we know the conditions to be met in the individual plant, as the weight of argument will undoubtedly be in favor of the first in some cases, and of the second in others.

Mr. Main's point regarding use of exhaust steam in certain plants is well taken, and in many cases would be a predominant factor in deciding for the isolated plant.

In some plants the cost of power is a small item as compared with the other costs of manufacture, but in many plants it is a leading factor, and whether large or small it is looked after very sharply in an up-to-date plant. No official of a company is going to fool himself as regards the costs of one department by trying to hide part of them in the costs of another. To-day it is a cold business proposition, one mill or factory against another, and if a small percentage can be saved in the power department it is looked upon just as favorably as though it was saved in another department.

If the central station can make that saving to the owner of a plant, any broad minded man will let the station do it; on the other hand, the saving must be proved. The manager knows what his fuel, labor, supplies, repairs, insurance, etc., cost him, and if he finds he can produce his power for one cent per kw-hr., he will not pay a central station two cents for it.

I know of a textile plant generating its own power with turbine-driven generators and using a large percentage of the steam from the second stage of the turbine for dye house purposes, which is producing its power at less than one cent per kw-hr. including proper items for insurance, depreciation and taxes.

The figures check those given by Professor Jackson very well in toto, but are divided somewhat differently; the fuel cost being somewhat greater but the labor cost less. The saving obtained, by bleeding the turbine, also compares favorably with the saving shown by Mr. Mains' figures for the use of receiver steam.

I cannot agree with Mr. Hale's deduction regarding the use of exhaust steam. The methods employed by the central station are hardly comparable with those of the manufacturer. The central station has had to transmit its exhaust steam a considerable distance, and its use has been governed by parties not under their jurisdiction; some days (on account of cold weather) they would have a heavy call on their mains, and perhaps a few days following very little would be used. The manufacturer does not depend on his heating alone to use the exhaust, but has processes of manufacture requiring steam at low pressure, and the departments employing these processes are placed very near the power station and the drips returned to it at fair temperature. Further, if he did not have this exhaust steam to call upon he would have to furnish it from some other and more expensive source.

While I should favor the buying of power from a central station that could supply it at less or even at the same figure the isolated plant can produce it for I am, yet, to be convinced that a broad rule can be set forth to definitely decide the matter.

LIGHTING

I thoroughly agree with Mr. Stickney that the subject of industrial lighting deserves a great deal of study. Not only different plants require different systems of lighting, but the various departments of the same plant may require different illumination. One point which he did not mention, however, is one which was brought to my notice during some recent illuminating tests in a mill, where it was found that fully as much attention had to be given the distribution of the lighting units as to the diffusion of light.

With the same foot-candles in each case, the single tungsten drop lamps gave much more satisfactory illumination to the operatives than either the intensified arcs or tungsten clusters, owing to the better distribution of the light between the machinery. In other parts of the same mill, the intensified arc gave the better satisfaction, and in still other parts the enclosed arc was most advantageous. Where color matching was required, the dioxide vapor lamp was accepted as best adapted for the work.

A manufacturer to-day cannot afford to be without good illumination, for aside from better quality and quantity of light, there undoubtedly is a physiological effect upon the operatives which is advantageous, and the man who lays out a scheme of lighting for a factory must know not only the illuminating power of the lamps and their value, but must familiarize himself with the processes of manufacture in that plant.

MOTORS

Mr. Nye's expression of the requirements of an induction motor is undoubtedly to the point, but it must not be forgotten that the questions of power factor and efficiency must be reckoned with, especially in the larger installation, in order to obtain continuity of operation in the station as well as in the factory.

A motor can be too sturdy in many cases when the interest on the investment is taken into consideration, and there are two sides to the question of how much overload capacity is necessary for the manufacturer to provide in his standard motors. A great many industrial plants require practically no overload capacity in their motors, while others must have a considerable margin in the motor to meet the maximum demand required of it. It seems, therefore, that this question must be decided by the user and his engineer, and motors ordered to suit the requirements of their factory. Most of the electrical manufacturers of to-day have two types of motors, one for the first conditions mentioned above, and another type having considerably greater overload capacity to meet just the requirements stated as desirable by Mr. Nye. By having these two types of motors, better characteristics are obtained for each service than could be obtained if a single motor was designed to meet all kinds of service, and allows the customer who has the lighter work to obtain his motor at a less cost.

N. W. Dalton: In textile mills where the units require little power, the superiority of an electric drive admits of no question. Some of the conclusions derived from experience with induction motors in large plants are herein outlined. While in special cases the individual drive may be installed, with a large number of tiny motors, generally the group drive should be used.

What principles should govern the number of machines in each group?

First, as few *different* sizes of motors should be used as possible. Consideration of the requirements in the way of spare motors, repair parts, switches, wiring, etc., will make this clear. A study of the possible grouping of machinery in the different mills (carding, weaving, spinning, etc.) will show that a few motor ratings will cover all cases.

Second, as to motor speed. A large proportion of textile machinery is designed to be driven from slow running shafting and it follows that motors should be of moderate speed. The argument against this view is answered in every plant where the lower speed motors prevail. While speeds near 1000 rev. per min. may look right to the purchasing agent, the man who has to drive the slow running main shaft will make good the cost of the larger frame if the motor is wound for double the number of poles.

Floor space is too valuable to devote any of it to motor and driving belt. Motors should therefore be inverted and bolted to the ceiling at truss line.

Third, grouping of machinery should be limited to 50 or 60 h.p. Making our motors something under two tons. The reason of this limit is ease of handling. These motors can be drawn around mills yards on the ordinary wagon or truck. They will go up and down on the ordinary elevator without the use of hoisting tackle. The writer uses a hand truck for drawing motors around mills. This is merely an open plank frame with small cast wheels, the opening being large enough so that the frame can be drawn around the motor. The frame is fitted with an iron tripod. From the center of the tripod is dropped a threaded hook, while a hand-wheel with nut gives the necessary power to lift a two-ton motor from the floor, whence it can be easily drawn to its place.

Larger motors, say four or five tons, must be moved on skids with rollers. Some types of older mill floors will not stand this use and timbers must be laid for rollers, and in some cases shores used.

Spur-geared blocks are most economical of effort. Those of one ton rating weigh 80 or 90 pounds so that a man can easily place them. A pair will quickly hoist a motor in to place, while a single one furnishes the necessary power for replacing bearings and making repairs—work that does not necessitate lowering the motor. Thus by limiting the motor size we can get along with less repair apparatus, which is a great consideration in emergencies.

Fourth, while smaller motors than the largest size adopted are necessary, motors should in all cases be kept as near the largest size as possible. Smaller motors mean danger from overloading, due to shafting out of line, hot bearings, and other minor troubles. Such things are relatively unimportant in the larger sizes. Still, small sizes must be used in textile work where large areas of some kinds of machinery consume but very little power.

RELIABILITY

While the electric machinery will cause fewer interruptions in the production of goods than almost any other part of the plant, still a stoppage of a motor or generator causes more attention than almost any other accident. All efforts towards greater reliability will be well spent, as the electric drive still has a reputation to acquire and maintain.

The greatest cause of failure in induction motors lies in the starting devices. Immunity from delay is best secured by having these entirely separate from the motors. A voltage reducing device in the motor leads is to be preferred. In case of failure it may be short-circuited and a temporary starter used, until repairs can be executed, without delaying production. When the starting device is located inside the rotating secondary, the matter of repairs may involve a considerable delay. In this limited space, and exposed to dirt and careless usage, no system of sliding contacts can ever give satisfactory performance.

The motor with internal starting resistance has a high starting torque with low starting current. The resistance of the secondary when up to speed is very low, thus giving the motor little slip. These are desirable characteristics, but they are outweighed by the matter of reliability. The lack of reliability seems to be more in the operator than in the motor, for some of these motors run several years with no delays whatever.

The device always furnished for starting is an auto-transformer with a double-throw switch. Would it not do to use a cast iron grid resistance? This is simpler, cheaper, easier to install and repair. The starting position should be held by hand against spring pressure so that the switch cannot be left in the starting position.

With the oil-immersed switch, it is best to have lock, so that the switch can not be thrown to the running point until it is first drawn into the starting position.

For sizes of 100 h.p. or less, and voltages not over 600, air-break switches are the most satisfactory. The oil switch is awkward to install and difficult to inspect. Often it has wood mounting and flexible leads. Some would not be safe to operate without the oil, so that the oil is a necessary adjunct and not a additional safeguard. The oil itself besides being a nuisance is often a source of danger, as some grades are very easily ignited after standing for some time. The air-brake switch is constantly in sight of the operator and any trouble is seen; while the oil switch often gives the first hint of trouble by refusing to work. Practically all the troubles of air-break switches are confined to burning of contacts and cutting in hinges; minor troubles which are easily repaired.

The air-break switch will prove unsatisfactory if used in sizes under 100 amperes capacity from want of mechanical strength, though it does not follow that all switches of higher rating are mechanically as strong. Switches must have a quick break attachment. This, unless carefully designed, is apt to give trouble. It should be strong and not interfere with operation of the main switch in case it gets into trouble. Carbon-break switches have not proved satisfactory.

Motors of the smaller sizes do not require any starting device but may be thrown directly on the line. The limit of size to which this method of starting may be carried depends on the connected machinery. Too sudden acceleration is destructive to belting. In general, textile machinery is disconnected from the shaft while the motor is accelerating, so that the starting torque required is light.

The second greatest cause of motor failure is due to bearing trouble. The bearing metal is babbitt except in smaller sizes where bronze is sometimes used. Experience with bronze demonstrates that it is very unsatisfactory. Where babbitt is used the air-gap should be sufficient to allow for the starting of the metal before the rotor strikes the primary. The smoke when the babbitt runs will attract the attention of the attendant and the motor can be stopped before the laminations strike. The latter will sometimes shift cutting the insulation of conductors.

Overloads are supposed to be prevented by fuses or safety devices. The exigencies of service are such that this is rarely the fact. A larger fuse is an easier solution than a little care and judgment. The real protection against destructive overloads lies in the use of a portable ammeter and the exercise of considerable vigilence by the electrical department. Motors should be capable of carrying reasonable overloads, and the behavior of those overloaded should be watched to ascertain the effect on temperature. In the factory where the writer has charge, not a single motor has been lost by destruction of windings, except where laminations shifted due to bearing failure.

A word as to motor design. Ventilating slots through the iron laminations are useless as they are promptly plugged by flyings. The cleaning of a hundred or more motors is no small task and if left for nights and Sundays will not be done. The only solution seems to be to clean while running. The rotating parts should be so designed that the air blast will clean them when motor is working. This is not universally the case with the motors now furnished.

The bearing on the pulley end of a motor should be designed so that it may be replaced in case of failure without the removal of the pulley. Pulleys have a way of rusting fast to the shaft and requiring some time to effect their removal. On some of the smaller motors an opposite effect has been noted. The pulleys work loose and destroy the key-seat in the shaft. A more liberal design of shaft and key is needed.

If paper pulleys are used they should have metal hubs. The variety having a piece of metal inserted to hold key will not stand up in hard service.

LIGHTING

Mills where a large proportion of the help consists of women operate from 7 a.m. to 6 p.m. only. The lighting hours are few in the year, but the lighting must be ample. We are practically confined to the carbon filament lamp, for the problem is to keep down the first cost of the installation. On alternating-current circuits the enclosed arc lamp with proper globes and diffusers gives so little illumination as to be out of the question, the tantalum lamp has no length of life and the tungsten lamp is too delicate and costs too much. In certain places where the cost of power enters, due to the necessity of burning lamp for long hours, 27 volt tungsten lamps are fairly satisfactory although in some instances they blacken very quickly.

Local lighting, inherited from gas lighting days, seems to be the desire of the mill from the office to the machine hand. General illumination has to be demonstrated before it will be accepted. In general this is the better form, but not universally. In some mills a compromise form has to be adopted.

In calculations of lighting, a certain, or rather uncertain, factor is introduced by the character of the flyings that collect on the lamps. In a spinning room for instance the wool flyings are easily cleaned from lamps and full illuminating power is secured. Where the flyings carry certain amounts of dyestuffs and starch, allowance must be made, as the labor of cleaning and the inconvenience caused thereby amount to more than the excess of power necessary to bring the lighting up to standard.

Running boards with wires cleated to them should never be used. Drops of incandescent lamp cord are a nuisance and should be done away with wherever possible. They should never be placed in a card room nor used to light Axminster looms. They are successful in spinning and drawing rooms.

Clusters of a cheap variety are the best solution for mill lighting. They should have heavy galvanized iron shades. The leads are protected by being carried down the iron pipe support. The shades receive the blows of ladders, poles and other long objects carried around mills and save the lamps from destruction. Where the machinery is of a class to transmit little vibration to the building, clusters may be rigidly secured. Some classes of machinery will cause the building to vibrate, no matter how heavily built. Under these circumstances it is necessary to hang cluster stems from a hook.

Three phase circuits are best for power, but for lighting, the matter of balancing is a nuisance. If we are confined to 125-volt lamps, the amount of copper in a mill 1000 feet is rather large. The best distribution appears to be a geometrical arrangement of 250-volt three-wire circuits. By arranging two single-phase circuits in quadrature and alternating each bent on the 250-volt circuit there is not the least trouble in keeping the sides of the three-wire system balanced and the circuits will balance on the three-phase sides. This easily acquired balance continues through the many changes in lighting that a growing plant affords.

H. W. Peck: These papers are much more general than I would wish. We need data regarding actual facts obtained, giving good, bad, and average performance, especially the last for the sake of the manager or investor. It is noticeable in both Mr. Jackson's and Mr. Main's papers that they give practically the best performance of the machinery which they are discussing, and state this fact, but they do not state what they have found to be, or believe to be, average performance, *e.g.*, Mr. Jackson says, " The cost is probably fully that large," and again, " The cost is ordinarily much higher "

I would suggest also that in discussions of this kind the cost and other items regarding performance be reduced to the basis of the kilowatt-hour. It is conceded by the authors that electrical distribution of power is most general, so that this basis will apply in the majority of cases. If the plant is so small, simple and compact as to make mechanical distribution a possibility—and investigation shows it has advantages—a correction factor due to these advantages can readily be applied to the determined cost of electric power at the switchboard. Thus Mr. Jackson's " Round estimate of the cost of power in machine shops and the like is $60 per h.p.-yr." becomes 3 cents per kw-hr. His costs of 0.65 cents and 1 cent per i.h.p. per hr., which he increases by 50 per cent for mechanical distribution, can with equal correctness be increased by from 50 to 70 per cent to give the cost per kilowatt-hour at the switchboard, thus enabling a direct comparison with central station power. Similarly, Mr. Main's figures for pounds of coal per horse power per hour increase from 1.75 and 3, to about 2.95 and 5.05 lb. per kw-hr. at the switchboard. The performance given on the basis of the indicated horse power per hour can be changed to a basis of a kilowatt-hour by multiplying by a factor between 1.55 and 1.7, the former for large units of, say, 1000 kw. capacity, and the other for smaller units of about 100 kw. capacity.

I would take exception to several matters in these papers as a general proposition, applying to textile mills, or to any other industrial establishment; in the first place, to the position taken that reliability is of secondary importance, and that no spare units should be considered necessary for an industrial establishment. This is certainly far more important for a small plant with only one or two units which would be very seriously crippled by the breakdown of one unit, than for a large central station with so many units that the load of any one could easily be carried by the remaining units. This gives a real factor of reliability without cost additional to what would be determined by good engineering practice as regards the amount of load normally carried by each machine. Likewise, if the power is as small a matter as five per cent of the rest of the business of an industrial establishment, it seems poor judgment to skimp on the power plant, which may cause a cessation of the other 95 per cent of the business. Both gentlemen concede the increased reliability of the larger power plants. I have in mind two comparatively small plants in Rochester where the cost for break down service from the central station during the first year of operation amounted to, in one case, 30 per cent of the operating cost of the plant; in the other case, 25 per cent. If central station service had not been available in these cases, and a spare equipment had not been provided, the business would have been practically shut down. I do not see, either, how it is possible to install these plants within such close limits of the actual requirements. In my experience with industrial plants, there is a very marked seasonal variation, and in most cases, a steady growth in power requirements. This, of course, makes the average load factor, considered over several years' time, much lower than the load factors given in these papers. In our experience, also, the lighting of the establishments amounts to from 10 to 25 per cent of the power requirements, and is of use for but short periods. This decreases the load factor much below that given in the papers.

This brings to mind another advantage which the central station possesses. Its growth has been steady but gradual and it has had the opportunity of making its additional equipment of the most modern type. This most efficient equipment can be used at the average load for the long-hour use while the less efficient and less valuable machines are operated for the peak load.

Neither paper considers the item of profit which should be earned on the power plant investment and operating capital to the same extent that it is earned on the rest of the investment --possibly 10 per cent; possibly 20 per cent; or at least to the extent of the central station profit, say 5 per cent. Mr. Main also passes over very lightly the matter of supervision on the part of the manager. I have found that the managers are required to expend considerable of their time and thought on the power problem. These managers are experts in business matters but are not engineers, and their time is expended to small advantage in power questions. In one of the cases cited above, where the breakdown service was so expensive, the manager said that he had spent about two-thirds of his time in connection with his plant.

As to the division of central station costs mentioned by Mr. Main, I would say that the production cost is about one-half; the distribution about one-third; and the general expenses, including advertising and commercial expenses, about one-sixth. In the specific case of the smallest customers who use just enough power to pay the minimum charge of one dollar, the central station companies certainly do lose money, *e.g.*, with an

8 cent kw-hr. rate for current, and a one-dollar-per-month minimum charge, the cost of maintaining and reading the meter, billing, and collecting, amounts to slightly over one dollar, while the 12½ kw-hr. may not represent more than 25 cents. For a large customer the meter costs are, of course, practically a negligible part of the total expense.

I have yet to find any industrial establishment that knows even within approximate limits the cost of its power, either in toto, or per unit. Such costs were recently promised me by one establishment, with the assurance that they had them exactly, and that it would be a simple matter to take them from the books in shape for me to use. They have since told me that it will mean several months' work to get this data, as they were quite surprised at the manner in which the costs had been entered. In this particular place they had a watthour meter on the switchboard, which in itself is quite unusual. Where they have not this means of knowing the amount of power generated the actual amount is almost invariably over-estimated.

R. D. De Wolf: In the article by Mr. Hale the writer has reached certain conclusions in regard to the use of decentralized plants, basing these conclusions on the experience met with under certain commercial and operating conditions. It should also be noted that the small plants abandoned by the Edison Electric Illuminating Company of Boston were not so situated that use could be made of the exhaust steam from the plants. As pointed out in Mr. Main's article, the mill which can use all of the waste products from the power plant will have the lowest cost; and this same condition exists when the power plant is operated by a central station company and that company is in a position to sell its waste products.

There are several conditions existing which make the operation of a decentralized heating and power plant particularly attractive. In plants of this type the operating conditions are determined not by a widely fluctuating electrical load, but by a fairly steady heating load. The heavy overloads met with in operating generating stations, lasting from one-half hour to an hour or two, are not encountered when the primary purpose of the plant is to supply steam for heating. On account of this great improvement in the load factor on a plant it is unnecessary to carry large reserve power units for peak loads, and the plant can be operated at or near its point of maximum efficiency the greater part of the time. As the plant is necessarily a non-densing plant, complicated auxiliary apparatus is dispensed with, and a simple type of machinery installed which can be operated by comparatively unskilled labor and requires less attendance. Automatic features can be included in the design of the installation, so that the plant can be operated with the minimum amount of labor per unit of output. In other words, the labor can be used as efficiently in a medium sized plant of this type as the higher grade labor is used in a much larger condensing plant.

When the plant can be so located as to handle a group of buildings of a diversified character, such, for instance, as a department store, a hotel, a theatre, an office building, and a manufacturing plant, the diversity factor of the steam load will be such that the resultant load on the plant will have only a comparatively small variation.

The type of apparatus installed in a plant of this character, as pointed out in Mr. Parker's remarks, will be comparatively simple and inexpensive. Complicated condensing apparatus will not be required, and there will be a corresponding saving in operating expense, due not only to decreased interest and depreciation charges, but to decreased repairs and supplies. With a plant of this character installed in the business district, where 250-volt direct current distributing systems are used, the high installation cost of a feeder from the distant central station is done away with, and the accompanying line losses saved. In estimating on a recent proposal I found that the approximate cost of installing a 500-h.p. non-condensing plant under such conditions was $25,000; while the cost of a duplicate plant at the central station about one-half mile away, together with the feeder cables, amounted to $94,000. Under these conditions the total operating cost and fixed charges of the non-condensing station per year was $22,590, and of the condensing station and distributing system was $25,790. The fixed charges in each case were $3,050 and $13,250.

These decentralized plants effect the distribution charges in two ways; first, the steam distributing cost; and second, the electrical distributing cost.

The advantages accruing under the heading of steam distributing costs are as follows:

1. Cost of distributing system is less, consequently fixed charges depreciation charges, and repairs are less.
2. Better distribution and better service can be given, as the distance to which steam is transmitted will not be great.
3. Condensation in the distributing system will be less, and the amount of condensed water in the mains which has to be taken care of will be correspondingly less.
4. The system as a whole can be made more flexible by means of tie lines between the different stations, or between the different distributing mains.

The attitude of the customer toward the use of steam can be decidedly influenced, due to the fact that the steam is generated in close proximity to the point at which it is required, rather than being generated at some distant point and transmitted with consequent loss of temperature and increased percentage of moisture in the steam.

The electrical distributing cost is greatly decreased as pointed out above, due to the elimination of expensive transmission lines, expensive generating units, etc.

The operation of plants of this character will enable the central station company to operate certain of its plants under those conditions which Mr. Main has found to be most economical for textile mills, *i.e.*, use can be made of all the waste products of the plant. I think that the manufacturer can be shown that the value of power and of these waste products to him are much more important than the five per cent value given by Mr. Main. If the cost of power is five per cent of the value of the product, this value being necessarily the selling price, then under average manufacturing conditions the factory cost of the product will not be more than 50 per cent of this selling price, and the power would then become 10 per cent of the factory cost. Furthermore, the cost of raw material entering into the product would probably form at least 50 per cent of the factory cost, and therefore the power forms 20 per cent of the manufacturing cost. Any economy which the manufacturer can make in his cost of power will, therefore, be an important item in his total cost of manufacture. When the central station is in a position to supply the manufacturer with all his requisite power, heat, and light, it can effect economies for him which would otherwise be absolutely impossible.

Referring to Mr. Parker's remarks in regard to the central station companies securing large business, it should be noted that they have not only been hampered in this; but that the profits which they could make from such a transaction have been limited to the profits accruing from the sale of power alone. When these large users can be supplied with the necessary steam, an additional source of profit will be introduced; and whereas the central station may have formerly been carrying a load of this character purely for its sentimental and advertising value, when the heat is supplied in addition, the load will become a profitable one.

In closing, I would like to point out one further advantage which the central station company has in handling business of this character. When a given manufacturer, whom we may call *A*, happens to be operating under conditions such that the exhaust steam from the generating apparatus required to furnish him his necessary light and power is just sufficient to give him the necessary heat and low pressure steam for industrial purposes, he will be operating under his most economical conditions, *i.e.*, the ratio between his light and power load and his heating load is one. His neighbor *B* may be operating under conditions such that this ratio is one-half; another neighbor, *C*, under conditions such that this ratio is 1½. The central station can combine these loads, furnish *A* with his total requirements at his old cost, or somewhat less, and make a considerable saving for both *B* and *C*. In this way, by using a sliding rate which will vary with the steam consumption and the ratio, the manufacturer will be enabled to effect an economy for himself by so arranging his processes of manufacture, etc., as to bring about the most economical operating condition for the central station.

Albert L. Pearson: Regarding motors, I agree in general with Mr. Nye as to the requirements which he has set forth for an induction motor, but feel that one or two points should be given further consideration.

The motor should have a high efficiency, particularly in installations where power is purchased. One per cent difference on a group of ten 100-h.p. machines means 10 h.p., the value of which is an appreciable amount to be added to or deducted from the power bill.

The power factor should be as high as possible, as the voltage regulation of the system is better, and in the case of a large installation considerable saving in copper may be made. An installation of induction motors, recently completed, shows one of the values of high power factor. The power company requires this to be maintained at 90 per cent at its measuring instruments; for anything under this it makes quite an additional charge. In this particular case a rotary condenser is used. Such a machine is fairly desirable provided about 70 per cent of its kilovolt-ampere rating can be turned into mechanical energy. In any case it is a much more troublesome machine than an induction motor, owing to complications of exciter, methods of starting, etc. The curves of efficiency and power factor should be as flat as possible to ensure the most economical operation at all loads, say from 50 per cent to 125 per cent.

The slip, or difference between synchronous and full load speed, should be small to insure, as nearly as possible, constant speed at the machines at all times. This is of special value in textile plants where one motor is used for driving four spinning frames, and in group drives for looms where close speed regulation is not only desirable but often necessary. This same thing applies to a group drive for spinning frames, but probably is not of so much importance as for the four-frame drives. In the case of individual drives this does not count for so much, as the driving gear will be arranged to meet the full-load speed of the motor.

The air gap should be reasonably large so that the motor will require a minimum amount of attention at this point. A small gap, unless carefully watched, is very apt to cause considerable annoyance from rubbing. The ventilation should be good and the ducts, etc., so arranged as to facilitate cleaning. It is desirable to have motors waterproof and the terminals enclosed, for such places as opening and picker rooms, so that all of the contents of a machine may be run out in case of fire.

In textile plants, an overload capacity greater than the standard two-hour rating is not necessary. The cost of a rating of 25 per cent overload continuously is an unnecessary investment. Unless the design is such that efficiency and power factor are their best at 80 per cent of their maximum rating, the point of ordinary operation, there will be a continuous and unnecessary loss.

Regarding the application of motors, there is no question as to the advantages resulting from individual drives, such as cleanliness from absence of overhead belting and shafting, improvement in illumination, decrease in cost of power, etc. In equipping a plant with electrical drives care should be taken that it is not " overmotored " as such a condition is sure to result in poor voltage regulation and generally unsatisfactory operation. It is often desirable to make tests after installing motors to make sure that proper machines have been selected. This applies more to the equipping of old plants where the power required is often questionable, than to new installations.

The power supply for industrial plants should never be at less than 550 volts, three-phase, 60 cycles, and very satisfactory results are being obtained from 2,080-volt motors above 20- or 25-h.p. sizes. Possibly, in the case of individual drives, where motors smaller than one horse power are used, better results may be obtained from 220 volts.

In a motor-driven plant the wiring takes the place of shafting in a mechanically driven one. This should be installed in a thoroughly first-class manner, protected from injury and so arranged that the voltage at the motor will never be lower than that at which it is rated. Fuses should never be used except on very small sizes of motors. Air-break switches should never be used. Oil switches should be as simple as possible. Current-carrying parts should be liberal, and contacts so arranged as to be easily renewed.

The first cost of motors and starting devices is too often the first consideration, rather than reliability and future operating costs. While the first cost of equipping a textile plant with motor drive may be more than for direct mechanical drive from a steam engine, this is more than offset by the reduced cost of maintenance and the convenience in operation. This is true for synchronous motors as well as induction motors, for a large number of mills in the South have been equipped with these machines using a rope drive the same as for a steam engine.

H. D. James (by letter): The papers this evening discuss the development of electric power for industrial purposes, but have very little to say about the adaptation of this power to industrial machinery. For years we have had electrical power available, we have recognized the advantages of a motor drive for smoothing out the load curve; then why is it that we did not long ago develop this market for power?

The writer believes that this development was retarded; first, by the improper application of motors. Attempts were made to utilize any motor for industrial purposes provided it had the proper characteristics for the electrical power supply. Tests were not made to determine the amount and duration of the load. Often the motor was applied without the designing engineers having any knowledge of the conditions under which the motor was to operate.

Second, the commercial controllers available were unsuitable for the service and few engineers were making a specialty of this design. The few controller engineers were not associated with the men designing the motors so that there was no mutual adjusting of the apparatus to suit industrial conditions, although at that time the railway field was well developed.

Third, central station managers were making little effort to advise their customers what applications were advisable and assisting them to get satisfactory results.

About five years ago systematic efforts were begun to investigate this field. Where motor drives were not satisfactory, tests were made to determine the actual characteristics of the load. The conditions surrounding the motor were noted; the method of connecting the motor to the load was studied. Experiments were made to develop the best method for controlling the motor for each individual application. This led manufacturers to bring out special motors having the proper electrical and mechanical features to suit particular applications, and capable of satisfactory control.

The controller problem, however, shows the most marked development. The hand-operated controllers have been simplified and made more serviceable. A rapidly increasing line of automatic controllers has been placed on the market. We have developed electrical devices to replace the human brain in the operation of motors. The motor has been made to execute a complicated cycle of operation by means of a small master switch or push button. These controllers, although seemingly complicated are remarkably substantial and easily kept in repair.

There are few drives to which an electric motor cannot be applied profitably if the application is made by a competent engineer. Unfortunately, the number of engineers competent to develop new applications of electric motors is limited. This condition of affairs is largely due to the fact that many engineers do not realize the importance of investigating these applications. A few of the large industries have developed a corps of electrical engineers who have given their whole attention to motor applications. These industries have made rapid strides in electrical development, but unfortunately for the central station, these large corporations have their own power plants.

To make the greatest profit on their investment the central stations must investigate motor applications, either by using the experts trained by large motor manufacturers or else by developing their own corps of experts.

Two articles in the February 1910 issue of the *Electric Journal* give instances of each of the above cases. Consulting engineers would do well to retain controller experts capable of devising special apparatus when necessary, or applying standard controllers to special cases with more intelligence than is often displayed. The many cases of dissatisfaction with motors and controllers which have come to the writer's attention during the last few years, have generally been due to lack of exact information at the time the apparatus was ordered. It is impossible to extend the use of motor drive unless the customer is satisfied. No matter who is to blame for the trouble, the central station is the loser. The elaboration of central station practice and advantages is of no avail unless we have a market for the power, and motor driving is considered by all as a very desirable element of the load.

Begin with the machine the motor drives and work back to the central station. Furnish the customer with power in the form best suited to his uses. If his machinery requires direct current motors, transform your power to direct current; perhaps a synchronous motor will improve your line characteristics. Do not try to " ram an induction motor down his throat " to save your investment in converting apparatus. A failure at one place may prejudice the local trade against the induction motor and prevent its use at another place where it is the best motor for the service. It is not enough to furnish a motor that will turn over. We must use a motor that can be successfully controlled and then see that the customer has the proper control and is instructed how to use it.

C. A. Graves (by letter): Mr. Main states that the chief items of cost in textile mills are material and labor. Such mills, therefore, should locate in or near cities where cheap labor can be obtained instead of locations where cheap power can be obtained. Also the mill owners should welcome every improvement which will give steady uniform power, as this means increased output without increased labor cost.

It has been demonstrated in numerous instances that central station service, because of its more uniform voltage and frequency, has increased the output in various industries. Therefore owners should be willing to pay for the power which enables them to obtain this increased output. Central stations, because of their reserve equipment and duplicate distribution line, can guarantee continuous service, as is done by the Brooklyn and New York companies in their contract with New York City.

Mr. Hale expresses the situation very well when he says that central stations have no cheap unreliable power for sale.

Regarding the question of load factor, textile mills, I am informed, do not run ten hours per day, every working day in the year, but are shut down about two weeks for inventory and repairs and often Saturday afternoons in the summer time. Another point; curve drawing wattmeters which have been installed on the switchboards of various industries show that the hands do not start working until 7:30 and that the best work, or the most power taken is between 10 o'clock and 11 o'clock. After that time, the load gradually falls off until noon. The same thing happens in the afternoon, except that the load seldom goes as high as in the morning. These facts, then, when taken into account, bring the load factor of the mill below that of large central stations.

The basis of figuring cost of power at $33, per kw-hr. of capacity of plant is not an accurate method, as most plants have a capacity larger than their average load, and some few will run overload part of the time. The proper basis is the maximum load.

Let me give an illustration. One of the recent customers of the Brooklyn Edison Company with a 500-h.p. installation, who was selling power to one of his tenants for $50 per h.p-yr., taking the rated horse power of the motors as a basis, found upon installing a wattmeter, that he was receiving 1¼ cents per kw-hr., for the current, besides furnishing motors. Another extreme case which came to my notice was that of a man selling power at $60 per h.p-yr. for a 10-h.p. motor when the wattmeter showed he was charging at the rate of 20 cents per kw-hr. If these tenants had been charged on the basis of their maximum demand and the current consumption, the charges would have been more just. With the accurate measuring instruments used in the sale of electric current, the old terms employed have to be more accurately defined.

J. H. Gardiner (by letter): Mr. Stickney's paper is evidently intended to be but a brief review of the question of industrial lighting and to touch only the salient points of a very comprehensive subject. It contains much excellent information admirably condensed. The recommendation of general, as opposed to strictly local illumination, is undoubtedly correct from both a physiological and a practical standpoint, and accords with the best modern practice.

In the paragraph treating of lamps, however, it seems as though a brief statement in reference to the Nernst glower lamp might well have been made in view of the peculiar adaptability of this type of lamp to industrial lighting. The features which commend it particularly for this work are its ruggedness, the natural downward distribution of the unit, thus obviating the necessity of reflecting glassware which is always troublesome in an industrial establishment; and most important of all, the low maintenance cost. Maintenance cost becomes the preponderating factor in the total, where the cost of electrical energy is as low as in the case of large industrial installations, and is often the determining one when the choice of high efficiency systems is considered.

H. D. Jackson (by letter): Mr. Hales' paper was entirely from the central station man's point of view, and does not take into consideration the conditions governing power cost in most industrial plants. In the first place, there is no inherent reason why an industrial power plant of fair size should not produce power approximately as cheap as the central station even of large size. The power plant of an industrial establishment can, if necessary, be built with all of the refinements used in the central station, and the operating cost of the plant made very low, nearly as low as the central station, the only difference being the slight gain in economy of large units over moderate sized units, so that as far as operating expenses go, there is no reason why the smaller plant should suffer materially in comparison with the larger.

As a rule, the fixed charges against the industrial plant would not be greater than against the central plant, as the industrial plant would not be duplicated, whereas the central station plant would have to use extra apparatus in order to preserve continuity of service. This being the case, the cost of power including all charges, fixed and operating, of the two plants situated in the same locality and under the same conditions, would not vary materially.

The above is based on both plants being operated under the same conditions as regards load factor. It is a fact, however, that the central station load factor is very much lower than that of the industrial plant, and the load of the central station far more fluctuating. It is well recognized that a low power factor or a fluctuating load increases to a considerable extent the power cost. This being the case, the difference in the power cost between the two stations would be materially diminished. In some cases this may be to a certain extent offset by the shutting-down period of the industrial plant. This, however, would not influence conditions to a very great extent, as the central station has periods of this character also, although shorter in duration and not complete shutdowns.

The industrial plant is not as a rule as well located for producing power as the central station, so that an increase to the power cost must be made due to increased cost of fuel, etc., in the industrial plant's location. On the other hand, when the total cost of power at the industrial plant switchboard is figured, that is the end of the power cost when generated by the plant itself: whereas this point at the central station is only the first step. The power in this case has yet to be delivered to the customer. According to most central station men, the cost of delivering the power to the customer, metering, billing, etc., is equal to or greater than the cost of production. This being the case and the difference in cost of power slight if plants are built along the same lines as regards refinement, the central station would find it impossible to *deliver* power at the same price the plant could produce it for.

Mr. Hale speaks of the insurance factor of the central station. In order to insure continuity of service, the central station must have not only spare apparatus, but also duplicate lines for distribution—otherwise the power is no more certain than that of the industrial plant. To use an old phrase: " A chain is no stronger than its weakest link ", and the single line distributing system is in this case the weak link, which is quite as apt to fail as the high grade unit in the industrial plant, so that the insurance factor of the central station exists only in the imagination. The failure of a unit in the industrial plant affects but that plant. The failure of the central station in either line or plant may affect many plants.

In order to sell power to an industrial plant, the central station must of necessity be able to produce it at a very much reduced cost as compared to the industrial plant; and the costs of distribution, such as maintaining the distributing system, cost of metering, billing, collecting, and other charges incidental to central station service—must be reduced to a minimum and the cost of power as delivered to the customer has to include all of these items. The cost of power in an industrial plant consists of all of the items incident to the production of that power, but has absolutely nothing to do with the costs of distributing it.

So far, we have considered two plants for producing power alone, and no other use of steam has been taken into account. Most industrial plants have use for heat, either to warm the buildings or for manufacturing purposes. If exhaust steam will serve the purpose, this can readily be taken from the engine, under which condition a much less costly plant will be installed, reducing the fixed charge, also reducing the operating charge, as the steam thus used cannot be properly charged up entirely against power, as it would have to be produced in some way if the engines did not exist, nor can the boilers required for this steam be entirely charged up against power, as they would also have to exist for producing steam if power was purchased. Thus the greater the steam required for industrial purposes, the less the cost of power, not only as regards operation, but also in fixed charges.

A paper presented at a joint meeting of the American Society of Mechanical Engineers and the American Institute of Electrical Engineers, New York, March 8, 1910.

TEST OF A 15,000-KW. STEAM-ENGINE-TURBINE UNIT

BY H. G. STOTT AND R. J. S. PIGOTT

During the year 1908 it became apparent that owing to the cost of increasing traffic in the New York subway, it would be necessary to have additional power available for the winter of 1909-1910.

The power plant of the Interborough Rapid Transit Company, which supplies the subway, is located on the block bounded by 58th and 59th Streets, and by 11th and 12th Avenues, adjacent to the North River; it contains nine 7500-kw. (maximum rating) engine units, besides three 1250-kw. 60-cycle turbine units which are used exclusively for lighting and signal purposes.

The 7500-kw. units consist of Manhattan-type compound Corliss engines, having two 42-in. horizontal high-pressure cylinders and two 86-in. vertical low-pressure cylinders. Each horizontal high-pressure cylinder and vertical low-pressure cylinder has its connecting rod attached to the same crank, so that the unit becomes a four-cylinder 60-in. stroke compound engine with an overhanging crank on each side of a 7500-kw. maximum rating 11,000-volt, three-phase, 25-cycle generator. The generator revolving field is built up of riveted steel plates of sufficient weight to act as a flywheel for the two engines connected to it. This arrangement gives a very compact two-bearing unit. The valve gear on the high-pressure cylinders is of the poppet type, and on the low-pressure of the Corliss double-ported type.

The condensing apparatus consists of barometric condensers, arranged so as to be directly attached to the low-pressure exhaust nozzles, with the usual compound displacement circulating pump and simple dry-vacuum pump.

These engines and generator units are in general probably the most satisfactory large units ever built, as five years' experience with them has proved; their normal economic rating is 5000 kw., but they operate equally well (water rate excepted) on 8000 kw. continuously.

In considering the problem of how to get an additional supply of power, every available source was considered, but by a process of elimination only two distinct plans were left in the field.

The electric transmission of power from a hydraulic plant was first considered, but owing to the high cost of a double transmission line from the nearest available water power, and the impossibility of getting reliable service (that is, service having a maximum total interruption of not more than ten minutes per annum) from such a line, further consideration of this plan was abandoned.

The gas engine, while offering the highest thermo-dynamic efficiency at the same time required an investment of at least 35 per cent more than an ordinary steam-turbine plant with a probable maintenance and operation account of from four to ten times that of the steam turbine.

The reciprocating-engine unit of the same type as those already installed, was rejected in spite of its most satisfactory performance, on account of the high first cost and small range of economical operation. Reference to Fig. 1, Series A will show that the economic limits of operation are between 3300 kw. and 6300 kw.; beyond these limits the water rate rises so rapidly as to make operation undesirable under this condition, except for a short period during peak loads.

The choice was thus narrowed down to either the high-pressure steam turbine or the low-pressure steam turbine. There was sufficient space in the present building to accommodate three 7500-kw. units of the high-pressure type, or a low-pressure unit of the same size on each of the nine engines, so that the questions of real estate and building were eliminated from the problem.

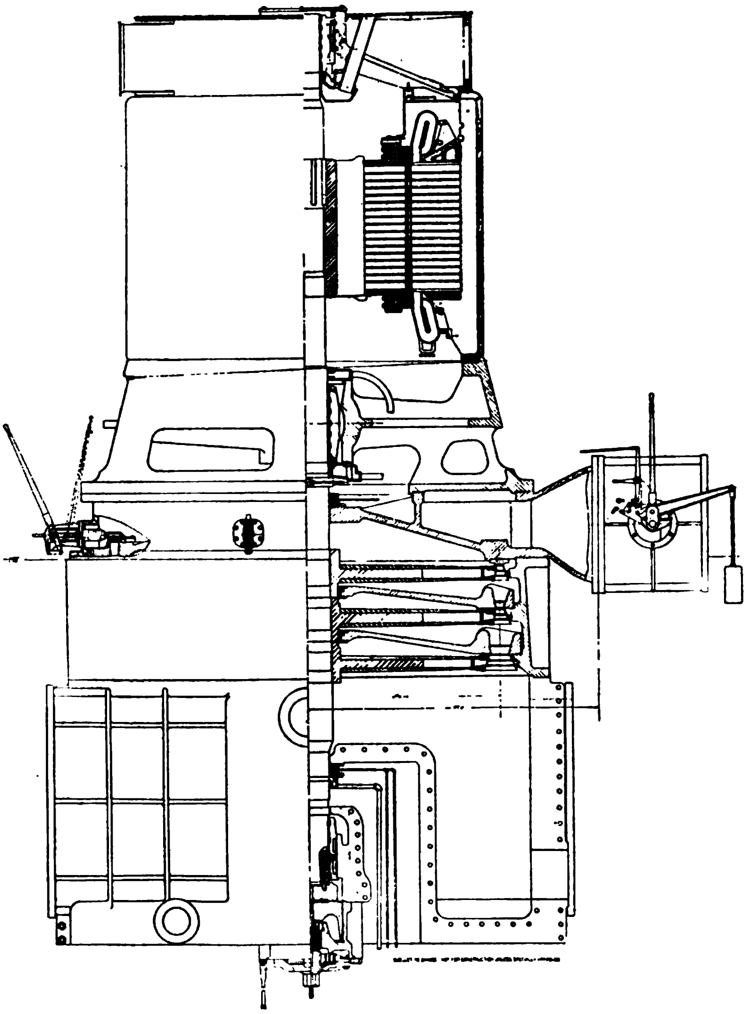
The first cost of a low-pressure turbine unit is slightly lower than that of a high-pressure unit, due to the omission of the high pressure stages and the hydraulic governing apparatus, but the cost of the condensing apparatus would be the same in both cases. The foundations and the steam piping in both cases would not differ greatly. The economic results, so far as the first cost is concerned, would then be approximately the same, if we consider the general case only; but in this particular instance the installation of high-pressure turbines would have meant a much greater investment for foundations, flooring, switchboard apparatus, steam piping and water tunnels, amounting to an addition of not less than twenty-five per cent to the first cost.

The general case of displacing reciprocating engines and installing steam-turbine units in their place was also considered. The best type of high-pressure turbine plant has a thermal efficiency approximately 10 per cent better than the best reciprocating-engine plant, but the items of labor for operation and for maintenance, together with the saving of about 85 per cent of the water for boiler-feed purposes and the 10 per cent of coal, reduce the relative operating and maintenance charges for the steam-turbine plant to 80 per cent, as compared to 100 per cent for the reciprocating-engine plant.

Assuming that the reciprocating engine plant is a first-class one and has been well maintained, about 20 per cent of its original cost (for engines, generators and condensers) may be realized on the old plant and so credited to the cost of the high-pressure turbine plant. But on the other hand, if the high-pressure turbine installation is to receive credit for the second-hand value of the engines, it must also have a debit charge for 100 per cent of the original reciprocating-engine plant which it displaced. The relative investments, therefore, upon this basis would be approximately equal for the high-pressure or the low-pressure turbine; but 80 per cent of the cost of the original engine plant would have to be charged against the high-pressure turbine plant, as against an actual increase in value (to the owner) of the engine by reason of its improved thermal efficiency, due to the addition of the low-pressure turbine.

The preliminary calculations, based upon the manufacturers' guarantees for the low-pressure and high-pressure turbines, showed that the combined engine-turbine unit would give at least 8 per cent better efficiency than the high-pressure turbine unit, so that it was finally decided to place an order for one 7500-kw. (maximum rating) unit, as by this means we would not only get an increase of 100 per cent in capacity, but at the same time give the engines a new lease of life by bringing them up to a thermal efficiency higher than that attained by any other type of steam plant.

The turbine installed is of the vertical three-stage impulse type having six fixed nozzles and six which can be operated by hand, so as to control the back pressure on the engine, or the division of load between engine and turbine. An emergency overspeed governor, which trips a 40-in. butterfly valve on the



Elevation and part section of low pressure turbine unit

steam pipe connecting the separator and the turbine and at the same time the 8-in. vacuum breaker on the condenser, is the only form of governor used. The footstep bearing, carrying the weight of the turbine and generator rotors, is of the usual design supplied with oil under a pressure of 600 lb. per sq. in. with the usual double system of supply and accumulator to regulate the pressure and speed of the oil pumps.

The condenser contains approximately 25,000 sq. ft. of cooling surface arranged in the double two-pass system of water circulation with a 30-in. centrifugal circulating pump having a maximum capacity of 30,000 gal. per min. The dry vacuum pump is of the single-stage type, 12-in. and 29-in. by 24-in., fitted with Corliss valves on the air cylinder. The whole condensing plant is capable of maintaining a vacuum within 1.1 in. of the barometer when condensing 150,000 lb. of steam per hr. when supplied with circulating water at 65 deg. fahr.

The electric generator is of the three-phase induction type, star-wound for 11,000 volts, 25 cycles and a speed of 750 rev per min. The rotor is of the squirrel-cage type with bar winding connecting into common bus-bar straps at each end. This type of generator was chosen as being specially suited to the conditions obtaining in the plant.

With nine units operating in multiple, each one capable of giving out 15,000 kw. for a short time, operating in multiple with another plant of the same size, it is evident that it is quite possible to concentrate 270,000 kw. on a short circuit. If we proceed to add to this, synchronous turbine units of 7500-kw. capacity, which, owing to their inherently better regulation and enormous stored energy, are capable of giving out at least six times their maximum rated capacity, the situation might soon become dangerous to operate, as it would be impossible to design switching apparatus which could successfully handle this amount of energy. The induction generator, on the other hand, is entirely dependent upon the synchronous apparatus for its excitation, and in case of a short circuit on the bus-bars would automatically lose its excitation by the fall in potential on the synchronous apparatus.

The absence of fields leads to the simplest possible switching apparatus, as the induction generator leads are tied in solidly through knife switches, which are never opened, to the main generator leads. The switchboard operator has no control whatever over the induction generator, and only knows it is present by the increased output on the engine generator instruments.

The method of starting is simplicity itself—the exciting current is put on the engine generator *before* starting the engine, and then the engine is started, brought up to speed and synchronized in exactly the same way as before. While starting in this way, the induction generator acts as a motor until sufficient steam passes through the engine to carry the turbine above synchronism, when it immediately becomes a generator and picks up the load. Three of these 7500-kw. low-pressure turbine units have been installed and tests run on Nos. 1 and 2. No. 3, having been just started, has not yet been tested.

Instead of inserting in this paper the enormous accumulation of data incident to these tests, we have divided the paper into two parts in the hope that it would thus be more accessible for reference, the first part giving the reasons for adopting this particular type of apparatus, with a brief description of the plant and a summary of the results obtained, and the second part containing all the principal data acquired during the tests, with sufficient explanation to make their meaning clear without reference to the text.

The tables and curve sheets are as follows:

Series A: Engine tests made in connection with acceptance tests, and also later to determine best conditions for operation.

Series B: Calculations and data furnished by turbine manufacturer to determine probable results when combined with engine data obtained in Series A.

Series C: Tests on No. 1 combined unit. This unit was hurriedly put into commission in order to obtain results to determine future developments. To get the piping done, old riveted steel pipe was used which was very leaky under vacuum. Results are valuable however as showing the effect of vacuum on performance as compared to Series E and F. Quality of steam entering turbine also poor.

Series D: Tests of No. 2 unit, with poor vacuum and poor quality of steam entering turbine.

Series E and F: Tests on No. 2 combined unit: conditions of vacuum and quality of steam entering turbine nearly standard, so that corrections are small.

In all results, except where specially noted, moisture corrections are simple corrections, *i.e.*, for each per cent of moisture only one per cent correction has been made. Vacuum corrections for the combined unit are 1 lb. for each inch variation from 28.5 in. when referred to 29.92 in. barometer.

The net results obtained by the installation of low-pressure turbine units may be summarized as follows:

a An increase of 100 per cent in maximum capacity of plant.

b An increase of 146 per cent in economic capacity of plant.

c A saving of approximately 85 per cent of the condensed steam for return of the boilers.

d An average improvement in economy of 13 per cent over the best-high pressure turbine results.

e An average improvement in economy of 25 per cent (between the limits of 7000 kw. and 15,000 kw.) over the results obtained by the engine units alone.

f An average unit thermal efficiency between the limits of 6500 kw. and 15,500 kw. of 20.6 per cent.

TABLE 1 SERIES A, ENGINE TESTS

No. of test	Eng. load kw.	Steam pressure lb. gauge	Steam temperature deg. fahr.	Steam superheat deg. fahr.	Receiver pressure (from temp.) lb. gauge	Vacuum std. in. 29.92 in mercury	Quality of steam per cent	Water per hr. lb.	Dry steam per hr. lb.	Rec. drain per hr. lb.	Steam to auxiliary lb.	Inject water temp. deg. fahr.	Disch. water temp. deg. fahr.	i.h.p. high-pressure h.p.	i.h.p. low pressure h.p.	i.h.p. total h.p.	Dry steam per kw-hr. lb.	Dry steam per i.h.p. hr. lb.
25	3100	180.1	388.3	9.7	9.13	28.81	100.55	56040	56349	2989	1517	36.8	55.7	2173	2306	4479	18.18	12.58
22	4008	176.7	383.9	5.7	16.87	27.99	100.32	68190	68407	4882	1866	38.4	58.3	2699	2815	5514	17.07	12.42
24	4977	174.4	387.8	10.6	21.7	28.00	100.58	85369	85865	5273	2949	36.8	65.3	3264	4076	7341	17.25	11.70
21	5984	173.9	387.5	10.5	25.9	28.00	100.60	103896	104519	6031	1699	37.73	69.5	3717	4714	8431	17.47	12.40
23	6772	173.3	385.5	8.7	30.0	27.71	100.50	124702	125326	6060	2091	37.7	70.4	4346	5732	10078	18.51	12.37
27	4992	173.9	387.3	10.5	10.44	28.11	100.60	89525	99062	5367	1826	37.76	72.66	3770	5184	6954	18.04	12.95
26	4970	173.2	386.1	9.4	15.21	28.00	100.53	86267	86724	5518	1728	35.9	61.1	3443	3452	6895	17.45	12.58
29	4976	174.9	386.9	9.4	20.41	28.00	100.53	85557	86010	5294	3034	38.1	75.0	3124	3722	6846	17.29	12.59
28	4970	174.3	388.8	11.7	25.35	28.02	100.66	85933	86501	4890	663	36.7	72.6	2982	4127	7109	17.42	12.17
31	3988	177.7	387.5	8.9	32.62	—	100.51	109317	109874	5948	—	—	—	2625	2372	4997	27.55	21.99
32	4980	176.2	386.7	8.7	36.93	—	100.50	128056	128695	6352	—	—	—	2835	3333	6168	25.84	20.88
30	4961	148.2	372.0	7.0	21.06	28.01	100.40	88041	88394	5082	1284	37.46	72.4	3068	4019	7087	17.82	12.48

TABLE 2—SERIES A

No. of test	Eng load kw.	B.t.u. added per pound water	B.t.u. rej. per pound water	Eff. Rankine per cent	Eff. thermal per cent	$\frac{\text{Eff}_T}{\text{Eff}_R}$ per cent	B.t.u. drains per cent	B.t.u. con's'r and rad'n loss per cent	B.t.u. mech. elec. loss per cent	Remarks
25	3100	1205	840	30.3	15.7	51.7	0.9	71.4	12.0	
22	4008	1202	865	28.0	16.7	59.6	1.3	70.0	"	
24	4977	1204	866	28.1	16.5	58.1	1.2	70.3	"	
21	5984	1204	866	27.1	16.3	58.2	1.1	70.6	"	
23	6772	1203	875	28.3	15.4	56.4	1.0	71.6	"	
27	4992	1205	865	28.2	15.8	56.0	1.0	71.2	"	
26	4970	1204	866	28.1	16.3	58.1	1.2	70.5	"	
29	4976	1205	866	28.1	16.4	58.6	1.2	70.4	"	
28	4970	1206	866	28.2	16.4	58.1	1.1	70.5	"	
31	3988	1205	1017	15.6	10.3	66.2	1.1	76.6	"	Non-condensing
32	4980	1204	1017	15.5	11.0	71.1	1.0	76.0	"	Non-condensing
30	4961	1200	875	27.1	16.0	59.7	1.1	70.9	"	

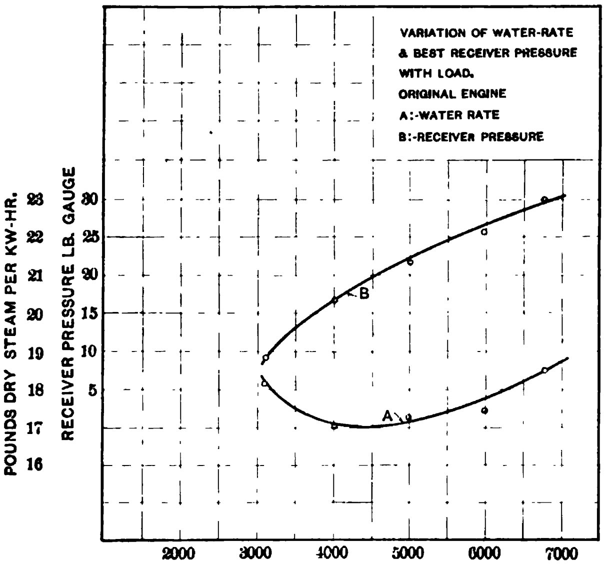


Fig. 1.—Series A

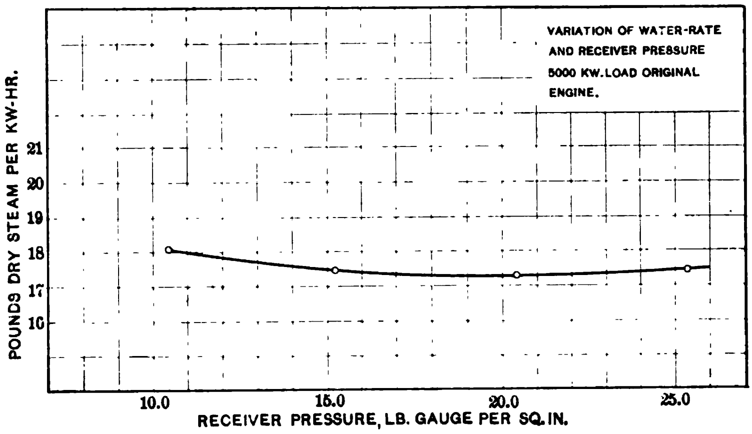


FIG. 2.—Series A

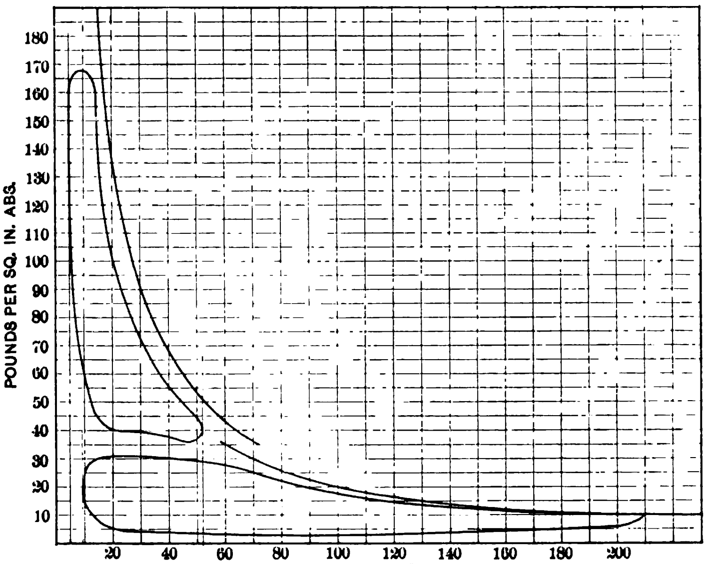


FIG. 3.—Series A, test 29

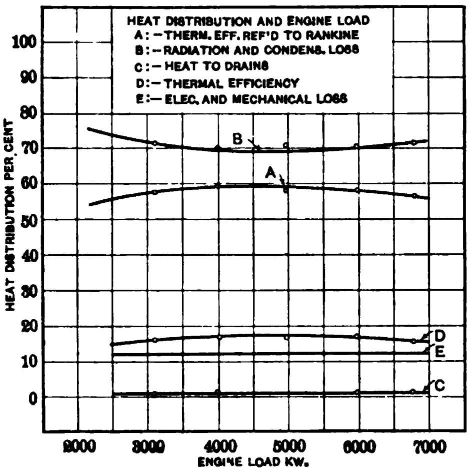


Fig. 3a.—Series A

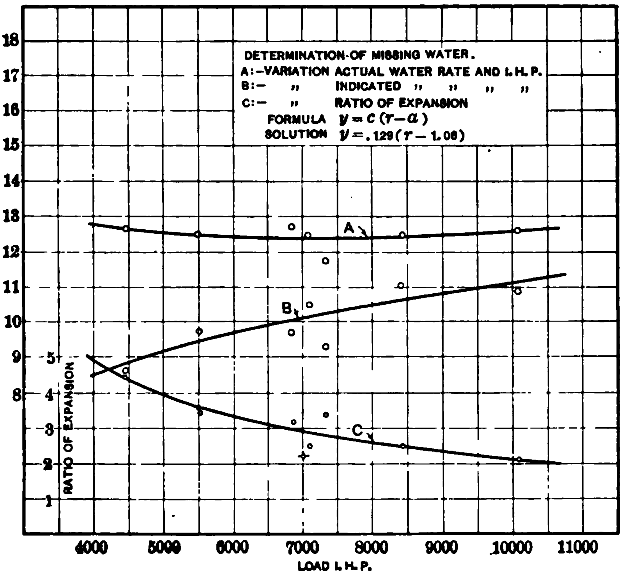


Fig. 4.—Series B

TABLE 3 SERIES B

No. test	Load kw.	i.h.p.	Ratio high press. / low press. i.h.p.	P_a lb. per sq. in. abs.	P_c lb. per sq. in. abs.	V_a cu. ft.	V_c cu. ft.	W_a lb. per cu. ft.	W_c lb. per cu. ft.	Steam per stroke high press. card lb.	r	y	Indic. water rate per i.h.p. lb. per hr.	Actual water rate per i.h.p. lb. per hr.	Actual water rate per kw-hr. lb. per hr.	Receiver press. per lb. sq. in. abs.	Exhaust press. lb. per sq. in. abs.	Steam press. lb. per sq. in. abs.	Steam press. total water lb. per hr.
25	3100	4479	0.943	137.32	66.12	10.78	7.56	0.3058	0.1544	2.131	4.80	0.469	8.57	12.59	18.18	19.8	0.9	191.5	56349
22	4008	5515	0.959	143.0	65.3	13.77	9.31	0.3176	0.1526	2.951	3.41	0.298	9.64	12.41	17.07	31.6	1.0	192.8	68407
29	4976	6846	0.840	142.4	73.8	16.64	9.30	0.3163	0.1709	3.670	3.11	0.302	9.65	12.56	17.29	36.4	1.0	190.9	86010
24	4977	7341	0.801	141.8	75.7	17.13	9.30	0.3151	0.1751	3.769	3.32	0.265	9.24	11.69	17.25	35.1	0.9	191.0	85865
21	5984	8431	0.789	141.8	74.1	21.48	9.29	0.3142	0.1716	5.154	2.42	0.128	11.00	12.40	17.47	40.6	0.9	191.0	104519
23	6772	10078	0.759	140.6	89.0	25.40	9.29	0.3126	0.2037	6.080	2.04	0.154	10.86	12.44	18.51	44.7	1.0	190.9	125326
31	3988	5900	1.403	143.7	72.2	19.83	7.56	0.3191	0.1675	5.058	3.11	0.206	15.43	18.62	27.55	47.3	14.7	192.2	109874
32	4981	7004	0.807	143.7	75.8	23.44	7.57	0.3191	0.1753	6.154	2.21	0.155	15.81	18.28	25.84	51.6	14.7	189.7	128695
Assumed cards, variable nozzle pressure																			
A	4050	5936	1.04	187.8	82.5	10.93	4.70	0.4107	0.1897	3.597	4.73	0.474	12.00	17.69	25.92	39.7	7.0	215	105000
B	5590	8192	1.05	182.2	96.0	16.45	"	0.3991	0.2186	5.537	3.14	0.268	12.18	15.45	22.63	46.0	10.0	"	126600
C	6710	9836	1.07	176.0	119.5	22.80	"	0.3862	0.2685	7.55	2.27	0.156	13.62	15.98	23.40	52.2	13.5	"	157300
D	7370	10792	1.10	168.6	122.8	29.83	"	0.3708	0.2753	9.71	1.73	0.087	16.30	17.72	25.95	58.5	18.0	"	191100
E	7740	11336	1.05	160.9	136.2	37.60	"	0.3549	0.3034	11.92	1.31	0.033	18.91	19.54	28.61	64.7	23.0	"	221400
Assumed cards, constant nozzle pressure																			
F	3875	5676	1.12	182.2	136.2	16.45	"	0.3991	0.3034	5.140	3.14	0.268	16.31	20.69	30.30	64.7	16.0	"	117400
G	5795	8484	0.988	176.0	"	22.80	"	0.3862	"	7.374	2.27	0.156	15.57	18.00	26.38	"	"	"	152700
H	7190	10540	0.974	168.6	"	29.83	"	0.3708	"	9.633	1.73	0.087	16.45	17.88	26.20	"	"	"	188500
I	8200	12008	0.938	160.9	"	37.60	"	0.3549	"	11.92	1.31	0.033	17.86	18.45	27.04	"	"	"	221700

TABLE 4—SERIES B

Assumed cards low pressure exhaust quality data

No.	Water p. hr. lbs.	High press. steam to low press cylinders per cent	Moisture at low press. admission per cent	Admission press. lb. per sq. in. abs.	Relief press. lb. per sq. in. abs.	Exhaust press. lb. per sq. in. abs.	r	Quality of low press. exhaust per cent	Comb. quality per cent	Dry steam turb. lbs. per hr.	
A	105000	93.2	2.5	37	9.5		2.76	90.6	84.4	88600	Variable nozzle press.
B	126600	94.3	3.0	43	14		2.47	90.9	85.7	108500	
C	157300	95.2	3.5	49	19		2.26	91.4	86.9	136700	
D	191100	95.9	4.0	55	24		2.10	91.6	87.8	167800	
E	221400	96.2	4.0	60	28		1.98	91.9	88.4	195600	
F	117400	96.8	3.0	60	20	17.5	3.30	90.8	84.5	99200	Constant nozzle press.
G	152700	95.7	3.5	"	20	"	2.94	90.5	85.5	130600	
H	188500	94.4	4.0	"	23	"	2.46	90.8	86.9	163800	
I	221700	93.1	4.0	"	27	"	1.98	91.6	88.7	196600	

REMARKS AND FORMULAE

Tests 21–29 inclusive, 8 hr.

Tests 31–32, 8 hr. atmospheric exhaust non-condensing.

$$\frac{\text{i.h.p.}}{\text{kw.}} = 1.465$$

$r = \frac{51.7}{V_a}$ for high-press. card = ratio of expansion.

$y = 0.129\ (r - 1.06)$ = missing water.

w = Sp. density at p.

$$W_a \times V_a = W_1 \qquad W_c \times V_c = W_2 \qquad W_1 - W_2 = W_3$$

$$\frac{W_3 \times 60 \times 4 \times 75}{\text{i.h.p.}} = \text{i. w. r. at high press. cut-off.}$$

I. w. r. $\times (1 + y)$ = a. w. r. per i.h.p. hr.

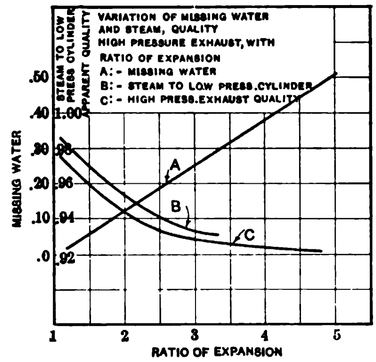


FIG. 5.—Series B

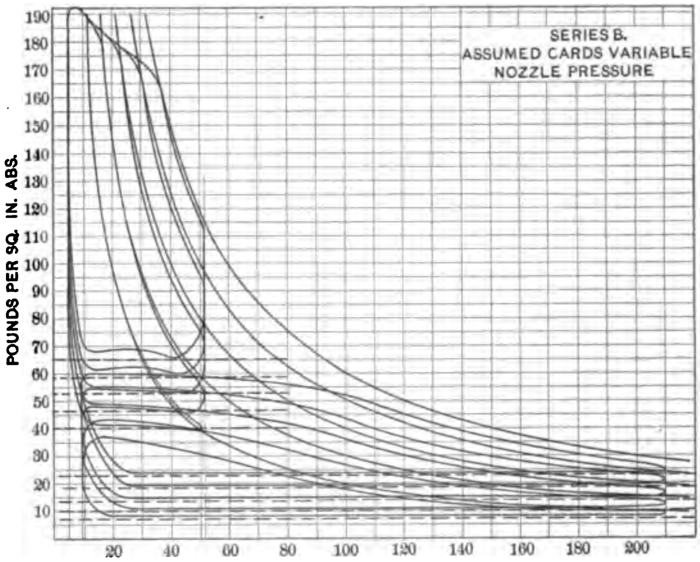


FIG. 6.—Series B

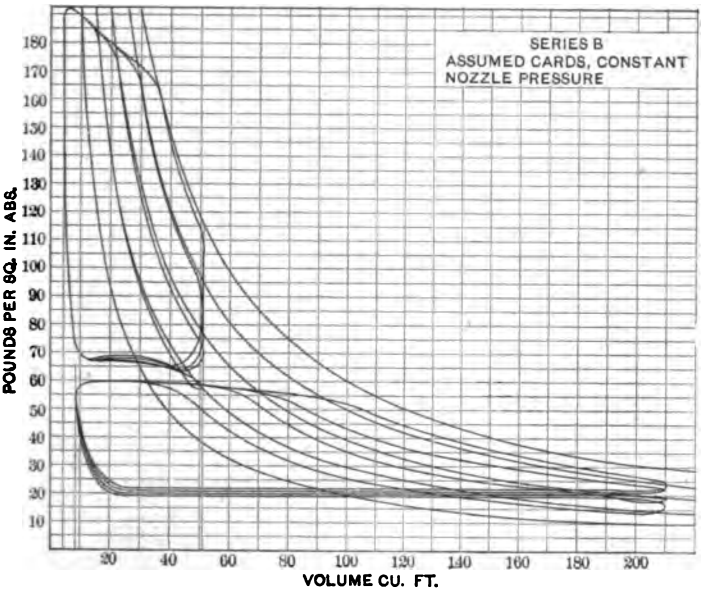


FIG. 7.—Series B.

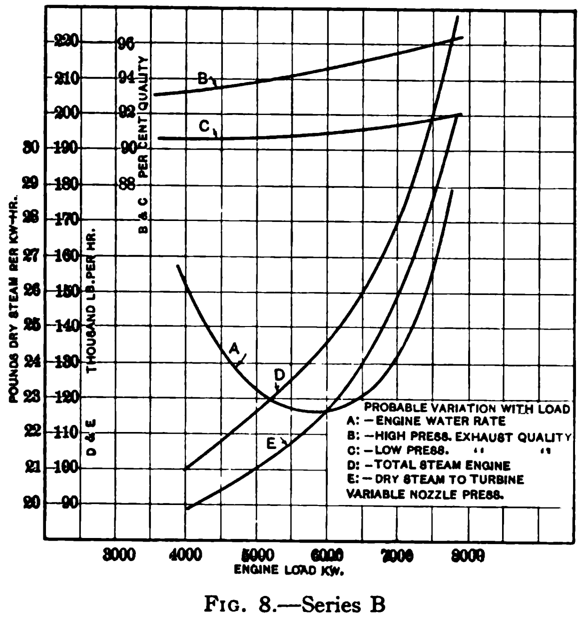


FIG. 8.—Series B

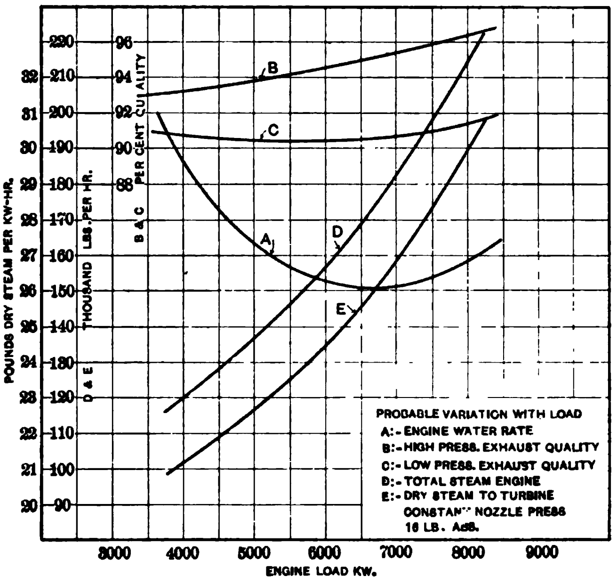


Fig. 9.—Series B

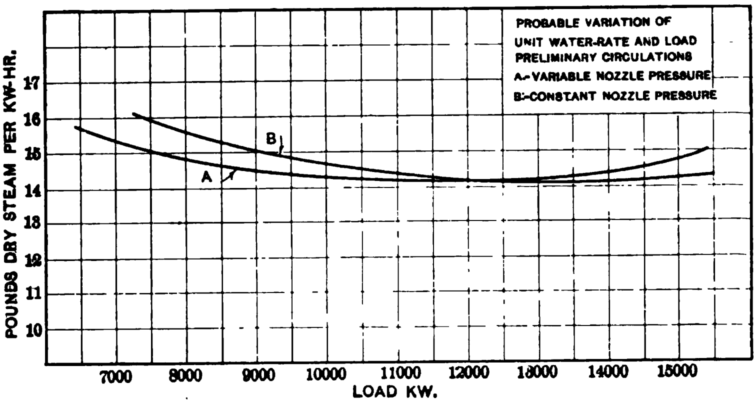


Fig. 10.—Series B

TABLE 5 SERIES C

Resume of observations — Corrected to 29.92 in. barometer and 14.7 lb. atmos.

		Loads			Pressures					Qualities		Water			Dry steam		Temperatures		
Test No.	Duration	Unit	Engine	Turbine	High press. steam	Receivers	Low press. steam	Low press. steam	Vacuum	High pressure steam	Low pressure turb.	Separator low pressure	Turbine discharge	Total unit	Turbine	Eng. and unit	Hot well cond.	Injection	Disch. circ. water
	hours	kw.	kw.	kw.	lb. gauge per sq. in.	lb. gauge per sq. in.	lb. abs. per sq. in.	lb. gauge per sq. in.	in mercury	Per cent	Per cent	lb. per hour	lb. per hour	lb. per hour	lb. per hour	lb. per hour	deg. fahr.	deg. fahr.	deg. fahr.
5	4	10220	6627	3690	174.4	36.2	12.72	—	28.03	97.08	90.89	3369	150170	153540	136500	149000	88.1	72.1	84.0
6	5	11320	6520	4870	173.4	35.7	17.22	1.52	28.34	96.96	94.09	2759	167190	169950	158200	164850	87.6	74.7	87.8
7	3	11150	6187	4960	173.4	33.9	17.36	2.66	28.55	97.06	90.17	1157	164945	166100	148350	161200	85.5	72.5	86.0
8	3	10970	6178	4840	170.2	49.6	17.36	2.66	28.44	97.15	88.62	654	161612	162270	143200	157700	86.9	74.4	86.6
9	2	11250	6560	4685	170.2	50.1	16.61	1.91	28.18	97.08	92.08	5830	164458	170290	151900	165300	87.8	72.8	86.3
10	1	12440	7060	5400	172.0	49.3	17.60	2.90	27.91	97.54	86.96	3133	185100	188230	161400	183600	89.5	72.0	83.3
11	2	8990	5195	3795	172.0	50.0	16.61	1.91	27.92	97.54	91.32	469	136850	137320	124890	133930	87.3	72.4	83.5
12	1	13240	7580	5610	172.6	48.8	17.06	2.36	27.99	98.32	85.06	6018	192290	198310	163500	194900	90.7	75.4	89.2
13	2	10240	6070	4220	172.0	47.1	16.80	2.10	27.98	98.50	91.05	825	156470	157290	142470	154900	88.2	72.8	83.8
14	2	11480	6140	5340	174.8	51.4	18.84	4.14	28.29	98.41	90.24	337	176210	176550	159010	173740	86.4	73.0	86.6
15	5	11504	6022	5468	170.8	48.1	19.45	4.75	27.51	97.83	95.15	—	167103	—	159000	—	91.8	78.2	93.5
16	7	11526	6314	5203	173.9	48.4	19.45	4.75	27.42	98.02	93.57	9633	167085	176718	157300	173200	92.9	78.6	91.5
17	5	11528	6084	5488	175.7	49.5	19.90	5.20	27.62	97.70	94.68	5111	179170	184301	169650	180100	86.4	73.6	86.7
18	6	10740	5916	4831	174.1	49.5	18.56	3.86	27.65	98.19	94.83	12554	149148	161702	141450	158750	89.7	72.8	83.6
19	6	14540	7860	6692	174.0	51.7	18.42	3.72	27.78	97.66	95.07	16404	201351	217755	191450	212700	90.9	72.2	88.2
20	4	14365	7373	6962	171.6	52.2	20.94	6.24	27.75	97.88	96.47	15423	196680	212103	189750	207750	90.3	72.6	93.7
21	6	10320	5632	4617	175.9	49.8	17.77	3.07	28.03	97.54	89.52	6486	144399	150885	129150	147100	87.8	72.5	84.4
23	6	13410	7460	5862	173.9	50.2	18.01	3.31	27.72	97.80	96.09	15760	195514	211274	188000	206800	91.1	73.0	87.0
24	6	12927	7033	5820	169.8	50.2	18.59	3.89	27.79	98.03	95.47	14439	173150	187589	165300	183950	89.8	73.3	86.8
25	6	9730	5142	4508	175.3	49.7	18.99	4.29	27.78	97.77	96.46	11189	134635	145824	129840	142600	88.8	72.3	82.8
26	6	11840	6470	5305	172.6	49.2	19.02	4.32	27.48	98.18	96.48	14090	161983	176073	156300	172900	88.2	73.1	84.9
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE 6 SERIES C

Test	Load	Results: Water rates (dry steam)							Guarantee and calculated water rates			Circ. water		Water rate		
		Turbine	Engine	Unit		Unit	Unit		Turbine	Engine	Unit			unit equivalent		
		Actual				moist corr.	total corr.		Constant nozzle pressure			Ratio	Total			
	kw.	Lb. per kw-hr.	Lb. per kw-hr.	Lb. per kw-hr.		Lb. per kw-hr.	Lb. per kw-hr.		Lb. per kw-hr.	Lb. per kw-hr.	Lb. per kw-hr.	C.W. / Dry st.	Gal. per min.	Lb. per i.h.p. hr. c.n.p.	Remarks	Formulae and notes
5	10220	36.98	22.48	14.57		14.0	13.53		28.42	26.03	14.42	89.0	26740	8.85	Varying nozzle press.	$27 = \frac{17}{4+[1+(1-12)]5}$
6	11320	32.34	25.30	14.45		14.1	13.94		27.30	26.04	14.07	80.5	26920	8.68	Auxiliary steam included c.n.p.	
7	11150	30.42	26.05	14.49		13.85	13.90		27.22	26.07	14.10	78.3	25800	9.10	Constant nozzle press.	28 = 27−(28.5−10)
8	10970	29.58	25.51	14.37		13.64	13.70		27.31	26.07	14.15	86.5	27960	8.76	Do	
9	11250	32.42	25.20	14.69		14.23	13.55		27.42	26.04	14.09	79.0	25980	9.03	Do.	
10	12440	29.89	26.01	14.76		13.95	13.36		27.00	26.08	13.88	93.5	30560	8.27	V.n.p.	
11	8990	32.91	25.79	14.89		14.36	13.78		28.29	26.99	15.10	94.5	25820	8.76	C.n.p.	
12	13240	29.15	25.71	14.72		13.90	13.39		26.90	26.46	13.90	76.5	30320	8.25	Do.	
13	10240	33.76	25.52	15.13		14.51	13.99		27.83	26.10	14.41	96.0	30200	9.01	Do.	
14	11480	29.78	28.30	15.15		14.47	14.26		27.02	26.10	14.03	78.6	25000	9.14	V.n.p.	
15	11504	29.06	—	—		—	—		26.97	26.24	14.01	69.0	23060	—	Aux. included c.n.p.	
16	11526	30.22	27.42	15.02		14.64	13.56		27.10	26.12	14.01	82.0	27400	8.93	C.n.p.	
17	11528	30.90	29.70	15.68		15.20	14.32		26.96	26.20	14.01	81.0	29020	9.53	Aux. included v.n.p.	
18	10740	29.26	26.84	14.78		14.41	13.56		27.31	26.30	14.22	98.0	29230	9.06	C.n.p.	
19	14540	28.60	27.05	14.62		14.30	13.58		26.63	26.69	13.80	66.0	26560	9.08	Do.	
20	14365	27.23	28.15	14.45		14.25	13.50		26.60	26.31	13.80	51.0	20050	9.05	V.n.p.	
21	10320	27.97	26.11	14.25		13.70	13.23		27.49	26.50	14.39	85.0	24520	8.52	C.n.p.	
23	13410	32.05	27.70	15.41		15.25	14.47		26.81	26.37	13.80	75.5	29520	9.81	Do.	
24	12927	28.40	26.14	14.22		14.0	14.29		26.82	26.16	13.81	78.5	27180	8.93	Do.	
25	9730	28.81	27.73	14.66		14.53	13.81		27.57	27.07	14.67	101.0	27200	9.33	Do.	
26	11840	29.45	26.71	14.60		14.44	13.42		27.04	26.09	13.96	91.0	24500	9.06	Do.	
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37

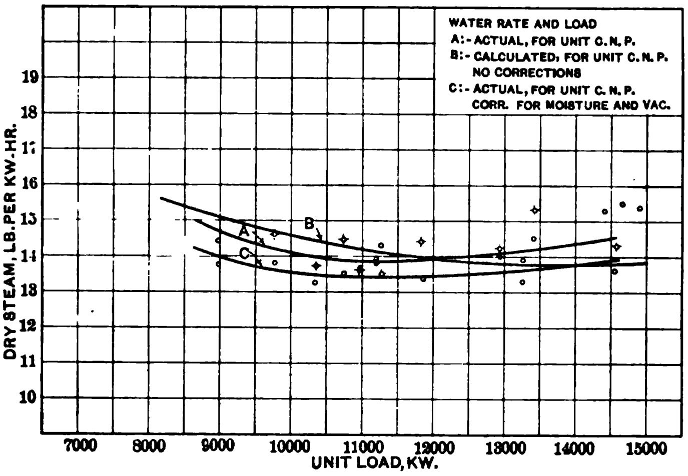


FIG. 11.—Series C

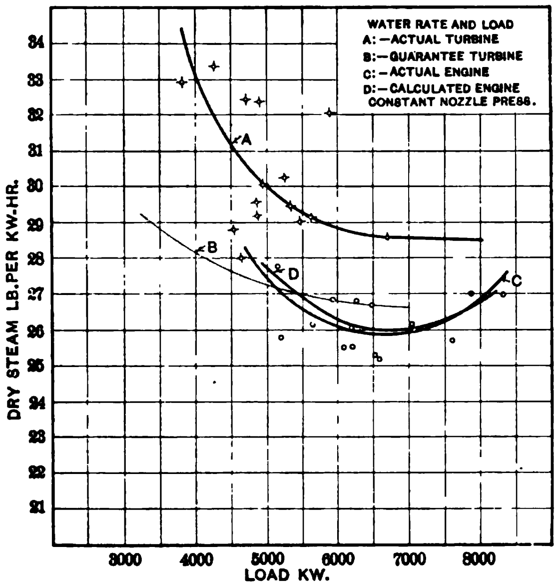


FIG. 11a.—Series C

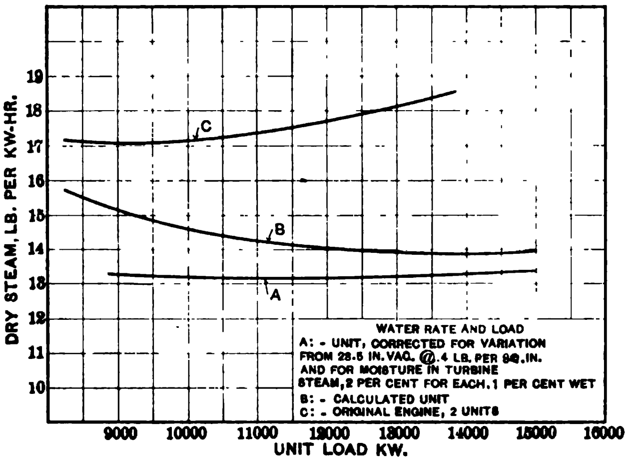


FIG. 11*b*.—Series C

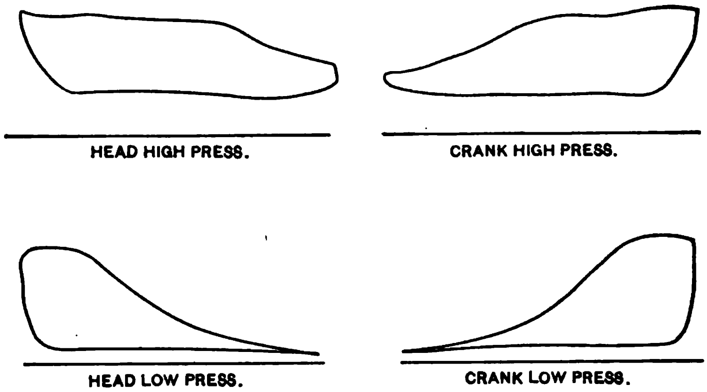


FIG. 12.—Series C

TABLE 7 SERIES D

Test	Duration hr.	Loads			Pressures					Qualities		Water lb. per hr.			Dry steam		Temperatures		
		Unit kw.	Eng. kw.	Turb. kw.	High press. steam lb. per sq. in. abs.	Receivers lb. per sq. in. abs.	Turb. steam lb. per sq. in. abs.	Vacuum lb. per sq. in. abs.	Vacuum 29.92 in mercury	High press. steam per cent	Turb. steam per cent	Total condensation	Turb. water	Total water unit	Turbine	Eng. and unit	Cond. hot well deg. fahr.	Circ. water injection deg. fahr.	Circ. water discharge deg. fahr.
27	6	9567	4875	4683	185.1	64.7	18.14	0.70	28.50	99.0	93.4	8636	133840	142476	125000	141100	78.6	38.80	58.60
28	6	10527	5819	4714	189.8	64.9	16.93	0.87	28.15	99.6	95.2	8570	146730	155300	139700	154700	80.4	39.53	67.04
29	2	11400	6410	5000	184.7	65.2	17.62	1.05	27.87	98.9	97.3	9601	162475	172076	158100	170300	81.3	37.40	67.77
30	4	11365	6590	4810	185.6	64.9	17.62	1.15	27.58	99.0	97.8	10088	161351	171439	157800	169700	84.5	39.20	73.90
31	6	12300	6930	5373	192.0	65.5	17.59	0.90	28.12	99.3	97.8	11006	166826	177832	163200	176800	78.64	36.54	66.00
32	6	13160	7490	5717	193.4	66.3	17.66	0.95	27.98	99.5	97.2	12142	179776	191918	174700	191000	75.34	35.70	69.72
33	4	16085	8505	7670	192.3	65.2	20.00	1.12	27.64	99.8	94.7	7312	247090	254402	234000	254000	86.44	35.05	73.41
34	6	14223	8183	6060	192.3	65.8	17.56	1.11	27.66	99.4	95.7	9361	206261	215622	197500	214300	89.06	34.88	74.30
35	4	13295	7783	5524	194.7	65.8	1713	1.20	27.49	99.5	95.4	11145	187214	198359	178600	197500	90.85	35.22	76.39
36	5	12217	7169	5033	192.7	64.3	16.28	1.05	27.78	99.8	93.8	13017	165908	178925	155500	178700	89.42	34.66	70.76
37	6	10043	5813	4184	190.4	63.9	16.40	1.02	27.84	99.4	93.7	9823	140932	150755	132000	149800	91.80	36.67	70.72

Test	Actual water-rates			Corrected Unit		I.h.p. engine			factor i.h.p.
	Eng.	Turb.	Unit	Moisture	Moist. and vac.	High press.	Low press.	Total	kw.
27	28.94	27.65	14.75	14.30	14.30	3861	3502	7363	1.511
28	26.69	30.15	14.68	14.37	14.02	4138	4359	8497	1.461
29	26.57	31.62	14.94	14.74	14.11	4445	4712	9157	1.429
30	25.74	32.81	14.93	14.74	13.82	4477	4727	9204	1.397
31	25.49	30.38	14.36	14.22	13.74	4753	5045	9798	1.414
32	25.50	30.57	14.51	14.29	13.77	5092	5583	10675	1.425
33	29.86	30.50	15.79	15.32	13.46	5902	6229	12131	1.426
34	26.18	32.60	15.07	14.78	13.94	5585	6018	11603	1.417
35	25.38	32.34	14.85	14.56	13.55	5246	5682	10928	1.404
36	24.92	30.91	14.62	14.29	13.57	4873	5421	10294	1.435
37	25.77	31.54	14.93	14.60	13.94	4248	4312	8560	1.473

TABLE 8 SERIES E AND F

			Loads			Pressures													
No. test	Date 1910	Duration	Total unit kw.	Engine kw.	Turbine kw.	Main steam abs. lb. per sq. in.	Main steam gauge lb. per sq. in.	Receivers abs. lb. per sq. in.	Receivers gauge lb. per sq. in.	Low pres. separator abs. lb. per sq. in.	Low pres. sep. gauge lb. per sq. in.	Low pres. sep. U-tube in. mercury	Vacuum Hg Col. in. mercury	Vacuum manom. in mercury abs.	Vacuum abs. lb. abs.	Barometer in. mercury	Std. vac. 29.92 Bar. in. mercury	Circ. water pump Suction in. mercury	Circ. water pump Discharge gauge lb. per sq. in.
38	Jan. 11	5	16172	8384	7784	197.0	182.3	64.2	49.5	20.60	5.90	10.94	29.30	1.50	0.74	30.63	28.42	12.7	12.0
39	11	5	13485	7798	5895	203.8	189.1	64.5	49.8	16.50	1.80	2.61	29.10	1.58	0.78	30.59	28.34	12.2	12.9
40	12	5	13038	7314	5711	196.1	181.4	63.8	49.1	16.20	1.50	1.82	29.46	1.22	0.60	30.61	28.72	11.0	12.8
41	12	5	12284	6938	5348	200.2	185.5	64.5	49.8	16.10	1.40	2.18	29.32	1.31	0.64	30.57	28.69	12.6	12.1
42	13	5	11252	6248	4938	197.0	182.3	64.0	49.3	16.24	1.54	2.20	29.41	1.32	0.65	30.65	28.60	9.9	14.3
43	13	5	10476	5824	4602	198.0	183.3	63.8	49.1	16.20	1.50	2.00	29.23	1.46	0.72	30.58	28.46	12.6	12.8
44	14	5	9408	4940	4426	198.8	184.1	63.8	49.1	16.10	1.40	2.28	29.47	0.93	0.46	30.31	28.99	9.5	11.6
45	14	1¾	9712	5916	3709	198.2	183.5	64.3	49.6	10.50		−7.48	28.96	1.22	0.60	30.21	28.70	11.6	11.6
46	15	½	12700	7180	5640	198.5	183.8	62.6	47.9	12.96		−2.78	29.45	1.03	0.51	30.32	28.89	13.75	9.5
47	15	½	11940	7060	4780	195.3	180.6	62.6	47.9	12.35		−1.80	29.72	1.03	0.51	30.32	28.89	12.9	9.9
48	15	3	9306	5865	3323	196.3	181.5	63.8	49.1	9.65		−10.49	29.13	1.20	0.59	30.33	28.72	12.0	10.6
								46.3	31.6										
49	15	1	10940	6640	4300	194.9	180.2	49.3	35.6	11.65		−6.62	29.19	1.13	0.56	30.32	28.79	12.1	10.9
50	15	4	15498	8169	7260	192.0	177.3	59.0	44.3	17.80	3.10	3.54	29.23	1.13	0.56	30.32	28.79	14.6	10.4
51	17	3	11240	6753	4376	194.0	179.3	55.0	40.3	11.50		−6.71	29.25	1.19	0.58	30.38	28.73	11.5	9.9
52	17	3	7200	4743	2400	196.5	181.8	41.5	26.8	7.97		−14.92	29.07	1.29	0.63	30.29	28.63	10.6	10.7
53	17	3	11927	7070	4834	199.0	184.3	52.9	38.2	12.75		4.58	29.10	1.25	0.61	30.26	28.67	13.2	10.1
54	26	3	14173	7820	6283	193.4	178.6	55.7	40.9	15.18	0.48	1.04	29.31	0.93	0.46	30.03	28.99	10.1	9.5
55	26	3	8347	5403	2910	197.4	182.7	43.0	28.3	8.21		−13.48	28.90	1.15	0.57	29.97	28.77	12.4	9.0
56	26	3	13033	7457	5550	197.2	182.5	54.3	39.6	14.09		−1.75	29.01	1.01	0.50	29.90	28.91	13.2	9.4
57	27	3	14580	7960	6583	199.7	179.2	59.6	45.1	15.57	0.87	+3.04	28.85	0.85	0.42	29.49	29.07	10.3	8.8
58	27	3	6673	4420	2213	197.7	183.2	40.1	25.6	7.08		−15.14	28.48	0.98	0.48	29.48	28.94	12.6	8.6
59	27	3	10007	6194	3804	199.1	184.6	47.3	32.0	10.35		−8.59	28.55	0.94	0.46	29.50	28.98	14.3	8.7
60	28	3	11820	6923	4860	195.1	180.5	51.6	36.9	12.10		−4.98	28.96	0.87	0.43	29.79	29.05	10.7	10.4
61	28	3	11480	6587	4893	196.8	182.2	51.4	36.7	12.34		−4.46	28.88	1.00	0.49	29.79	28.92	12.4	10.2
62	28	3	15860	8440	7410	195.0	180.4	63.4	48.8	17.84	3.14	7.60	28.73	1.19	0.58	29.79	28.73	13.9	9.9

TABLE 9 SERIES E AND F

No. test	Load kw.	High press throttling calorimeter				No. 1 separating			No. 2 separating			No. 1 throttling				No. 2 throttling		
		Av. main steam temp. deg. fahr.	Cal. discharge temp. deg. fahr.	Cal. discharge press gauge in. mercury	Quality per cent	Moisture lb.	Flow lb.	Quality per cent	Moisture lb.	Flow lb.	Quality per cent	Steam temperature deg. fahr.	Discharge temperature deg. fahr.	Discharge press vacuum in. mercury	Quality per cent	Discharge temperature deg. fahr.	Discharge press vacuum in. mercury	Quality per cent
38	16172	380.6	312.1	18.27	99.5	11.55	153.43	92.9				229.2	198.4	17.76	99.2			
39	13485	383.4	282.0	25.68	97.9	10.49	117.59	91.8				217.6	184.2	20.31	98.8			
40	13038	380.2	302.9	21.81	99.2	10.10	119.41	92.2				216.7	182.0	20.74	98.8			
41	12284	381.9	297.5	19.80	98.9	9.88	119.93	92.4				216.3	180.3	20.55	98.7			
42	11252	380.6	294.8	20.77	98.7	9.73	120.16	92.6	1.42	18.77	93.0	216.7	181.5	20.60	98.7	164.0	26.12	98.1
43	10476	381.0	291.8	20.42	98.5	8.86	111.94	92.6	3.18	46.47	93.6	216.7	182.9	21.50	98.8	168.9	26.23	98.4
44	9408	381.3	297.9	21.78	98.7	8.05	99.50	92.5	1.08	18.90	94.6	216.4	179.3	21.55	98.6	177.0	25.71	98.5
45	9712	381.1	294.8	21.92	98.7	1.10	14.10	92.8	0.79	11.95	93.8	195.4	172.5	23.70	99.2	159.5	27.37	98.6
46	12700	381.2	296.7	21.40	98.8	0.43	10.60	96.1	0.16	4.00	96.2	210.2	170.3	21.30	98.4	163.9	26.40	98.3
47	11940	379.9	304.0	20.63	99.1	0.29	9.10	96.9	0.16	3.60	95.8	203.3	176.0	22.48	98.9	165.7	26.72	98.6
48	9306	380.3	290.5	21.18	98.6	2.43	42.25	94.6	1.22	16.88	93.3	191.8	171.2	24.29	99.3	156.9	27.42	98.6
49	10940	373.7	299.0	21.05	98.9	0.74	16.77	95.7	0.41	6.90	94.4	200.3	178.3	22.62	99.3	167.3	26.76	98.7
50	15498	378.5	305.6	19.77	99.4	2.84	70.70	96.2	1.27	41.56	97.0	221.4	189.4	19.89	98.8	182.9	25.40	98.6
51	11240	379.4	292.6	21.93	98.6	2.04	51.67	96.2	1.15	19.96	94.5	199.8	174.8	22.68	99.0	165.0	27.04	99.1
52	7200	380.4	228.8	20.71	98.4	2.04	36.77	94.7	0.93	14.05	93.7	182.4	163.0	25.21	99.3	148.0	27.75	98.6
53	11927	381.4	294.4	20.64	98.6	1.79	56.20	95.3	1.11	21.66	95.1	204.7	177.0	21.96	99.0	168.8	26.73	98.7
54	14173	379.1	296.9	22.41	98.9	2.13	56.70	96.3				213.3	191.4	19.92	99.4			
55	8347	380.8	292.9	20.87	98.6	1.57	38.91	96.1				184.2	165.2	24.20	99.3			
56	13033	380.7	298.2	20.25	98.7	1.63	61.64	97.4				209.7	184.9	20.81	99.1			
57	14580	379.2	298.8	21.75	99.0	2.06	70.87	97.2				215.3	188.9	18.77	99.0			
58	6673	380.9	298.4	21.80	99.0	1.79	33.30	94.9				178.4	161.1	24.41	99.4			
59	10007	381.5	287.0	21.53	98.2	2.62	47.12	94.7				194.8	171.1	22.70	99.2			
60	11820	379.8	299.9	21.34	99.0	1.56	54.77	97.2				202.4	175.0	21.67	99.0			
61	11480	380.5	302.8	21.00	99.1	1.55	55.79	97.3				203.3	178.4	21.57	99.0			
62	15860	379.7	299.7	20.63	99.0	2.19	80.02	97.3				221.9	197.6	17.87	99.3			

TABLE 10 SERIES E AND F

	Thomas calorimeter								Exhaust from engine								
									Separating cal.			Throttling cal.					
No. test	Watt hr.	Steam temperature. deg. fahr.	Cal. discharge temperature deg. fahr.	Cal. discharge water lb.	Quality per cent	No. 1 Combined quality per cent	No. 2. combined quality per cent	Average quality per cent	Moisture lb.	Flow lb.	Quality per cent.	Steam temperature deg. fahr.	Cal. discharge temperature deg. fahr.	Cal. discharge press. in. mercury	Quality per cent	Combined quality per cent.	Quality by separator water and turb. steam quality per cent
38	6600	229.2	414.6	93.90	84.1	92.2		90.2									
39	5623	217.6	430.6	84.10	86.3	90.7		89.4									
40	4758	216.7	429.9	93.60	92.4	91.1		91.5									
41	3242	216.3	412.7	70.20	93.2	91.2		91.9									
42	4268	216.7	426.8	110.20	94.4	91.4	91.2	93.0									
43	5000	216.7	408.3	116.50	94.3	91.5	92.1	92.6									
44	4575	216.4	424.6	88.80	91.9	91.2	93.2	92.1									
45	1519	195.4	445.2	30.90	94.9	92.0	92.5	93.1									
46	500	210.2	356.9	20.40	98.5	94.6	94.6	95.9									
47	350	203.3	454.2	27.40	95.6	95.8	94.5	95.3									
48	2100	191.8	420.0	37.92	91.7	93.9	92.0	92.5									
49						95.0	93.2	94.1									
50	2377	221.4	346.5	81.70	95.8	95.0	94.4	95.1									
51	2100	199.8	420.7	47.70	95.4	95.2	93.6	94.7									
52	2300	182.4	395.5	58.40	96.5	94.0	92.4	94.3									
53	2500	204.7	433.2	59.00	96.2	94.3	93.8	94.8									
54	650	213.3	276.7	44.05	98.0	95.7		96.9	2.53	26.90	91.4	213.8	180.5	23.29	98.7	90.2	89.6
55	600	184.2	293.6	28.10	97.4	95.4		96.4	2.05	15.17	88.1	185.6	148.7	26.71	98.5	86.8	90.2
56	600	209.7	268.5	44.40	98.1	96.5		97.3	2.53	21.70	89.5	209.5	167.7	25.41	98.6	88.2	90.3
57	600	215.3	260.8	56.10	98.4	96.2		97.3	1.92	21.40	91.8	216.2	172.1	25.16	98.4	90.3	89.3
58	450	178.4	267.7	24.90	97.0	94.4		95.7	1.88	17.12	90.7	177.9	148.3	25.80	98.8	89.0	89.7
59	600	194.8	265.5	32.80	97.2	94.0		95.6	2.28	15.72	87.3	195.3	154.0	26.02	98.5	86.0	89.8
60	600	202.4	274.2	39.90	98.2	96.3		97.3	2.49	19.17	88.6	203.4	163.4	25.76	98.5	87.3	90.3
61	600	203.3	272.8	41.40	98.3	96.3		97.3	2.34	16.95	87.9	204.1	160.1	26.07	98.3	86.4	91.2
62	700	221.9	274.3	55.40	98.1	96.6		97.4	2.11	24.65	92.1	222.8	178.4	24.73	98.5	90.7	89.8

TABLE 11 SERIES E AND F

Test	West main steam deg. fahr	East main steam deg. fahr.	Average main steam deg. fahr.	West re-ceiver deg. fahr.	East re-ceiver deg. fahr.	Average re-ceiver deg. fahr.	East engine exhaust deg. fahr.	East separator inlet deg. fahr.	Separ-ator outlet deg. fahr.	Turb-ine bowl deg. fahr.	Con-denser deg. fahr.	Hot well water deg. fahr.	Circ. water injection deg. fahr.	Circ. water discharge deg. fahr.
38	381.0	380.2	380.6	297.0	297.4	297.2	230.5	230.1	229.2	228.5	90.90	71.20	37.66	57.28
39	384.1	382.8	383.4	297.3	297.4	297.4	218.7		217.6	217.0	94.60	76.23	39.85	62.51
40	380.3	380.1	380.2	296.1	297.5	296.8	218.0	217.6	216.7	216.1	84.45	70.97	32.03	51.84
41	382.4	381.4	381.9	297.0	297.7	297.3	217.9	217.2	216.3	216.3	87.17	73.41	33.95	56.76
42	380.2	380.9	380.6	296.9	297.0	297.0	218.6	218.6	216.9	216.9	87.18	75.25	31.82	56.67
43	380.6	381.3	381.0	296.8	296.6	296.7	217.9		216.7	216.3	89.32	80.17	32.75	57.14
44	380.3	382.2	381.3	296.9	296.5	296.7	217.6		216.4	216.1	73.87	59.42	31.63	41.98
45	380.3	381.8	381.1	296.8	297.7	297.3	208.2		195.4	196.7	86.72	66.20	32.22	43.97
46	379.7	382.7	381.2	295.0	296.0	295.5	209.0		210.2	208.0	77.20	63.70	40.20	53.10
47	379.0	380.8	379.9	295.3	296.0	295.6	205.0		203.3	204.0	80.00	63.00	36.00	46.85
				297.1	296.4	296.7	193.7			192.5				
48	379.6	381.0	380.3	276.3	275.8	276.1	190.5		191.8	189.4	84.86	60.58	32.90	42.06
49	377.8	381.6	379.7	279.6	280.4	280.0	202.0		200.3	201.0	83.50	62.60	31.38	53.86
50	376.7	380.2	378.5	291.5	291.5	291.5	222.6		221.4	221.0	82.23	65.69	31.51	50.08
51	379.0	379.8	379.4	287.2	286.8	287.0	203.4		199.8	199.8	83.16	65.18	37.50	43.10
52	379.7	381.0	380.4	268.9	270.2	269.6	183.8		182.4	180.8	85.70	58.15	31.47	39.81
53	380.5	382.3	381.4	285.5	283.2	284.4	205.7		204.7	204.6	83.65	65.65	31.46	45.37
54	376.3	381.8	379.1	287.1	288.7	287.9	215.6		213.3	213.3	81.20	57.26	33.54	47.77
55	378.0	383.5	381.8	271.8	271.7	271.7	187.0		184.2	183.8	81.00	58.64	33.08	41.30
56	378.4	383.0	380.7	285.8	286.5	286.2	209.3		209.7	207.6	74.70	60.72	33.40	50.10
57	377.0	381.4	379.2	293.0	291.6	292.3	217.5		214.9	215.5	67.41	53.21	33.28	47.60
58	379.4	382.5	380.9	267.5	267.9	267.7	177.4		177.4	176.3	78.20	53.85	33.18	39.46
59	380.0	383.0	381.5	277.5	277.4	277.5	195.7		194.8	194.1	78.30	59.12	33.40	43.66
60	377.9	381.7	379.8	283.2	283.0	283.1	204.4		202.4	202.4	74.04	59.60	33.25	46.00
61	378.5	382.4	380.5	283.0	282.5	282.8	205.0		203.3	203.2	77.18	61.74	33.06	47.23
62	377.5	381.8	379.7	296.3	296.3	296.3	223.9		221.9	221.8	82.42	62.79	33.64	56.00

TABLE 12 SERIES E AND F

Water per hour											Water rates					I.h.p.				
No.	Load kw.	Turbine water weighed lb. per hr.	Turbine water venturi lb. per hr.	Sep. and traps weighed lb. per hr.	Sep. water lb. per hr.	Traps Venturi lb. per hr.	Total engine water lb. per hr.	Dry steam engine lb. per hr.	Dry steam turbine lb. per hr.	Actual unit lb. per kw-hr.	Actual engine lb. per kw-hr.	Actual turbine lb. per kw-hr.	Corrected unit moisture only lb. per kw-hr.	Corrected unit total corrected lb. per kw-hr.		Average high pressure i.h.p.	Average low pressure i.h.p.	Total i.h.p.	Factor i.h.p. per kw.
38	16172	237480		7425	7175	250	244905	243700	214200	15.07	29.54	27.51	14.40	14.10		5640	6117	11757	1.404
39	13485	187193		9883	5881	4002	197076	193000	167400	14.32	24.76	28.38	13.48	13.10		5104	5847	10951	1.404
40	13038	170661		12271	6281	5980	182932	181500	156200	13.92	24.78	27.35	13.44	13.42		4931	5650	10581	1.447
41	12284	160229		12064	3628	8436	172293	170400	147200	13.88	24.57	27.51	13.39	13.28		4800	5306	10106	1.457
42	11252	147142		10927	2607	8320	158069	156100	136900	13.87	24.99	27.72	13.54	13.42		4250	4330	8580	1.374
43	10476	138766		9939	1801	7138	147153	145000	128500	13.85	24.90	27.91	13.47	13.21		4227	4280	8507	1.460
44	9408	122689		8387	227	8160	131076	129400	113000	13.75	26.19	25.53	13.32	13.59		3771	3490	7261	1.470
45	9712	121870		13160	4910	8250	135030	133300	113500	13.72	22.53	30.59	13.49	13.45		3819	4367	8186	1.385
46	12700	160960		18874	11242	7632	179834	177700	154400	13.99	24.75	27.38	13.62	13.77		4994	6313	11307	1.575
47	11940	142740		17385	8935	8450	160125	158700	136000	13.30	22.49	28.45	13.15	13.31		4675	5736	10411	1.475
48	9306	114372		12555	4744	7811	126927	125100	105800	13.44	21.34	31.84	13.25	13.25		4129	4321	8450	1.441
49	10940	134785		16565	8257	8308	151350	149700	126900	13.69	22.40	29.50	13.39	13.46		5039	4545	9584	1.444
50	15498	202656		19161	16661	2500	221817	220400	192900	14.22	26.99	26.55	13.96	14.03		5784	5825	11609	1.421
51	11240	133462		16689	8399	8290	150151	148100	126500	13.19	21.95	28.89	13.04	13.04		4585	5244	9829	1.456
52	7200	89158		10861	7170	3691	100019	98400	84080	13.67	20.75	35.04	13.52	13.43		3662	3478	7140	1.505
53	11927	143897		17901	8164	9737	161798	159500	136500	13.38	22.57	28.22	13.13	13.08		4995	4897	9892	1.400
54	14173	176565		19180	12930	6250	195745	193600	171050	13.66	24.75	27.22	13.54	13.81		5430	5370	10800	1.400
55	8347	99210		13733	6183	7550	112943	111400	95620	13.34	20.60	32.85	13.23	13.28		3907	3792	7699	1.425
56	13033	158112		18849	11159	7690	176961	174700	153850	13.40	23.43	27.72	13.28	13.47		5115	5120	10235	1.373
57	14580	182508		20011	14741	5270	202599	200700	177600	13.75	25.19	26.95	13.65	14.00		5376	5673	11049	1.388
58	6673	81533		11225	4900	6325	92958	91800	78000	13.76	20.78	35.27	13.65	13.87		3282	3170	6452	1.460
59	10007	120863		14578	6478	8100	135441	133050	115600	13.30	21.48	30.38	13.13	13.39		4452	4294	8746	1.413
60	11820	141930		17833	9873	7960	159763	158200	138100	13.38	22.84	28.41	13.28	13.61		5108	4796	9904	1.431
61	11480	143958		17101	8791	8310	161059	159600	141500	13.92	24.45	24.22	13.75	13.95		4728	4594	9322	1.414
62	15860	206603		19762	15705	4057	226365	224200	201300	14.14	26.58	26.56	13.99	13.99		5750	6538	12288	1.456

TABLE 13 SERIES E AND F

No.	Total load	B.t.u. distribution:unit is 1,000,000 B.t.u.															
		Supplied to unit		Supplied to turb. only		Engine kw. output		Turb. kw. output		Total kw. output		To con-denser		To hot well		Lost by radiation etc.	
test	kw.	B.t.u.	per cent	B.t.u.	per cent	B.t.u.	per cent	B.t.u.	per cent	B.t.u.	per cent	B.t.u.	per cent	B.t.u.	per cent	B.t.u.	per cent
38	16172	292.0	100	252.5	86.5	28.61	9.8	26.58	9.1	55.19	18.9	216.6	74.2	9.31	3.2	10.89	3.7
39	13485	232.6		196.6	84.6	26.36	11.3	19.88	8.6	46.27	19.9	168.4	72.4	8.28	3.6	9.64	4.1
40	13038	218.0		182.5	83.7	24.97	11.5	19.49	8.9	44.46	20.4	156.4	71.7	6.65	3.1	10.53	4.8
41	12284	204.7		171.8	83.9	23.67	11.6	18.25	8.9	41.92	20.5	146.9	71.7	6.64	3.2	9.23	4.5
42	11252	187.7		159.5	85.0	21.35	11.4	16.95	9.0	38.37	20.5	136.2	72.5	6.36	3.4	6.85	3.7
43	10476	174.5		149.8	85.9	19.93	11.4	15.76	9.0	35.68	20.5	127.3	73.0	6.69	3.8	4.77	2.7
44	9408	155.8		131.9	84.6	16.87	10.8	15.12	9.7	32.09	20.6	113.4	72.7	3.36	2.2	7.03	4.5
45	9712																
46	12700																
47	11940																
48	9306	150.5		122.3	81.3	20.14	13.4	11.46	7.6	31.61	21.0	107.6	71.5	3.27	2.2	8.06	5.4
49	10940																
50	15498	264.2		224.2	84.8	27.95	10.6	24.85	9.4	52.56	19.9	192.5	72.8	6.83	2.6	12.05	4.6
51	11240	178.0		146.0	81.8	23.16	13.0	15.05	8.4	37.85	21.3	126.5	70.9	4.43	2.5	8.84	5.0
52	7200	118.4		96.41	81.4	16.25	13.7	8.26	7.0	24.37	20.6	85.8	72.5	2.33	2.0	5.74	4.8
53	11927	191.8		157.8	82.3	24.16	12.6	16.53	8.6	40.66	21.2	136.4	71.2	4.84	2.5	9.84	5.1
54	14173	232.4		197.8	83.4	26.76	11.3	21.53	9.1	48.29	20.4	171.8	72.4	4.46	1.9	7.84	3.3
55	8347	133.8		109.55	81.9	18.48	13.8	9.97	7.5	28.45	21.3	97.9	73.2	2.64	2.0	5.77	4.3
56	13033	210.0		175.5	83.6	25.46	12.1	18.97	9.0	44.43	21.2	151.9	72.3	4.54	2.2	9.04	4.3
57	14580	240.7		205.4	85.4	27.20	11.3	22.51	9.4	49.74	20.7	170.9	74.4	3.87	1.6	8.10	3.4
58	6673	110.4		89.25	80.9	15.13	13.7	7.59	6.9	22.73	20.6	79.8	72.4	1.78	1.6	6.02	5.5
59	10007	160.0		133.6	83.2	21.13	13.2	12.99	8.1	34.12	21.3	116.7	72.9	3.28	2.1	5.87	3.7
60	11820	189.8		158.9	83.7	23.67	12.5	16.62	8.8	40.29	21.2	138.4	72.9	3.92	2.1	7.23	3.8
61	11480	191.8		161.5	84.2	22.47	11.7	16.70	8.7	39.17	20.4	140.5	73.3	4.28	2.2	7.83	4.1
62	15860	269.2		232.2	86.3	28.82	10.7	25.31	9.4	54.11	20.1	200.5	74.5	6.36	2.4	8.18	3.0

TABLE 14 SERIES E AND F

No. test	Load unit	Efficiencies									Heat to condenser			Remarks
		Rankine efficiencies			Thermal effic. ref'd to Rankine			Thermal eff. recov. hot well water			Ratio condenser water to steam	B.t.u. per sq. ft. per sec.	B.t.u. per sq. ft. per sec. per deg. rise	
		Engine	Turb.	Unit	Engine	Turb.	Unit	Engine	Turb.	Unit				
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent				
38	16172	16.7	18.2	30.1	70.3	60.0	65.0	11.7	10.9	19.5	53.5	2.58	0.0594	Constant nozzle pressure auxiliaries exhaust to heaters
39	13485	16.8	16.8	29.1	81.5	63.5	70.5	13.7	10.7	20.5	48.2	1.99	0.0459	" " " " " "
40	13038	17.8	18.4	30.8	76.9	60.0	60.5	13.7	11.0	21.1	52.9	1.86	0.0437	" " " " " "
41	12284	17.6	17.7	30.4	78.5	62.3	69.7	13.8	11.0	21.2	46.4	1.77	0.0428	" " " " " "
42	11252	17.4	17.8	30.3	76.4	61.8	70.1	13.6	11.0	21.2	42.7	1.65	0.0384	" " " " " "
43	10476	17.3	17.7	30.2	78.9	60.5	70.7	13.6	11.4	21.4	44.2	1.53	0.0345	" " " " " "
44	9408	17.6	18.8	29.4	73.2	62.5	71.8	12.9	11.7	21.1	107.7	1.37	0.0369	" " " " " "
48	9306	20.5	15.6	30.5	74.9	61.2	71.0	15.4	9.5	21.7	118.0	1.26	0.0266	Variable nozzle pressure auxiliaries exhaust to heaters
51	11240	19.7	16.4	30.8	76.7	53.6	72.0	15.1	10.5	22.2	150	1.28	0.0298	" " " " " "
54	14173	18.2	18.7	31.2	74.5	59.1	68.1	13.6	11.1	21.2	77.1	2.08	0.0512	" " " " " "
55	8347	21.2	17.5	30.5	74.6	52.6	71.5	15.8	9.2	21.8	11.2	0.92	0.0210	" " " " " "
56	13033	18.2	18.4	31.0	78.5	59.4	69.0	14.2	10.9	21.7	63.4	1.87	0.0566	" " " " " "
57	14580	18.0	19.5	32.2	74.0	57.0	65.4	13.6	11.1	21.0	77.5	2.16	0.0800	" " " " " "
58	6673	21.3	14.6	31.4	73.2	59.0	67.0	15.6	8.6	21.0	15.3	2.55	0.0608	" " " " " "
59	10007	19.5	16.7	31.3	78.5	60.0	69.8	15.3	10.0	21.8	108	1.41	0.0336	" " " " " "
60	11820	19.5	20.2	32.2	74.8	52.9	67.6	14.5	10.7	21.8	82.9	1.67	0.0485	" " " " " "
61	11480	19.6	17.6	31.4	69.8	60.4	66.9	13.7	10.7	21.0	108	2.40	0.0885	Variable nozzle pressure auxiliaries exhaust into separator
62	15860	17.2	18.7	30.0	74.0	59.4	68.9	12.7	11.1	20.7	49.0	2.52	0.0670	" " " " " " heaters

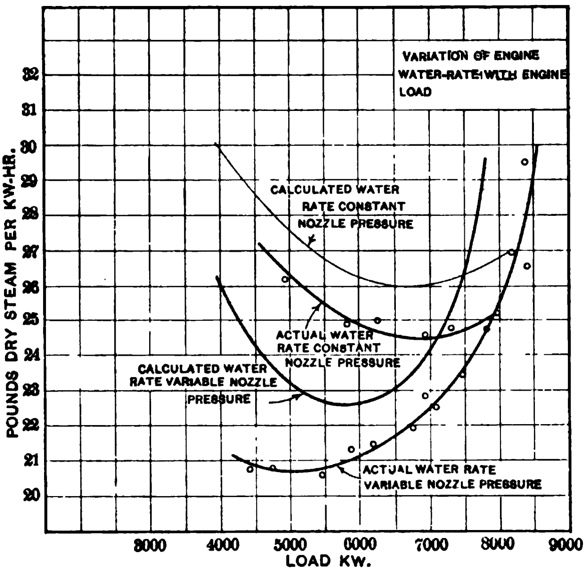


Fig. 13.—Series E and F

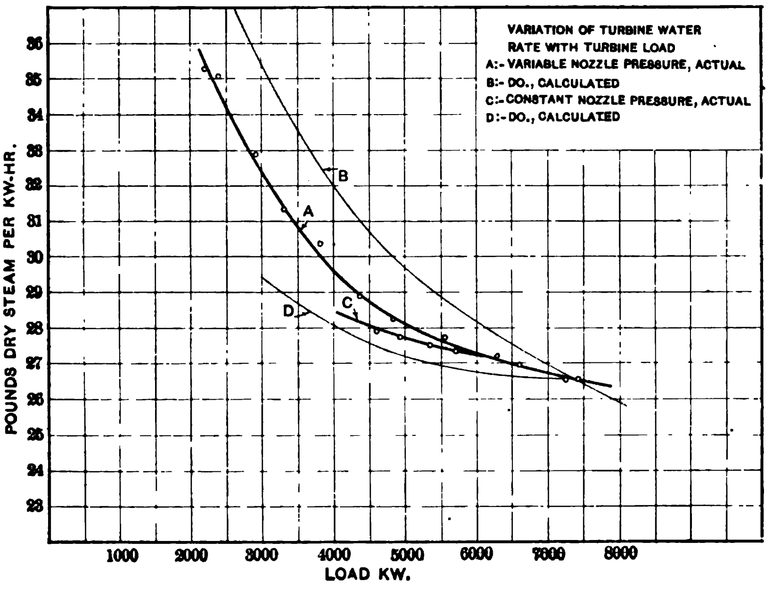


Fig. 14.—Series E and F

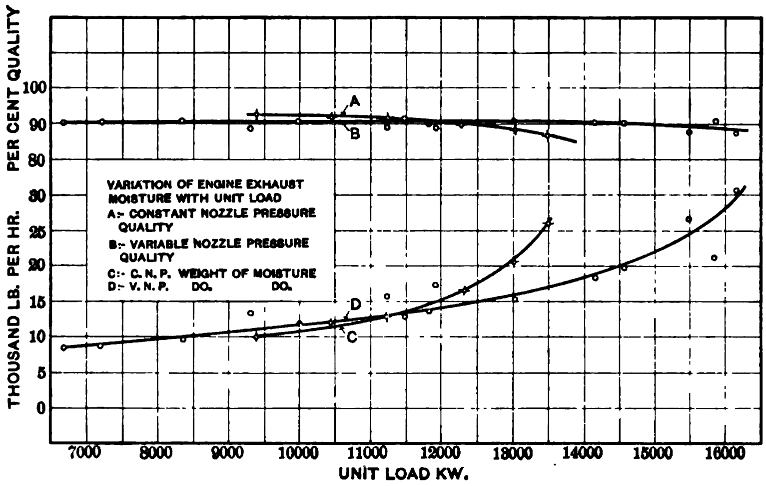


FIG. 15.—Series E and F

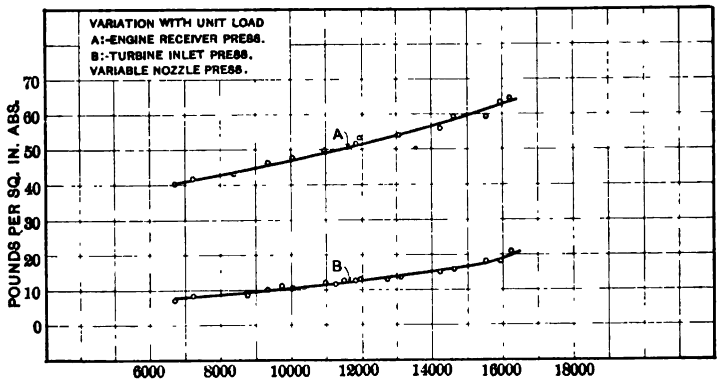


FIG. 16.—Series E and F

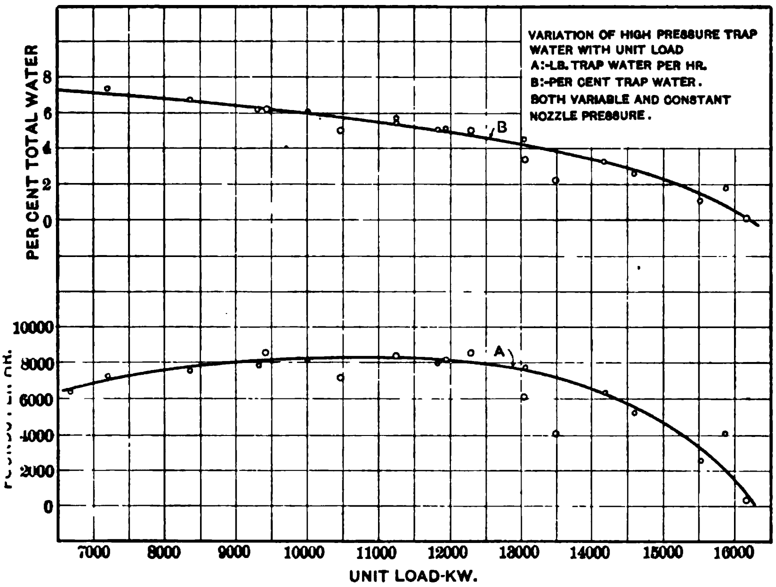


FIG. 17.—Series E and F

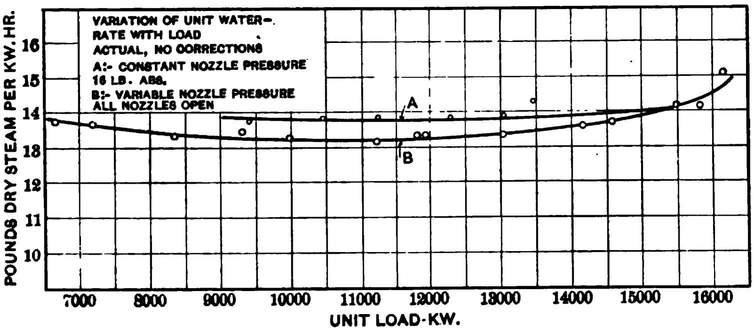


FIG. 18.—Series E and F

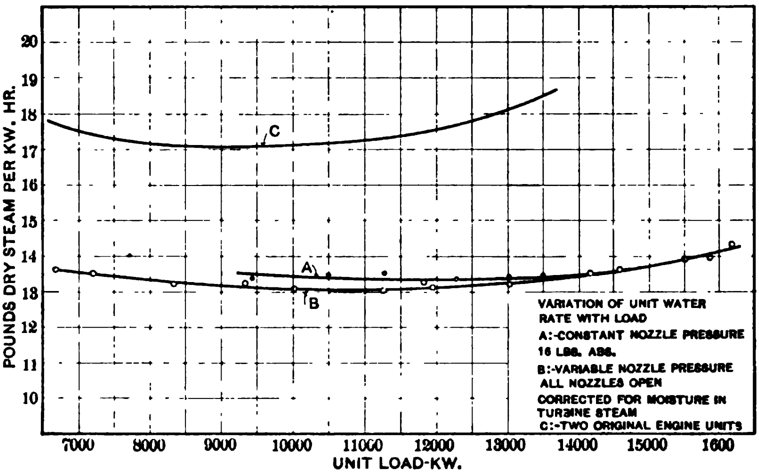


Fig. 19.—Series E and F

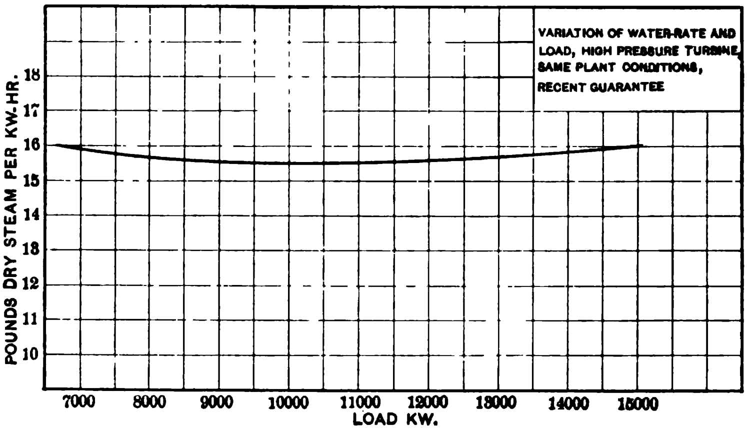


Fig. 19*a*.—Series E and F

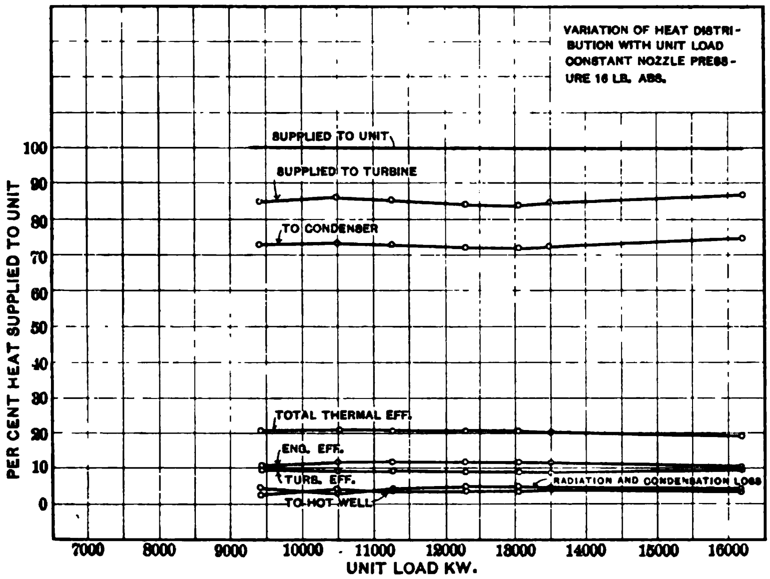


Fig. 20.—Series E

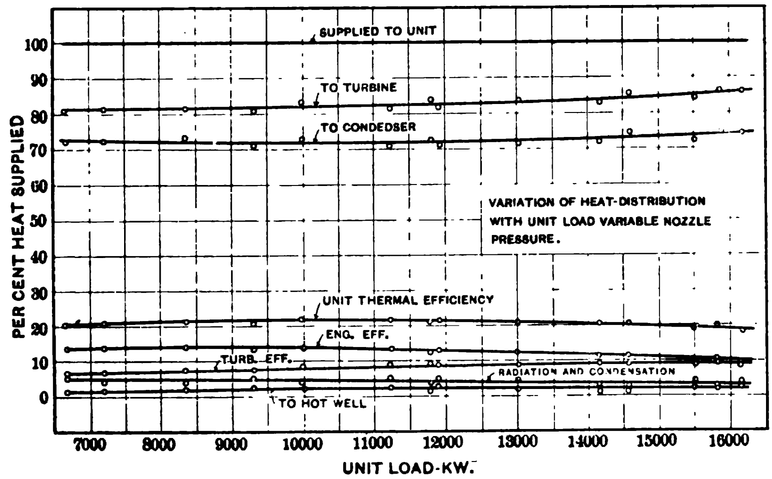


Fig. 21.—Series F

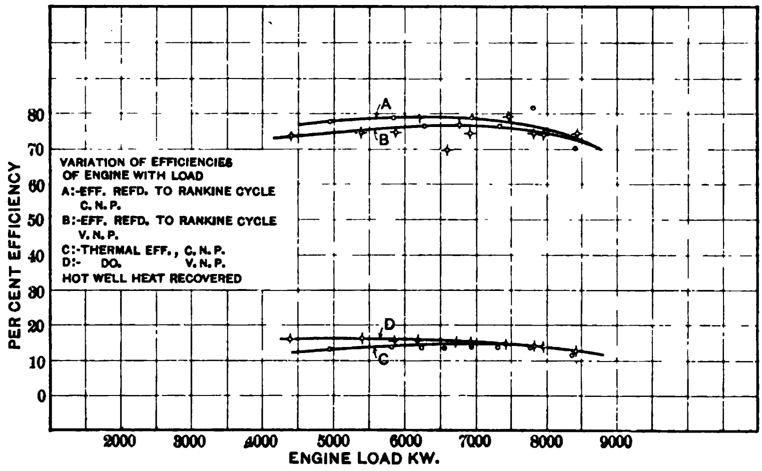


FIG. 22.—Series E and F

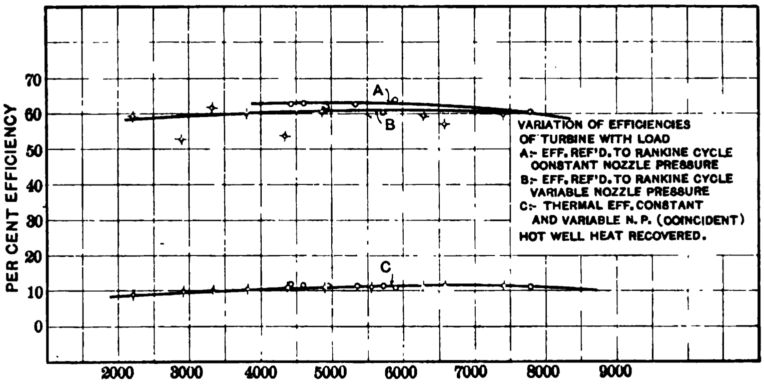


FIG. 23.—Series E and F

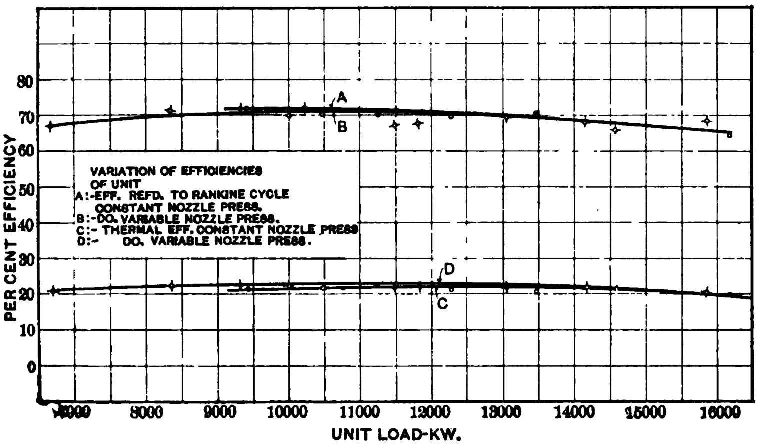


Fig. 24.—Series E and F

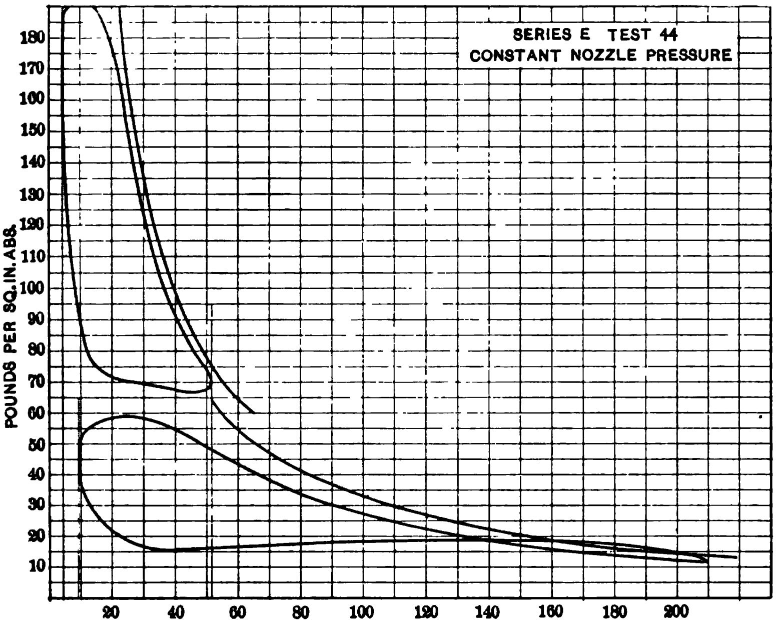


Fig. 25.—Series E, test 44

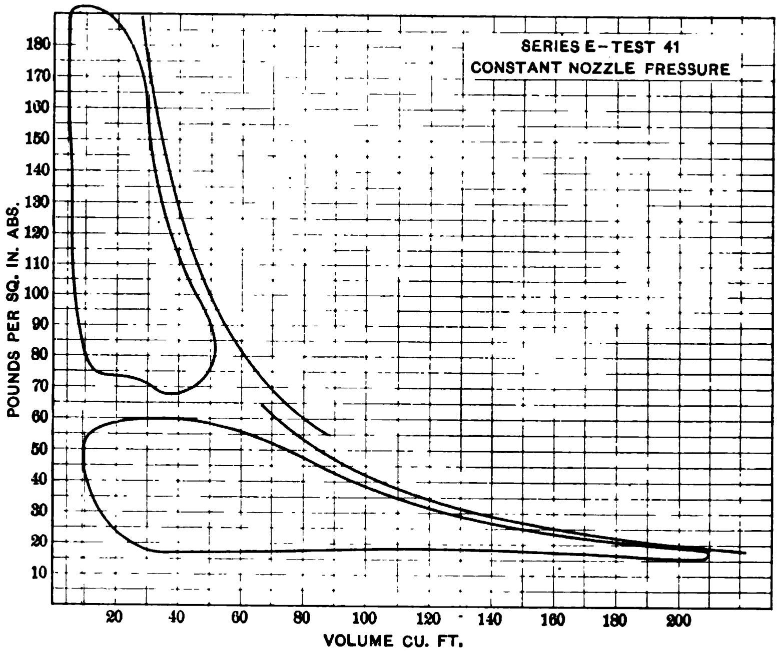


FIG. 26.—Series E, test 41

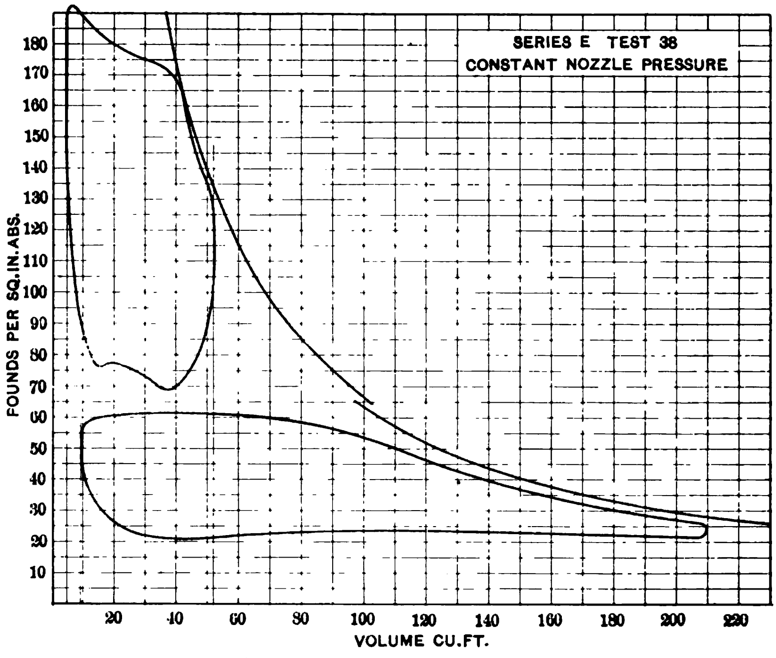


FIG. 27.—Series E, test 38

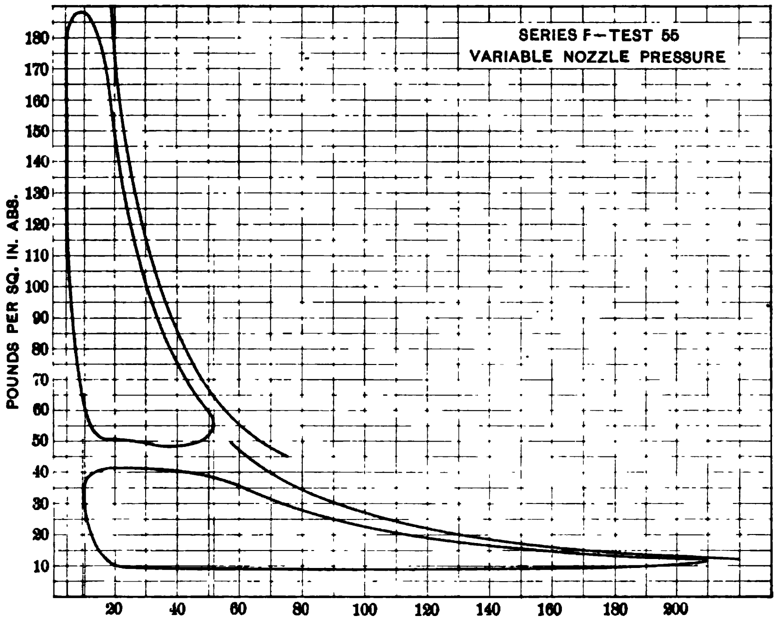


FIG. 28.—Series F, test 55

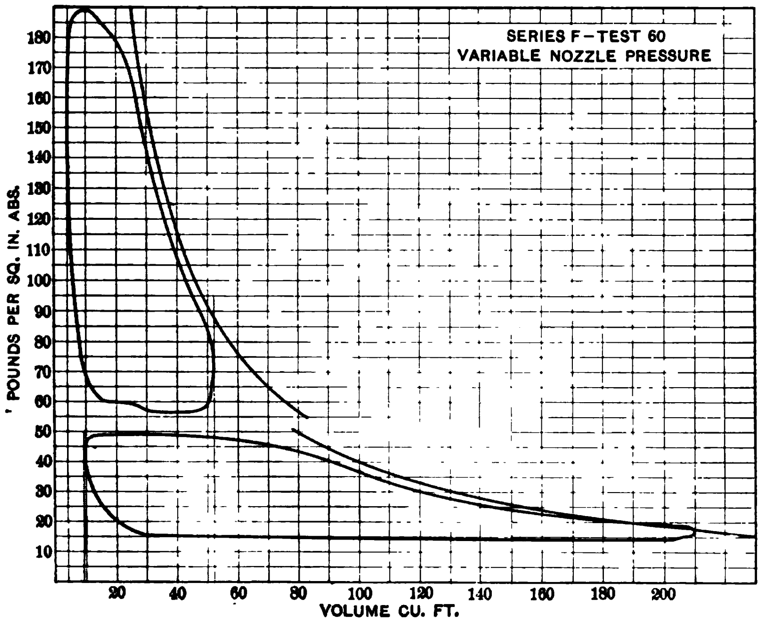


FIG. 29.—Series F, test 60

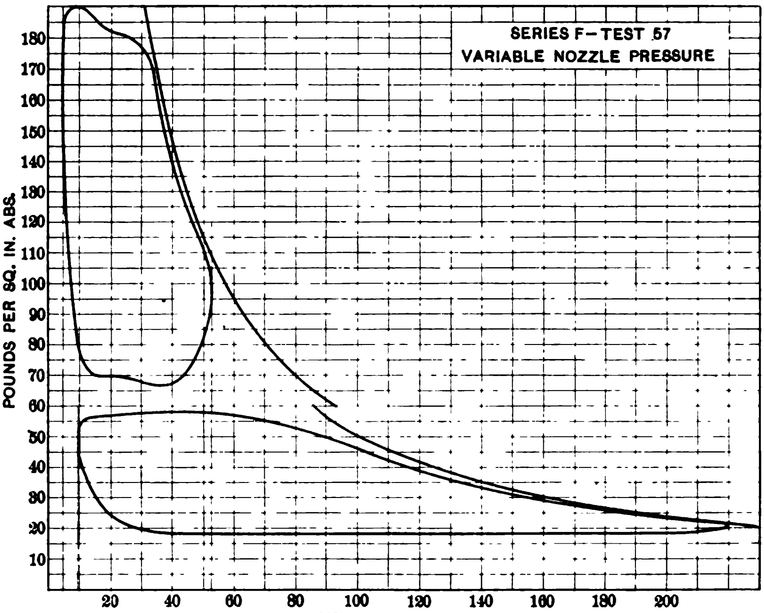


FIG. 30.—Series F, test 57

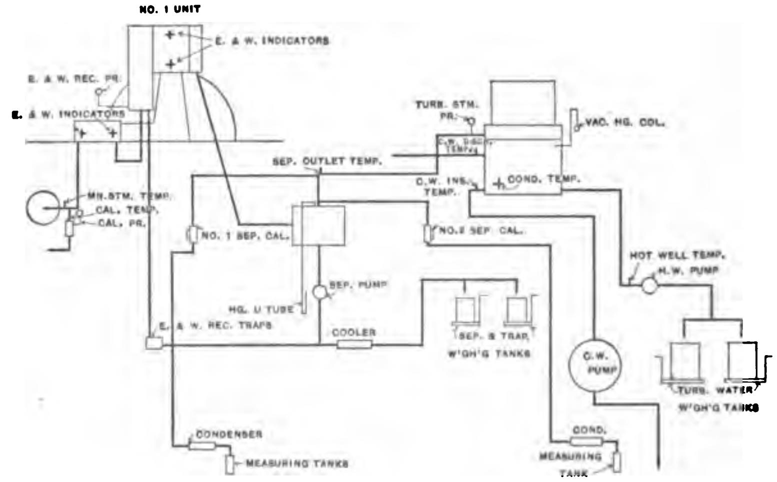


FIG. 31.—Series C, diagramatic test layout

The first point which presents itself in view of the remarkable results of these tests, is the question of accuracy of measurement. The actual unit water-rate is dependent upon three factors only: quality of steam entering the engine, kw. load, and weight of water per hour. The quality of high-pressure steam is easily and accurately determined by means of the ordinary throttling calorimeter. The load on the machines was determined by means of nine integrating meters: two meters each on turbine, engine and total load, connected by the 2-meter method; one balanced 3-phase meter each on turbine, engine, and total load. Each meter was calibrated once a week, and the error was always within one-half of 1 per cent.

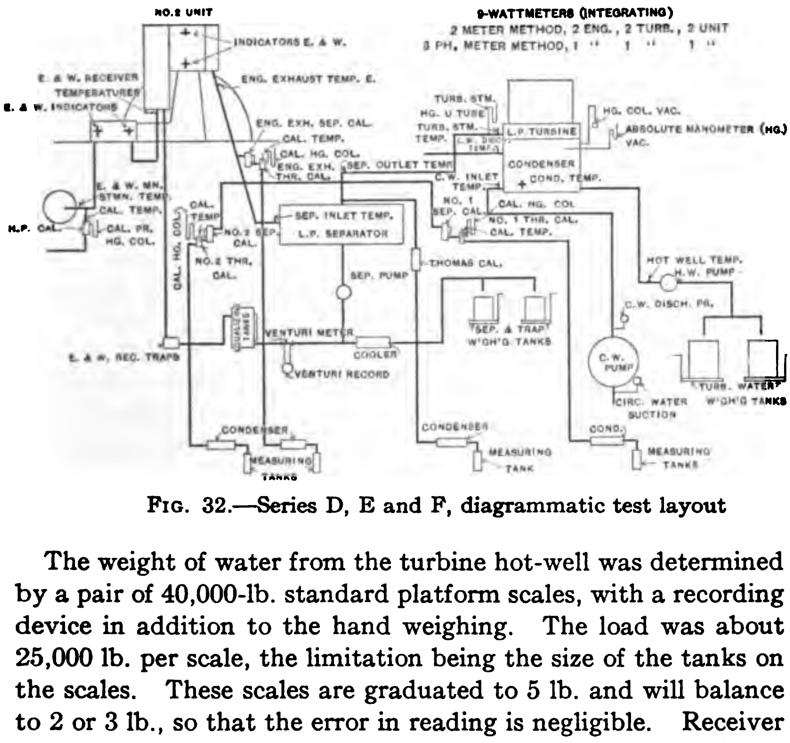


FIG. 32.—Series D, E and F, diagrammatic test layout

The weight of water from the turbine hot-well was determined by a pair of 40,000-lb. standard platform scales, with a recording device in addition to the hand weighing. The load was about 25,000 lb. per scale, the limitation being the size of the tanks on the scales. These scales are graduated to 5 lb. and will balance to 2 or 3 lb., so that the error in reading is negligible. Receiver trap water and low-pressure separator water was weighed together on a pair of 2000-lb. platform scales, reading to ½ lb. All scales were calibrated with standard 50-lb. weights before testing.

The actual trap water weight was obtained by interposing a 1-in. Venturi meter with recording device in the line to the scales; this was also calibrated by scales and found correct to less than 1 per cent, and the low-pressure separator water obtained by difference.

For examination of thermodynamic conditions within the machines, the most important determination is that of quality of the low-pressure steam to the turbine, since on this depends one of the important corrections to guaranteed conditions. There were no experimental data available that we could discover, bearing on low-pressure quality determinations, so the investigation was made incidental to the tests, from which the following

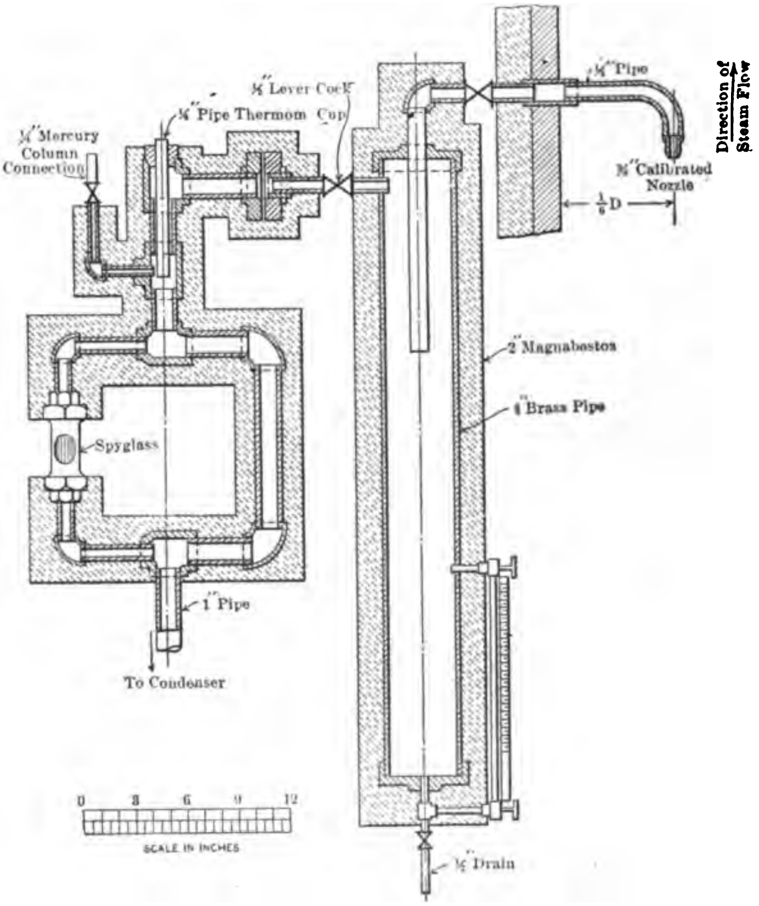


FIG. 33.—Low pressure separating-throttling calorimeter

was established. The ordinary standard perforated pipe sampler is absolutely worthless in giving a true sample, and it is vital that the sample be abstracted from the main without changing its direction or velocity until it is safely in the sample pipe and entirely isolated from the rest of the steam. Multiple orifice nozzles are of no use, as in all cases one orifice will supply practically all the steam, leaving the others useless. After much experimenting with various styles of samplers, all of which were failures the single orifice curved tube (Fig. 33) was adopted.

The reason for failure of other styles is plain; if any sudden turn is made by the wet steam in entering the sample nozzle, the entrained moisture, by reason of its immensely greater specific gravity and slight skin friction in the tenuous surrounding fluid, will continue with unchanged direction and a dry sample will enter the nozzle. In other words, the sampler becomes a very fair separator. Again, if the velocity in the sampler is greater than that in the main, even though there be no separating action with the proper sampler, the steam will accelerate into the nozzle, and the moisture will not, giving a dry sample; and the reverse is true if the velocity is less in the sampling nozzle than in the main. The reason this very simple action has not been noted in connection with high-pressure steam is the smaller difference in specific gravity of water and steam, the enormously greater skin friction and the small percentage and highly-divided state of the moisture present.

The successful types of calorimeter for very wet steam were the Thomas electric, and a combination of a separating calorimeter with a throttling calorimeter. By the use of the separating calorimeter most of the moisture was removed, and the small remainder was registered by the throttling calorimeter. At first glance it seems as if, with an initial pressure of 12 lb. to 20 lb. absolute, the throttling calorimeter has no capacity, but by putting a vacuum of 28 in. on the discharge side of the calorimeter, an available heat is obtained sufficient to evaporate 2 or 3 per cent of moisture. When the moisture became less than this, we used the throttling calorimeter direct, eliminating the separating calorimeter altogether. The separating-throttling combination was afterward tested for radiation loss and found to lose less than 0.1 per cent at proper flow. Fig. 33 shows this combination instrument. The large size is necessary on account of the very high specific volume of steam at low pressure.

Referring to Fig. 33, the ⅜-in. brass nozzle on the sampler is arranged to point in exactly the opposite direction to the steam flow; the lip of the nozzle is filed to a knife-edge to avoid disturbing the steam current around the sampler mouth by impact and eddies against a sensibly thick lip. The diameter of the brass nozzle is carefully measured and, if necessary, reamed smooth. This form of sampler fulfills the requirements noted above; it takes out the sample without disturbing its direction, by virtue of its position and knife-edged orifice, and the velocity can be kept correct by determining the flow from the following simple formula:

$$w = \frac{Wa}{A}$$

where

w = lb. per hr. flow through calorimeter.
W = lb. per hr. flow through steam main.
a = area of sampler nozzle.
A = area of main.

The sampler is allowed to extend into the pipe one-sixth of the pipe diameter, which has been found to give practically true average flow.

The ½-in. valve at the sampler is opened wide, and the ½-in. lever cock between separating and throttling calorimeters is used to regulate the flow, the throttling action taking place at this point. The rest of the calorimeter is under vacuum, the discharge being connected to a small cooler to condense the steam and then to a volumetric measuring tank. The top of this tank, which is entirely closed except for the pipe connections, was connected with the turbine condenser by a ¼-in. pipe, which gave an available vacuum of over 28 in. without affecting the measuring in any way. The spy-glass is very useful in proving that the calorimeter is working properly, for when the superheat in the throttling calorimeter gets below 6 or 8 deg. it sometimes happens that some moisture goes by, in which case the spy-glass immediately shows it up, no matter how small the quantity. As the spy-glass is most conveniently made of ¾-in. gage glass, more area is required to take away the steam from the calorimeter, and this was done by adding a by-pass of 1-in. pipe around the spy-glass. This allows free flow to take place and does not affect the function of the glass.

The percentage of moisture taken out by the separating portion of the instrument divided by the total percentage of moisture gives the efficiency of the separating calorimeter, which turns out to be much lower than is ordinarily supposed, from 60 to 80 per cent.

For the rest of the measurements steam pressures throughout were taken with high grade thermometers, graduated to 1 deg. and in many cases as low as 0.2 deg., as these are in every case preferable to gages for saturated steam. All pressures below 15 lb. gage and all vacua were measured by mercury column, in addition to temperatures.

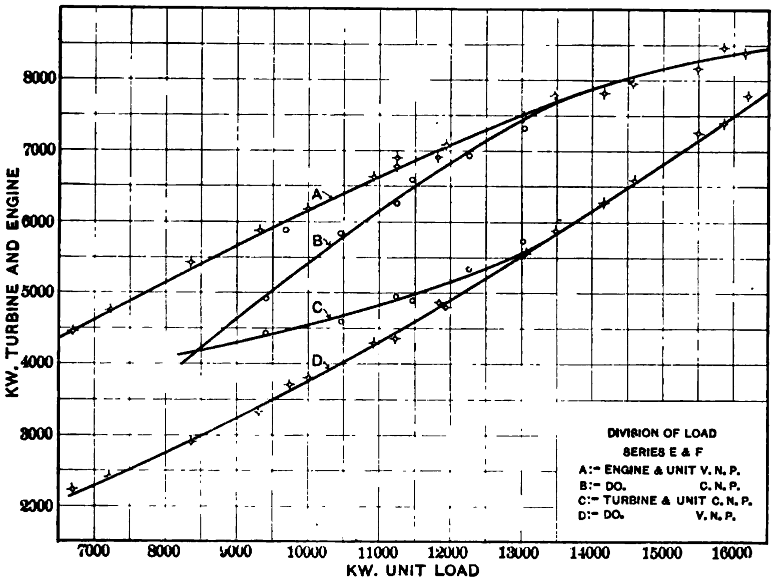


FIG. 34.—Division of load, series E and F

Table 1, Steam to Auxiliaries, includes for tests 25, 22, 24, 21, 23 and 26, the circulating water pump steam only; test 27, circulating water pump and dry vacuum pump; test 29, circulating water pump, dry vacuum pump and boiler feed pump; test 30, boiler feed pump alone.

Fig. 11 and Fig. 11a show variation of points is due to errors in earlier low-pressure calorimetry, before the standard instruments were settled upon.

Table 12, the column of Unit Water-Rate Total Correction, is based on a standard vacuum of 28.72 in. instead of 28.5 in., as the higher figure was the average vacuum of the series of tests. Consequently the absolute amount of correction was reduced, which is of course very desirable, in view of the uncertainty of correction factors.

In Fig. 14 these water rates are uncorrected for moisture, etc.

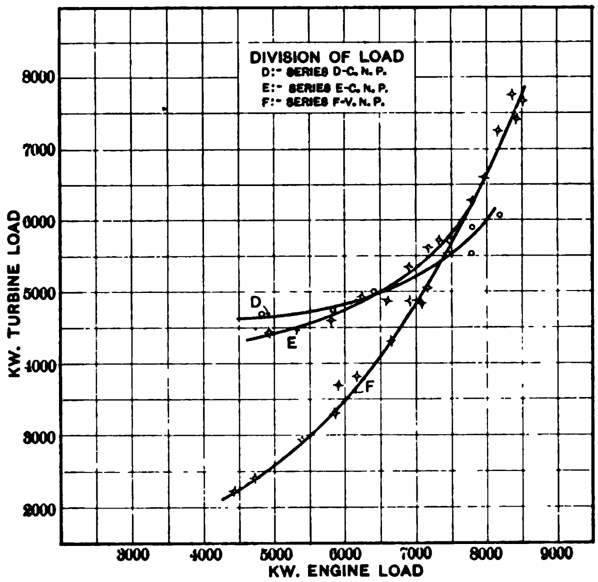


FIG. 35.—Division of load, series D, E and F

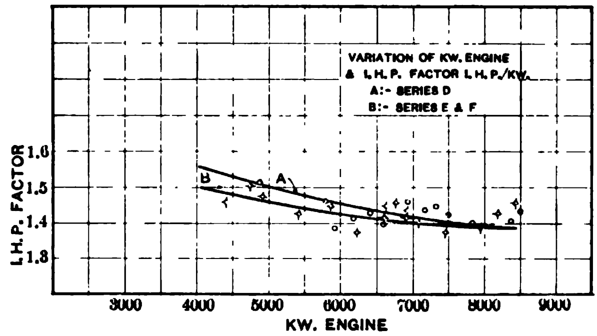


FIG. 36.—Variation of kw-engine and i.h.p. factor

In Fig. 32 the calorimeters were drawn for the sake of clearness, as if they were situated at some distance from the sampling points; actually they were, as in Fig. 1.

Figs. 34 and 35 and 36 serve to show the variation in load between engine and turbine, and the effect of change of efficiency of the two machines.

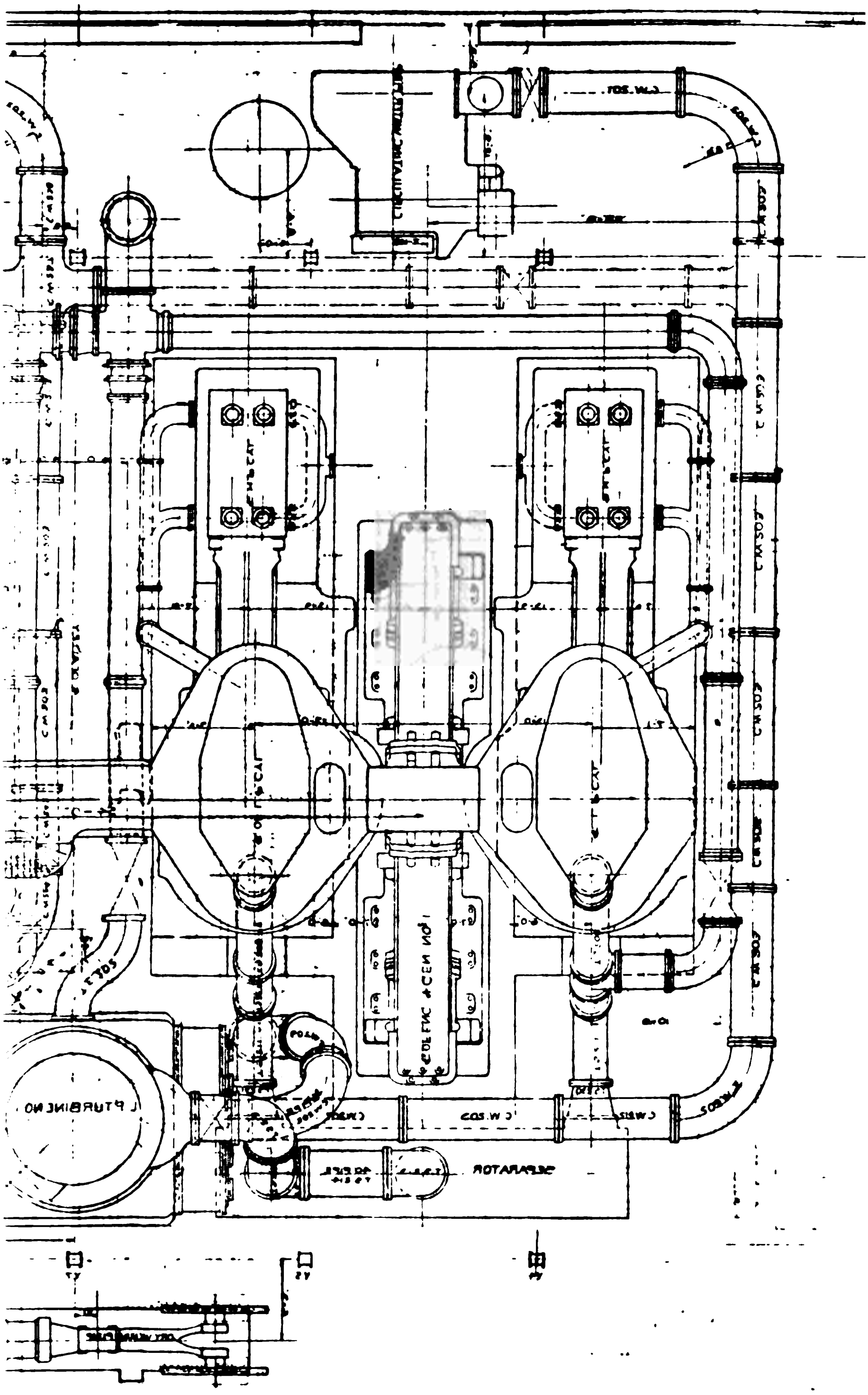
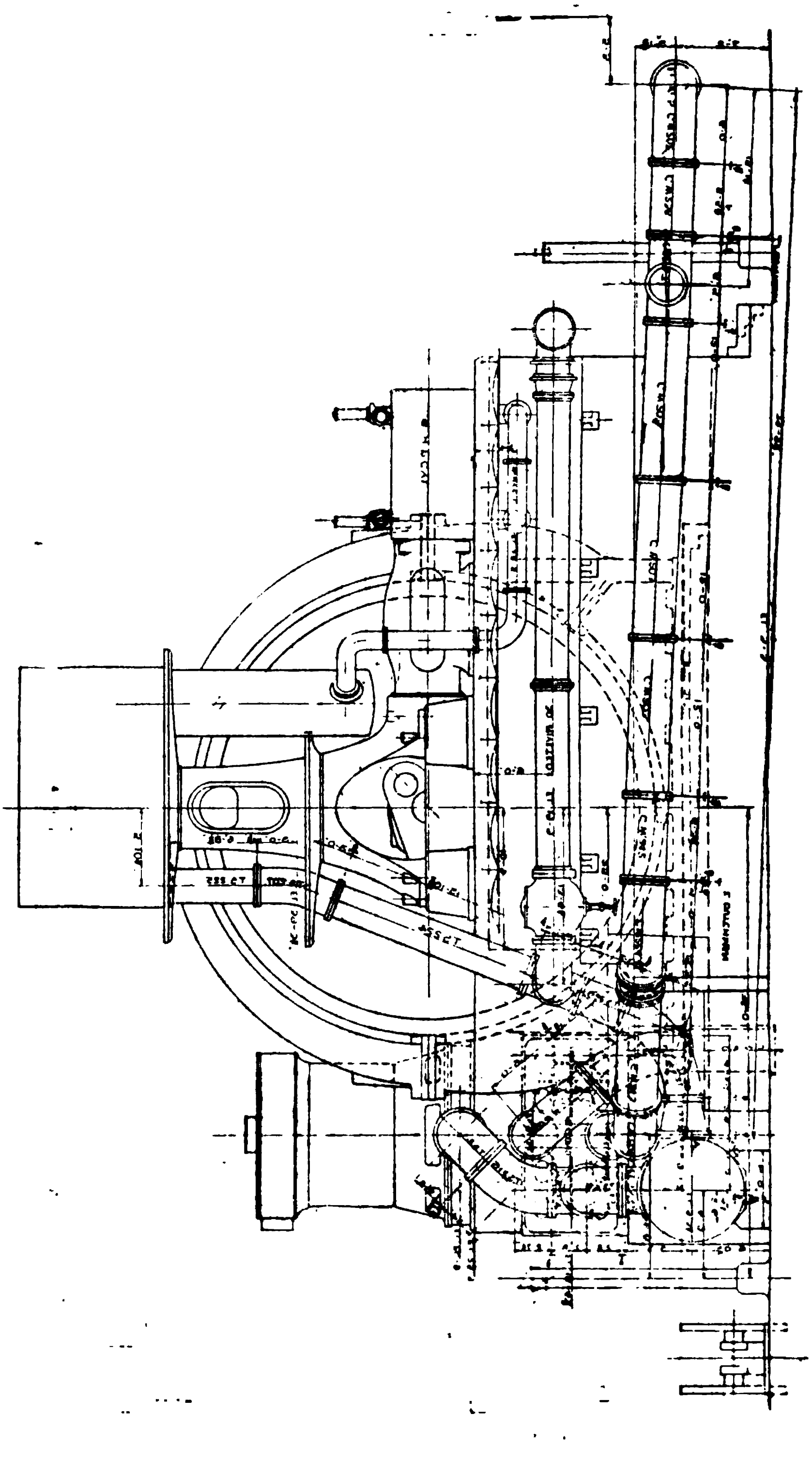
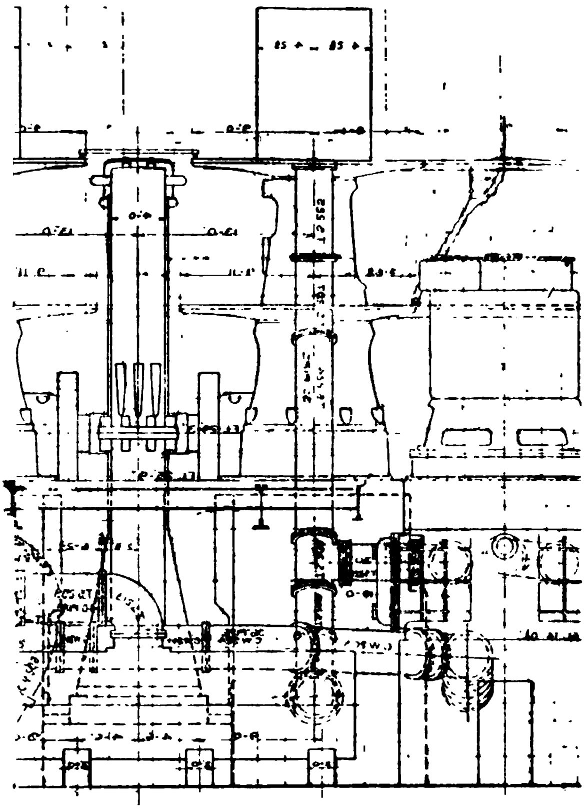


PLATE I.—End elevation and plan of engine and low-pressure turbine units.





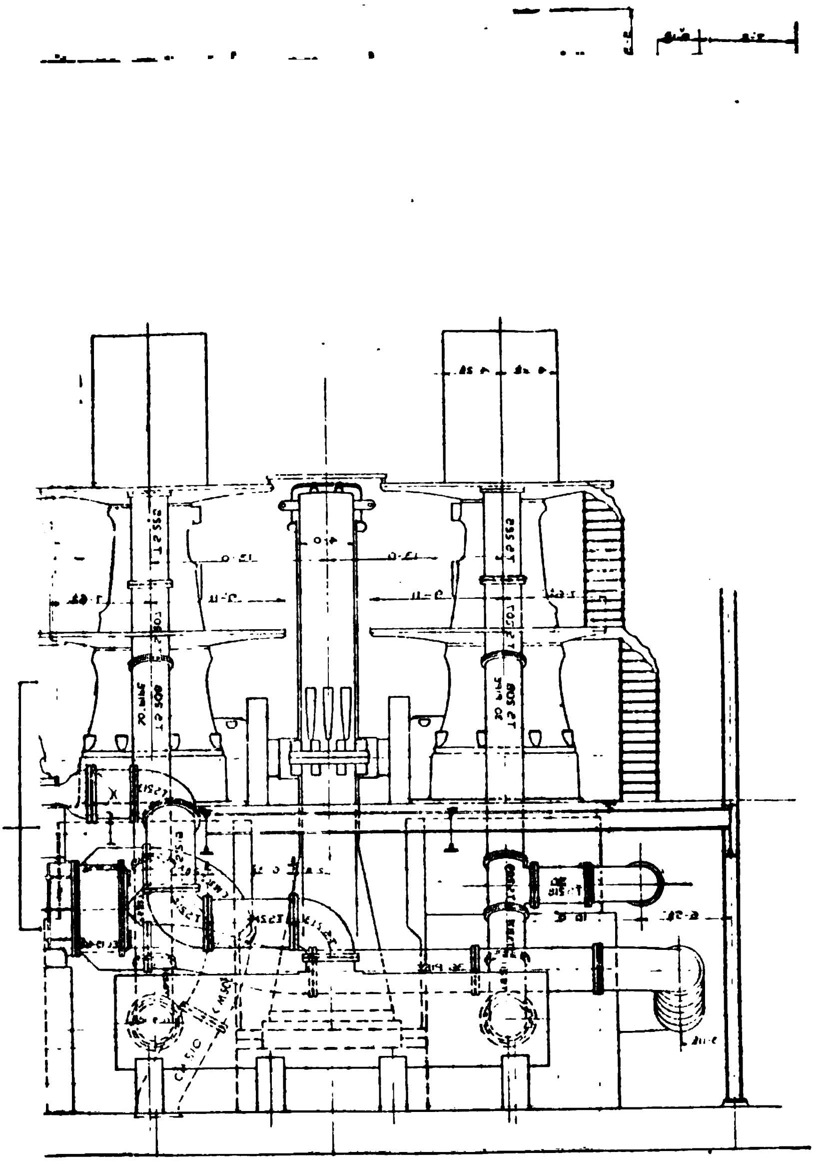


PLATE 2 Side

FORMULAE AND CONSTANTS

Engine.

Two high-press. cylinders 42 by 60 in., 9-in. rod

Two low-press. cylinders 86 by 60 in., 10-in. rod.

Rev. per min. 75.

Two 14-in. steam mains.

Two 16-in. high-press. exhausts.

Two 30-in. low-press. exhausts.

Clearances.

High-press. head 9.5 per cent. Crank 10 per cent.

Low-press. head 4.77 per cent. Crank 4.78 per cent.

Average total volume high press. 51.7 cu. ft.
low-press. 209.9 cu. ft.

Average displacement high press. 47 cu. ft.
low press. 200.3 cu. ft.

i.h.p. constant. High press. 15.38. Low press. 65.57 (average)

All combined cards worked out on average basis. Marks and Davis tables used for steam data.

Table II.

E_r = Rankine thermal efficiency, cyclic.

E_t = Engine thermal efficiency.

H_1 = Heat in initial steam at press. p_1 quality x (total per hr.)

H_2 = Heat in steam at p_2, x_2, after adiabatic expansion from p_1, x_1, (total per hr.)

$$\frac{H_1 - H_2}{H_1} = E_r \quad E_t = \frac{\text{kw.} \times 3412}{H_1} \quad \frac{E_t}{E_r} = E_e$$ = engine efficiency referred to rankine cycle.

No heat recovered.

Table III.

p_a, V_a = pressure and volume at high press. cut off, lb. per sq. in. and cu. ft.

p_c, V_c = press. and volume at high press. compression.

W_a = specific density at p_a,

W_c = specific density at p_c.

$V_a W_a - V_c W_c = W$, lb. indicated steam per stroke.

$$\frac{W \times 75 \times 4 \times 60}{\text{i.h.p.}}$$ = indicated water rate (I.W.R.)

I.W.R. $(1+y)$ = A.W.R., (actual water rate)

$y = 1.29\,(r - 1.06)$ kw.$\times 1.465$ = i.h.p.

$r = \dfrac{51.7}{V_a}$ for high press. cycle = ratio of expansion.

Table IV.

Q_e = Total dry steam per hr. to engine.

Q_f = Trap water per hr.

X_e = low press. exhaust quality.

$(Q_e - Q_f)\,X_e$ = dry steam to turbine, Q_t.

Table VI and VII

X_t = quality of steam to turbine after passing separator.

$1 - X_t = W$, wetness of steam to turbine after passing separator.

K_e = engine kilowatt output.

K_t = turbine kilowatt output.

Q_e = dry steam to unit per hr.

$\frac{Q_c}{K_e+K_t}$ = actual water rate W for unit.

Q_f = trap water per hr.

Q_s = separator water per hr.

X_1 = high press. quality.

$$\frac{Q_e}{X_1} - Q_s - Q = Q_t'$$

$$Q_t'\,X_t = Q_t$$

$\frac{Q_t}{K_t}$ = actual turbine water rate, W_t

$\frac{Q_e}{K_e}$ = actual engine water rate, W_e

$\frac{Q_e}{K_e+K_t\,(1+W)}$ = unit water rate, corrected for moisture in turbine steam, W'

$W' - (28.5 - p'_s) = W''$ total corrected unit water rate.

p'_s = actual vacuum obtained, in mercury.

Tables IX and X.

All throttling calorimeters.

$$X_1 = \frac{H_2 + K\,(T - t_2) - Q}{L}$$

H_2 = total heat per lb. saturated steam at p_2, calorimeter discharge press.

X_1 = quality.

K = separator heat superheated steam at p_2, T.

T = temperature superheated steam in calorimeter.

All separating calorimeters.

$X_2 = \frac{W_f}{W_m + W_f}$ t_2 = temperature saturated steam at p_2.
Q = heat per lb. of the liquid.
L = latent heat vaporization per lb. at p_1.

W_m = moisture.
W_f = flow.

All combination separator-throttle calorimeters.

$X_1 X_2 = X_1$ combined quality.

Thomas electric calorimeter.

$$\frac{\frac{3.412E}{W} - K(T - t)}{L} = 1 - X$$

E = watt-hr. input.
W = lb. steam flow.
K = as above.
T = as above
t = saturated steam temperature at p.
L = latent heat per lb. at p.
X = as above.

Table XII, see VI, VII.
Tables XIII, XIV.

$E_t = \frac{\text{kw. } 3412}{H_1}$ for engine turbine or unit.

$E_t' = \frac{\text{kw. } 3412}{H_1 - Q}$ for unit and turbine only.

E_t = thermal efficiency no heat recovered.
E_t' = thermal efficiency hot well heat recovered.

DISCUSSION ON "TEST OF A 15,000-KW. STEAM-ENGINE-TURBINE UNIT", NEW YORK, MARCH 8, 1910

W. L. R. Emmet: While some few applications of low-pressure turbines in connection with electric-generating engines have been put into operation before that which is described in this paper, such cases are relatively unimportant and I think that in all of them the application has been made to a station which was formerly operated non-condensing.

In recent years the science of steam engineering has advanced very rapidly and as the cost of fuel has increased the cost of apparatus has diminished so that we now find ourselves in a position where the question of investment is of much less relative importance than formerly, the value of the product being so very large in proportion to the cost of the apparatus required. For this reason we generally cannot afford to use any apparatus but the best, no matter how great its cost.

The operation of stations by turbines alone is simpler and generally more economical than that of stations which use reciprocating engines and there are many cases where it might be better to install high-pressure turbines instead of coupling low-pressure turbines with existing reciprocating engines. The results shown by Mr. Stott's paper, however, should demonstrate to many station managers that they cannot afford to run reciprocating engines alone when such an improvement can be accomplished by the addition of low-pressure turbines. I regret that Mr. Stott has not dwelt at more length upon the saving in investment and operation which has been effected by this installation, although his tests and explanations afford most of the data necessary for such comparisons. The increase of firing capacity due to the changes made in many of the boilers sometime ago has greatly contributed to the comparisons of the remarkable improvement accomplished. Comparisons of the original conditions in this plant with the ultimate development of the present plan afford a very striking example of what can sometimes be done with an old station.

The results in steam consumption shown by Mr. Stott's tests are very decidedly better than the best results which have ever been accomplished with turbines alone, the advantage in water rate amounting to about 2 lb. per kw-hr. as compared with the best turbine results. It is possible that this station will never produce power more cheaply than the best modern turbine stations are now doing with equal fuel, but the difference cannot be great and when the enormous investment saving is considered, the great value of this change will be apparent.

Some of these curves given in the paper would seem to indicate that the results accomplished by the turbines were inferior to those guaranteed or expected, whereas in fact all guarantees and expectations have been rather exceeded. The reason for this apparent discrepancy is that Mr. Stott has not made allowance for the losses introduced by the presence of moisture in steam entering the turbines, whereas the guarantees on the turbines were based upon dry steam. Mr. Stott has reported the facts as they exist and as they are influenced by such methods of moisture separation as he has used. If the separation were more perfect the turbine results as shown by the curves would be much better and it is probable that with more experience, an almost complete absence of moisture in the steam turbine can be provided for. In Schenectady, where we are operating two large low-pressure turbines on exhaust steam from a reciprocating engine plant, we are running with steam which is almost completely dry. The reason for this is that the steam has to pass horizontally through a long pipe which ends in a separator and is drained before it reaches the separator. This arrangement gives the steam ample time to throw down its moisture and the last vestige of it is taken by the separator. In most applications of low-pressure turbines and engines, such an arrangement can be provided for, while in the installation referred to in this paper the delivery of steam from engine to turbine is in a downward direction and through very short pipes in which little separation or collection of moisture into drops can occur.

Max Rotter: The success of an enterprise of such magnitude and novelty required, on the part of those responsible for it, a very considerable courage and confidence in engineering calculations. The test results and Mr. Stott's deduction from them will exercise no small influence on all who are interested in the production of power on a larger scale.

One matter of practical interest is the elimination of the moisture and oil from the steam during its passage from the engine exhaust to the turbine inlet. Tests 45 to 62 seem to show that the moisture remaining in the steam, as it entered the turbine, amounted to an average of over 4 per cent. Can it be assumed that this may, without re-heating or increased pressure drop, be reduced to zero. If not, then the inefficiency of the separation must be considered as one of the losses inevitable in an installation of this kind, and corrections for moisture entering the turbine should properly be omitted, as such losses would be on a par with the losses in the low-pressure stages of a high-pressure turbine, due to the water of liquefaction delivered to them from the high-pressure stages. It is not the same as a correction for moisture in the steam as originally delivered to the engine, for the engine and low-pressure turbine, with their necessary connecting elements, must be considered as a single unit and it is proper to correct only for conditions due to the imperfection of external apparatus serving the unit. For instance, while a correction for moisture in the steam would be made in testing an engine as a unital piece of apparatus, no such correction would be made in testing, as a unit, the complete plant of such engine and its boilers. The correction of 1 per cent in consumption per 1 per cent of moisture delivered to the turbine is the usual full allowance for the internal losses caused by such moisture; as obviously no deduction of the moisture itself can be made, this having been already allowed for in determining the dry steam delivered to the engine. This correction of 1 per cent is thus equivalent to the customary correction of 2 per cent in consumption per 1 per cent of moisture, as applied to a high-pressure turbine performance. The elimination of oil is probably more important as affecting the maintenance of the efficiency of the turbine and surface condenser than that of the boilers.

One of the most interesting features of the paper is the comparison of this engine and low-pressure turbine installation with an installation of high-pressure turbines. It is not clear whether the high-pressure turbine referred to by Mr. Stott is one of a capacity equivalent to that of the low-pressure turbine only, or to that of the combined engine and low-pressure turbine unit. The latter would certainly be proper and seems to be that considered by Mr. Stott in his statements regarding relative costs; but the high-pressure turbine efficiencies shown in Fig. 19*a*, Series E and F, are apparently those of a considerably smaller machine. Nor is it quite proper to compare the efficiencies of two units on the basis of the test performance of one as against the guaranteed efficiencies of the other. A business man will not guarantee more than necessary, nor will he guarantee under any circumstances the best he can hope to do under test. Furthermore, a slight change in operating conditions might materially affect such a comparison. For instance, the majority of modern high-pressure turbine plants operate with some superheat, of which the high-pressure turbine can take greater advantage than can the engine and low-pressure turbine unit. The frequency of the turbo-alternator, in so far as it determines the speed of the turbine, will also exercise some influence upon the results. At 59th Street the slow speed of 750 rev. per min. is somewhat unfavorable to the turbine. A higher turbine speed would, in the case of the engine and low-pressure turbine unit, increase the efficiency of the turbine only; that is, the improvement in efficiency would apply to only about one-half of the total load of the unit; whereas, in the case of a high-pressure turbine of a capacity equivalent to that of the combined unit, the improvement in efficiency would apply to the full output of the machine. The comparative operating expenses must also be considered, and these are unquestionably lower for the high-pressure turbine than for the combined unit.

For the purpose of comparing the steam consumptions of the two types of apparatus, the final results gvien in Table 12, Series E and F, have been replotted herewith on Fig. 1 and curve A drawn through the points. This curve therefore shows the steam consumption of the combined unit, corrected to dry saturated steam at the engine throttle at 180 lb. gage, dry saturated steam at the low-pressure turbine throttle at variable pressure, and a vacuum equivalent to 28½ in. referred to a 29.92-in. barometer. Curve B refers to a high-pressure turbine unit operating with dry saturated steam at 180 lb. gage and a vacuum of 28½ in. referred to a 29.92-in. barometer, at a speed of 750 rev. per min., and having a capacity about equivalent to that of the combined engine-low-pressure-turbine unit. This latter curve shows the steam consumptions it would be perfectly safe to expect from such unit under test, and it is probable that a consumption 0.3 to 0.4 of a pound lower would be attained. In making guarantees, from 1 to 1½ lb. per kw-hr. would be added. A comparison of these curves would indicate that the average difference of 8 per cent as given by Mr. Stott is ample, and 13 per cent as given by him too high.

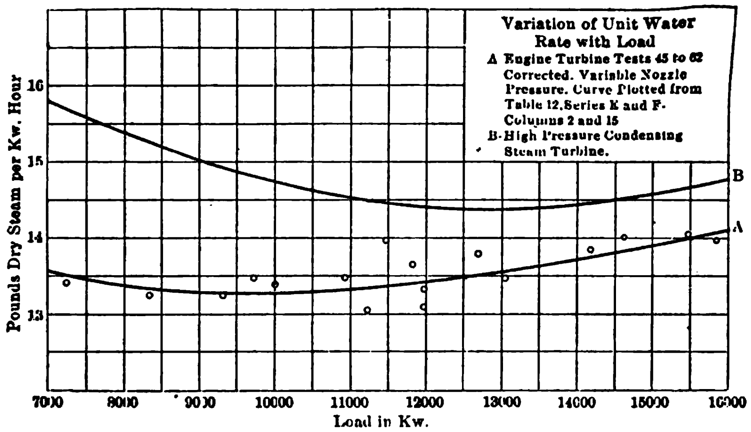


Fig. 1.—Results in Table 12, series E and F

To indicate the effect of a change in operating conditions, curves A and B (Fig. 2 herewith) have been plotted to show the performance of the units when operating under the conditions above mentioned, except that the steam is superheated 100 deg. fahr. It will be noted that the advantage of the combination as against the single unit is materially lowered.

That the high-pressure turbine consumptions, as shown by the curves, are reasonable is proved by a recent unassailable test of this type of turbine, with steam at 180 lb. gage, superheated 100 deg. fahr., and a vacuum of 28½ in. referred to a 29.92-in. barometer, which showed a consumption of 14.02 lb. per kw-hr.; the turbine having a normal capacity of only 4000 kw. at 1800 rev. per min.

An improvement in efficiency of 13 per cent in the 59th Street plant would almost seem to warrant a combined engine and low-pressure turbine unit as an initial installation, and it would be interesting to learn whether Mr. Stott would consider such an installation for extensions of this plant beyond the capacity obtainable by adding low-pressure turbines to all of the existing engines.

The conditions for which low-pressure turbines are being considered have multiplied much faster than anticipated. For instance it has been proposed to operate a turbine by means of steam from natural geysers, which is perfectly feasible. The steam would be obtained by passing the hot water through vessels in which a pressure drop would take place and part of the water be evaporated. With such an arrangement it would be necessary to handle 30 to 50 lb. of water to obtain 1 lb. of steam at a pressure slightly below atmosphere.

Another use for low-pressure turbines is that of generating

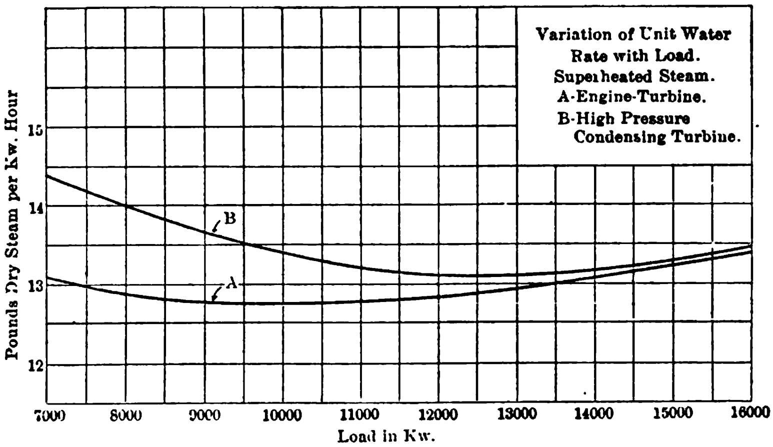


FIG. 2.—Curves A and B, showing performances of units when operating under given conditions

power from hitherto wasted industrial steam. For instance, a turbine is now being installed in an automobile tire factory where the retorts used for vulcanizing are filled with high-pressure steam for a certain period, the major portion of this steam being then blown out into the air before the retorts are opened for recharging. This steam will henceforth be collected in a receiver, in which its pressure will drop approximately to atmospheric, and from which it will be delivered to a low-pressure turbine for use. The supply of steam is almost constant and will generate 1000 to 1200 kw., the only cost being the fixed charges, labor, and the water required for condensing.

Every improved method or appliance is exposed to the danger of being retarded in the progress it really merits by a few ill-advised applications, and there are conditions under which it would be better not to advocate low-pressure turbines as additions to reciprocating engines. In almost all instances figures will show a saving of steam as achievable by such combination, but the cost of power production in a great many industrial plants is so small an item compared with the other expenses, that a reduction of even 25 per cent in fuel consumption is frequently insignificant when weighed against other considerations.

A low-pressure turbine should not be installed where its steam supply depends upon an old and unreliably decrepit engine. The proper thing here is an independent high-pressure condensing turbine. And as a high-pressure condensing turbine of the same capacity as the engine and low-pressure turbine combined will give so nearly the same efficiency as the combination, the boilers and the condensing apparatus will cost about the same for either installation, the fuel consumption will be about the same, and the engine can be set aside for emergency use.

There are numerous instances where compound engines are not overloaded but underloaded. Many of them are running non-condensing and it is a condenser and not a low-pressure turbine that is needed. The beneficial effect of adding a condenser to an underloaded compound engine is twofold; firstly, it will lower the mean effective pressure at which the engine attains its best efficiency and, therefore, if the engine is underloaded, it will bring the point of best efficiency nearer the running load; and secondly, there is the increased efficiency directly due to condensing.

The installation of a low-pressure turbine may also be a doubtful expedient in a plant which is being electrified and in which the engine is belted or coupled to a lineshaft so that the direct load is decreasing while the electric load is increasing. Of course a generator could be added to the engine, and a low-pressure turbine run in connection with this; but beyond the combined capacity of these it would become absolutely necessary to install a new unit. Under such circumstances the best course would be the installation of a high pressure condensing turbine to start with.

E. F. Miller: I recently made some calculations upon the economy of the low-pressure turbine and found in figuring over some of the tests quoted an apparent efficiency of 76 to 80 per cent of that obtained from the non-conducting engine. I also worked up the efficiencies and steam consumption of the Rankine engine using dry steam at a pressure of 15.6 lb. and exhausting at 28-in. vacuum. The same calculations were made at other pressures down to about 6 lb., as shown in Table 1. Taking the efficiency of the generator as 83 per cent and the mechanical efficiency of the engine as 90 per cent, the steam consumption per kw-hr. was obtained.

Assuming the ratio of efficiency of the low-pressure turbine to that of the non-conducting engine as 63, 67.5 and 72 per cent, the steam consumptions per kw-hr. were calculated. Table 1 affords a simple means by which steam consumptions may be compared.

TABLE 1 STEAM CONSUMPTIONS OF LOW-PRESSURE TURBINES AT VARYING PRESSURES

Abs. press. at entrance	Temp. at entrance deg. fahr.	Abs. press. at exit	Temp. at exit deg. fahr.	Quality of steam at entrance	Quality of steam at exit	Thermal Eff. of Non-cond. eng. %
15.60	215	1.005	102	1.000	0.8785	15.93
14.13	210	1.005	102	1.000	0.8827	15.38
11.53	200	1.005	102	1.000	0.8916	14.23
9.34	190	1.005	102	1.000	0.9007	13.03
7.51	180	1.005	102	1.000	0.9125	11.75
5.99	170	1.005	102	1.000	0.9203	10.48

Steam per h.p.-hr. of non-cond. eng. per cent	Steam per kw-hr. of non-cond. eng. calling mechanical eff. of eng. 90 per cent and eff. of generator 93 per cent	Steam consumption per kw-hr. of low-press. turbine assuming ratio of act. eff. to that of non-conducting eng. as 63, 67.5 and 72 per cent		
14.72	23.55	33.6	31.4	29.4
15.23	24.36	34.8	32.5	30.4
16.50	26.40	37.7	35.2	33.0
18.09	28.94	40.1	38.6	36.2
20.13	32.20	46.0	42.9	40.3
32.66	36.26	51.8	48.3	45.3

Edward L. Clark: A number of cases have arisen where mills driven mechanically have desired to increase their power by the use of low-pressure turbines. The introduction of the low-pressure turbine in such places is accomplished in a novel and effective manner by tying the electric load and the mechanical load together by means of a synchronous motor or generator. The synchronous motor may either be belted or coupled-direct to the main line shaft driven by the engine, and then electrically interlocked with the generator connected with the low-pressure turbine. With this method, the low-pressure turbine requires no governor and merely delivers power in proportion to the quantity of steam exhausted by the engine.

It is important in the selection of a low-pressure turbine that it should be capable of utilizing the entire engine exhaust. In this arrangement, the turbine may be regarded as the low-pressure cylinder of a triple-expansion engine, and manifestly a proper ratio between the low-pressure turbine and engine cylinders should be chosen. If this feature is not observed, the expansion of the steam will not be efficiently carried out or there will be free escape of a part of the steam through the relief valve between the engine and turbine. However, a properly selected turbine will pick up the electrical load and the surplus power that it is delivering will go through the synchronous motor, thereby lightening the load of the engine. When the engine is thus relieved of a portion of its load, it naturally gives less steam to the turbine until the whole system automatically balances between the mechanical load and the electric load.

An important feature of operating the low-pressure turbine without a governor is that vacuum comes back on the engine at all loads, the amount of this vacuum being proportional to the amount of load carried by the turbine. By thus varying the inlet pressures on the turbine and maintaining them below atmospheric pressure, looping of the low-pressure card on the engine at light loads is avoided and the low-pressure valves operate smoothly and without noise at all loads. At the same time, both the engine and turbine run in combination at maximum efficiency through their entire range, and the curves obtained are about as straight as the one in Mr. Stott's test.

It will be seen that the flexibility of such an outfit is independent of the mechanical load and the turbine can accomplish practically anything that a high-pressure turbine can accomplish. The gain in power with the synchronous motor system amounts to nearly 100 per cent, due to the fact that the increased rating of the non-condensing engine over what it is at best economy condensing is approximately 20 per cent, which should be added to the 80 per cent additional power given by the low-pressure turbine.

Assuming that an engine running under 125 to 130 lb. pressure consumes per indicated horse power 15 lb. steam-condensing and 21 lb. non-condensing, if we divide the additional steam required when running non-condensing by the kilowatts obtained from a low-pressure turbine, we obtain a kilowatt for very close to 12 lb. additional steam per kw-hr. This must compare with a water rate of say 20 lb. on a high-pressure turbine under the same steam conditions.

An interesting point is that the economies obtained for the combined engine and turbine would be equivalent to a consumption of about 11 to 11½ lb. per indicated horse power in steam engine practice, so that we better the engine economy over what it is at its best point when run condensing, besides producing a kilowatt for less steam than in a high-pressure unit.

In the majority of cases the low-pressure turbines have been installed in plants having from 125 to 140 lb. of steam, and the relative gain is just as marked as in the stations carrying 195 lb. of steam and high degrees of superheat.

E. D. Dreyfus: It is interesting to note the remarkable difference in Rankine cycle efficiency between the engines and the low-pressure turbines. This looks as if there is some opportunity for improvement on the low-pressure turbine. Mr. Flanders of East Pittsburg, has made quite a study of turbine efficiencies, and has found that a high-pressure complete expansion turbine operating with 175-lb. steam pressure and 100-deg. superheat will give the same Rankine cycle efficiency as a low-pressure turbine at the same vacuum and using dry saturated steam.

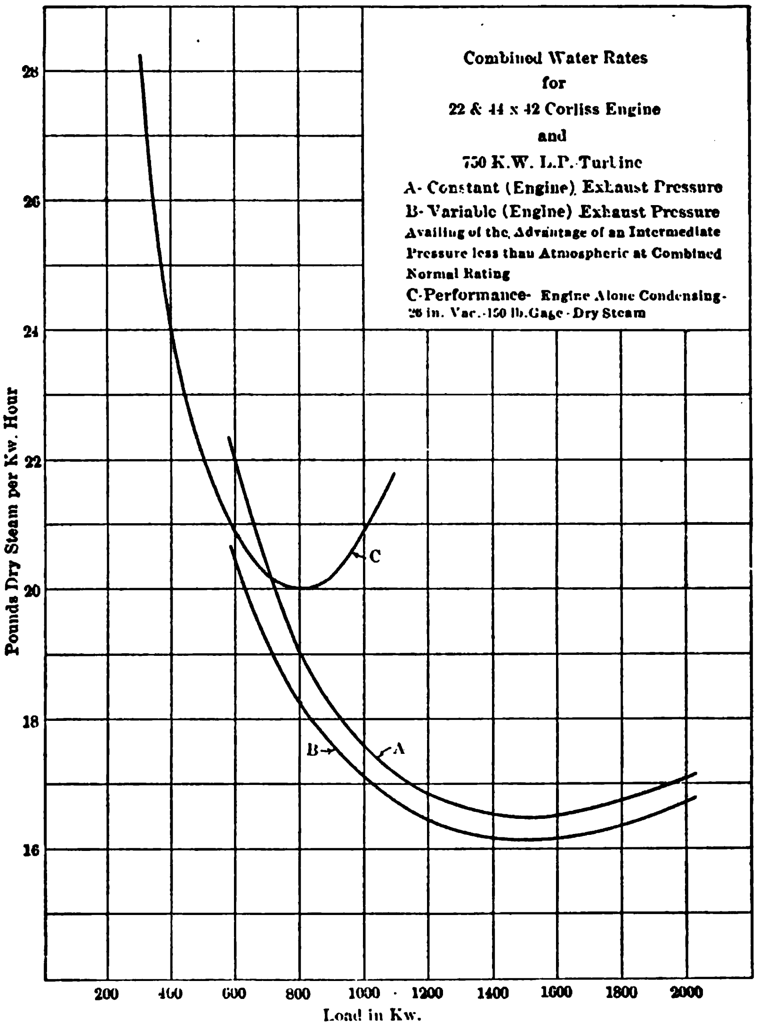


FIG. 1

The gain in economy of 13 per cent, as stated by Mr. Stott, is what would be expected when we consider that this unit is operating on dry and saturated steam. I must, therefore, differ with Mr. Rotter, as I know of no complete expansion economies on record that do not agree to a large extent with what Mr. Stott has brought out. A Rankine cycle efficiency of 70½ per cent on a complete expansion machine, but no turbine performance reaching this degree of efficiency has to my knowledge been recorded in this country. Some have gone as high as 67.8 per cent, but as far as I am able to learn, any record of a complete expansion machine that has exceeded 70 per cent is within closed doors.

I am very much interested in observing the results obtained with constant and variable exhaust pressure. When this question first came up in low-pressure turbine work, variable exhaust pressure was looked upon with disfavor by some designers and engineers, while others advocated this method because of the better results obtained with it. It is now quite evident that in the neighborhood of 5 per cent additional economy is obtained by running with variable exhaust pressure. As Mr. Stott has stated, it is obvious that unless the piping and apparatus between the engine and turbine are in very good condition, good vacuum will not obtain. I find, however, that there are a number of low-pressure turbine installations where the low-pressure turbine is coupled with two or more compound Corliss engines with moderately long connections, and they secure a vacuum in the neighborhood of 28½ or 29 in. The overall economy, even in the small 1000-kw. unit, indicates the same relative gain as shown by Mr. Stott's results. Fig. 6 and Fig. 7 in Mr. Stott's paper, show the desirability of variable pressure operation on account of looping of the cards.

Mr. Stott mentioned in the first part of his paper that the maintenance account of a complete gas-engine plant would be from four to ten times that of a turbine station. To the best of our ability in collecting information and judging working conditions, we do not find it comes up to this factor, and the same thing is true in England according to a paper presented before the Institution of Electrical Engineers on November 17, 1908. This paper was very thoroughly discussed at London, Dublin and Manchester, both favorable and adverse comment being made, but the prevailing opinion seemed to be that the maintenance cost of the complete gas plant would not much exceed that of the steam turbine plant; in fact, the author of this paper claimed it to be the same. When the producer and boiler are considered, there is reason for this statement.

Regarding the statement that the results obtained closely approach gas-engine efficiencies, gas-engine coal consumption is usually given for 12,000 to 13,000-B.t.u. coal, but considering 14,500-B.t.u. coal in both steam and gas plants, a material difference of 20 to 25 per cent will easily be obtained in favor of the gas equipment over the most efficient steam machinery.

The value of the low-pressure turbine is rapidly bringing about its extensive use in connection with the gas engine, availing of the waste heat of the jacket and exhaust.

Charles P. Steinmetz: The paper deals with a combination of the low-pressure steam turbine with the induction generator, which, while possibly not familiar to some, is assuming a very high industrial importance.

The electrical part of the unit, the induction generator, is not a new type of machine. Its existence was known and its characteristics and behavior investigated and discussed many years ago; but only now has the industry developed in such a manner as to give conditions in which the induction generator is preferable to the synchronous generator.

There are two kinds of alternating-current generators: the synchronous generator, which is the ordinary alternating-current machine with which we are familiar, and the induction generator. Constructively, the stator or stationary structure of both types of alternator is practically the same in construction. It comprises a polyphase winding, in which the electromotive force is induced by the rotating magnetic field, arranged in a laminated structure. The difference between the synchronous generator and the induction generator is in the rotor. In the synchronous generator this is a revolving magnetic field excited by direct current; while in the induction generator it contains a short-circuited winding the same as the armature winding of the familiar induction motor. From this variation results the difference in the production of the magnetic field which by its rotation induces electromotive force in the stationary generator winding. The magnetic field of the synchronous generator is produced by the action of the direct current in the field poles; that of the induction generator is produced by the reaction of the alternating currents issuing from the induction generator. As a consequence the synchronous generator must run in step with the frequency of the alternating system; that is, the rotor must move exactly one pole for every reversal of voltage in the external system. Conversely, the induction generator cannot run in step with the frequency but must always run faster, exceeding synchronism by an amount depending upon the load, so as to cause the induction in the short-circuited windings which produces the currents therein. That means that synchronizing is not required in the induction generator. Furthermore, since the induction generator does not depend upon running in step with any other machine, the possibilities of see-sawing, the so-called hunting which may occur in the synchronous machine, cannot exist with the induction generator.

The difference in the production of the magnetic field of the two types of alternating-current generator is the cause of the very characteristic variations in their performance. The magnetic field of the synchronous machine and, therefore, the electromotive force induced in its armature, depends on the direct current supplied to its field winding, but is essentially independent of the load of the machine. It is dependent only in so far as the current output and the power factor modify the field, varying it in the manner expressed by the term " regulation of the machine ". The induction-motor field is produced by the reaction of the currents issuing from the machine. The induction generator, therefore, has no regulation and no magnetic field, independent of the voltage at the terminals and the load, but the magnetic field of the induction machine is produced by the reaction of the currents at a value corresponding to the voltage produced at the induction-generator terminals by the synchronous machines connected to the same system. The induction generator depends in its magnetic field and voltage on the excitation of the synchronous machines in the same system; that is, it can generate only when connected to a system to which synchronous machines are also connected, whether synchronous generators, motors, converters or equivalent apparatus. It has no voltage of its own and cannot operate on a system on which no synchronous machine is connected.

The regulation of such a combined system of synchronous and induction machines, therefore, is the regulation of the synchronous machines operating on the system. Any change of load varies the voltage as it would be varied if this change of load occurred on the synchronous machines in the system. The induction generator is merely a machine feeding electric power into the system but not participating in the voltage regulation or voltage control and having no direct effect on the voltage. While the synchronous machine at open circuit has a terminal voltage, the induction generator ceases to generate and has no voltage at its terminals at open circuit if it is disconnected from the alternating system. In a synchronous generator, even when short-circuited, the electromotive force continues to be induced in the armature windings because the magnetic field is still there as produced by the direct current. The synchronous generator therefore has a short-circuit current which may be many times full-load current, since the total induced electromotive force must be consumed inside of the synchronous generator armature. An induction generator, when short-circuited, has no voltage at the terminals, and therefore receives no current, has no magnetic field, and ceases to generate. In the induction generator when short-circuited, the current dies down from its previous normal value to zero at a rate depending on the resistance and inductance of the internal circuit in just the same manner as the current in a reactive coil, for instance, would die down when the coil is short-circuited and the impressed voltage withdrawn from it. The short-circuit current of the combined system of synchronous and induction generators is therefore only the short-circuit current of the synchronous generators.

There results therefrom also the characteristic difference that the synchronous generator can generate current of any character, energy, reactive or wattless lagging, or leading, depending on the nature of the system to which it is connected, or the power factor of the supply system; while the induction generator can generate only energy current, and in addition continuously consumes or receives a certain amount of reactive or wattless lagging current required for its excitation. This latter it receives from the synchronous generators or the synchronous motors and converters in the system. The induction generator, therefore, cannot supply alone a general alternating-current system, for instance, a system of light and power distribution, which requires energy current, as well as reactive, or wattless lagging current; and where a combination of synchronous and induction generators is used, all the lagging current of the system must be supplied by the synchronous generators, and in addition the lagging current also consumed by the induction generator for its excitation.

In a system in which there is considerable lagging current, a very large percentage of induction generators is a questionable advantage, since it may throw an excessive overload in current on the synchronous generators, the latter having to supply all the lagging current. On a system requiring no lagging current, or being built to supply lagging current, as rotary converters or synchronous motors, which is the type of system on which Mr. Stott's generators operate and is usual in the large electric power-generating and distributing systems, mainly of 25-cycles, there is no lagging current required because the system can be run at unity power factor or even at leading current, and the synchronous motors and converters can be caused to supply the lagging exciting current of the induction generators. There the induction generator is at its greatest advantage.

The difference may possibly be described by saying the synchronous generator generates electric current while the induction generator generates electric power. That is, the synchronous generator supplies electric current to the system whether this current is a power current or a wattless, powerless current; the induction generator can supply only power current and no wattless current. The induction generator, therefore, is the typical converter from mechanical into electric power. It consumes mechanical power, supplies electric power without depending in its supply on field excitation, speed, synchronism or any other feature. It is consequently the ideal machine to float on an alternating-current system, by receiving whatever mechanical power is available and supplied to it a low-pressure steam turbine from the exhaust steam of reciprocating engines; or in the hydraulic turbine from whatever water power there may be available. It receives the mechanical power and converts it into a proportional amount of electric power, at whatever voltage the system happens to run on, and at any speed, speeding up just above that for which the system is set by its frequency, but with no necessary regulation. Its straight and simple function is the conversion of one kind of energy to the other, separate entirely from the problem of regulation and adjustment which is thrown over into the synchronous machines in the same system. This is what makes the induction generator a simple and convenient apparatus for cases like that described in the paper and for all others where mechanical power is to be picked up from water powers here and there, and is too small, possibly, to warrant installation of specific regulating mechanism.

There is an interesting and somewhat unexpected result shown by the tests, namely that the efficiency was found higher when operating the turbine with varying nozzle pressure than when operating with constant nozzle pressure. The explanation of this is given by the curves in Fig. 13 and Fig. 14. In the latter the efficiency of the low-pressure turbine is higher for constant nozzle pressure, just as expected, but constant nozzle pressure of the turbine means constant exhaust pressure of the steam engine and with this and the varying load, as shown in Fig. 13, the efficiency of the steam engine falls off, dropping from the maximum point at a rate which is so much greater than the gain in efficiency of the steam turbine that the combined efficiency shows an advantage in favor of varying nozzle pressure. This illustrates the fact that the turbine side is much less sensitive to variations of the operating conditions from its best condition than the steam engine is, and that to get maximum economy in the operating conditions the engine should be favored. But that also throws a side-light on one of the reasons why the Rankine efficiency of the turbine is less than that of the steam engine part, because all the unfavorable conditions of operation must be thrown on the turbine side of the cycle to get maximum average resultant efficiency.

The gain in efficiency due to the addition of the low-pressure turbine is on the lower side of the cycle, because of the possibility of extending the expansion below the exhaust pressure of the low-pressure cylinder of the steam engine, an extension impossible with the reciprocating engine. The combined apparatus gains in the ability of the turbine to do what the reciprocating engine is not able to do. This must be kept in mind when comparing the low-pressure turbine and steam-engine plant with the high-pressure turbine plant.

The reciprocating engine in general cannot gain by superheat as much as the steam turbine gains, and comparison of the combined efficiency of a saturated-steam reciprocating engine and low-pressure turbine with a high-pressure turbine is not quite fair to the latter, because on the high-pressure side, the steam turbine can get an additional gain in efficiency by using superheat which the reciprocating engine cannot to the same extent. In comparing things it is always difficult to get conditions which are equally fair to both types of apparatus because the conditions of proper operations are different in each.

J. W. Lieb, Jr.: The author is somewhat optimistic in his estimate that it would be possible to realize as much as 20 per cent of the installation cost from the sale of used apparatus. It would probably be necessary to accept a lower figure, but the result, however, would be still more in favor of the installation of the low-pressure turbines.

In the application of the induction generator we have a solution of the problem which combines simplicity of construction and operation with a minimum of installation cost. The induction generator is also of notable assistance in solving the otherwise very difficult problem of handling through the available types of switching gear the enormous energy which might with the usual types of apparatus be difficult to handle in case of a short circuit on the bus bars.

The results of the condenser tests are particularly interesting on account of the high rates of heat transference, considerably in advance of the results hitherto attained.

The paper is a notable contribution to the economics of power plant engineering and the apparatus described should serve to give a new lease of life to otherwise antiquated engine-driven equipments, although it would be difficult to find another case where the application could be made with such manifest advantages.

D. S. Jacobus: I visited the plant of the Interborough Company while Mr. Stott's tests were being made and desire to commend most highly the degree of accuracy observed and the general character of the work.

The economy of all piston steam-engine installations may not be improved as much as 25 per cent by adding a low-pressure turbine. By examining the paper on tests made at the plant of the Pacific Light and Power Company at Redondo, California, presented to this Society by Mr. Weymouth, it will be found that the heat consumption with a steady load with piston steam engines was about 21,800 B.t.u. per kw-hr. The heat consumption was obtained by dividing the heat of combustion of the oil burned at the boilers by the net electrical output in kilowatt-hours at the switchboard. The efficiency in the tests of the combined unit by Mr. Stott is 20.6 per cent based on the heat in the steam consumed, and if we take the efficiency of the boilers at 76 per cent, a figure obtainable with oil, the heat of combustion of the fuel burned at the boilers would be 21,800 B.t.u. The difference between Mr. Stott's figures and those obtained at the Redondo plant is, therefore, about 12 per cent. There is a further allowance for the fact that the steam was superheated about 100 deg. fahr. in the Redondo tests and this would increase the figure and make it come more than 12 per cent. It does not seem possible that the introduction of a low-pressure steam turbine at the Redondo plant could ever reduce the heat consumption 25 per cent, bringing it down to 18,600 B.t.u. per kw-hr.

The results obtained by Mr. Stott are very close to those which can be secured with large gas engines. The economy of 21,800 B.t.u. could be reduced with proper superheat to about 20,000

B.t.u. per kw-hr., which would be all that could be expected of a producer-gas plant if run on a commercial swinging load with high daily peaks and periods of low power. In a 15 days' continuous test made at the Redondo plant where the load varied daily through a wide range from high peaks to periods where but little load was on the station and where there was a lay-over period of 4½ hours per day, the heat consumption averaged about 25,000 B.t.u. per kw-hr. and it is questionable whether a producer-gas-engine installation could do very much better with a load of this character.

Mr. Schauber: In regard to the statement that the result obtained with the engine-turbine-unit had closely approached the best efficiency obtained in gas-engine practice, I desire to call attention to the installation of four 2000-kw. units at the Illinois Steel Company, operating on blast furnace gas. Records kept for six months under working conditions show a consumption of 15,000 B.t.u. per kw-hr. at the switchboard. When this result is compared with the 21,000 B.t.u. per kw-hr. at the 59th Street station, the comparison is more in favor of the gas engine than the statement made in Mr. Stott's paper.

D. S. Jacobus: The 15,000 B.t.u. quoted by Mr. Schauber is based on the heat of combustion of the blast furnace gas used by the engines. If there had been a producer this value would correspond to that computed on the basis of the low heat value of the gas, and where allowance is made for losses through all auxiliaries, this figure would have to be divided by about 0.7 to give the heat units in the original fuel. This would give a much higher heat consumption, say, over 20,000 B.t.u. per kw-hr.

G. R. Parker: The question often arises as to the smallest size of plant in which a low-pressure turbine can profitably be made, and while no accurate data is yet available, I consider it doubtful if very satisfactory results can be obtained in plants of less than 300 or 400 kw. This is due to the fact that the actual cost of producing power in small installations, is not made up so largely of coal as it is in large installations, the labor and the numerous operating expenses constituting a much larger percentage of the cost.

A word of appreciation is due Mr. Emmet for the persistance with which he has worked on the problems of the turbine industry, through many early trials and difficulties, until his latest and possibly his greatest achievement, which Mr. Stott has so ably presented. I feel confident that engineering posterity will give due credit to Mr. Emmet.

O. Junggren: The over-all efficiency shown by Test 51, Table 8, is 72½ per cent of the total available energy between the steam entering the engine and the recorded exhaust pressure of the turbine. Test 42 shows an efficiency of 69.6 per cent, and another, 68.7 per cent under different conditions of load and vacuum. A high-pressure turbine, working under the same conditions of steam pressure and vacuum, would probably not give as high an efficiency over such an available range of load as that given by the combined unit, but a high-pressure turbine of approximately the same size could reasonably be expected to give 70 to 70½ per cent at the most economical load, although fractional efficiencies would not be as good as for the combined unit. A high-pressure turbine would be considerably cheaper than the combined unit and in the near future high-pressure turbines will be made having as high an efficiency as the combined unit, and still be cheaper than a combination of engine and turbine. The vacuum obtained in these tests are quite remarkable and show what can be done in actual practice.

F. Samuelson said that the field for variable-pressure turbine work, not yet developed in America, has been fully opened up in England and the business is in a very healthful condition. Low-pressure turbines of various types have been employed and all are proving fairly successful. The chief difficulty in the installation of these machines has been to meet the Board of Trade regulations as to constant back pressure on hoisting engines. Accidents are sometimes caused by a drop in back pressure at the engine, due to demands upon the accumulator by the turbine. To prevent this trouble a simple automatic valve has been employed between the engine and the accumulator to shut off the supply from the engine when the accumulator pressure falls to atmospheric. While the regulating valve is closed the turbine is supplied with steam at a reduced pressure. This valve works equally well between the turbine and the accumulator, but the capacity of the latter is much reduced because of the small pressure limit between which it operates. This results in the use of high-pressure steam in the turbine on short stoppage of the engine.

The Authors: Refiguring one of the assumed cards (Card C, Table B) for 100 deg. superheat, we get an actual water rate of 12.9 lb. per h.p. instead of 13.6 with saturated steam, since the missing water and leakage is cut to less than 0.1 of the original value in the high-pressure cylinder. As the missing water in the high-pressure cylinder forms about 0.6 of the total missing water, we shall have 0.46 of the original missing water in this case, or $0.156 \times 0.46 = 0.072$, say roughly 0.08. The B.t.u. supplied per hour $= 12.9 \times 9836 \times 1259 = 159{,}800{,}000$. Radiation and conduction, 1 per cent = 1,598,000 B.t.u-hr. High-pressure cylinder work $= 5080 \times 2545 = 12{,}940{,}000$ B.t.u-hr.; this leaves 145,262,000 B.t.u. in the steam at high-pressure exhaust, or $\frac{145{,}262{,}000}{126{,}900} = 1145$ B.t.u. per lb. At 52.2 lb. absolute, this corresponds to a quality of 96.8 per cent or 3.2 per cent moisture; of this about 2 per cent will be thrown down as receiver drain.

The heat thus removed is $0.02 \times 126{,}900 \times 253 = 643{,}000$ B.t.u., leaving 144,619,000 B.t.u. in 124,360 lb. of steam, delivered to the low-pressure cylinder. Low-pressure radiation, 0.01 × 144, 619,000 = 1,446,000; low-pressure work = 4756 × 2545 = 12,100,000; leaving 131,073,000 B.t.u-hr., or 1065 B.t.u-lb. which at 13.5-lb. absolute exhaust pressure gives a quality of 91.5 per cent, or 113,800 lb. dry steam available for the turbine. This will give 3,700 kw. on the turbine, which added to the 6710 kw. on the engine gives 10,410 kw. at 12.18 lb. per kw-hr. as against 14.2 lb. with saturated steam. In actual practice the 14.2 rate was cut down to 13.25, and it is reasonable to expect the same sort of result under superheat.

The reciprocating engine, when designed for superheat, makes just as good use of it thermodynamically as a steam turbine, but will not stand so much superheat. The point has been raised, that a moisture correction on the turbine is not fair, since without reheating it is not possible to reduce the moisture in the turbine steam to zero. It is fair in this sense, that in order to compare the various water rates on the same basis, it is necessary to reduce all steam conditions to a standard and that standard is naturally dry steam. Moreover, when the moisture gets as low as 1 per cent or 2 per cent the correction is negligible in amount, and the curve of corrected water rate is substantially true. It is quite possible that a separator can be designed that will take out all but 0.2 or 0.3 per cent of moisture; and in this case the correction justifies itself.

H. G. Stott: In reply to the question by Max Rotter as to whether it would be advisable to install in a new plant such a combination as described in the paper, the accompanying diagram (Fig. 1) showing the factors entering into the cost of power, will answer his question. For example, with a low load factor, it is quite evident that the all-important point is to keep down the fixed charges, for when the load factor is less than 20 per cent, the fixed charges are of vastly greater importance than any possible gain of efficiency due to a better type of prime mover. This is true of any plant, and the curve shows the futility of attempting to carry peak loads by means of gas engines, water power or any other prime mover necessitating a large investment per kilowatt. On the other hand, with loads having a load factor of over 60 per cent especially where fuel cost is high, the investment factor is of relatively small importance, and the all-important matter is to keep down the maintenance and operating charges by using the most efficient type of plant obtainable, provided that it is at the same time thoroughly reliable.

The total cost of power can be obtained from these curves by simply taking the sum of the ordinates above and below the axis for any load factor desired.

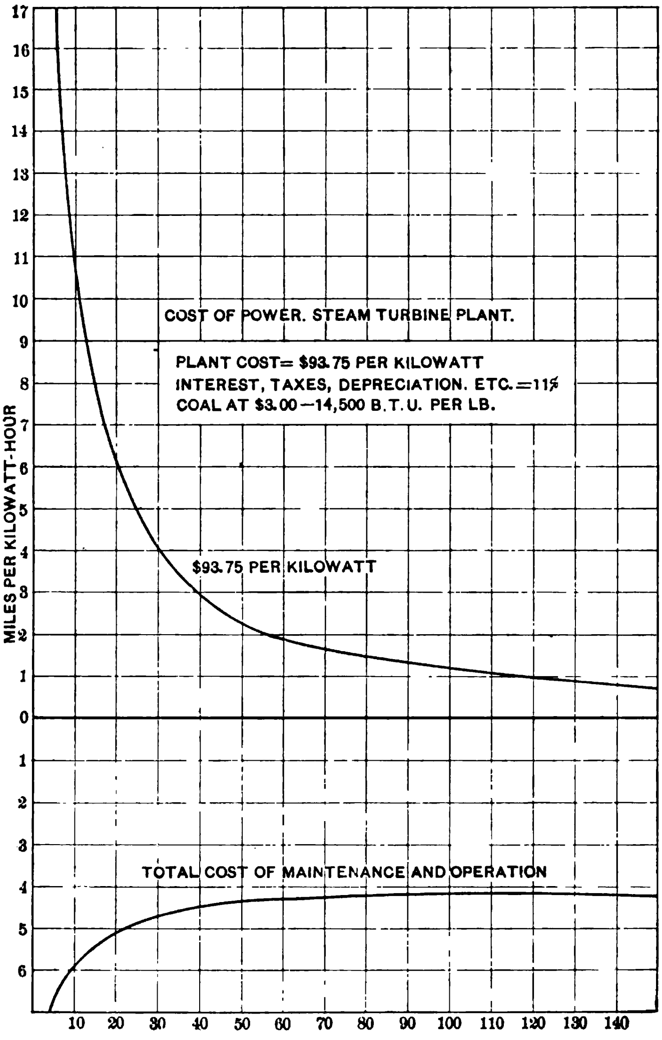


FIG. 1—Diagram of factors entering into the cost of power.

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ELECTRIC MINE HOISTS

BY D. B. RUSHMORE AND K. A. PAULY

Of primary importance in mine installations is the hoist, which has a very direct bearing on the successful operation of a mine. Conditions vary greatly with different mines, and especially in different localities. Such factors as depth, incline, the number of levels, permissible or desirable speeds, conditions of ore, etc., are always more or less special in each case. Veins of ore are never exactly duplicated, and the nature of the ground through which shafts are sunk may considerably modify permissible values. As mining laws are made by the different states they necessarily vary somewhat, and, even when not fully observed, they introduce factors which qualify the conditions of hoisting men and ore. The amount of timbering required is often of importance as relating to hoisting conditions. Methods of loading ore affect the time required, as also does the question of the use of cars or skips. Safety precautions must be very carefully considered, and the number of men in each mine, the number of compartments, and often the method of removing water from the mine must have careful consideration.

While a general discussion of the subject of hoisting is possible, most cases are entirely special and can be considered only in connection with the peculiar conditions pertaining to that particular installation.

The cost of installation of the hoisting plant may be an appreciable amount, while the cost of raising the ore may be but a small part of the total operating charge. In many cases, however, the output of the mine is limited by the capacity of the hoist, and the latter thus becomes of the first importance. Where shafts have not been sunk to their final depths the conditions of operation are of necessity constantly changing, and it is impossible to predetermine with exactness the precise conditions of operation which will be followed in practice.

Power for Mines. Power is used for drilling, tramming, pumping, ventilating, hoisting, compressing air, crushing rock and for many minor operations. In coal mines, the washeries and breakers, and in metal mines, the mills and concentrators, are ordinarily located in proximity to the shafts. The problem of lighting always exists.

Owing to the distances between different points of applications of power, not only the question of utilization but also that of transmission becomes of importance. Three forms of power, steam, compressed air and electricity, are to be considered. Originally, of course, the power must come from coal or water power.

Choice of System. The choice of the best system of hoisting in any particular case is the result of considering carefully many different factors. Most important among these is the cost of operation and installation. In this regard the location of the power house to ensure the best and cheapest supply of fuel and water is of primary importance. It is highly desirable to group a large number of mines, so that they may be supplied from one power station. As a rule, mining shafts are not well-situated as regards the supply of coal and water, so that it is usually necessary to transmit power for some distance, and this is best done by electricity. The problem then becomes one of the utilization of power, or the generation of electricity by means of steam turbines or gas engines. In metal mining, fuel is usually expensive and often but little water is available at the mines, so steam hoisting engines are generally run non-condensing. Where the reverse is the case, it is in most cases cheaper to transmit electricity to the mines than to pump condensing water there.

Efficiency of Steam Plants. Steam hoisting plants are known to be very inefficient, but the exact figures are usually difficult to obtain. With non-condensing engines and an extremely intermittent load on both engines and boilers, the economy necessarily is very poor. Steam engines must be designed for starting conditions, where they take steam under full stroke, and this necessitates their running with an early cut-off when hoisting. With a number of plants close together, there is no way of returning power to the line or of smoothing the peaks of the load. It is impossible, when a steam engine is used, to store power in retardation. There is also a limit in the depth at which steam engines can be satisfactorily placed, and their installation in mines is thus very undesirable.

Advantages of the Electric System. In many cases the electric system of hoisting has advantages which give it decided preference. The power house may have the most favorable location —power may be taken from some existing transmission system, or a water power may be developed for the purpose. Power may be centrally generated at the highest efficiency, and distributed over a large area. Electricity is most easily applied to all work on both the surface and the interior of mines. One of its greatest advantages in practice is the ease of making extensions to the development. With one station and many individual loads, an overlapping of peaks occurs, and a consequent reduction in boiler and generating capacity is effected. The cost of installation and operation is much reduced, a much improved load factor results and fewer operators are required.

For underground pumping and tramming, and where the hoists are located in the mine, electricity has every advantage. For use with electric hoists, safety devices have been developed which prevent over-winding and which also limit the acceleration. Power can be returned to the system in braking and in lowering unbalanced, and a much higher fuel economy can be obtained.

The use of hoists operated by compressed air has long been considered and at present some installations are being made. With the usual features of such equipment it is necessary to cool the air during compression and to re-heat it before use. In general, serious questions would arise concerning the efficiency of any system using compressed air for hoisting. The efficiency of an electric hoisting system is not open to question, and can be figured with exactness. There is no reason why advocates of compressed air systems should not be required to give the same guarantees and to state positively just what efficiency they are sure of obtaining.

Motor Characteristics

Large electric mine hoists are almost universally driven either by shunt-wound direct-current motors or polyphase induction motors, the characteristics of which especially adapt them to meet the peculiar conditions imposed. While in many of their characteristics these two types of motor are similar, they differ widely in others, which are of more or less importance depending upon special conditions of individual cases.

Fig. 1 gives the efficiencies, currents and speeds of the direct-current shunt motor at various loads for constant impressed voltage, and Fig. 2 gives similar curves for the induction motor, to which is added the power-factor curve. By reference to these curves it will be seen that the free-running speed of each motor is limited, and that the variations in speed with changes in load are small; that each becomes a generator when driven above speed, and may therefore be used as a brake when lowering unbalanced loads, returning power to the supply system; that the efficiencies of both when operating either as motor or generator are virtually the same for corresponding loads.

The speed of the shunt motor for a given load may be varied between standstill and full speed either by changing the potential of the supply system, or by inserting resistance in series with its armature. However, because of the inefficiency of this latter method of control, it is seldom, if ever, used in connection with large hoist motors. The only practical method of obtaining a similar variation in the speed of an induction motor is by changing the amount of resistance connected in its armature circuit. Fig. 3 shows the efficiencies of the shunt motor at various speeds when exerting full-load torque, the variations in speed being obtained by voltage control, and the efficiencies of the induction motor being under similar conditions, except that in this case the variations in speed are obtained by armature rheostatic control. By reference to the curves it will be seen that for a given torque, the efficiency curve of the shunt motor at reduced speeds resembles that for the constant speed motor at reduced loads, while the efficiency curve of the induction motor is a straight line between full-load efficiency and speed, and zero efficiency and speed. From this it follows that, for a given value of torque, the input to the shunt motor at reduced speeds, except for very low speeds, is approximately proportional to the speed, while the input to the induction motor is constant and independent of the speed. It will also be noted that the shunt motor may be driven as a generator at reduced speeds, while the induction motor can be made to generate only when driven above synchronous speed. Where the conditions are such that it is desirable to drive the hoist at reduced speeds for any considerable lengths of time, the efficiency of the induction motor drive may be improved by using a motor designed for two speeds,

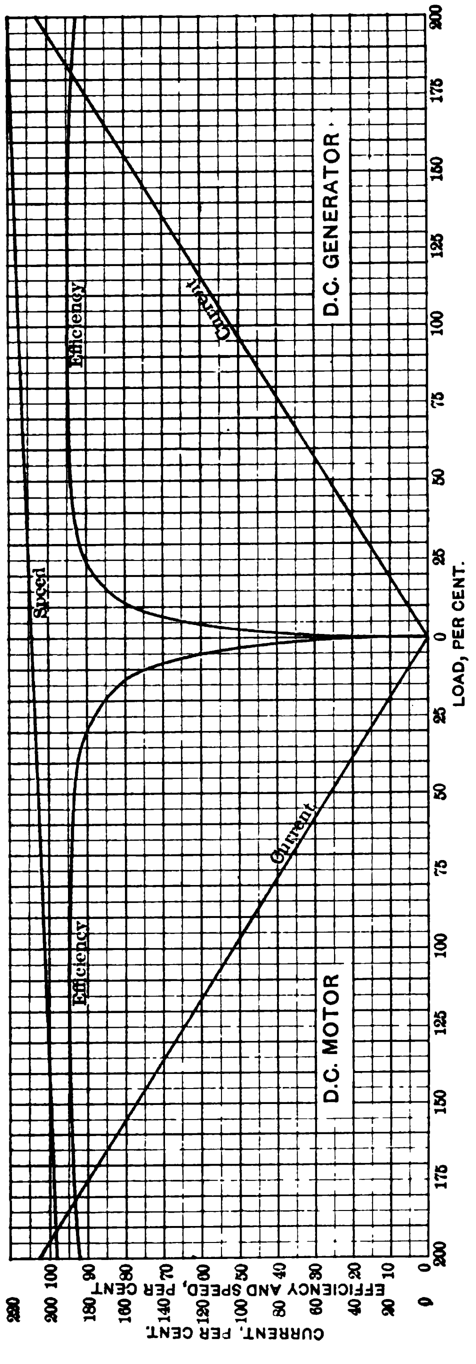
D.C. GENERATOR
D.C. MOTOR
Speed
Efficiency
Current
Speed
Efficiency
Current
200
175
150
125
100
75
50
25
0
25
50
75
100
125
150
175
200
LOAD, PER CENT.
0
10
20
30
40
50
60
70
80
90
100
EFFICIENCY AND SPEED, PER CENT
0
20
40
60
80
100
120
140
160
180
200
220
CURRENT, PER CENT.

FIG. 1

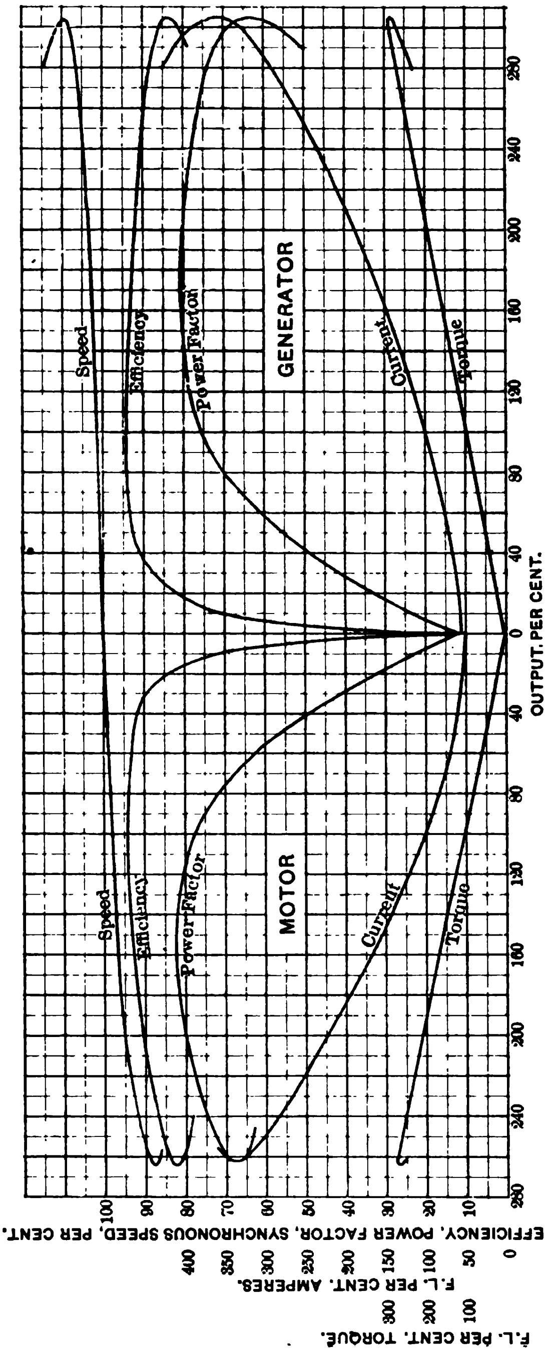
GENERATOR
MOTOR
Speed
Efficiency
Power Factor
Current
Torque
Speed
Efficiency
Power Factor
Current
Torque
OUTPUT, PER CENT.
280
240
200
160
120
80
40
0
40
80
120
160
200
240
280
EFFICIENCY, POWER FACTOR, SYNCHRONOUS SPEED, PER CENT.
100
90
80
70
60
50
40
30
20
10
F.L. PER CENT. AMPERES.
400
350
300
250
200
150
100
50
0
F.L. PER CENT. TORQUE.
300
200
100

FIG. 2

or by using a concatenated set, but the advantages gained are seldom sufficient to offset the increased first cost and the necessary complication of the control.

The number of poles, and therefore the diameter of an induction motor, is determined by its speed and the frequency of the supply system, the number of poles varying inversely as the speed for a given frequency, while the frequency of the e.m.f. generated in the armature of a direct-current motor is independent of the supply system. While this is of little importance in the designing of motors of moderate speed for gearing, it permits of a better proportioning of the length and diameter of shunt motors of very slow speed than is possible in the case of similar induction motors for direct connection, especially where the frequency of the supply system is 60 cycles.

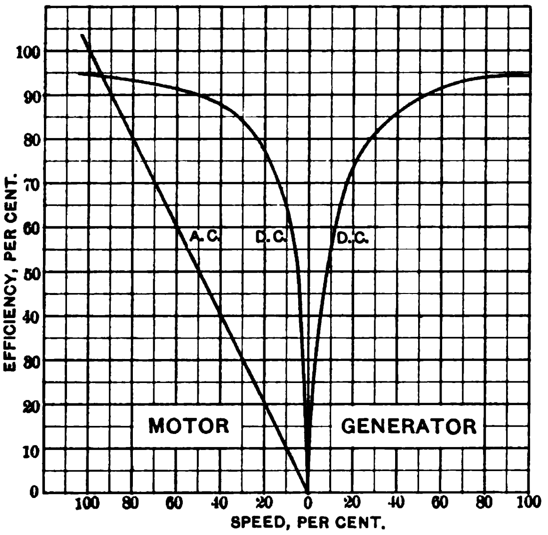

FIG. 3

As pointed out, the efficient speed control of the shunt motor is only obtained by varying the voltage of the supply system, the usual method being to provide a generator for each motor and varying the generated potential. As mine shafts are usually scattered over a considerable area, and the conditions in close proximity to the shafts are not such as to permit of the economical generation of electric power, the central electric station is usually placed at a considerable distance from the hoists, the power is generated and transmitted to the mines as alternating current and is then transformed at each shaft into direct current by motor-generator sets. The losses caused therein must be charged against the shunt motor when comparing its efficiency with that of the induction motor, which may be connected either directly or through highly efficient static transformers with the alternating-current distributing system. The torque and current for the two types of motor are approximately proportional within their operating limits.

Hoist Load Diagrams

Before discussing the various systems of electric hoisting it will be well to consider the nature of a mine-hoist load. Mine hoists may be divided into six types, depending upon whether the rope is wound on a reel, a cylindrical drum, conical drum, cylindro-conical drum, Whiting drums, or carried over a Koepe disk, the choice of any particular type depending largely upon the depth of shaft, the maximum permissible hoisting speed, the location of the hoist with respect to the shaft, the number of levels which are being worked simultaneously, and whether or not the shaft conditions permit the use of a tail rope.

The hoists are generally operated in balance, that is, the weight of the skip (or cage and car as the case may be) carrying the ore, is balanced by a similar empty skip which is lowered in a second compartment simultaneously with the hoisting of the loaded skip in the first, the loaded skip being dumped at the top and the empty one loaded at the bottom, and the cycle then repeated. To permit of adjustment of the length of the ropes for hoisting from different levels, it is customary to use two reels or drums mounted on the same shaft, one being keyed to the shaft and the other being driven by it through some form of clutch. The length of rope on the Koepe disk hoist or the Whiting hoist cannot conveniently be adjusted for different levels except within very small limits.

For the purpose of comparing the load diagrams of the different types, each hoist is assumed to lift 8000 lb. of ore in a skip weighing 5000 lb., from a vertical depth of 2500 ft. at an average speed of 2000 ft. per min., allowing 20 sec. for acceleration and 15 sec. for retardation. The rope for the reel hoist is assumed to be 5 inches x ½ inch, weighing 4½ lb. per ft. and that for the others 1⅜ inches round steel rope weighing 3 lb. per ft.

Reel Hoist. As its name indicates, the reel hoist consists of two large reels on which the rope supporting the skips is wound in a spiral, the distance between the flanges of the reels being approximately equal to the width of the flat rope used. The reel hoist is generally used where it is necessary to place the hoist very close to the shaft. As the minimum diameter of the reel, usually from 5 to 8 ft., is limited, and as its maximum diameter is determined by the thickness and length of the rope, the depth from which hoisting may be done at a given average speed by reel hoists is governed by the maximum permissible hoisting speed.

Let us assume that the loaded skip is at the bottom of the shaft and that the empty skip is at the top. Then the length L_a of the ascending rope with the skip at any point in the shaft may be obtained from the equation

$$L_a = D - 2\,\pi\,a\,r_1 - \pi\,a^2\,b$$

and its moment, M, about the drum shaft by

$$M_1 = (D - 2\,a\,\pi\,r_1 - \pi\,a^2\,b)\,r\,n\cos\phi$$

in which D = depth of shaft; b = thickness of the rope; n = the weight of the rope per foot; r_1 = the radius of the rope on the reel when the skip is at the bottom of the shaft; a = the number of turns of the reel in raising the skip from the bottom of the shaft to the point in question; $r = r_1 + a\,b$ = the radius of the rope on the reel after a turns and ϕ = the angle which the shaft makes with the vertical.

The moment of the ascending load is obtained from the equation:

$$M_2 = (W_1 + W_2)\,r\cos\phi$$

where W_1 = the weight of the skip (or cage and car as the case may be) and W_2 = the weight of the ore.

Plotting M_1 and M_2 against revolutions of the reel, we obtain curves M_1 and M_2 in Fig. 4.

The moments M_1' of the descending rope may be plotted from the values obtained for the ascending rope, by simply assuming the center of coördinates in Fig. 4 transferred from the left to the right side of the curves, turn No. 10 of the descending load corresponding to turn No. 81 of the ascending load, etc.

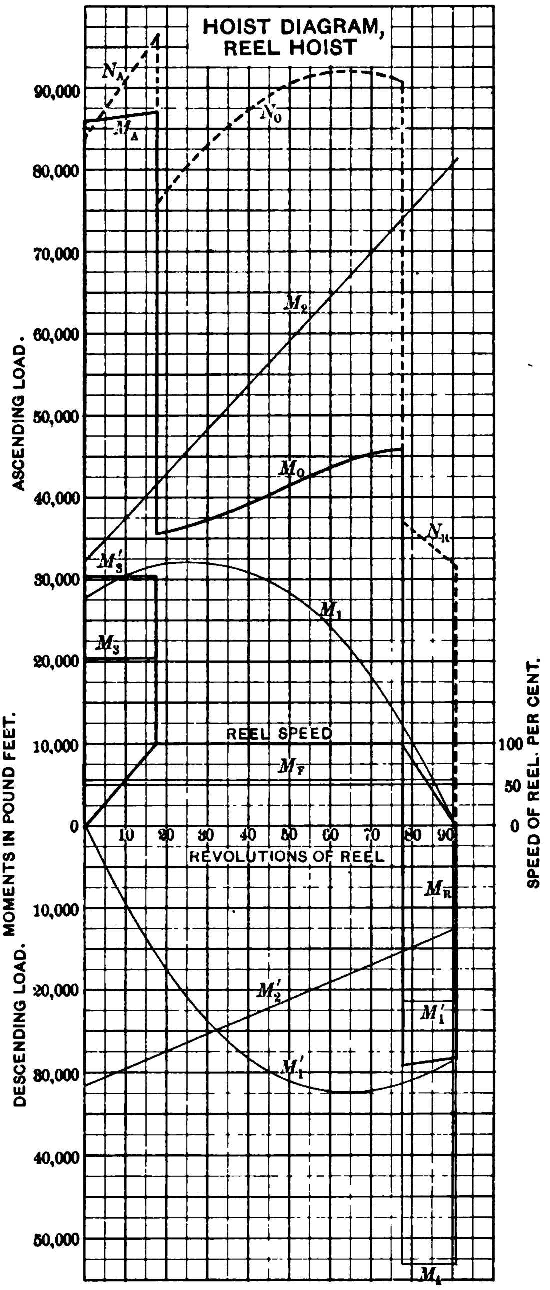
HOIST DIAGRAM, REEL HOIST
ASCENDING LOAD.
DESCENDING LOAD. MOMENTS IN POUND FEET.
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
10,000
20,000
30,000
40,000
50,000
N_A
M_A
N_0
M_2
M_0
N_R
M'_3
M_1
M_3
REEL SPEED
M_F
10
20
30
40
50
60
70
80
90
REVOLUTIONS OF REEL
M_R
M'_2
M'_1
M'_1
M_4
100
50
0
SPEED OF REEL. PER CENT.

FIG. 4

Similarly, the moment M_2' of the descending load may be obtained by substituting W_1' for W_1+W_2 in the equation for M_2, and plotting as directed for the descending rope.

Moments M_1' and M_2' are plotted below the reference line, since their tendency to rotate the reel is opposed to that of M_1 and M_2.

Denoting the moment of the total friction and windage by M_f the resultant moment M_0 of the ascending ore skip, rope and friction and the descending skip and rope is expressed by $M_0 = M_1+M_2-M_1'-M_2'+M_f$, which is the moment of the force, or the torque which must be applied to the reel to raise the ore.

The moment M_f of the friction is extremely difficult to obtain, and varies considerably with local conditions, but it is usually assumed to be approximately 15 per cent of the average value of $M_1+M_2-M_1'-M_2'$.

During the period of acceleration, a force additional to that required to raise the load and overcome friction, must be applied to the reel for accelerating the reels, ropes, etc. Assuming a uniform rate of acceleration, the moment M_3 of the force necessary for accelerating the ascending load, rope and one reel and clutch, may be determined from the equation

$$M_3 = \frac{\Sigma\, W\, S}{g\, t_a}\, p$$

where $\Sigma\, W$ = the sum of the weights of the skip, ore, rope, one reel and clutch, and sheave reduced to a common radius of gyration p; S = the speed at the end of the radius of gyration in feet per second at the end of acceleration; $g = 32.2$, and t_a the time of acceleration in seconds.

Similarly, the moment M_3' of the force required for accelerating the descending skip, rope, etc., may be found from the equation

$$M_3' = \frac{\Sigma\, W'\, S}{g\, t_a}\, p$$

where $\Sigma\, W'$ = the sum of the weights of the descending skip, rope, reel, and sheave reduced to the radius of gyration p.

$$S = 2\,\pi\, p\, R$$

Where R = the revolutions of the reel per second at full speed.

When the time allowed for making one complete trip is given, R may be found from the following equation

$$R = \frac{-r+\sqrt{r_1^2+\frac{2D}{\pi}}}{b} \times \frac{1}{T-.5\,(t_a+t_r)}$$

Where T = total time of lift in seconds (not including time for loading or dumping).
t_a = time for acceleration in seconds.
t_r = time for retardation in seconds.

At the end of the cycle all of the energy stored in the revolving parts of the hoist and its load is returned as the load is brought to rest. The moments M_4 and M_4' of the retarding forces may be found from the expressions for M_3 and M_3', respectively, substituting for ΣW and $\Sigma W'$ the corresponding weights at the beginning of retardation.

Throughout the cycle there is a gradual increase in the speed of the ascending ore skip and unwound rope, and a similar decrease in the speed of the descending skip and unwound rope, but the accelerating and retarding forces are small and their moments may be neglected.

The resultant moments M_A and M_R during the periods of acceleration and retardation respectively are expressed by the equations

$$M_A = M_1+M_2+M_3+M_3'+M_F-M_1'-M_2'$$

$$M_R = M_1+M_2+M_F-M_1'-M_2'-M_4-M_O'.$$

M_A, $M_O\,M_R$ of Fig. 4 is the resultant moment diagram for balanced hoisting under the conditions assumed.

While hoists are generally operated in balance, it is frequently necessary to run them unbalanced for short periods while repairs are being made. The moment diagram $M_A\,M_O\,M_R$ for unbalanced hoisting is obtained from the equations

$$M_A = \frac{M_F}{2}+M_1+M_2+M_3$$

$$M_O = \frac{M_F}{2}+M_1+M_2$$

$$M_R = \frac{M_F}{2}+M_1+M_2-M_4 \cdot$$

The speed of the ascending or descending skips in feet per minute, at any point, may be obtained from the equation

$$V = 120\,\pi\, r\, R$$

Cylindrical Drum Hoists. The cylindrical drum hoist is the type almost universally used for comparatively shallow shafts, and very frequently for the deeper ones. It consists of two cylindrical drums, upon which the rope is wound in one or more layers, the diameters of the drums varying from 5 or 6 feet to 25 feet.

The general equations for determining the several moments which make up the reel moment diagram, are made applicable to the cylindrical drum hoist by simply making b equal to zero.

For the cylindrical drum

$$R = \frac{O}{2\,\pi\, r} \times \frac{1}{T - .5\,(t_a + t_r)}$$

The moment diagrams for the cylindrical drum hoist are shown in Fig. 5. The notches in the diagram are due to the increase in diameter of the drum with each layer of rope.

By reference to the figure, it will be seen that M_0, the resultant moment of the ore skips and ropes, is very large at the first part of the cycle and decreases very rapidly toward the end of the cycle, this being due to the influences of M_1 and $M_1{}'$, the moments of the rope. This difference in M_0 at the beginning and at the end of the cycle, increases with the depth of the shaft, the weight of ore per trip remaining constant; or for the same depth of shaft with reductions in the weight of ore hoisted, M_0 often becoming partially zero or negative toward the end of the cycle. The harmful effect of this extreme variation in M_0 is two-fold. First, the engine must be larger than otherwise necessary in order to start the hoist, and second, it operates at an inefficient cut-off at the end of the cycle. To reduce this variation in M_0 at the beginning and at the end of the cycle, the conical drum has been introduced.

Conical Drum Hoists. In the conical drum hoist, the ropes are wound in single layers on two large cones, the rope being wound from the small to the large end of the cone. The method of determining the moment diagrams is the same as for the reel hoist, making b equal to the increase in the radius of the cone for one turn of the rope. By reference to Fig. 6, which shows the moment diagrams for the conical drum hoist, it will be noted that

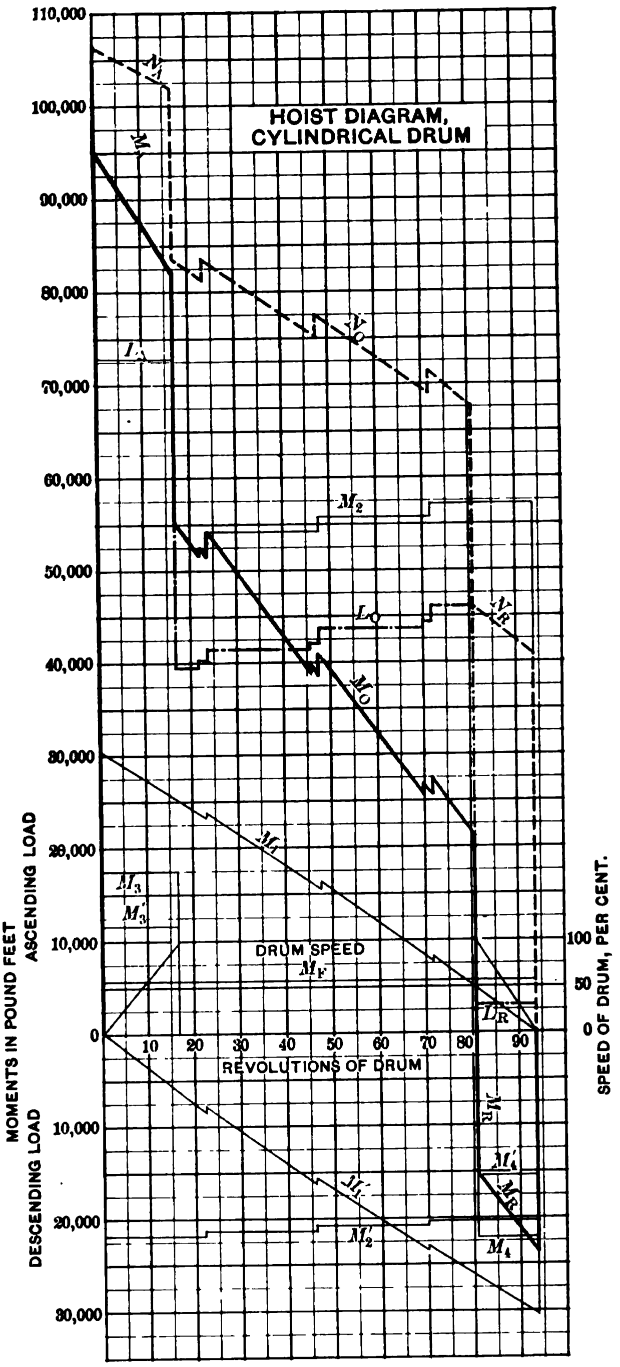
HOIST DIAGRAM,
CYLINDRICAL DRUM
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
10,000
20,000
30,000
MOMENTS IN POUND FEET
ASCENDING LOAD
DESCENDING LOAD
10
20
30
40
50
60
70
80
90
REVOLUTIONS OF DRUM
DRUM SPEED
100
50
0
SPEED OF DRUM, PER CENT.
N_A
M_A
L_A
N_O
M_2
L_O
N_R
M_O
M_1
M_3
M_3'
M_F
L_R
M_R
M_4'
M_R
M_1'
M_2'
M_4

Fig. 5

the unbalancing due to the rope in the shaft, has been entirely compensated for; in fact M_0 actually increases toward the end of the cycle. By varying the angle of the cone, M_0 may be made to increase or decrease toward the end of the cycle, or remain practically constant.

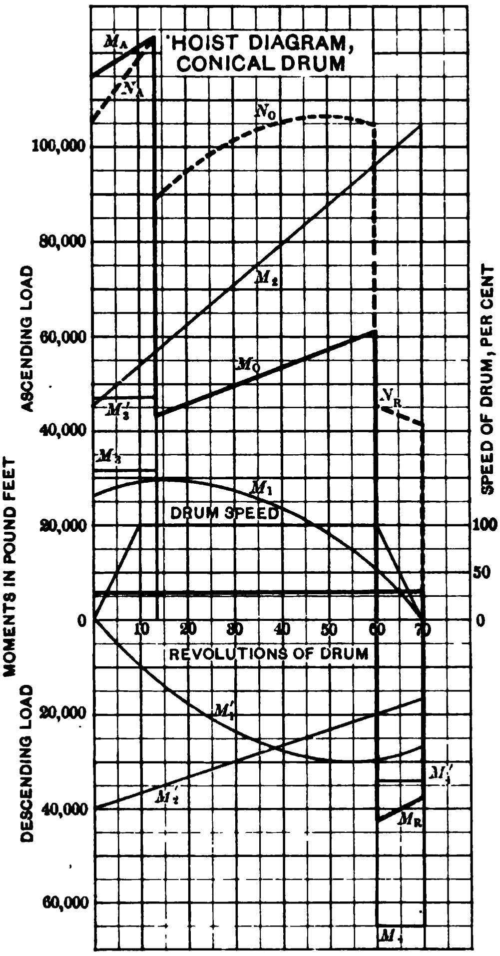

Fig. 6

Cylindro-conical Drum Hoist. The use of the conical drum as was the case with the reel, is limited to comparatively shallow shafts. For depths below which the use of the conical drum is impracticable, it is necessary to compromise, using a drum which as its name indicates, is a combination of cone and cylinder.

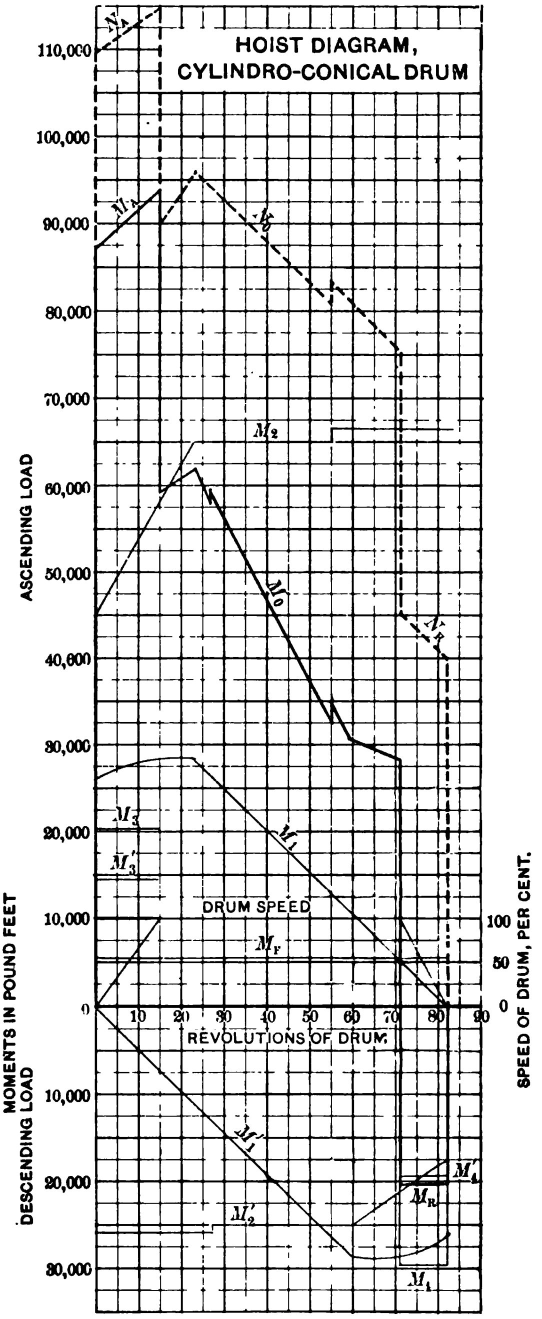
HOIST DIAGRAM,
CYLINDRO-CONICAL DRUM
MOMENTS IN POUND FEET
ASCENDING LOAD
DESCENDING LOAD
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
10,000
20,000
30,000
N_A
M_A
N_0
M_2
M_0
N_R
M_3
M'_3
M_1
DRUM SPEED
M_F
10
20
30
40
50
60
70
80
90
REVOLUTIONS OF DRUM
M'_1
M'_2
M'_4
M_R
M_4
SPEED OF DRUM, PER CENT.
100
50
0

FIG. 7

The rope is wound from the small end of the cone over the conical part of the drum in a single layer, then onto the cylindrical portion in one or more layers, depending upon the length of the rope. The load diagram is readily obtained by dividing the cycle into two parts, and treating the conical and cylindrical portions of the drum separately, determining the moments over the conical part as directed for the conical drum hoist, and over the cylindrical portion as directed for the cylindrical drum hoist. The moment diagram, Fig. 7 shows very clearly the effect of the conical portion of the drum, although the improvement in shape of the moment curve, over that for the cylindrical drum, is not so marked as it is for greater depths of shaft.

Tail Rope. The skips or cages are sometimes connected by a tail rope which passes over a sheave at the bottom of the shaft, thus making the total weight of the ascending and descending ropes the same, independent of the location of the cages in the shaft. The effect of the addition of the tail rope is shown in Fig. 5, L_A, L_0 L_R being the moment diagram resulting from the addition of a tail rope to the cylindrical drum hoist, which otherwise remains unchanged.

Koepe Disk Hoist. A type of hoist very common throughout Europe, but which has never been installed in America, is that known as the Koepe disk hoist, which consists simply of a large grooved wheel over which the rope passes once, the friction between the disk and the rope being sufficient to move the cages or skips in the shaft. Hoists of this type are always operated in balance and a tail rope is used with them. They are not well adapted for hoisting from several levels, because of the fixed position of the cages or skips, which can be changed only with difficulty to correspond with different levels. The moment diagram of this type of hoist is similar to that of the cylindrical drum hoist with a tail rope, except that b_0 will be a horizontal line, the notches due to the different layers of rope on the drum not being present in the Koepe disk hoist diagram.

Whiting Hoist. In order to increase the arc of contact between the rope and the wheel, Mr. Whiting substituted two narrow drums for the Koepe disk, the drums being placed one directly in front of the other, and the rope being passed four or five times over both drums. For the purpose of taking up the stretch in the rope and making small adjustments of the cages, one side of the rope is carried back over a moveable sheave mounted on a carriage resting on rails, the adjustments being made by chang-

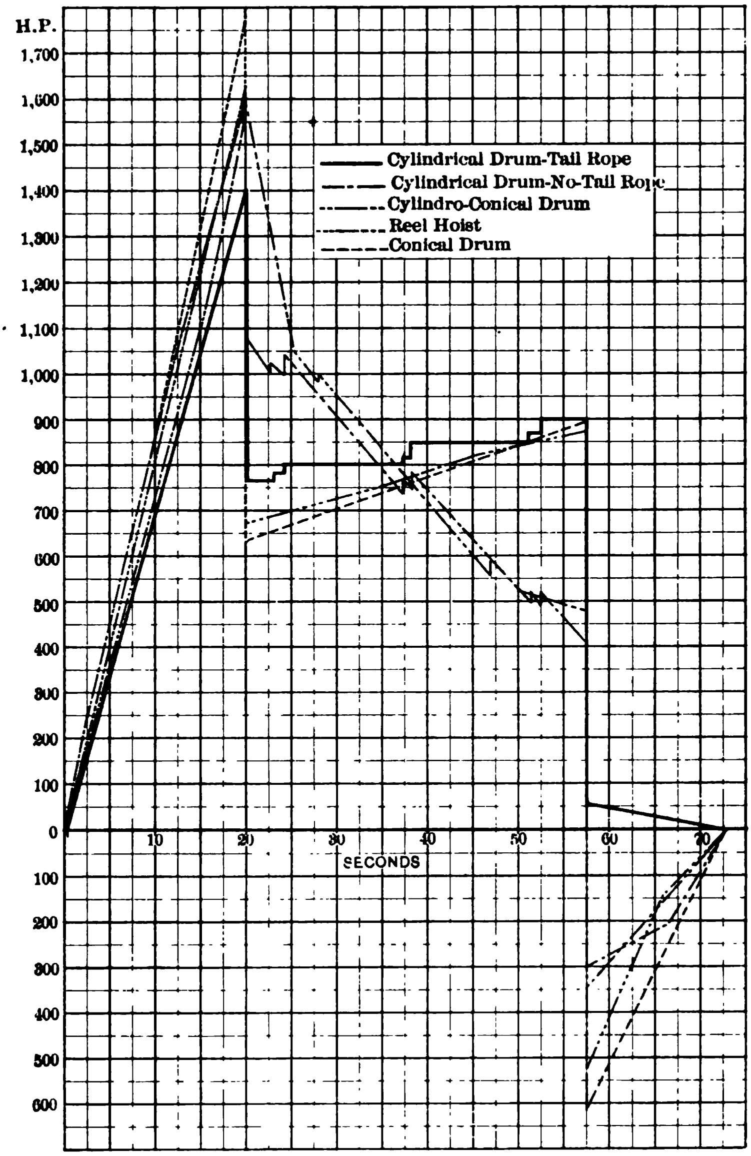
H.P.
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
100
200
300
400
500
600
10
20
30
40
50
60
70
SECONDS
Cylindrical Drum-Tail Rope
Cylindrical Drum-No-Tail Rope
Cylindro-Conical Drum
Reel Hoist
Conical Drum

Fig. 8

ing the position of the carriage. Whiting hoists are always operated in balance and seldom if ever without a tail rope. The moment diagram is exactly similar to that of the Koepe disk hoist.

The moment diagrams may be transformed into horse-power time diagrams by the use of the equation

$$\text{horse power} = \frac{2\,\pi\,M\,R}{550}$$

where M = the moment in pound feet and R = revolutions of the drum per second.

The horse-power diagrams corresponding to the moment diagrams of Figs. 4, 5. 6 and 7 are shown in Fig. 8, the curves for the balanced hoisting only being shown. Attention is called to the difference in the heights of the peaks during acceleration, the magnitude of these peaks having an important influence on the design of a motor for driving the hoist, its efficiency for the complete cycle, and the cost of power, if power is purchased.

SYSTEMS OF ELECTRIC HOISTING

The early application of electric power to mine hoisting was confined to small hoists, moving cars on inclines or hoisting light loads vertically from comparatively short depths. The complete success of these early installations led to the use of electric motors for winding from greater depths, until to-day ore is hoisted by electric power from some of the deepest mines in the world. The use of electric motors for driving the hoists, permits of the substitution of a large central electric generating station, which operates at a comparatively high load factor and which is placed where the conditions are more favorable for the economical development of power than they are at the mines, in place of isolated steam plants located at the shafts where condensing water is seldom available and where fuel is often expensive. The speed of the hoist motor when lowering unbalanced loads is automatically limited to approximately the hoisting speed. Safety devices in the nature of limit switches can readily be applied to prevent over-winding, and the acceleration of the hoist is made automatic; all of which tend to minimize the possibility of accident resulting from carelessness on the part of the operator. Not only is the speed limited when lowering unbalanced, but a large part of the energy, which with the steam-driven hoist is absorbed by the brakes, is returned to the electric supply system, thereby improving the economy of operation and reducing the wear on the mechanical brakes.

Many systems of electric hoisting have been proposed, each with the view of meeting some peculiar condition, or eliminating some real or apparent objection in the others, but virtually all the installations are confined to four systems, shown in Figs. 9, 12, 15 and 20. To assist in the comparison of the several systems, the authors have assumed a hoisting cycle, for both balanced and unbalanced operation, and have calculated the current and power taken by each system under the conditions assumed.

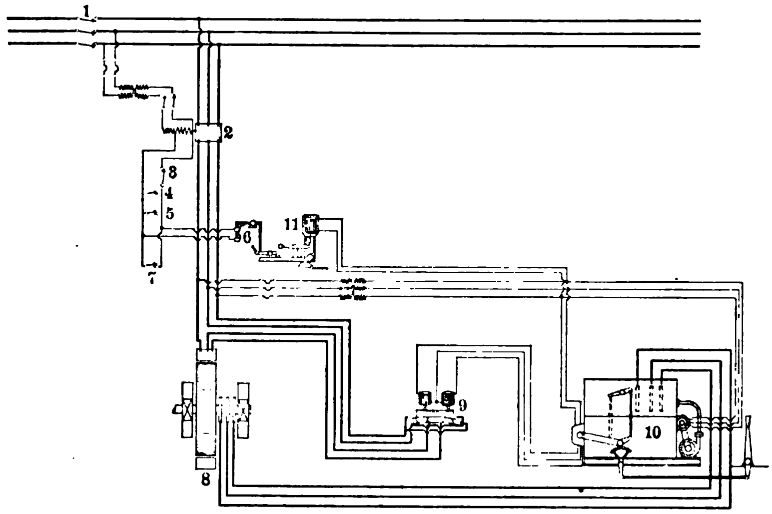

Fig. 9.—No. 1–2 Line switches. No. 3-4-5-6-7 safety switches for preventing overwinding and stopping the hoist, No. 8 hoist motor, No. 9 reversing switch, No. 10 liquid controller, No. 11, automatic brake.

The first and simplest system is shown in Fig. 9, and consists of a polyphase induction motor, direct connected or geared to the hoist drum. The speed of the motor is controlled by a variable resistance in its rotor circuit, which, because of the magnitude of the currents, involved, is usually some form of water rheostat. A common type of water rheostat consists of a tank, usually of boiler plate riveted together, and divided into two compartments; one the rheostat proper, and the other a cooling tank. The electrolyte is pumped from the cooling tank into the rhoestat proper, entering at the bottom of the rheostat and flowing out over the top of an adjustable weir, back into the cooling tank. The resistance in the rotor circuit is varied by changing the height of the electrolyte in the rheostat proper by means of the adjustable weir. The electrodes are usually thin iron plates hung on insulators, all phases being in the same compartment. At least one electrode per phase is of extra length, extending below the lowest level of the liquid, in order to prevent

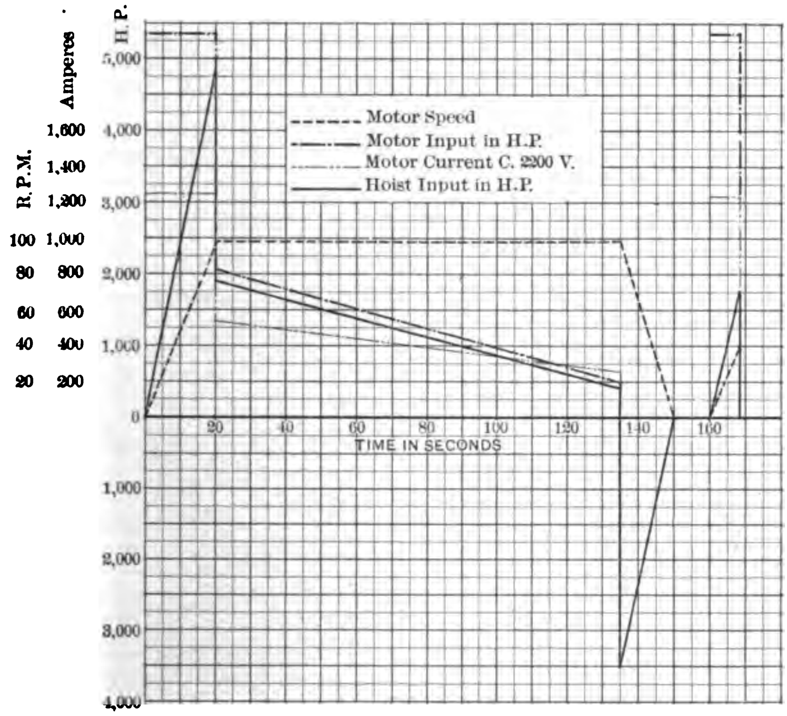

Fig. 10

the rotor circuit from being opened. The most common form of electrolyte is a simple salt solution. The control of the rheostat is by means of a lever located on the operating stand.

Figs. 10 and 11 give the current and power curves for one complete balanced and unbalanced cycle, respectively. Frequently the cage is moved a few feet only, to obtain a proper setting of the cage or skip. The power taken for such short movements is shown by the right hand curves of Fig. 10. In these curves, as well as in those which apply to the other systems,

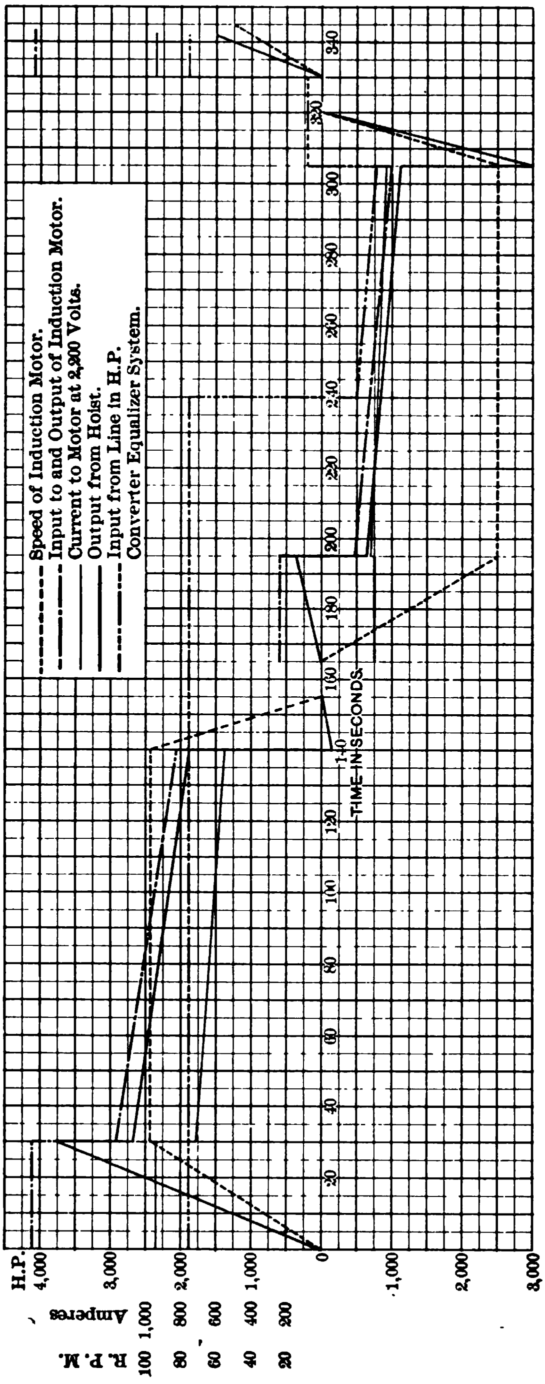
Speed of Induction Motor.
Input to and Output of Induction Motor.
Current to Motor at 2,200 Volts.
Output from Hoist.
Input from Line in H.P.
Converter Equalizer System.
H.P.
4,000
3,000
2,000
1,000
0
1,000
2,000
3,000
Amperes
1,000
800
600
400
200
R.P.M.
100
80
60
40
20
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
TIME IN SECONDS

Fig. 11

power delivered to the hoist is shown above the reference line and that returned by the hoist, below it.

By reference to the curves, it will be noted that the horse power and current taken by the motor are constant during the period of acceleration; that the efficiency for this period is very low, approximately 45 per cent; that no power is returned to the supply system during the period of retardation, and that the power consumption for small movements of the cage or skip is very large. On the other hand, the efficiency during the period when the hoist is running at full speed is high, approximately 90 per cent, and no power is consumed while the hoist is at rest.

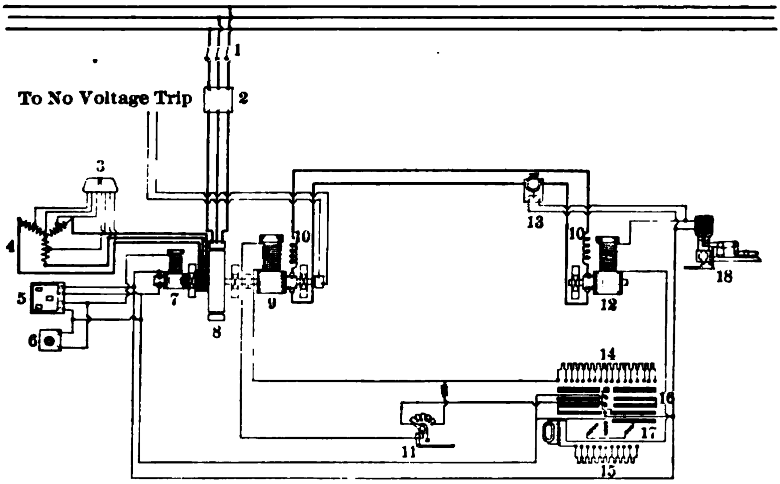

FIG. 12.—No. 1-2 line switches; No. 3-4 controller and resistance, induction motor; No. 5-6 Tirrill regulator and rheostat for exciter; No. 7-8-9 motor generator set; No. 10, commutating pole and compensating field winding; No. 11 safety device; No. 12 hoist motor; No. 13 circuit breaker; No. 14-15-16-17 rheostat and controller for generator and hoist motor; No. 18 automatic brake solenoid.

The efficiency over the complete cycle obviously decreases rapidly with a decrease in the time during which the hoist is driven at full speed. It follows from this that when hoisting is to be done from several levels, the efficiency at the maximum depth alone cannot be used as a basis for comparing the hoist driven by the induction motor with other systems. The efficiency of the cycle increases with an increased rate of acceleration, from which it follows that an induction motor for hoisting should be designed for a high maximum output to permit of a rapid acceleration.

The power returned to the system when lowering the empty skip unbalanced is shown by the right hand curves of Fig. 11. A comparison of the power taken by the motor in hoisting the loaded skip with that returned when it is lowered empty, shows that approximately 20 per cent of the power taken for hoisting is returned in lowering.

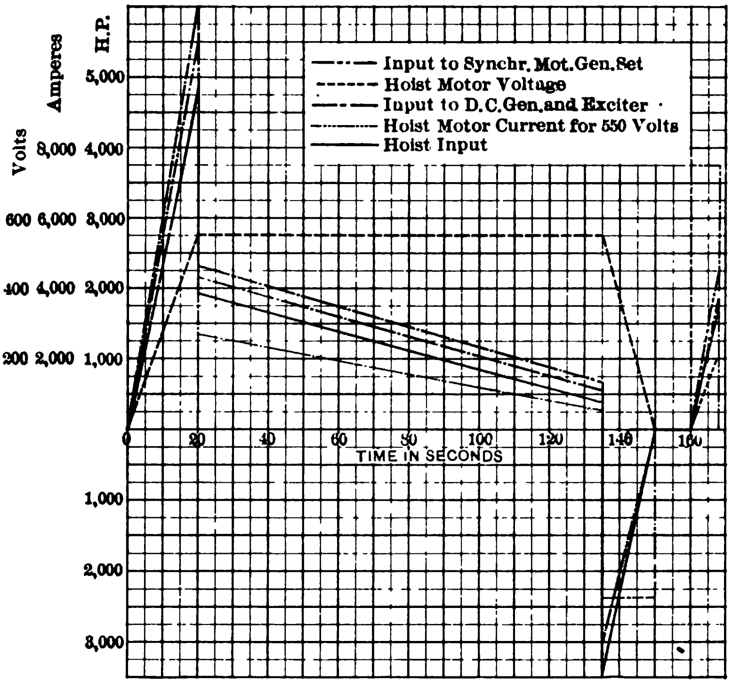

FIG. 13

The second system is that shown in Fig. 12. In this system the hoist is driven by a direct-current shunt-wound motor receiving power from the alternating-current supply system through a synchronous or induction-motor-generator set. The hoist motor is controlled by varying the voltage of the generator, which is separately excited, one generator being used for each motor.

The power and current curves for the balanced and unbalanced cycle, are shown in Figs. 13 and 14 respectively. These curves show that the power consumed during acceleration, is much

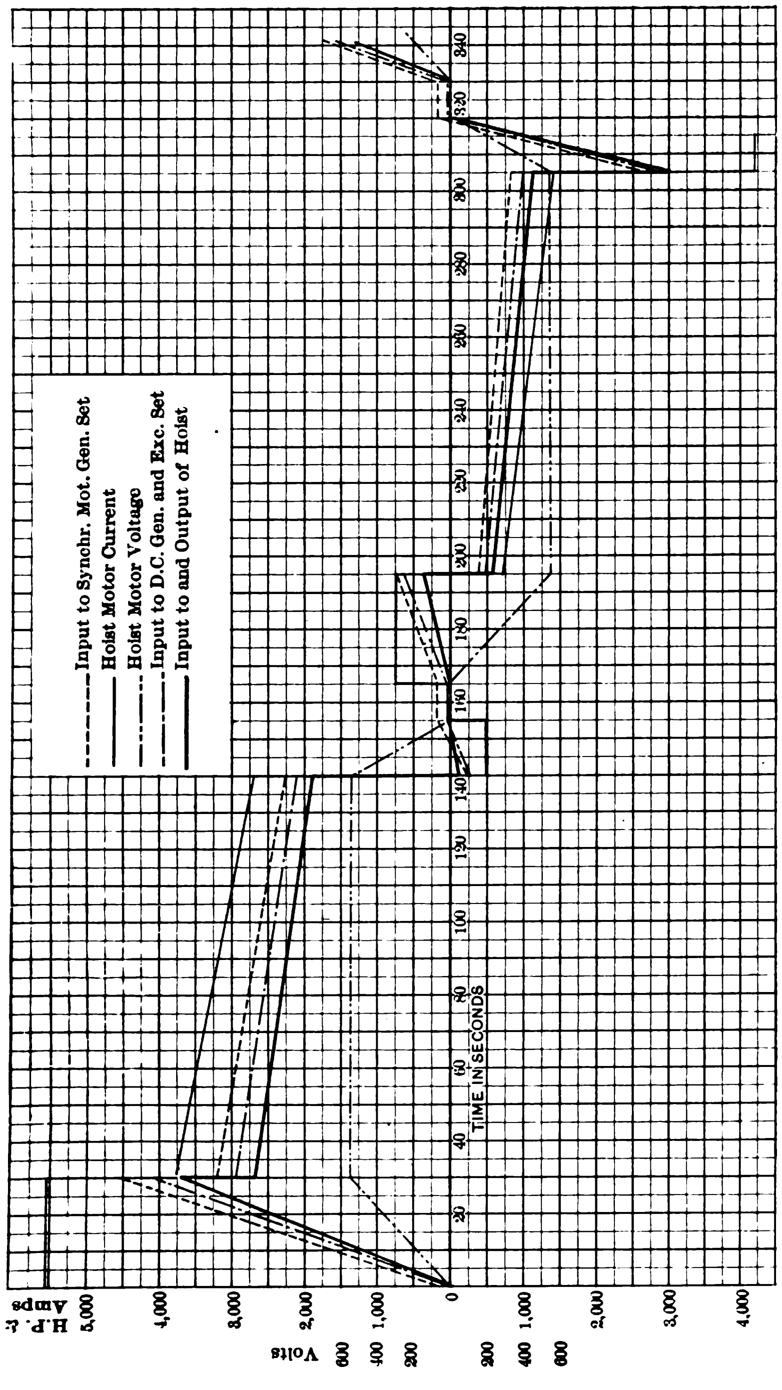
Input to Synchr. Mot. Gen. Set
Hoist Motor Current
Hoist Motor Voltage
Input to D.C. Gen. and Exc. Set
Input to and Output of Hoist
TIME IN SECONDS
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
H.P. & Amps
5,000
4,000
3,000
2,000
1,000
0
1,000
2,000
3,000
4,000
Volts
600
400
200
200
400
600

Fig. 14

smaller than for the induction hoist motor, the efficiency then being approximately 80 per cent, and that a considerable part of the energy stored in the revolving parts of the hoist is returned to the supply system as the hoist is brought to rest. On the other hand, the efficiency when the hoist motor is running at full speed, is lower than that for the induction hoist motor, being approximately 82 per cent, and the losses of the motor-generator set when running light, must be supplied during the time when the hoist is at rest. In view of the fact that a mine hoist is idle 50 per cent or more of the time under ordinary conditions, this is an item in the total power consumption which cannot be neglected. It follows from what has been stated, that the advantage of the direct-current hoist motor over the induction hoist motor in the efficiency through the complete cycle is greatest for short lifts, in which case the period of acceleration is a large percentage of the total cycle and the time during which the hoist is idle is a minimum.

By reference to the curves of Fig. 14 it will be seen that approximately 30 per cent of the power consumed in hoisting the ore unbalanced is returned to the system when the skip is lowered.

No definite rule can be laid down by which a choice can be made between the two systems, each having advantages and disadvantages peculiar to itself which have a more or less important bearing on the choice, depending upon the special conditions of the individual problem. The first system has the advantages of low first cost and simplicity, but is often at a disadvantage in respect to efficiency. On the other hand, the higher efficiency of the second system is frequently more than offset by its increased first cost and its greater cost of maintenance.

Both systems are open to the objection that the power drawn from the supply system fluctuates between very wide limits during each cycle, generally reaching a maximum during acceleration, becoming negative during retardation for the second system, zero, or practically so, at the end of the cycle, and negative when lowering unbalanced for both systems. The effect of this wide fluctuation in the load during each cycle, is to seriously impair the voltage regulation of the supply system unless its capacity is large as compared with the fluctuations, or unless the number of hoists driven from the same system is sufficient to produce a fairly uniform load, which is seldom the case for a mine power system. Also, if power is purchased, the price is usually made up of two components; one based on the total kilowatt hours consumed, and the other on the maximum demand.

It therefore becomes necessary in most cases to provide some means whereby power may be taken from the supply system and stored during the portion of the cycle when the demand for power is less than the average, and returned when the demand exceeds the average.

Fig. 15 shows such a system, the third, in which advantage is taken of the low first cost and efficiency of the flywheel as a means for storing and returning large quantities of power for short intervals. This system is similar to the second, except for the addition of a flywheel to the induction motor-generator set, and an automatic regulator for varying its speed. In its most common form, this regulator consists of a water rheostat connected in series with the induction motor armature. The resistance is varied by means of moveable electrodes suspended from an arm mounted on the shaft of an induction motor, which is connected in series, either directly or through series transformers, with the induction motor of the flywheel set. The regulator motor is so connected that its torque opposes the weight of the electrodes, which are partially counterbalanced to reduce the size

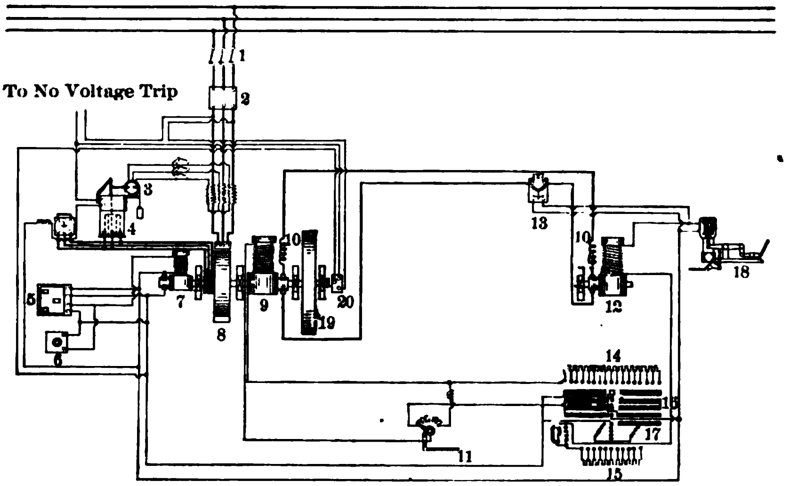

FIG. 15.—No. 1–2 line switches; No. 3–4 slip regulator; No. 5–6 Tirrill regulator and rheostat; No. 7–8–9–19 fly-wheel motor generator; No. 10 commutating pole and compensating field winding; No. 11 safety device; No. 12 hoist motor; No. 13 circuit breaker; No. 14–15–16–17 rheostat and controller of generator and hoist motor; No. 18 automatic brake solenoid; No. 20 speed limit device.

of the regulator motor to a minimum, and permit of an adjustment of the regulator for different values of line current. When the line current exceeds the value for which the regulator is adjusted, the torque of the motor overbalances the weight of the electrodes, lifting them and inserting resistance in the armature circuit of the induction motor. This causes it to slow down, and allows the flywheel to assist in driving the generator during the peak loads. The sensitiveness of this regulator varies with the line current, but within the range of ordinary operation the line current may readily be held within 5 per cent either side of the mean, provided the hoisting is done at a uniform rate and the regulator is adjusted for the average load. In actual practice the regulator must be set for the maximum condition, so that under ordinary conditions of hoisting, the current is limited rather than maintained constant.

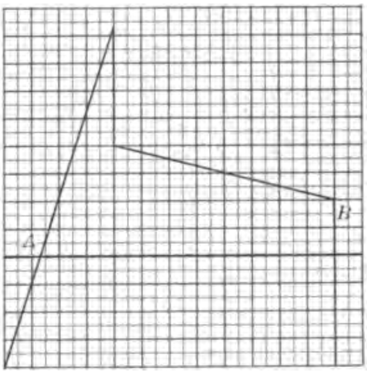

FIG. 16

The weight of the flywheel is determined from the hoist diagram by correcting it for the losses in the hoist motor and generator. Let Fig. 16 be such a diagram, and let *a*, *b* represent the average for the cycle. Then the energy represented by the portion of the diagram above the average line must be delivered by the flywheel during the peak load. The weight of the flywheel may be obtained from the equation

$$W = \frac{2gE}{Y_0^2 - Y_1^2}$$

where W = effective weight of wheel, Y_0 = the velocity of the wheel at a, Y_1 = the velocity of the wheel at b, and E = the energy in foot-pounds to be delivered by the wheel. It is the usual practice to make Y_0 approximately 300 ft. per second, in which cases the actual weight of the wheel is approximately equal to 1.33 W.

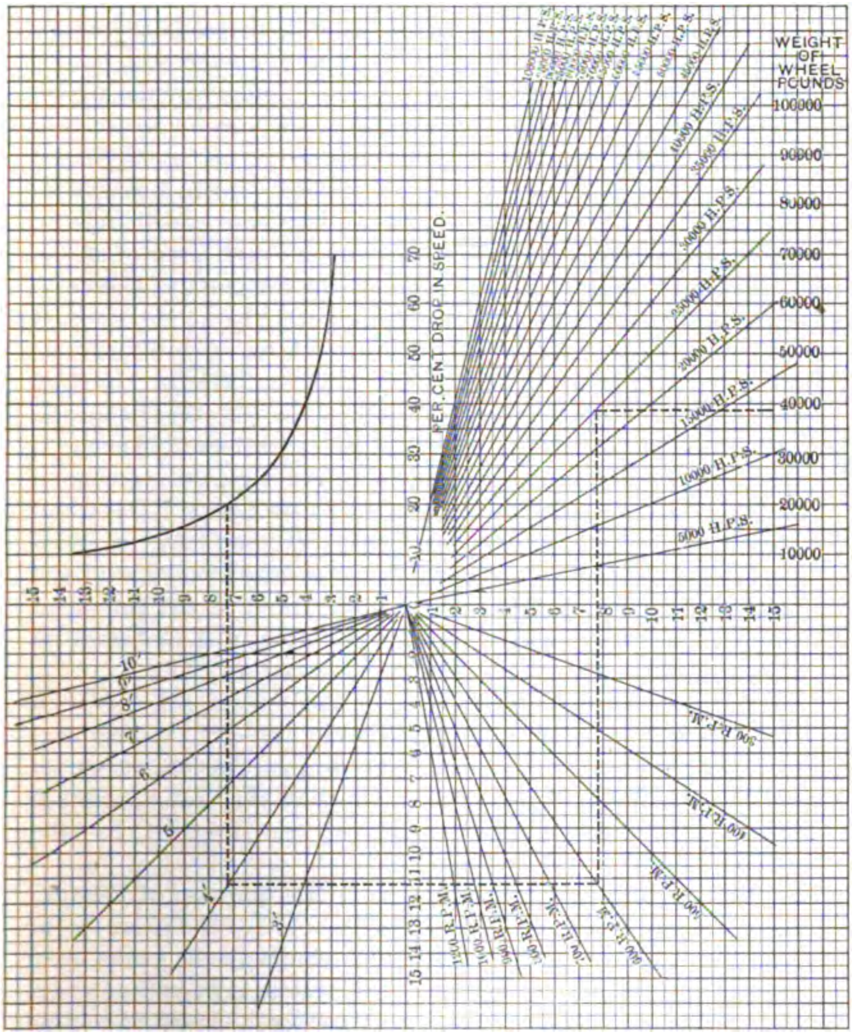

Fig. 17

A convenient method of obtaining the effective weight of a wheel is shown in Fig. 17. Having decided upon the radius of gyration in feet, and the speed in revolutions per minute, the weight of a wheel required to deliver any number of horse power seconds from 0 to 100,000 with any change of speed from 10 per cent to 70 per cent may be obtained by the use of this diagram. To find the weight of a wheel, begin with the curve in the upper right hand corner of the diagram, and follow the line corresponding to the per cent change in speed until it intersects the curve, and then to the left until it interesects the line corresponding to the radius of gyration of the wheel, and so on as indicated by the dotted line, which assumes a wheel having a radius of gyration of 4 feet, running at 600 rev. per min. and delivering 25,000 horse-power seconds with a 20 per cent drop in speed. The effective weight of the wheel is approximately 39,000 lb. From the shape of the curve in the upper right hand corner, it follows that the weight of the wheel increases very rapidly for drops in speed less than 15 per cent, and that little is gained by increasing the drop beyond 35 per cent. On the other hand, the cost of the motor and generator decreases, and the efficiency of the induction motor increases, and therefore the power consumed per cycle decreases as the drop in speed decreases. The usual practice is to allow approximately 15 per cent drop in speed for balanced operation, but as the flywheel must take care of the unbalanced cycle without reducing the speed of the generator so low as seriously to affect its commutation, it is necessary to vary this value considerably in special cases.

The power and current curves for this system are shown in Figs. 18 and 19. The drop in the power curve of the balanced cycle during the period of rest, is due to fact that the regulator is set for the maximum condition, which in this case is hoisting unbalanced, this setting being above that required for the balanced cycle.

The fourth system is used when, for the purpose of meeting some peculiar condition, it is advisable to drive the hoist by an induction motor and at the same time eliminate the peaks from the station load. The adoption of this system is warranted when the hoist is located underground at such a distance from the surface that it becomes necessary to transmit power to it by alternating current, and when the shaft is not large enough to allow the flywheel of the motor generator set, to be taken underground.

Fig. 20 shows this system, which it will be noted is the first system, to which has been added a converter equalizer, consisting of a rotary converter connected on the alternating-current side to the supply system, and on the direct-current side to a motor driving a large flywheel. The field of the direct-current motor is controlled by a regulator actuated by the line current. When the power taken by the hoist motor drops below the average, the field of the motor is automatically reduced, and the flywheel is speeded up, the power being taken from the supply system.

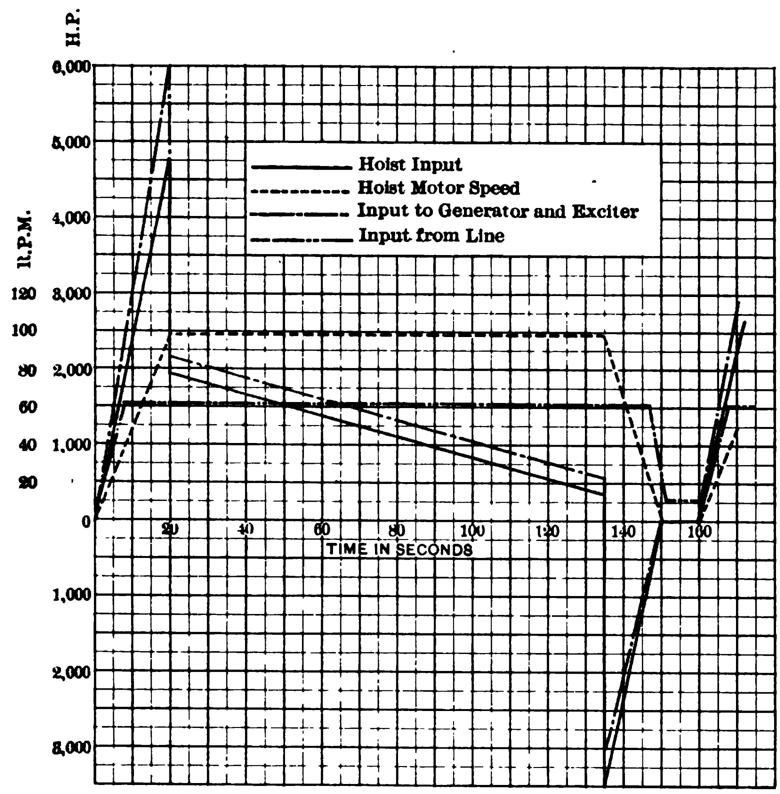

FIG. 18

When the hoist-motor load exceeds the average, the operation is reversed, the flywheel slowing down and returning power to the system.

Fig. 11 gives the current and power curves which are those of the first system to which has been added the input curve with converter equalizer. The efficiency of this system is generally slightly lower, and the weight of the flywheel is slightly greater

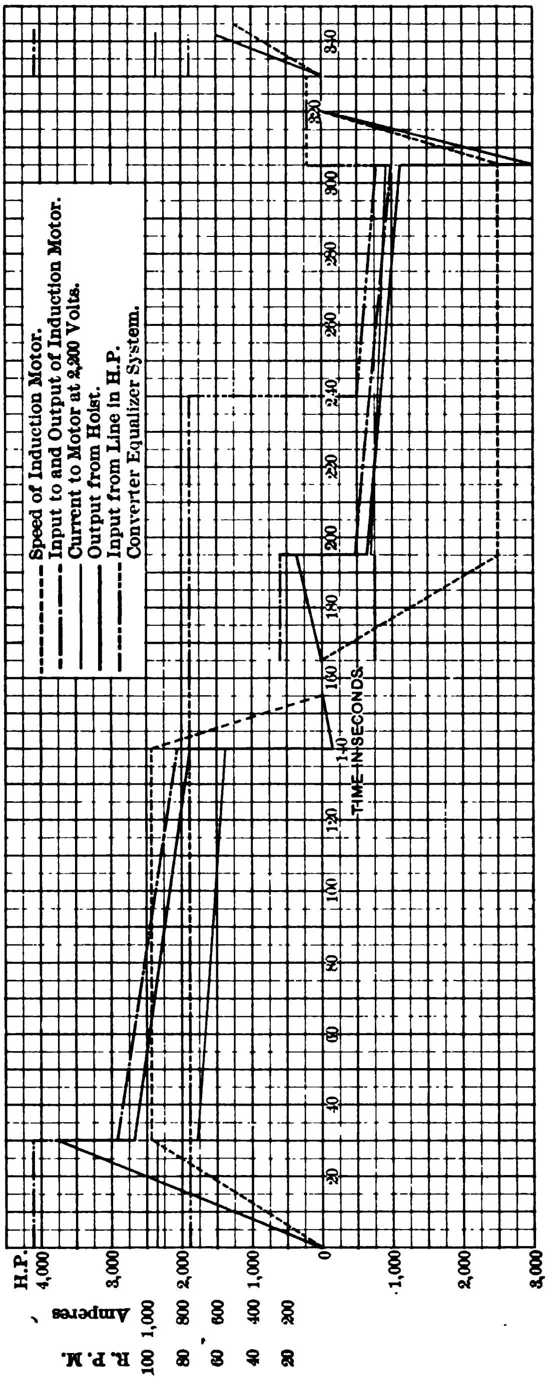
Speed of Induction Motor.
Input to and Output of Induction Motor.
Current to Motor at 2,200 Volts.
Output from Hoist.
Input from Line in H.P.
Converter Equalizer System.
H.P.
4,000
3,000
2,000
1,000
0
1,000
2,000
3,000
Amperes
1,000
800
600
400
200
R.P.M.
100
80
60
40
20
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
TIME IN SECONDS

FIG. 11

power delivered to the hoist is shown above the reference line and that returned by the hoist, below it.

By reference to the curves, it will be noted that the horse power and current taken by the motor are constant during the period of acceleration; that the efficiency for this period is very low, approximately 45 per cent; that no power is returned to the supply system during the period of retardation, and that the power consumption for small movements of the cage or skip is very large. On the other hand, the efficiency during the period when the hoist is running at full speed is high, approximately 90 per cent, and no power is consumed while the hoist is at rest.

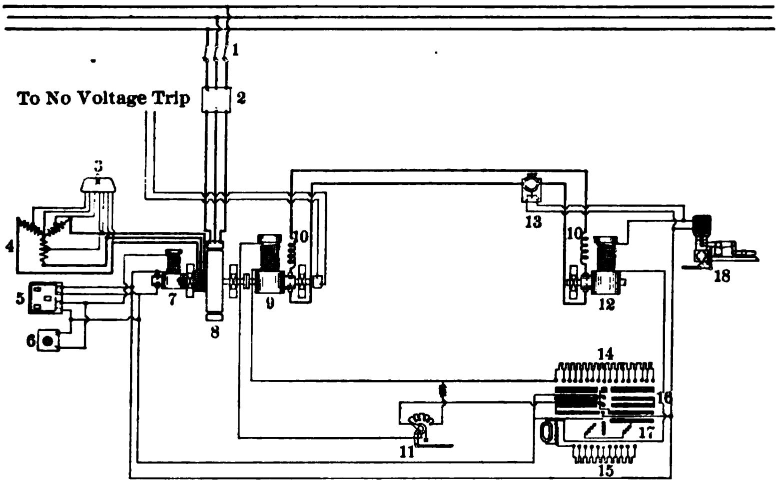

FIG. 12.—No. 1-2 line switches; No. 3-4 controller and resistance, induction motor; No. 5-6 Tirrill regulator and rheostat for exciter; No. 7-8-9 motor generator set; No. 10, commutating pole and compensating field winding; No. 11 safety device; No. 12 hoist motor; No. 13 circuit breaker; No. 14-15-16-17 rheostat and controller for generator and hoist motor; No. 18 automatic brake solenoid.

The efficiency over the complete cycle obviously decreases rapidly with a decrease in the time during which the hoist is driven at full speed. It follows from this that when hoisting is to be done from several levels, the efficiency at the maximum depth alone cannot be used as a basis for comparing the hoist driven by the induction motor with other systems. The efficiency of the cycle increases with an increased rate of acceleration, from which it follows that an induction motor for hoisting cuited, the booster is thus connected across the supply system and the speed of the flywheel is at its maximum. To accelerate the hoist, the short-circuit is opened, and the potential of the booster is gradually reduced to zero, reversed, and brought up to full potential in the opposite direction, the power stored in the flywheel during the idle period being returned.

It has been proposed, and at least two installations embodying the idea are now in process of construction, to substitute compressed air for steam. The present hoist engines would be used with slight modification of their valves to accommodate them to compressed air, the compressors for supplying the air to be driven by electric motors. It is impossible, however, to gather sufficient details regarding the system to predict the results which will be obtained.

A typical mine-hoist log is given in Table A, which is the condensed log for 24 hours, taken at a mine under actual conditions.

TABLE A

TIME IN MINUTES AND SECONDS

Interval	Hoisting ore	Hoisting men	Hoisting waste	Other hoisting	Shifting	Rest
7–8 A.M.	—	10–2	6–37	6–28	7–39	29–14
8–9	24–5	—	3–0	2–47	6–44	23–24
9–10	14–2	3–55	5–0	6–12	15–15	15–56
10–11	30–25	—	12–0	1–30	8–35	7–30
11–12 M.	57–55	—	—	1–5	1–0	—
12–1 P.M.	3–35	1–0	17–5	2–55	4–29	30–56
1–2	51–10	1–50	—	1–45	4–0	1–15
2–3	20–10	—	—	2–40	12–5	25–5
3–4	44–0	—	—	0–51	5–25	9–44
4–5	—	7–38	—	1–25	0–38	50–19
5–6	—	—	—	—	0–35	59–25
6–7	—	13–8	—	1–23	0–27	45–2
7–8	21–27	—	16–42	1–54	2–1	17–56
8–9	51–7	1–8	—	4–57	1–59	0–49
9–10	54–17	—	—	1–30	1–30	2–43
10–11	48–22	1–42	—	—	2–53	7–03
11–12 M.M.	—	—	8–39	4–16	0–40	46–25
12–1 A.M.	34–51	1–52	—	—	0–30	22–47
1–2	53–14	—	—	2–49	—	3–57
2–3	50–25	—	—	1–10	—	8–25
3–4	—	7–50	—	25–43	1–0	25–27
4–5	—	—	—	55–47	0–34	3–39
5–6	—	—	—	5–14	—	54–46
6–7	—	—	—	3–09	—	56–51

Table B gives a condensed summary of this log, and also that of another mine under actual operating conditions.

TABLE B

	Mine A			Mine B	
	Min.	Sec.	Per cent	Approx. min.	Approx. per cent
Hoisting ore and waste....	628	8	43.7	428	30
Other hoisting............	185	15	12.9	171	12
Shifting..................	77	59	5.4	120	8
Rest......................	548	38	38	721	50

The estimated distribution of power consumed for hoisting is given in Table C. Attention is called to the close agreement between the estimates for the power consumed in hoisting ore and waste, which, in view of the fact that the estimates were made entirely independent of each other, should add considerable weight to the figures. One estimate is based on figures obtained by indicating the hoisting engine, and the other forms the basis for the distribution of the costs of hoisting.

TABLE C

	Distribution of power in per cent of total	
	Mine A	Mine B
Hoisting ore and waste................	55	51
Other hoisting........................	28	23
Shifting..............................	17	26

The curves in Fig. 21 give the total tons hoisted, and the total kilowatt hours consumed (per day of 24 hours), the kilowatt hours consumed per ton (2000 lb.) foot, and the load factor for each of the four systems when hoisting 10,000 lb. per trip in balance from vertical depths, varying from 400 ft. to 2600 ft. by a reel hoist. Fig. 22 gives similar curves for hoisting 20,000 lb. of ore per trip in balance, from depths varying from 3000 ft. to 8000 ft., by a cylindrical drum hoist, the shaft making an angle of approximately 38 degrees with the horizontal, and the depths being measured on the incline.

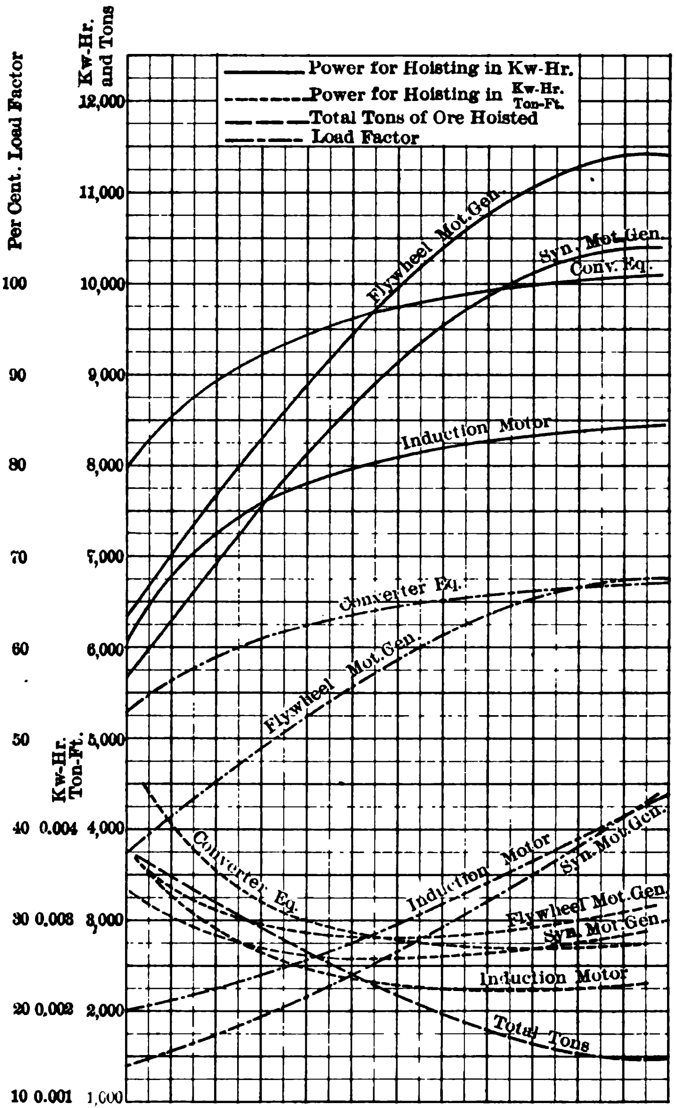
Power for Hoisting in Kw-Hr.
Power for Hoisting in $\frac{\text{Kw-Hr.}}{\text{Ton-Ft.}}$
Total Tons of Ore Hoisted
Load Factor
Per Cent. Load Factor
Kw-Hr. and Tons
Kw-Hr. / Ton-Ft.
12,000
11,000
100 10,000
90 9,000
80 8,000
70 7,000
60 6,000
50 5,000
40 0.004 4,000
30 0.003 3,000
20 0.002 2,000
10 0.001 1,000
600
1,000
1,400
1,800
2,200
2,600
LEVEL IN FEET
Flywheel Mot.Gen.
Syn. Mot.Gen.
Conv. Eq.
Induction Motor
Converter Eq.
Flywheel Mot.Gen.
Converter Eq.
Induction Motor
Syn.Mot.Gen.
Flywheel Mot.Gen.
Syn. Mot.Gen.
Induction Motor
Total Tons

Fig. 21

Table D gives the power consumption for the various systems for hoisting 6000 lb. in balance from one level in a compound shaft, the hoist load diagram for which is given in Fig. 23. The shaft drops vertically 800 feet and then continues for 1320 feet on an incline of 38 degrees with the horizontal.

TABLE D

	Power for hoisting in kw-hr.	Power for hoisting in kw-hr, ton ft.		Total tons hoisted	Load factor
First system....	3900	0.00307*	0.00234†	786	25
Second "	3450	0.00272	0.00206	"	19.2
Third "	4019	0.00315	0.00240	"	62
Fourth "	4910	0.00386	0.00295	"	63.6

* Values are based on the total vertical lift 1613 feet.
† Values are based on the total distance lift 2120 feet.

The values given in these curves and table, include the power consumed in " other hoisting " and " shifting ", on the assumption that the power consumed in hoisting ore is 53 per cent of the total power. Also in the values for the synchronous motor-generator set (second system) no credit is allowed for the power returned during retardation.

These curves and table show clearly the effect of the shape of the hoist diagram on the power consumed by the various systems. At the upper levels the period of acceleration is a large part of the total cycle, and we find the power consumed by the induction-motor hoist to be greater than that for the hoist driven by the direct-current motor, power for which is supplied by a synchronous or induction-motor-generator set. In the case of the cylindrical drum hoist, for which the peak during acceleration is much greater than for the reel hoist, the power consumed by the induction motor is greater for all levels. Also a similar relation exists in the power curve when a converter equalizer or a flywheel motor-generator set is used.

If a cylindrical drum is used instead of a reel, the curves of Fig. 21 for the direct-current hoist motors will remain practically the same, but those for the induction hoist motor will be raised, crossing those of the synchronous motor generator set toward the end of the curve; and if a cylindro-conical drum is substituted

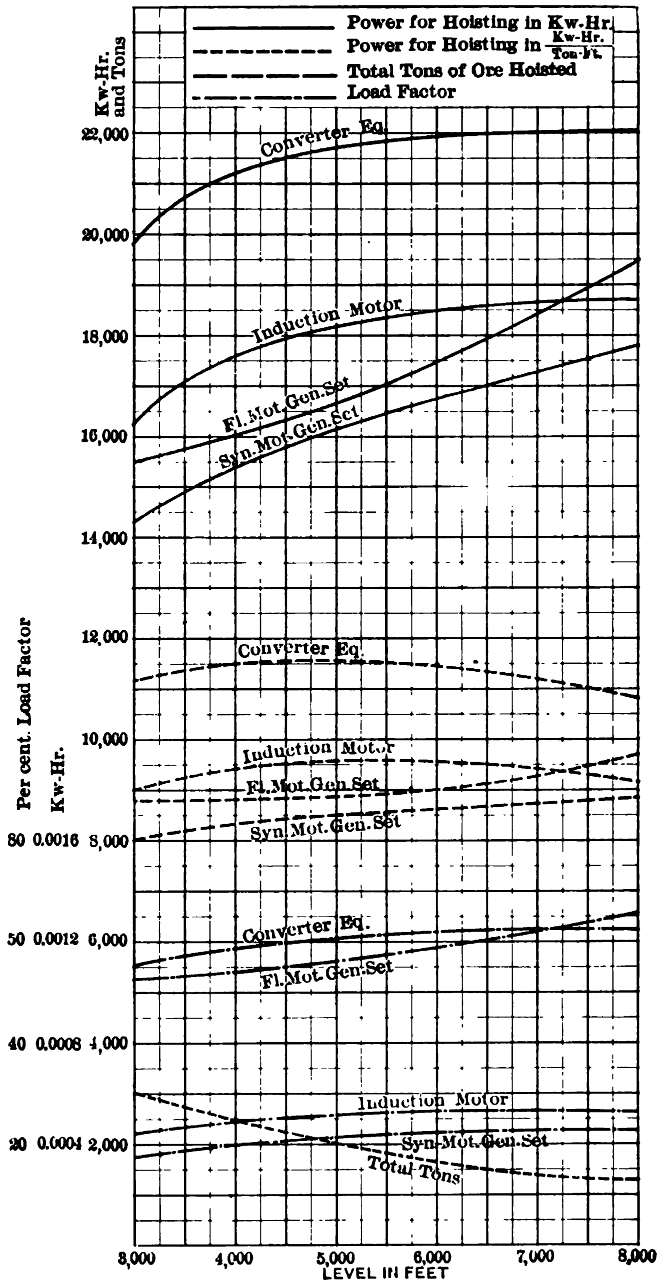
Power for Hoisting in Kw-Hr.
Power for Hoisting in Kw-Hr./Ton-Ft.
Total Tons of Ore Hoisted
Load Factor
Kw-Hr. and Tons
Per cent. Load Factor
Kw-Hr.
22,000
20,000
18,000
16,000
14,000
12,000
10,000
80 0.0016 8,000
50 0.0012 6,000
40 0.0008 4,000
20 0.0004 2,000
Converter Eq.
Induction Motor
Fl.Mot.Gen.Set
Syn.Mot.Gen.Set
Converter Eq.
Induction Motor
Fl.Mot.Gen.Set
Syn.Mot.Gen.Set
Converter Eq.
Fl.Mot.Gen.Set
Induction Motor
Syn.Mot.Gen.Set
Total Tons
3,000
4,000
5,000
6,000
7,000
8,000
LEVEL IN FEET

FIG 22

for the cylindrical drum of the larger hoist, the induction-motor curves of Fig. 22 will approach those for the direct-current hoist motor.

The values for the different levels, shown by the curves, are based on the assumption that all the ore is taken from the corresponding level. Where ore is hoisted from several levels, the total power consumption per day may readily be obtained from the power consumption per ton foot, or by use of the curves of " Total Tons Hoisted " and " Power for Hoisting in Kw-hr."

While the curves given, cover specific cases only, the examples chosen are typical, and by interpolating between the power consumed per ton foot for the 8000 ft. and that for the 2500 ft. hoists, the power per ton foot may be obtained for hoisting from any depth. Due correction is to be made for the inclination of the 8000 ft. shaft by dividing the values given by 0.616 to obtain the equivalent values for a vertical shaft. From the total kilowatt hours consumed per day and the load factor, the cost of power for hoisting electrically can readily be obtained.

TABLE E

	Coal burned tons per day	Ore hoisted tons per day	Tons ore / tons coal
Hoisting from 2000 ft. level small hoist:			
Steam hoist	47.0	1780	40
Elec. hoist First system	13	"	137
Second "	15	"	119
Third "	16	"	110
Fourth "	15	"	119
Hoisting from 6000 ft. level large hoist:			
Steam hoist	65.5	1580	24
Elec. hoist First system	23	"	69
Second "	24	"	66
Third "	25	"	63
Fourth "	27	"	59

A comparison between steam and electric hoisting, is given in Table E in which the coal and rock ratio for each are given for the 2000 ft. and the 6000 ft. levels respectively. In determining these values, it is assumed that the steam hoisting engines are non-condensing, that the steam consumptions are 65 lb.

and 55 lb. per indicated horse-power hour respectively for the large and small hoists, and that power for the electric hoists is supplied from a modern steam-turbine station using units of 1000 kw. each, or larger for the smaller hoist and 2500 kw. or larger for the larger hoist.

In determining these ratios, 10 per cent has been added to the total kilowatt-hours per day as given in the curves, to cover the losses in transmission.

In addition to the saving in fuel which may be realized by the use of electric hoists, there is a very material reduction in the labor, the cost of which is chargeable against the hoist. This may amount to the wages of one or two men in the boiler house if power is developed by the mining company, or of the whole boiler-house force if power is purchased, and frequently the wages of one man in the hoist house.

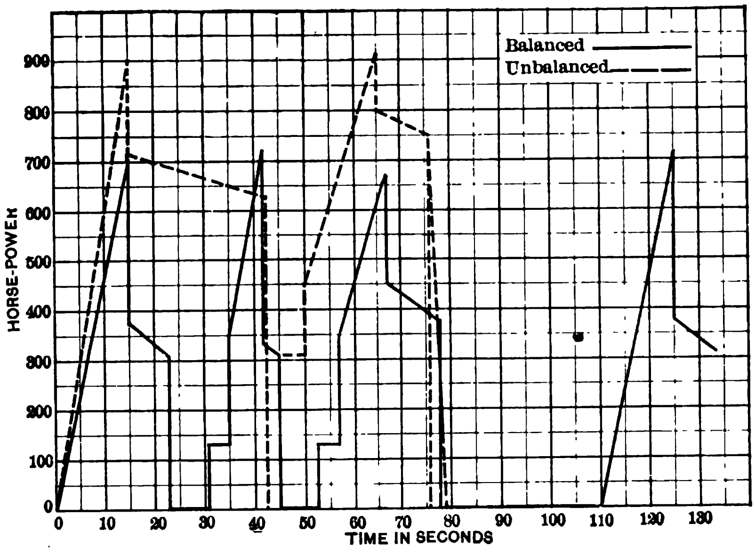

FIG. 23

So many factors which vary between wide limits for different localities enter into the comparative costs of hoisting electrically and by steam, that each individual case must be treated by itself, but the following comparison will serve as an indication of the general result of a more detailed investigation.

Take for example the reel hoist, the power curves for which are shown in Fig. 21, and assume that the average condition of hoisting is that represented by hoisting from the 2000 ft. level; that good steaming coal can be purchased for $3.50 per ton; that power can be purchased for the equivalent of 1.1c. per kw-hr., on a 50 per cent load factor, and, if steam driven, that the engine will be non-condensing.

In order to obtain a load factor of 50 per cent, it will be necessary to install either the third or fourth system of electric hoisting, and, to be conservative, let it be assumed that the third is chosen.

Total cost of power per year for electric hoist at 1.1c. per kw. hr	$35,300
Fixed charges on the excess cost of the electric over the steam hoist (approx. $25,000)	2,500
	$37,800
14100 tons coal at $3.50 per ton	$49,350
Boiler-house force (3 men at $3.25 per day)	2,925
One oiler	900
	$53,175
	37,800
Approximate annual saving with electric hoist	$15,375

As this saving of $15,375 is the result of an additional expenditure of $25,000 for the electric hoist, it is proper for a new installation to base the rate of interest equivalent to this saving on this additional first cost, from which it follows that the interest realized on this investment is 61.5 per cent. If, on the other hand, it is a question of replacing an existing steam hoist, the interest should be based on the total cost of the electric installation, in which case the very substantial rate of 30 per cent will be realized.

The hoist, above all other parts of the mine equipment, must be kept in commission at all times, and this fact must be borne in mind in installing an electric hoist. The transmission lines must be carried on substantial poles over a well-cleared right-of-way, duplicate lines being installed where possible and the lines being adequately protected against disturbances from lightning. If these precautions are properly taken, the electric can be made as thoroughly reliable as the steam-driven hoist.

Summing up, the advantages of the electric hoist are: first, greater economy, resulting from the centralization of the development of power in a large central electric station, favorably located for the economical development of power and from a reduction in the operating force, from the increased life of the rope and the greater life of the brakes; second, greater safety in operation; third, especially, adaptation for underground installations, and fourth, the fact that it permits of the utilization of water power which is frequently available in mining districts.

A paper presented at the 245th meeting of the American Institute of Electrical Engineers, New York, March 11, 1910.

LARGE ELECTRIC HOISTING PLANTS

BY WILFRED SYKES

The development of large electrically-driven hoisting plants has gone on simultaneously with that of balancing systems designed to equalize the input, thus relieving the generating stations of excessive peak loads. It will be readily understood that success from a commercial standpoint could hardly be hoped for with large plants requiring a maximum of 2000 or 3000 horse power unless the average load had some reasonable relation to the maximum, excepting, of course, those cases where the generating stations were of such capacity that the peak loads did not interfere with the operation or regulation of the plant generally. Such cases are, however, seldom met with, a notable instance being the mines at Johannesburg, which are to be supplied with power by the Victoria Falls Co. There it is intended to use three-phase motors up to 2000 h.p. maximum for hoisting, but owing to the large amount of power required for other purposes, the peak loads due to these motors will not materially affect the generating stations, which will have a capacity of about 100,000 kw. In the majority of cases where electric hoists are used the mines have either their own generating plants or purchase power under such conditions that the cost is materially affected by the load factor, and for economical working it is essential that the average load should be as high as possible. When a mine generates its own power it will usually be found that the proportion of the hoisting load to the rest of the requirements is very large, especially with deep mines, and the peak loads necessitate special provision being made to prevent them from interfering with the operation of the other part of the plant. The success of electric hoisting plants in

Europe when motors up to 3500 h.p. have been used, superseding steam hoists, has demonstrated that by carefully studying the subject there is no difficulty in securing very satisfactory results, not only from an operating, but also from a commercial standpoint. When considering large hoisting plants with the idea of driving them electrically it is essential that the load characteristics should be carefully studied, to determine not only the correct size of the machine, but also the system to be adopted. With steam-driven hoists this is not absolutely essential, for since the worst conditions are provided for, they cannot very well be overloaded; but as the output of electric motors is usually limited by the heating, rather than by the maximum safe load, the output at all points of the hoisting period must be known in order to design intelligently the electrical part of the equipment, including also any equalizing system which may be adopted. In this paper it is proposed to describe briefly some methods used by the author for the determination of load diagrams and also the characteristics of balancing systems and their economy.

Cylindrical drum hoists. This is the most common type of hoist and the load diagram is very simply obtained. Dealing first with a single-drum hoist, with one cage without any counter balance, the static moment at the beginning of the trip will be,

$$M = (W+Rl+C)\,r+F+A$$

when M = total moment or torque in ft. lb.
R = weight of rope per ft.
l = depth of shaft in ft.
C = weight of cage in lb. (including cars).
r = radius of drum in ft.
F = total friction expressed in ft. lb.
A = accelerating moment in ft. lb.
W = weight of load to be hoisted.

As the cage is hoisted, rope will be wound on the drum and the load will be correspondingly reduced. With electrically-driven hoists the rate of acceleration is usually constant so that the distance traveled during this period will be

$$S\,t \div 2$$

when S = full speed of hoist in ft. per second.
t = time of acceleration.

Therefore, at the end of the accelerating period the load will be,

$$M_1 = \left(W + C + R l - \frac{S\,t \times R}{2}\right) r + F + A$$

The hoist having reached full speed the accelerating moment drops out giving,

$$M_2 = \left(W + C + R l - \frac{S\,t \times R}{2}\right)\ r + F$$

During the full speed period the load will be uniformly reduced by the rope wound on the drum until at the end of this period there remains only the amount of rope corresponding to the distance traveled during retardation, or,

$$M_3 = \left(W + C + \frac{S\,t_2 R}{2}\right) r + F$$

when t_2 = time of retardation.
To bring the load to rest the energy stored in the moving parts must be absorbed either in lifting the load or by the brakes. At the beginning of retardation the load is therefore,

$$M_4 = \left(W + C + \frac{S\,t_2 R}{2}\right) r + F - V$$

when V = retarding moment.
At the end of the trip the load will be,

$$M_5 = (W + C)\,r + F - V$$

Considering the case of a double-drum hoist, the conditions are somewhat different as the cages balance one another. At starting we have

$$M = (W + R\,l)\,r + F + A$$

During acceleration the weight on the loaded side will be reduced by that of the rope wound on the drum, but from the second drum a corresponding length of rope will be unwound so that the effective load will be reduced by twice the weight of the rope wound on the drum, or,

$$M_1 = (W + R\,l - S\,t \times R)\,r + F + A$$

At the beginning of the full speed period the load is as above except that there is no accelerating moment. The load continues to decrease as the rope is wound on one drum and off the other, until at the end of the full speed run we have,

$$M_3 = (W - R\,l + S\,t_2\,R)\,r + F$$

At the beginning of retardation the load is

$$M_4 = (W - R\,l + S\,t_2\,R)\,r + F - V$$

and at the end of the trip,

$$M_6 = (W - R\,l)\,r + F - V$$

In order to work out the load diagram as above, it is of course necessary to have such data as weight of load, rope, cages, etc., but on the question of time and speed, acceleration and friction, a few remarks may not be out of place.

Time. As usually presented, the problem is to obtain a certain maximum output per hour, usually a good deal more than the average, so as to allow for delays. A certain time will be required for changing the cars and after deducting this from the time per trip, the actual hoisting time is obtained. This of course applies to balanced hoisting and, with a single cage, time must be allowed for lowering. If we suppose that our experience indicates that a certain period, $t + t_2$ will be reasonable for acceleration and retardation, the full hoisting speed will be,

$$S = \frac{l}{T - \frac{t + t_2}{2}}$$

when T = actual hoisting time; or supposing that the full speed is given, the time available for acceleration and retardation is

$$2\left(T - \frac{l}{S}\right)$$

Acceleration and retardation. The accelerating moment will depend upon the total mass of the moving parts and the velocity. It will generally be found convenient to reduce all the moments of inertia to the drum radius. The total will be made up of the load, cages, ropes, sheaves, drums, gearing and motor, the first three of which can be readily determined. The inertia of the sheaves will depend on the design, but if data are not available we may approximate by taking $\frac{W r_1^2}{g} = 25 r_s^2$ for each sheave; when r_s = radius of sheave, and for each of the drums $100 r^2 W'$ when W' = width of drum. These are of course only rough guides and the actual figures should be obtained if possible. If the weights are known it is safe to take the radius of gyration, or $r_1 = 0.8r$, in calculating the inertia. The gearing, if any, must be worked out from the weights and dimensions and the motor data can only be obtained by making a rough estimate of the size and picking out a suitable machine. The total amount of inertia I_1, reduced to the drum will be therefore,

Traveling parts $\frac{(W + 2 l R + 2C) r^2}{32}$

Sheave $25 r_s^2 \times \left(\frac{r_s}{r}\right)^2$

Drum $100 r^2 W'$

Gearing $\frac{W r_1^2}{g} \times \left(\frac{O_1}{O}\right)^2 + \frac{W r_1^2}{g} \times \left(\frac{O_2}{O}\right)^2$ etc.

Motor $\frac{W r_1^2}{g} \times \left(\frac{M_s}{O}\right)^2$

When r_s = radius of sheave in ft.
O = speed of drums in rev. per min.
$O_1\, O_2$ = speed of the different parts of the gearing, O_1, being main gear $= O$, O_2 = countershaft speed and so on, each part of the gearing being worked out separately, M_s = motor speed.

The angular velocity of the drum is,

$$\omega = \frac{2 \pi N}{60}$$

when N = rev. per min.

The accelerating moment is

$$A = \frac{I_1 \omega}{t}$$

and the retarding moment

$$V = \frac{I_1 \omega}{t_2}$$

Friction. The friction is very difficult to determine, as it varies with the condition of the shaft, cages, sheaves, hoist and speed. For moderate speeds the friction may be taken for a direct-coupled hoist as being equal to an extra load of from 5 per cent to 7½ per cent of the total suspended weight, including ropes, cages and load, and with a geared hoist, from 7½ per cent to 10 per cent, but this is only a rough guide and it is necessary to depend on experience more than anything else. Instead of calculating the static moment of the load at various points a very simple graphic method may be used. Referring to Fig. 1 draw $c\,d$ and $e\,f$ at right angles to $a\,b$, the distance between them being equal l/S, and on $c\,d$ lay off to a suitable scale the value corresponding to F, drawing $g\,h$ parallel to $a\,b$, and above this, fix the point $x = (W + Rl)\,r$, and also on $e\,f$ set off the value $y = (W - Rl)\,r$. On either side of $c\,d$ and $e\,f$ draw the verticals $j\,k$ and $l\,m$ and $n\,o$ and $p\,q$ at a distance representing half the period of acceleration and retardation respectively. Connect $x\,y$ and draw the horizontals $x\,w$ and $y\,v$. From the point where $x\,y$ intercepts $l\,m$ and $n\,o$, draw $x'w$ and $y_1\,v$. On $j\,w$ from w set off the value corresponding to the accelerating moment w_1 and draw parallel to $w\,x'$, $w_1\,x_2$ and on $v\,q$ from v the retarding moment v_1 drawing parallel to $y_1\,v$, $y_2\,v_1$. The complete torque diagram is the area $k\,w_1\,x_2\,x'\,y_1\,y_2\,v_1\,q$ and the total running line is shown by $k\,q$. To convert the values in ft.-lb. to horse power we must multiply by the angular velocity ω and divide by 550. For practical purposes we may consider that the current taken by the motor will be proportional to the torque and, as the heating depends upon the current, the torque diagram must be taken as the basis for calculating the capacity of the machine required. The usual method is to assume that the heating varies as the square of the current and that the heat is carried away from the motor at a constant rate. On this basis the size of the motor would be,

$$HP=\sqrt{\frac{\frac{HP_1^2+HP_2^2}{2}\times t+\frac{HP_3^2+HP_4^2}{2}\times t_1+\frac{HP_5^2+HP_6^2}{2}\times t_2}{T_1}}$$

when HP_1 HP_2 HP_3 HP_4 HP_5 and HP_6 correspond to the values at w_1 x_2 x' y_1 y_2 and v_1 respectively,

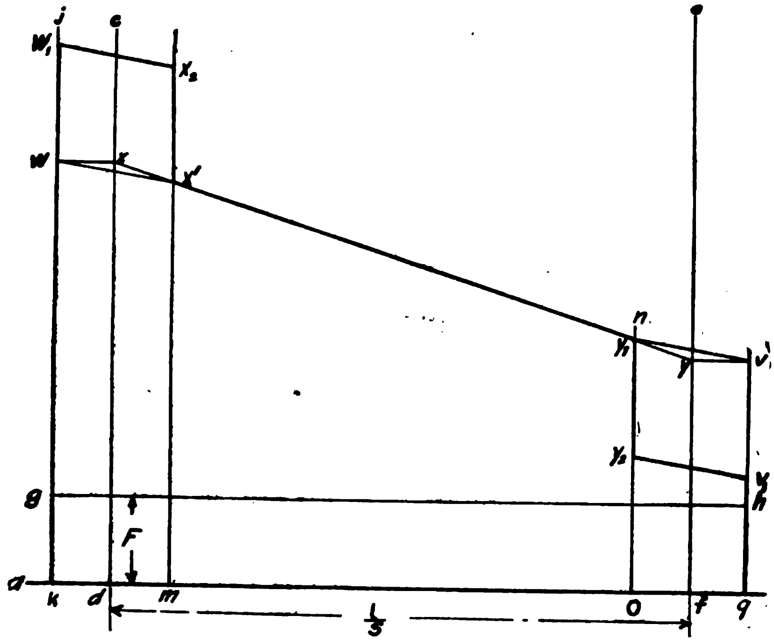

FIG. 1

t, t_1 and t_2 = time of acceleration, constant speed and retardation respectively,

T_1 = total time for each trip, including the period of rest.

This assumption is not altogether true for with induction motors there are extra losses in the rotor at starting, and with direct current machines the reverse is the case. The total losses do not increase exactly as the square of the current, nor is the heat carried away at the same rate all the time, but this gives a guide to the size of the motor required and if a proper allowance is made for these inaccuracies, the proper size of machine can be fixed very closely.

Whiting and Koepe hoists. These hoists are used to some extent, the latter very largely in Germany, and as a tail rope is generally used with the former, and always with the latter, they may be taken together. By using a tail rope of the same weight as the hoisting rope, the load to be hoisted becomes the only unbalanced part of the whole system and the diagram is very easily obtained. At the beginning of the trip the total load is

$$M = W\,r + F + A$$

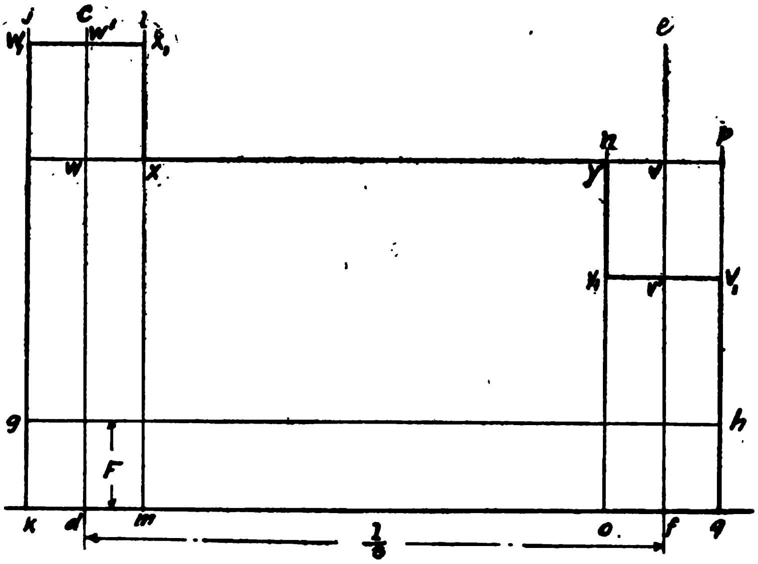

Fig. 2

At the end of the acceleration the only difference is that the accelerating moment disappears leaving

$$M_2 = W\,r + F$$

During retardation we have

$$M_5 = W\,r + F - V$$

The diagram may be readily obtained graphically as before. Referring to Fig. 2, set off $d\,f$ equal to l/S and draw $c\,d$ and $e\,f$.

Parallel to $a\,b$, plot $g\,h$ representing the friction, and above the $w\,v$ equal to $W\,r$. Draw $j\,k$, $l\,m$ and $n\,o$, $p\,q$ as before, the distance between them and $c\,d$ and $e\,f$ being equal to half the time for acceleration and retardation respectively. From w set off w' corresponding to the accelerating moment drawing $w_1\,x_1$ parallel to $w\,x$. From v set off v' corresponding to the retarding moment. drawing $y_1\,v_1$ parallel to $y\,v$. The area $k\,w_1\,x_1\,x\,y\,y_1\,v_1\,q$ represents the torque diagram for the motor which should be treated as before in order to determine the size of the motor. In connection with Koepe pulleys, and also to some extent with Whiting hoists, it is necessary to determine the factor of safety against the rope slipping. On one side the maximum pull on the rope is made up of cage, load, rope weight, acceleration of these parts and of one sheave. On the other side there is rope weight, and cage minus the acceleration of these parts and of one sheave. Reducing the weights of the sheaves to the pulley radius the accelerating pull will be

$$\frac{(W+C+R\,l+S')\,a}{32}$$

when a = acceleration in ft. per sec.

S' = weight of sheave reduced to pulley radius.

On the other side it is

$$\frac{(C+R\,l+S')\,a}{32}$$

In order to cause slipping the greater pull must exceed the smaller one multiplied by $e^{\alpha\mu}$ when

e = base of nat. log. 2.7182.

α = angle of contact of rope on sheave in radius.

μ = coefficient of friction between rope on pulley = 0.18.

Usually the angle of contact is about 190 degrees so that for the rope to slip we must have

$$\left\{ W+Rl+C+\frac{(W+R\,l+C+S')\,a}{32} \right\} > 1.82 \left\{ Rl+C-\frac{(R\,l+C+S')\,a}{32} \right\}$$

With Whiting hoists the angle of contact is 180 degrees and the multiplying factor is, 1.75×number of wraps around driving sheaves.

Conical drum hoists. The determination of the load diagram for this type of hoist is somewhat more complicated than that for the hoists already dealt with. The object of conical drums is to compensate for the unbalanced load due to the rope, and to do this completely the following conditions must be met

$$r\,(W+Rl+C)-r_1 C = r_1\,(W+C)-r\,(C+Rl)$$

when r = minimum radius.
r_1 = maximum radius.

This gives the proper dimensions for the beginning and end of the trip, but at intermediate points there are slight unbalanced loads if a plain conical drum is used. The variation from the ideal condition, however, is unimportant. From the smaller radius the greater can be obtained as follows:

$$r_1 = r\left(1+\frac{2\,Rl}{2C+W}\right)$$

The length of the surface of the drum will be

$$L = \frac{l \times d}{\pi\,(r+r_1)}$$

when d = space required for each turn of the rope.

In order to obtain the same output as with a cylindrical drum the maximum speed will be approximately in the ratio of

$$\frac{r+r_1}{2} : r_1$$

which gives a value a little too high, as the rope is not at the maximum radius when retardation begins, but it is, however, near enough when making preliminary calculations in order to determine what average speed can be assumed. It will be found more convenient when dealing with this type of hoist to calculate the distance traveled in terms of revolutions of the drums instead of in feet. Supposing that a certain maximum speed S_{max} is fixed by considerations such as shaft construction, etc., the mean speed S_m will be

$$S_m = \frac{S_{max}\,\frac{r+r_1}{2}}{r_1}$$

which, expressed in revolutions per second, is

$$\text{Rev. per sec.} = \frac{\dfrac{S_{max}\,\frac{r+r_1}{2}}{r_1}}{2\pi\,60\,\frac{r+r_1}{2}} = \frac{\dfrac{S_{max}}{r_1}}{2\pi\,60}$$

The total number of revolutions to be made per trip is

$$\text{Rev. per trip} = \frac{l}{2\pi\,\frac{r+r_1}{2}}$$

The time available for acceleration and retardation is therefore:

$$t+t_2 = 2\left\{T - \frac{\dfrac{l}{2\pi\,\frac{r+r_1}{2}}}{\dfrac{\frac{S_{max}}{r_1}}{2\pi\,60}}\right\} = 2\left\{T - \frac{\dfrac{2l}{r+r_1}}{\dfrac{S_{max}}{60\,r_1}}\right\}$$

$$= 2\left\{T - \frac{120\,l\,r}{S_{max}\,(r+r_1)}\right\}.$$

The speed in rev. per sec. being known, the revolutions can be readily found. The distance traveled during acceleration will be

$$l_1 = 2\pi\left(r + \frac{i\,z}{2}\right)z$$

i = increase in radius per turn = $r_1 - r \div$ rev. per trip
z = revolutions during acceleration.
z^1 = revolutions during retardation.

During retardation the distance traveled will be

$$l_2 = 2\pi \left(r_1 - \frac{i\, z^1}{2}\right) z^1$$

The inertia of conical drums may be taken as approximately, $200\, W' \frac{r^2 + r_1^2}{2}$ if the weight is not known.

Static moment. The variation of the static moment may be easily followed if the drum is considered as being extended so as to complete the cone with the apex at *a* Fig. 3. The area of the cone will be proportional to the square of the radius O, and as the weight of the rope on the drum will be proportional to the area covered, assuming an even spacing between the turns, it will be seen that it will also vary as the square of the distance from *a*. The length of the completing cone l' will be

$$l' = \frac{l \times r}{r_1 - r}$$

The number of turns of rope on this part will be

$\frac{l'}{d}$ when d = space taken by each turn of rope in ft.

and the length of rope $= \pi r \frac{l}{d}$

If the total weight of the rope on the drum and completing cone is considered as a separate load, none being wound on the drum, the static moment would vary with the distance from *a*, being $R\, L' \times$ radius. The amount of rope wound on the drum, however, varies with the square of the distance from *a* and the equivalent static moment as the cube; consequently the actual static moment for any point will be,

$$M_r = R\, L'\, r_2 - R\, L'\, r_1 \left(\frac{r_2}{r_1}\right)^3$$

when M_r = static moment of rope.
R = weight of rope in lb. per ft.
L' = total length of rope wound on drum and completing cone.
r_2 = any radius.
r_1 = maximum radius of drum.

From the above it is very easy to determine the static moment diagram by plotting a few points and drawing a curve through them; or graphic methods may be used.

Referring to Fig. 3, set off on $a\,b$ from a, the distance $a\,b'$ corresponding to the number of turns of rope on the drum and completing cone. Parallel to $a\,b$ draw $a_1\,b_1$, the distance between them being equal to $(L\,R+W+C)\,r_1$ and from b' drop the vertical $b'\,b_1'$. From the point a' corresponding to the smaller end of the drum, drop the vertical $a'\ a_1'$. A straight line from a to b_1'. would represent the static moment if none of the rope were wound on the drum, but, as pointed out, this value must be decreased by a certain amount, varying as the cube of the distance from a. On $b'\,b_1'$ lay off the value $L\,R\,r_1$ to Z leaving $z\,b_1'$ representing the actual static moment at the end of the trip and connect $a\,z$. If a cubic parabola is drawn between a and z, the distance between it and $a\,z$ will be the static moment diagram for the rope, and between the curve and $a\,b_1'$ the static moment diagram for the loaded side of the hoist. This may be done by a simple graphical method. Divide $a'\ b'$ into any number of parts and draw the verticals 2, 3, 4, etc. from $a\,b$ to $a_1\,b_1$. From the points of intersection with $a\,z$ draw the horizontals I, II, III, etc. to $b'\ b_1'$ and with $b'\,z$ as a diameter draw the semicircle. With b' as a centre describe the arcs $I\,I'$ $II\,II'$ $III\,III'$, etc., and from the intersections with the semicircle draw horizontals to $b'\,b_1'$ and from these points vectors to a. The intersection of I' and $a'\,a'_1$, II' and 2, III' and 3, etc., are points on the cubic parabola. This arrangement gives the diagram on the base $a\,b_1'$ but we can obtain it on $a_1\,b_1$ if, instead of drawing the vectors to a, they are drawn to a_1. The static moment for the unloaded side can be obtained in the same way. On $a'\ a_1'$ from a_1', lay off p corresponding to the static moment of the cage or $C\ r$ and draw $p\,z$. Parallel to $p\,z$ draw $I'\ I_1$, $II'\ II_1$, etc., and from the intersections with $a'\ a_1'$ the vectors to b_1, the distance of which from b_1' corresponds to the number of turns on the completing cone. The intersection of $I_1\ b_1$ with $b'\ b_1'$,$II_1\ b_1$ with 2, $III_1\ b_1$ with 3, etc., are points on the static moment diagram for the unloaded side. The distance between the two curves thus obtained is the resultant static moment for the hoist. In Fig. 3 a case has been taken where the static moment at the end of the trip is the same as at the beginning, the radii being obtained as already shown, and it will be noticed that the resultant moment is not quite a straight line, but the deviation is so small that it can be neglected. It will therefore be seen that if the condition for the complete compensation of the rope weight is met by properly proportioning the radii of the drum the static moment during the whole period may be taken as

$$M = (W+C)\,r - C\,r = W\,r$$

Inertia. It will be found convenient to reduce the inertia of the sheaves to the drum radius, assuming that it varies instead of the speed, which of course gives the same result. The equivalent

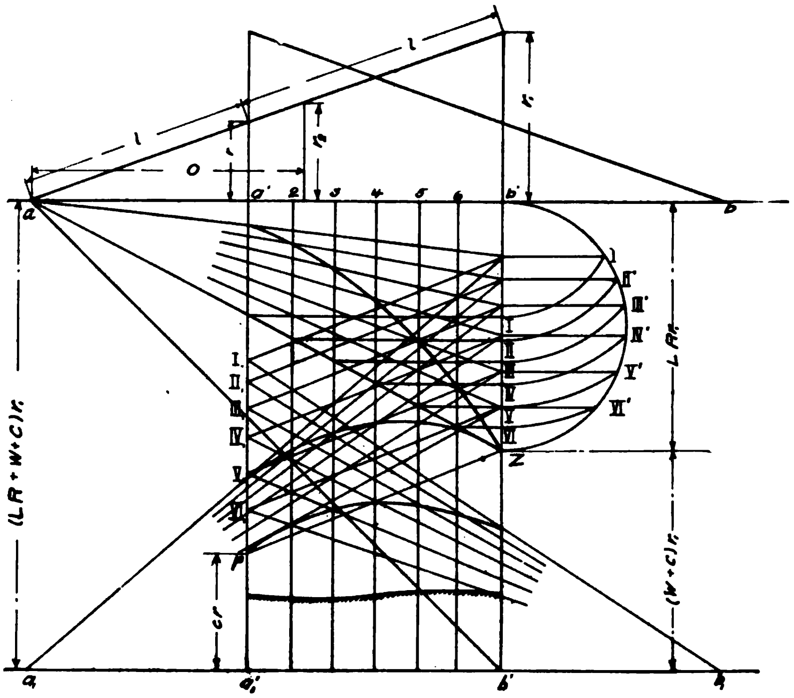

FIG. 3

inertia will therefore vary with the square of the drum radius, being a maximum at the larger radius when it is equal to

$$I_s \frac{r_s^2}{r_1^2}$$

in which I_s = inertia of sheave, and
r_s = radius of sheave.

If a simple parabolic curve is drawn from a point b' corresponding to the apex of the cone, Fig. 4 to the end of the drum on the line $b' b_1'$ the maximum value corresponding to $I_s \frac{r_s^2}{r_1^2}$, the part between the smaller and greater radii, $a_2\, b_2$ corresponds to inertia of one sheave. By drawing a similar curve for the second sheave from b_1', $a_3\, b_3$ will correspond to the inertia of the second drum and by adding the two the combined inertia curve $a_4\, b_4$ may be obtained. It will be seen that this curve varies very little from a straight line and for practical purposes the total inertia of the sheaves may be taken as constant at

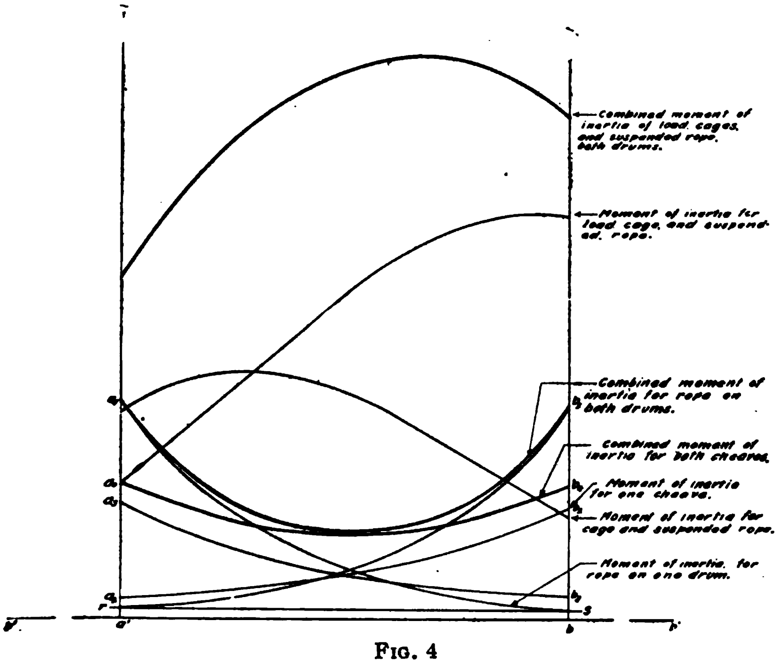

FIG. 4

$$I_{st} = I_s \frac{r_s^2}{r^2} + I_s \frac{r_s^2}{r_1^2}$$

The inertia of the load and suspended rope may be obtained from the static moment diagram. As the moment of inertia is $\frac{W r^2}{g}$, if the static moment or $W r$ is multiplied by $\frac{r}{g}$

the various values are found, and by taking a few points and multiplying by the corresponding radius and dividing by 32, a curve is easily obtained.

The same must be done for the unloaded side, and the two curves which are thus obtained are combined. The form of these curves is shown in Fig. 4 and it will be found that for practical purposes no great inaccuracy will be introduced if the inertia is taken as the average of the two.

$$I_L = \frac{\left\{(W + C + Rl)\, r^2 + C r_1^2\right\} + \left\{(W + C)\, r_1^2 + (C + Rl)\, r^2\right\}}{2g}$$

In the above the suspended rope has been allowed for but the rope on the drum must also be considered. It has been seen that the amount of rope on the drum will vary as the square of the radius and as the inertia of any mass also varies at the same rate the inertia of that part of the rope on the drum will vary r^4. By drawing a fourth degree parabola from the apex of the cone b' to the point on b_5, Fig. 4, corresponding to the value

$$I_R = \frac{R l r_1^2}{2g}$$

the inertia of one rope will be obtained and a similar curve from b_1' to a_5, will give the value for the second rope. By drawing a horizontal $r s$ from the points of intersection with a' and b the inertia of the part on the completing cone is subtracted, that above the base $r s$ representing that on the drums. By combining the curves thus obtained the total inertia of the rope on the drums will be obtained. As this curve does not vary very much from a straight line and the total value is small, it is sufficient for practical purposes to consider the inertia of this part of the total as being constant at

$$I_{Rl} = \frac{Rl \dfrac{r^2 + r_1^2}{2}}{g}$$

The inertia for all parts having been found, the load diagram may be determined in the same way as with cylindrical drum **hoists.**

Reel hoists. The reel hoist may be considered as a conical drum, the radius of which increases at each turn by an amount equal to the thickness of the rope. In order to compensate completely for the weight of the rope, the inner and outer radii must be determined in the same way as with a conical drum, the ratio being

$$r_1 = r\left(1+\frac{2\,R\,l}{2\,C+W}\right).$$

The increment by which the radius is increased being fixed by the rope thickness, it will be seen that the inner and outer radii must be such that with the full amount of rope on the reel the proper ratio is obtained. This ratio being fixed, it is obvious that there is only one value for the inner radius which will give the correct value for the outer radius with a certain rope thickness. The space occupied by the rope with a full reel is

$$Q = \pi\,r_1^2 - \pi\,r^2$$

and if the radii are taken in inches the length of the rope in feet will be

$$l = \frac{\pi\,r_1^2 - \pi\,r^2}{12\,d}$$

when d = thickness of rope in inches.

Taking $x = \frac{r_1}{r}$ we obtain,

$$\pi\,(x\,r)^2 - \pi\,r^2 = 12\,l\,d$$

$$\pi\,(x^2-1)\,r^2 = 12\,l\,d$$

$$r = \sqrt{\frac{12\,l\,d}{\pi\,(x^2-1)}}.$$

It may be that the value for r thus found will be too small for the size of the rope taken, the bending stresses being too high, and in this case it will be necessary to reduce the thickness and increase the width, but the permissible variation in this direction is comparatively small since only a few thicknesses are manufactured commercially. When the depth exceeds 1500 to 2000 ft. it will be found practically impossible to secure a complete compensation for the rope weight because the inner radius is so small that a suitable rope is not obtainable. Having fixed the radii, the load diagram may be determined in the same manner as that of a conical drum hoist.

Balancing systems. Practically all balancing systems utilize a flywheel, the speed of which is varied so that it gives up or absorbs energy according to the demands of the system. A storage battery may also be used for the same purpose and under certain circumstances it may be more economical than a flywheel, as the losses with the latter are constant and independent of the load, while the storage battery losses only occur when the battery is being used.

The main requirements of a balancing system are that it should be capable of preventing the peaks from coming on generating stations, it should be automatic in action, and the losses connected with it should be as low as possible.

The first practical system to be introduced was that proposed by Mr. Carl Ilgner, which, in various modified forms, has been very widely adopted for all classes of heavy work where greatly fluctuating loads have been taken care of. The Ilgner system as arranged for use with an alternating current source of supply consists of an alternating current induction motor with a wound rotor, coupled to a direct current generator, which, in turn, feeds a direct-current shunt-wound hoist motor. Coupled to the motor generator is a suitable flywheel designed to take care of the peak loads. The fields of the hoist motor and of the direct current generator are excited separately by a small exciter coupled to the motor generator set, means being provided for automatically maintaining its voltage constant when the speed of the set varies. The speed of the motor generator set is controlled by means of an automatic slip regulator operated by the line current. The scheme of operation is as follows:

At the beginning of a hoist cycle the flywheel will be running at full speed, all resistance being cut out of the motor rotor. In order to start the hoist, the generator will be gradually excited in the proper way to obtain the desired direction of rotation. As the speed of the hoist motor with constant field excitation will be practically proportional to the voltage of the generator, when the latter is increased the speed of the hoist will also increase until with full voltage the maximum speed is obtained. The only rheostatic losses at starting are those in the regulator controlling the generator field, which are negligible.

When the load on the induction motor exceeds the mean value for which the slip regulator is set, resistance is automatically introduced into the rotor so as to cause a reduction of speed, thus enabling the flywheel to give out a portion of energy stored in it and thereby assisting the motor to drive the generator. The speed will be automatically reduced so as to maintain constant input to the three-phase motor until the fly-wheel has given out all the energy required in excess of the mean value. When the load falls below this mean value the regulator will cut out the resistance in the rotor causing the set to increase in speed, thus storing energy in the flywheel and keeping the demand on the line constant.

The use of resistance in the rotor of the three-phase motor introduces a certain loss which will average half the slip between full and minimum speeds, but, as a rule, this loss is comparatively small compared with the output of the plant.

The question as to the most economical value to adopt is a very complicated one, depending as it does upon the first cost of the flywheel, the running losses, the time the plant is in service, etc. It will be seen that should the plant run for considerable periods without load it might be advisable to allow a fairly large slip and to use a light fly wheel so that the constant loss would be small. On the other hand, if the plant runs continuously, the intervals between trips being short, the slip regulator losses will bear a totally different relation to the input, and under such circumstances a relatively small slip and a heavy flywheel might be the most economical arrangement. It has been found in practice that a slip of 12 per cent to 15 per cent is about the most economical value, although in some plants a slip up to 20 per cent is provided for. Since the energy stored in the flywheel is proportional to the square of the velocity, it will be seen that by increasing the slip a proportional increase is not obtained in the output. Thus with a 15 per cent slip the energy available will be 28 per cent of the total stored in the flywheel. With 20 per cent slip the amount available is only increased to 36 per cent.

The Ilgner, or motor generator arrangement, is the most important of all equalizing systems, probably 90 per cent of the plants installed being designed on this principle. It will be noted that the whole of the power used by the hoist is transformed and also that there are no rheostatic losses at starting.

Fig. 5 shows the general connections of a hoisting plant on the Ilgner system with alternating current supply and from the description given the functions of the various parts will be easily followed.

Another system of importance, suitable for alternating current, which has a quite large field of application, is that known as the converter system, the principle of which is altogether different from that of the Ilgner system.

Fig. 6 shows the connections of this system as applied to three-phase hoisting plants. The hoist motor in this case is of the three-phase induction type with a wound rotor, being started by means of a rheostat. In order to equalize the demand on the line, the equalizing system is connected in parallel with the generator station. It consists of a rotary converter and a direct current machine to which is coupled a suitable flywheel. The operation of the arrangement is as follows:

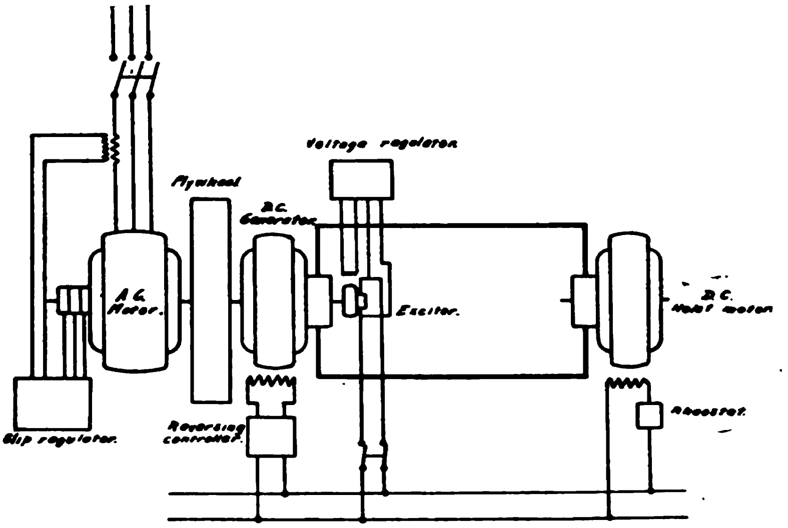

FIG. 5

The rotary converter acts only as a connecting link between the alternating current system and the equalizing set, which consists of a shunt-wound direct-current machine and the fly wheel. The field of this machine is controlled by a regulator, operated by the main line current. At the beginning of a trip the flywheel is running at full speed, and when the load exceeds the mean value, the regulator automatically strengthens the field of the equalizing machine so that it acts as a generator driven by the flywheel. The amount of energy given to the line will depend on the requirements in excess of the mean, as the regulator will continue to cut out resistance so long as there is any tendency for the line current to increase above the mean.

When the demand drops below the average the regulator will weaken the field, causing the machine to run as a motor, which taking energy from the line, speeds up the flywheel, the rate at which resistance is introduced to the field depending on the difference between the demand on the line and the mean load. In this way energy is stored in the flywheel and the line load is kept constant. The rotary converter changes either direct current to alternating current or vice versa, depending on whether the flywheel set is giving up or absorbing energy. It will be seen that the speed variation is obtained by field regulation, so that the loss is negligible, whereas with the Ilgner system it is from 7½ per cent to 10 per cent of the input to the driving motor. This is a very important feature in equalizing systems with direct current machines, as a much greater slip can be economically obtained, it being the usual practice to allow from 20 per cent to 25 per cent, and consequently the fly wheels can be comparatively light. The machines of the equalizing set need only be large enough to deal with the loads which exceed the mean value, and under ordinary circumstances the capacity will not be more than about half that of a motor generator set for the same duty. The equalizing equipment is quite independent of the hoisting motor, so that it may be out of service and the only difference will be that the peak loads will come on the line,

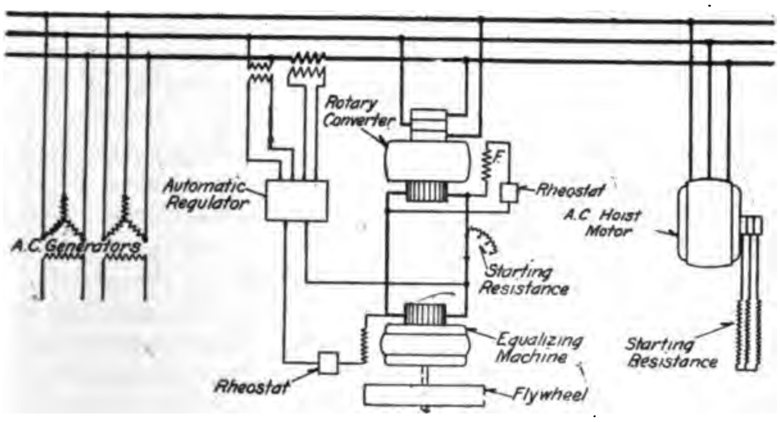

Fig. 6

but with the Ilgner system the hoist is dependent upon the motor generator.

The main difference between the two systems is that the Ilgner method provides for starting the hoist motor by voltage control without any rheostatic losses, while the converter arrangement makes no provision for doing so. When considering the economy of both systems this difference must be considered, as starting losses are often a large proportion of the total input. The question of starting is one of the most important ones with large hoists, and on this account the Ilgner system is preferred for heavy work. Motor generator sets without flywheels have been installed in a number of instances for the sole purpose of obtaining a simple and efficient method of starting. With small hoists the starting devices are not difficult to design and this feature, together with the fact that one converter equalizing equipment may be used for a number of hoists, gives this arrangement an advantage over the Ilgner system, especially as the cost is somewhat lower. It will be seen that the converter equalizing equipment is not necessarily located near the hoist, which is an important feature when it is inside a mine. In this case a high tension system may be used, transformers being placed between the converter and the line, and the equalizing set being in the power station or substation on the surface.

When the power supply is direct current the speed of the driving motor of the motor generator set is varied by shunt regulation and the slip may be made between 20 per cent and 25 per cent. With the other arrangement the converter is omitted, the equalizing machine being connected directly across the line. This latter arrangement is very simple, and so long as the starting of the motors can be done rheostatically, it appears to be the most reasonable system to use. A number of variations of the above arrangements have been employed but the principles are the same. There is another arrangement which under certain circumstances has some value. Its main feature is a reversible booster set, the voltage of which is the same as the line voltage. The general arrangement is shown in Fig. 7, from which it will be seen that the starting of the hoist motor is arranged for by regulating the booster field. When the hoist is at rest the booster has full field, both the booster and the motor running as motors off the line, a small current always passing through the hoist motor. When the hoist is started the booster field is weakened, the back e.m.f. being reduced, and a current flows through the hoist motor sufficient to start it. The difference between the input of the hoist and the load on the line corresponding to the current taken, is used by the booster, running as a motor, to drive the motor as a generator, thus returning power to the line. The field of the booster is gradually reduced until it is zero, when the line voltage will be applied directly to the hoist motor. The field is now reversed and the booster voltage is added to that of the line until with full excitation the pressure across the hoist motor is twice that of the supply system. This arrangement is manifestly only suitable where the line voltage is low and is not more than half the maximum pressure for which the motor can be conveniently built. The size of the booster set will be half the total input to the hoist motor. By adding a flywheel to the set and by providing for automatic regulation of the motor field the line load may be equalized. In the case of large plants, two hoist motors may be used connected in series and a supply voltage of 500 to 600 volts may be adopted, giving 1000 to 1200 volts at the motors.

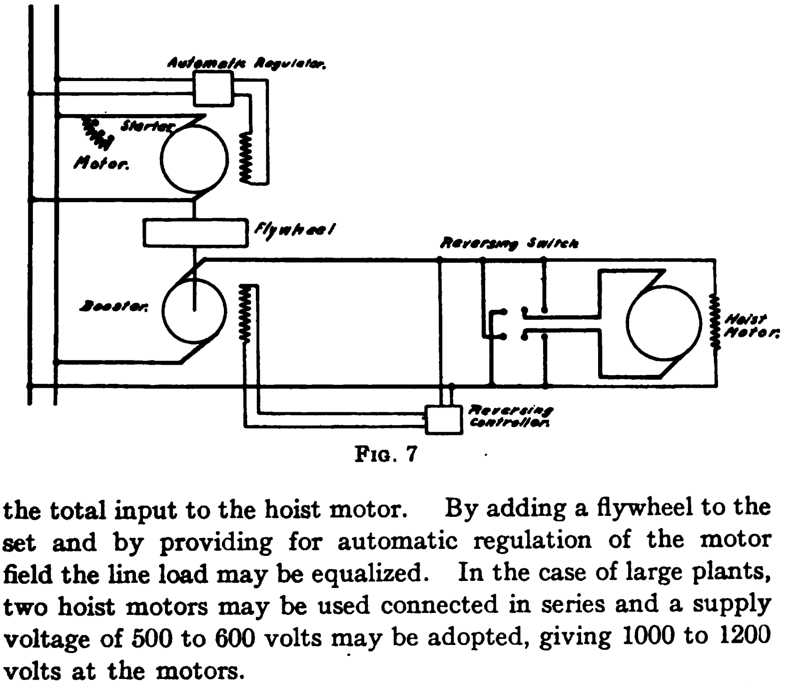

Fig. 7

Characteristics of balancing systems. The load diagram for the hoist motor having been determined as already described, it is used as a basis for the calculation of the dimensions of the fly wheel and the output of the various machines required according to the systems adopted. Dealing first with general principles, it will be noted that the energy in any moving body is

$$E = \frac{W V^2}{2 g}$$

when E = energy in ft. lb. per sec., from which it will be obvious that for any variation of speed the energy given up or absorbed will be proportional to the square of the minimum and maximum velocities, or,

$$E = \frac{W(V^2 - V_1^2)}{2g}$$

when V = maximum velocity in ft. per sec.
V_1 = minimum velocity in ft. per sec.

In the case of a revolving wheel the velocity taken is that at the radius of gyration or the point at which, if all the weight could be concentrated, would give the same effect as when distributed throughout the wheel. This radius is proportional to the square of the distance of the various masses from the center and for a flat circular disk of radius r it is

$$\text{Radius of gyration} = \sqrt{\frac{r^2}{2}} = 0.707\,r$$

With wheels of irregular section the radius of gyration will depend upon the distribution of the weight. It will be obvious that the higher the velocity the greater will be the amount of energy available for a given change of speed, and therefore for a certain output the weight will be reduced as the square of the increase in velocity. For this reason balancing systems are provided with flywheels running at a high peripheral velocity, the limit being fixed by the class of material used. In Europe cast steel has been almost exclusively used, one or two steel manufacturers having made a specialty of this type of casting to withstand the stresses due to centrifugal force. Small cast steel wheels have been built for peripheral speeds up to about 23,000 ft. per min., but for large wheels, on account of the difficulty of obtaining sound castings, the limit is in the neighborhood of 17,000 to 18,000 ft. per min. By carefully designing such wheels the radius of gyration may be made somewhat greater than that of a plain disk and the average of a number of cases worked out by the author gave the value of 0.78 r.

It will be understood that the permissible stresses in a cast steel wheel must be lower than those of a mild steel plate on account of the uncertainty as to the quality of the casting and the difference in the strength of the two, since with the latter, if the thickness is not too great, a perfectly homogeneous material can be obtained. For this reason the author has used flywheels built up of ordinary commercial steel plate. As the strength of the material and the stresses may be accurately determined it is quite permissible to run such wheels up to 24,000 or 25,000 ft. per min., if desired, without the stresses exceeding more than about half the elastic limit. Although the radius of gyration of such a wheel is somewhat less than that of a well-designed cast steel wheel, the increase in velocity permissible more than compensates for this difference. In plants already installed, speeds of about 22,000 ft. per min. have been used because it was not desired nor necessary to go higher, but when the weight of the wheel is limited by considerations other than running economy, there is no reason why the higher limits given should not be used with perfect safety. Comparing a cast steel wheel having a peripheral velocity of 18,000 ft. per min. with a disk running at 22,000 ft. per min. this ratio of the weights, assuming the radii of gyration to be 0.78 and 0.707 respectively, will be

$$(18{,}000^2 \times 0.78) : (22{,}000 \times 0.707)$$

or

$$1 : 1.35$$

It will be seen that under ordinary circumstances a plain disk will weigh about 74 per cent of a corresponding cast steel profile wheel, and since the cost per pound is little, if any, higher, when the difference in weights is considered, the built-up wheel is actually cheaper.

In order to determine the weight of the flywheel required to equalize any given load, it is necessary to determine the amount of energy which it must give out each hoisting cycle. In the case of the Ilgner system, the load on the driving motor will be made up of the output of the hoist motor plus the losses in both the motor and generator, so that in order to maintain the line load constant the flywheel must take care of all the excess of input to the generator above the mean value. The input diagram for the generator is easily obtained by taking the main points of the hoist motor diagram and adding the various losses corresponding to these points. For the sake of convenience the losses in the hoist motor and the generator may be assumed to consist of two parts; one, due to iron losses, friction and windage being constant; and the other, due to the copper and brush drop, varying with the square of the load. The excitation is provided for separately and need not be considered when determining the generator input.

It should be noted that the power diagram and not the torque diagram must be taken as a basis, as the actual input to the hoist is the product of the torque and speed, being zero at the beginning of the trip and a maximum when full speed is obtained When a motor is rheostatically controlled the difference between the power and torque diagrams is absorbed by the resistances,

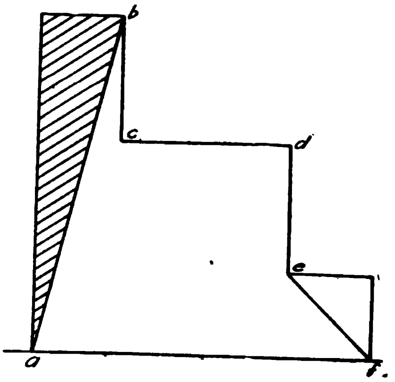

Fig. 8

but with voltage control these losses are obviated. In Fig. 8 which is a load diagram for a Koepe hoist, the shaded portion represents the loss due to rheostatic control, and the area enclosed by *a b c d e* and *f* the power diagram.

The most convenient method for calculating the losses is to plot a curve made up as above, which can easily be done when the characteristics of the machines which it is intended to use are known. The load diagram will be a sufficient guide as to the size of the hoist motor and the generator, the latter being taken as about 10 per cent larger than the former. When, as is frequently the case, the hoist returns energy to the system during retardation, it should be noted that the losses in the two machines must be subtracted from the values obtained from the load diagram. The input diagram for the generator having been determined, the mean output of the three-phase motor is readily obtained. From the various loads and the times that they are applied, the total input per trip in horse power seconds is found, and if this value is divided by the total time required for one trip, including the period of rest when loading and unloading the cages, the average input is found. Taking this as the motor output for the time being, the loads in excess of this value will have to be taken by the flywheel. If energy is returned to the system by the hoist this value must be subtracted from the total before determining the mean input. Referring to Fig. 9 the line *a b* represents the mean input to the generator and the shaded portion the fly wheel output. It will be obvious that as the mean load is carried by the motor, the same amount of energy will be imparted to the flywheel during the periods when the demand is below the average as is given up during the time when it exceeds this figure. Therefore at the end of the cycle the flywheel will be running at the full speed again. Taking the flywheel output in h.p. sec., as found from the input diagram the weight required will be

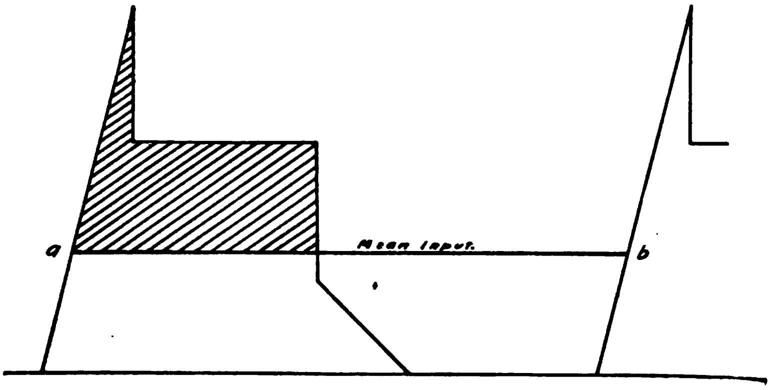

FIG. 9

$$W = \frac{E' \times 550 \times 2g}{V^2 - V_1^2}$$

when W = flywheel weight in lb.
E' = flywheel output in h.p. sec.
g = 32.2.

V = maximum velocity at radius of gyration in ft. per sec.

V_1 = minimum velocity at radius of gyration in ft. per sec.

The flywheel output is multiplied by 550 to reduce it to ft. lb. sec. The actual output of the three-phase motor will be the mean load as found from the diagram plus the losses due to windage and friction of the flywheel, the average slip regulator loss which is equal to half the maximum slip, and the power required to drive the exciter. The friction of the flywheel bearings is readily found when the size of the bearings is known, an average value for the coefficient of friction being about 0.004. The windage loss is not easy to determine but from a number of experiments made by Dr. E. Becker in Germany on wheels varying from 6 ft. 6 in. to 14 ft. 6 in. in diameter and 4 in. to 31 in. wide, the weights being from 3 to 50 tons and the peripheral speeds 18,000 to 21,000 ft. per min., the following result was obtained,

$$\text{h.p.loss} = 0.0513\, V^{2.5} \times 0.093\, D^2\, (1 + 0.465\, B^2)\, 10^{-5}$$

for smooth surface wheels.

when V = peripheral velocity in ft. per sec.
D = diameter in ft.
B = width in ft.

The wheels tested gave results corresponding so closely to the above that it would appear to be fairly reliable.

In the case of the converter system only the part of the load diagram above the mean value is to be considered, the remainder having no influence on the balancing plant. Taking the loads in excess of the mean value found from the load diagram plus the hoist motor losses the actual output of the flywheel will be this amount plus the losses in the converter and equalizing machine, which must also include the excitation. The flywheel weight is then determined in the same way as with the motor generator system. It should be noted that the average input to the motor must include the rheostatic losses at starting or, in other words, the torque diagram must be taken and not the actual power diagram, as with the Ilgner system. The real demand on the line will equal the average found as above, plus the losses in the equalizing system which are caused by the double conversion, and the flywheel windage and friction. In the case of a motor generator system with a direct current driving motor, there is no loss due to the slip regulator, because all the regulation is in the motor field and the loss is negligible. With the converter system applied to a direct current plant there are no converter losses. These two systems contain the principles of all other equalizing arrangements and the same methods here indicated can be used for determining the characteristics of the different parts of any proposed system.

Economy of electric hoisting. When considering hoisting installations it is difficult to make any generalizations as to the economy, for each case must be considered separately. When mines have a power station already installed it is undoubtedly cheaper to adopt an electric hoist, even if it means an extension of the generating capacity, on account of the lower operating expenses and attendance, but whether it is better to have an equalizing system or not will depend on conditions. If the hoist is comparatively small possibly it will affect the total load very little. In the case of deep metal mines the hoisting load will usually be found to be quite a large proportion of the total, increasing with the depth. In order to obtain the benefits of an electric hoist in such a case, it is necessary to use some equalizing system to increase the load factor, and when this is done the hoisting cost per ton of material handled can be brought to a very low figure. When the costs of hoisting with a simple non-condensing steam plant and with an electric hoist are compared, the latter is undoubtedly the more economical, but when it is a question of using a modern compound condensing steam hoist with automatic cut off, a little more consideration is necessary. Under certain circumstances such a steam plant may have lower costs, but there are very few instances which, when properly investigated, do not show that the electric plant, if properly designed, is the more advantageous. In making comparisons care should be taken to avoid using any theoretical cycle as a basis, for the only true ground to work on is the actual duty over a considerable period, taking into consideration the time when the hoist is idle, as well as when it is running. With an ordinary plant the actual useful work done may be from 50 per cent to 75 per cent of the possible output, depending on the circumstances. This may be to the advantage of the electric plant or otherwise. The load factor of an electric plant is the ratio of the mean input to the maximum, and the effect on a generating plant will depend on the other power requirements and the load factor. If, for instance, the general load is 500 kw. and the load factor is 50 per cent, the generating capacity required is 1000 kw. The addition of a hoisting load of, say, 300 kw. with a load factor of 33 per cent will increase the required capacity to 1900 kw. and will reduce the load factor to 42 per cent. If, by means of an equalizing system, the hoisting load factor is brought up to 80 per cent, the total load factor will be 65 per cent. The cost of power with different load factors may be readily obtained if records are kept of the various items entering into the total. With a steam-oper-

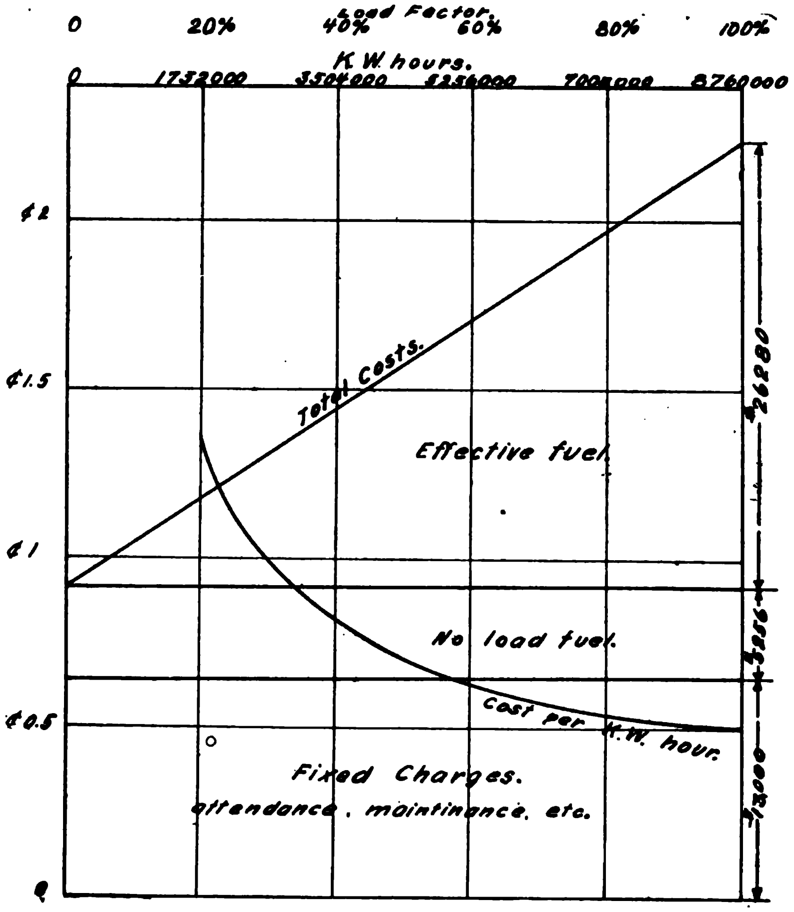

FIG. 10

ated generating plant the total cost will be made up of fuel, water, oil and waste, interest, depreciation, attendance, maintenance and repairs. Practically the first two are the only ones which vary with the load and a certain proportion of them is also constant. As an approximate guide, it may be considered that the fuel consumption when running idle will be about 20 per cent of the full load value and the water about the same. The remaining four-fifths will vary directly with the load so that we have a condition represented by Fig. 10. Suppose, for example, a plant of 1000 kw. capacity, the capital cost of which installed is $80 per kw., the coal consumption at full load being 2½ lb. per kw. hr., the cost being $3 per hr. With interest at 5 per cent and depreciation also 5 per cent and maintenance, stores and attendance at $5000 per year, the total fixed charges will be $13,000. Assuming that water is free, the coal required, running light or a basis of 24 hours per day, is about 1752 tons, which at $3 amounts to $5256 per year, making the total constant charges $18,250. The capacity of the plant when running at full load continuously will be 8,760,000 kw-hr. per year and the effective fuel required to produce this output is 8,760,000 × 2 = 17,520,000 lb. or 8760 tons, costing $26,280. This together with the fixed charges makes a total of $44,536, giving a cost per kw-hr. of 51c. With 50 per cent load factor the effective fuel consumption would be 4380 tons, costing $13,140, and the total running cost $31,396. The output would be 4,380,000 kw-hr. per year so that the cost per kw-hr. is 72c. In this way a curve may be readily plotted and it will show how a balancing system reduces the cost of power by increasing the load factor. The above method is not absolutely correct, since other factors enter into the running costs, but it is sufficiently close to enable a fairly accurate estimate to be made, for any particular case. In order to find the average load factor for the hoist the total consumption per trip must be taken as a basis. In the case of a balancing system the input may be considered as being made up of two parts, one being constant, representing the light running losses, and the other the total per trip minus this value. Supposing, for instance, that a plant is designed to equalize completely the load on the basis of 30 trips per hour, the input being 10 kw-hr. per trip and the light running losses of the motor generator set will be about 20 per cent of this figure, or 60 kw-hr. per hour. As designed, the load factor is 100 per cent, but if the average number of trips is 20 per hour the total consumption, instead of being 300 kw- hr. is $60+20\times8 = 220$ kw- hr., and the load factor $\frac{220}{300} = 0.73$. From the daily or weekly output the real load factor of the plant may be obtained in this way and the actual running costs may be ascertained. When dealing with a steam plant the same methods must be adopted and it will be found that the losses when the plant is idle are often very great, and, although on a certain definite cycle the running cost may be worked out to a figure which approaches that of the electric plant, the average economy might be very much lower. The actual power consumption of a well-designed electric plant with a motor generator equalizing set has been found from a great number of tests to be about 1.6 to 1.7 kw. per shaft horse power, and for a plain hoist without any equalizing system, about 1.25 kw. is a fair figure. When considering the running costs the transmission losses must be taken into account. With an electric plant the line losses will be as a rule small, but with a steam hoist the condensation in pipes, etc., is generally appreciable.

In conclusion, it may be well to draw attention to a few advantages of electric hoists from an operating standpoint. The most important is the complete control afforded over the hoist when running, enabling the operator to work much quicker and with greater certainty. The ease with which the braking can be taken care of electrically makes it possible to manipulate the hoist with the greatest precision, the mechanical brakes being used only for holding the load. Under certain circumstances energy may be returned to the system by the hoist, which reduces the power consumption, but the main point is that it obviates the excessive wear on the brakes which would otherwise have to absorb this energy. Electric hoists may be fitted with devices for automatically reducing the speed and preventing overwinding, which are absolutely certain in their action, and on this account the authorities in Germany allow men to be hoisted at a speed up to 2000 ft. per min., whereas, with steam hoists the limit is fixed at 1000 ft. per min. An electric motor is a very simple machine and requires considerably less attention than a steam engine needs, and the splendid service which it gives under the most severe conditions disposes of any question as to its reliability.

DISCUSSION ON "LARGE ELECTRIC HOISTING PLANTS", NEW YORK, MARCH 11, 1910

Edward J. Cheney: In connection with the torque diagram shown in Fig. 1 of his paper, Mr. Sykes gives a formula for computing the motor horse power. The evident intention of this is to reach the root-mean-square value of the cycle. This formula is not mathematically correct because the mean square of a sloping line is not one-half the sum of the squares of each end. The expression should be,

$$(a)\ HP = \sqrt{\frac{\frac{HP_1^2+HP_2^2+HP_1 HP_2}{3}\times t+\frac{HP_3^2+HP_4^2+HP_3 HP_4}{3}\times t_1+\frac{HP_5^2+HP_6^2+HP_5 HP_6}{3}\times t_2}{T_1}}$$

which holds good for all cycles, whereas the formula given in the paper is correct only for cycles with horizontal lines, such as Fig. 2, and is considerably in error where the lines have as much slope as in the usual hoisting cycle.

Ordinarily t and t_2 are small compared with t_1, and consequently $H\,P_1$ and $H\,P_2$ are nearly equal, and $H\,P_5$ and $H\,P_6$ are nearly equal, and the formula given above may be simplified without introducing any appreciable error, to the expression

$$(b)\ HP = \sqrt{\frac{HP_a^2\times t+\frac{HP_3^2+HP_4^2+HP_3\,HP_4}{3}\times t_1+HP_b^2\times t_2}{T_1}}$$

where $H\,P_a = \frac{H\,P_1+H\,P_2}{2}$ and $H\,P_b = \frac{H\,P_5+H\,P_6}{2}$

After having found the correct root-mean-square value it does not follow that this should be the motor rating. As Mr. Sykes points out, the heat is not carried away at the same rate all the time, the reason being that at standstill and at the reduced speeds of acceleration and retardation, the ventilation is less than at full speed. Now a motor rating is ordinarily taken to mean the rating at which the motor will operate continuously at full speed with a given temperature rise, and apparently this is a very convenient basis and worth maintaining. In order to put hoist motors on this basis and make them comparable with other types they should have such a rating that when operated continuously at full speed at that rating they would have the same temperature rise as when operated on the normal hoisting cycle.

The root-mean-square value of the cycle as determined from the above formula must, therefore, be corrected by such a factor as shall represent the difference between the average dispersion of heat over the cycle and the dispersion of heat at full running speed. This factor depends upon the relative amount of time at reduced speeds, and also upon the relative importance of ventilation and conduction in cooling effect, and so upon motor speed and general design. It will be readily apparent that a high speed motor is more dependent upon ventilation than a slow speed motor, and the compactly built induction motor more than the comparatively open direct current motor.

The designer must, therefore, determine this factor in individual cases, but for a general approximation it may be taken that the cooling during acceleration and retardation is 75 per cent, and during standstill 50 per cent of that at full speed. From expression (**b**), we would then derive the following expression for the correct horse power rating of motor:

$$\text{(c)}\ HP = \sqrt{\frac{HP_a^2 \times t + \dfrac{HP_3^2 + HP_4^2 + HP_3\,HP_4}{3} \times t_1 + HP_b^2 \times t_2}{.75\,t + t_1 + .75\,t_2 + .5\,t_3}}$$

where t_3 = time at standstill.

As the generator runs at nearly full speed all the time, no such correction need be made in its rating, and instead of being 10 per cent greater than the hoist motor, as stated by Mr. Sykes, it will very frequently be actually less. In a flywheel set, the motor of the set has no peaks to increase its heating, and so we may have the rather amusing case of a motor driving a generator of greater rating, which in turn supplies power to a motor of still greater rating. Apparently in such cases the efficiency has somehow become reversed, but really the ratings are perfectly logical when properly viewed.

In considering the converter equalizer as compared with the Ilgner system, it must be admitted that in the latter, the flywheel set transforms all the power, while in the former, the flywheel set only transforms the fluctuations above the mean. It must, however, be borne in mind that in the Ilgner system, the power is only transformed once, while in the other system, the excess power must be taken through the transformers, converter and equalizer to the flywheel and, later on, taken back again in reverse order to the line. With very peaked cycles, such as we usually have, this means that the converter and equalizer are not so small compared with a motor generator set. The flywheel must store more energy in the converter system, because the rheostatic losses of the induction hoist motor add to the peak. Taking these facts into consideration, and after a careful comparison of the two systems under various conditions, we must take exception to Mr. Sykes' statement that the converter system is the cheapest to install.

As Mr. Sykes points out, the rheostatic losses of the induction hoist motor with the converter system must be balanced against the losses in the slip regulator of the Ilgner system. Here, also a comparison of typical cycles will show the Ilgner system to have the advantage. The real argument in favor of the converter equalizer system seems to be the fact that the hoist is not dependent upon the flywheel set, and even this fails when the generating station is too small to handle the hoist without a balancing system. The converter system also has some advantages where more than one hoist is to be equalized, but where several hoists are operated the diversity factor may be depended upon to smooth out the line load, and a balancing set is hardly necessary.

A paper presented at the 245th meeting of the
American Institute of Electrical Engineers,
New York, March 11, 1910.

TESTS OF AN ILGNER ELECTRIC HOIST

BY R. R. SEEBER

In the copper mining district of northern Michigan a fair-sized mine usually operates two or more shafts along the strike of the lode, these shafts being usually at least a thousand feet apart. The tonnage to be hoisted from each shaft is large, —from 13,000 to 25,000 tons per month. The hoisting engines used are generally steam-driven, non-condensing, duplex engines with Corliss valves, supplied by steam from separate boiler plants where the distance between shafts is great.

In an attempt to centralize power plants and secure central station economies, the Winona Copper Company installed an electric hoist of the Ilgner type, with Ward Leonard control. A brief description of this plant appeared in the *Engineering and Mining Journal* of July 19th, 1909 . The only point of variation from the simple Ilgner set lies in the connection of two generators to a single induction motor by flexible couplings. These generators serve motors which operate hoisting drums at separate shafts viz. No. 4 shaft Winona, and No. 1 shaft, King Philip. The hoist for No. 4 shaft is about 1,700 ft. from the power plant and in this building the motor-generator set is placed. No. 1 King Philip hoist is 1,500 ft. from the motor-generator set. The equipment of the motor-generator set is as follows:

In the middle of the set is a 12-pole, 450 h.p, 600-rev. per. min. 2,080-volt, three-phase, 60-cycle, variable-speed, induction motor, connected on each side to a 20-ton flywheel which is 10 ft. in diameter, and to a 6-pole, 170-kw, 575-volt, interpole, direct-current generator. On each side of the shaft is placed a separate exciter which delivers current at 125 volts. The lubrication of the four main bearings that support the flywheels and direct-current generators is supplied by two sets of oil pumps, belt-driven from the shaft.

The hoist motors are 6-pole, 200-h.p., 430-rev. per. min. 550-volt motors, and are shunt-wound. The fields, both of this motor and the direct-current generators are excited by current from the exciter on the motor-generator set, which is kept at a constant voltage of 125 by voltage regulators. The current in the hoist motors is varied and reversed through controllers of the usual railway type, placed in the field circuit of the generators. The first point on the controller operates a contactor which closes the main circuit from the generator to the motor.

The alternating current for operating the motor-generator passes through a regulator which automatically varies the resistance in the rotor of the motor-generator set in proportion to the demand of the motor for current.

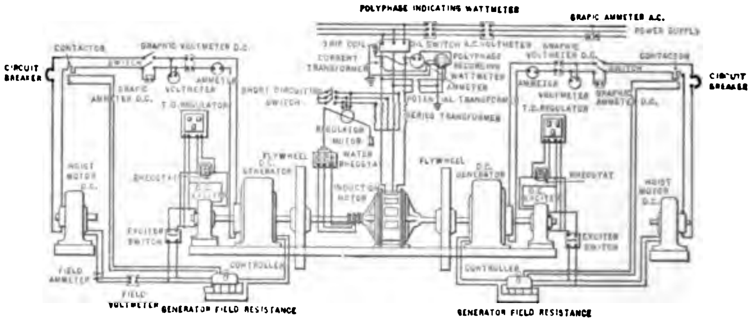

FIG. 1.—Diagram of connections of motor-generator set

During February, 1910, detailed tests of this set were made to determine the performance under varying conditions, and to procure coal-to-rock ratios to compare with ratios for steam hoists under similar conditions.

On the switchboard controlling the set, the following instruments were already installed:

Alternating current indicating ammeter.
Recording wattmeter.
Direct-current ammeter and voltmeter for each direct current generator.

In addition for the purposes of this test, the following instruments were installed, as shown on the diagram Fig. 1:

Two 600-0-600 direct current graphic voltmeters, one in each generator circuit.

Two 800-0-80 direct current graphic ammeters, one in each generator circuit.
One 125-ampere alternating current graphic ammeter.
One 125-volt direct current indicating voltmeter.
One 100-ampere direct current indicating ammeter.
One indicating wattmeter with necessary current transformers.
One 600-rev. per min. tachometer.

No. 4 shaft Winona is served by the hoist drum in the same building as the motor-generator set. This is an old duplex steam hoist, with the cranks disconnected. The motor drives the old crank shaft through gearing. The drum is seven ft. in diameter and holds 1,500 ft. of rope. The rope is 1⅛ in. in diameter and weighs two lb. per ft. No. 4 shaft is double-compartment and the skips work in balance. Because at present very little hoisting is being done in this shaft, only the south skip is used for loads and the north skip carries 2,100 lb. of rock to lessen the starting moment. At the time of the test the north skip had filled with ice, so that the total counterbalancing weight was 3,300 lb. This caused more power to be used for the lowering of the south skip than for hoisting it. The loaded skip weighed 5,400 lb. Of this amount, 3,300 lb. is counterbalanced leaving only 2,100 lb. of rock and the hoisting rope as the net load.

No. 1 shaft King Philip is operated by an old geared steam hoist, with the cranks disconnected and the crankshaft geared to the motor in the same manner as at No. 4 Winona. The drum is five ft. in diameter and holds 1,200 ft. of one-inch rope, weighing 1.58 lb. per ft. The shaft is built with two compartments but only one skip is running, leaving the hoist unbalanced.

The skips in both shafts are the same and weigh 2,900 lb. each. Each holds 2.7 tons of rock when full. The test was conducted under normal working conditions and the loads varied. During the time of test, a man was stationed at the brace of each shaft to observe the fulness of the skips. The average distance of the rock from the top of the skip was estimated for each load and a correction was applied.

The work at present being done at these shafts is comparatively small, because only development work is under way. Since all reliable information that I had concerning the operation of steam hoists was at a hoisting rate of 12,000 to 15,000 tons per month, we arranged to hoist from each shaft for an hour at near this rate. During all this time the curve-drawing instruments were in operation and gave accurate records of each operation. Readings of the alternating-current wattmeter, voltmeter, and ammeter were taken every five seconds. The starting and stopping time of each of the hoist movements was taken, and the nature of the load recorded. The speed of the motor generator set was taken at regular intervals.

The following tabulations show the levels from which rock was hoisted during this one-hour test, also the total number of skips, total rock hoisted from each level, the average load, the distance from the level to the dump on the incline of the shaft, 70 deg. and the product of load and distances; also totals and averages. This rate of hoisting corresponds to about 19,000 tons per month or rather more than the rate of the steam hoists with which it is compared.

WINONA SHAFT

Level	Skips	Load		Distance	Load distance
		Tons	Average		
9th	5	11.9	2.4	918 ft.	10924
10th	4	10.2	2.5	1018 ft.	10384
11th	4	10.2	2.5	1118 ft.	11403
12th	3	7.7	2.6	1218 ft.	9379
	16	40		1052 ft.	42090 At 600 ft. equivlent to 70.15 tons

KING PHILIP SHAFT

Level	Skips	Average load		Distance	Load-distance
		Tons	Average		
5th	1	2.0	2.0	425′	850
6th	6	13.2	2.2	524′	6917
7th	—	—	—	623′	—
8th	5	10.2	2.04	729′	7436
9th	3	4.95	1.65	832′	4119
10th	4	9.45	2.36	932′	8807
11th	—	—	—	1034′	—
12th	3	7.4	2.5	1135′	8399
—	22	47.2	2.15	Average 774	36528 At 600′ equivalent to 60.88 tons

Adding the total tons hoisted at Winona to the total tons hoisted at King Philip during the same period gives an equivalent of 131 tons hoisted from a depth of 600 feet in a 70-deg. incline. The total kilowatt-hours taken by the motor-generator set during this hour was 211. This output was determined by reading an indicating wattmeter every five seconds and taking the average. The power necessary to hoist one net ton of rock from a depth of 600 ft. on the incline was 1.61 kw-hr.

Tests of our power plant, under present light-load conditions, have shown that it requires about four pounds of coal to produce one kilowatt-hour delivered on the switch board of the motor-generator set. The amount of coal required to hoist a ton from this distance is therefore 6.44 lb. giving a coal-to-rock ratio of 1 to 310.

Winona........ 70.15 tons
King Philip.... 60.88 "
131.03 " hoisted at 600 ft. depth on 70 deg.
211 kw-hr. taken by set.
1.61 kw-hr. per ton.
6.44 lb. coal per ton at 4 lb. coal per kw-hr.
Coal-to-rock ratio = 1 to 310.

For purposes of comparison with the steam hoist conditions, I have tabulated the results in rock hoisted and kilowatt-hours taken by the motor-generator set for an average day.

16 hours 211 kw. = 3,376 kw-hr.
4 " 80 kw. = 320 "
1 hour 55 kw. = 55 "
Total of 3,751 kw-hr.
3 hours shut down.
Total of 24 hours.

Rock is hoisted during but 16 hours of the time, making the total rock hoisted for both shifts 2,096 tons; or 1.79 kw. hr. are required to hoist one net ton of rock from a depth of 600 ft. on a 70 deg. incline. This makes the coal-to-rock ratio for the above conditions 1 to 279.

The theoretical value of kilowatt-hours per ton hoisted taken from Fig. 21 of the paper presented by Messrs. Rushmore and Pauly* is 1.7 kw-hr. Taken from the curves in Fig. 22 for the 8,000-ft. hoist, this value is 1.55 kw-hr.

At the D shaft of the Champion Copper Company, a 24-in. by 60-in. duplex Corliss engine operates a double conical hoist drum. The shaft inclination is about 70 deg. the skips working

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* A. I. E. E. TRANSACTIONS, 1910, page 284.

in balance. The boiler plant supplies the rock house engine and dry in addition to supplying the hoist. For the first four days of November, 1905, the boiler plant supplied the hoist alone. The coal-to-rock ratio for these four days, at 600 ft. average depth, was 1 to 154. Using a percentage of fuel burned for the rock hoisted, obtained from results of this four days' test (68.4 per cent to hoist), the ratio for the remainder of November was 1 to 185; showing gain by better boiler load. For December of the same year on the same basis, the ratio was 1 to 166. The average load of rock was 2.1 tons, the total amount hoisted in a month being about 15,000 tons.

At the Winona mine, No. 3 shaft was operated in June, 1907, by a separately-fired boiler plant. The hoist is a duplex geared hoist with a rolling valve. The shaft is inclined 70 deg. from the horizontal and the skips work in balance. The average load of rock was about 2.1 tons. In June, the coal-to-rock ratio at 600 ft. depth. figured as before, was 1 to 124. In August and September, 1907, this hoist was supplied from a larger plant, the hoist being 15 to 20 per cent of the whole load. The distribution of coal which we made gives a ratio of 175 to 200.

The following tabulation compares these ratios:

Electric hoist, two shafts, Winona; coal-to-rock ratio 1 to 279.
Champion *D* hoist; steam (alone); coal-to-rock ratio 1 to 154.
Champion *D* hoist, with rockhouse; coal-to-rock ratio 1 to 185.
Winona No. 3 hoist, steam (alone); coal-to-rock ratio 1 to 124.
Winona No. 3 hoist, steam, (central plant)—coal-to-rock ratio 1 to 175, to 1 to 200.

I feel satisfied from these figures that, even with steam generated in a central plant, a coal-to-rock ratio of 1 to 200 is about all that can be expected from steam hoists of this type, under the given conditions. This shows a coal saving by the electric method of 25 per cent over the steam method.

Fig. 2 shows the operation of the motor-generator set and both hoist motors for a typical section of about nine minutes length, taken from the one-hour test. The curves here shown will serve to describe most of the operation. The top curve shows the alternating current input plotted from five-second readings of the indicating wattmeter. The average for the nine minutes is 208.25 kw. or slightly below the average input for the hour.

The second curve shows the speed of the motor generator set, the extreme variation being from 440 to 480 rev. per. min. during this period.

The next three curves show the volts, amperes, and kilowatts output of the direct-current generator driving the No. 1 King Philip motor.

The last three curves show the volts, amperes, and kilowatts

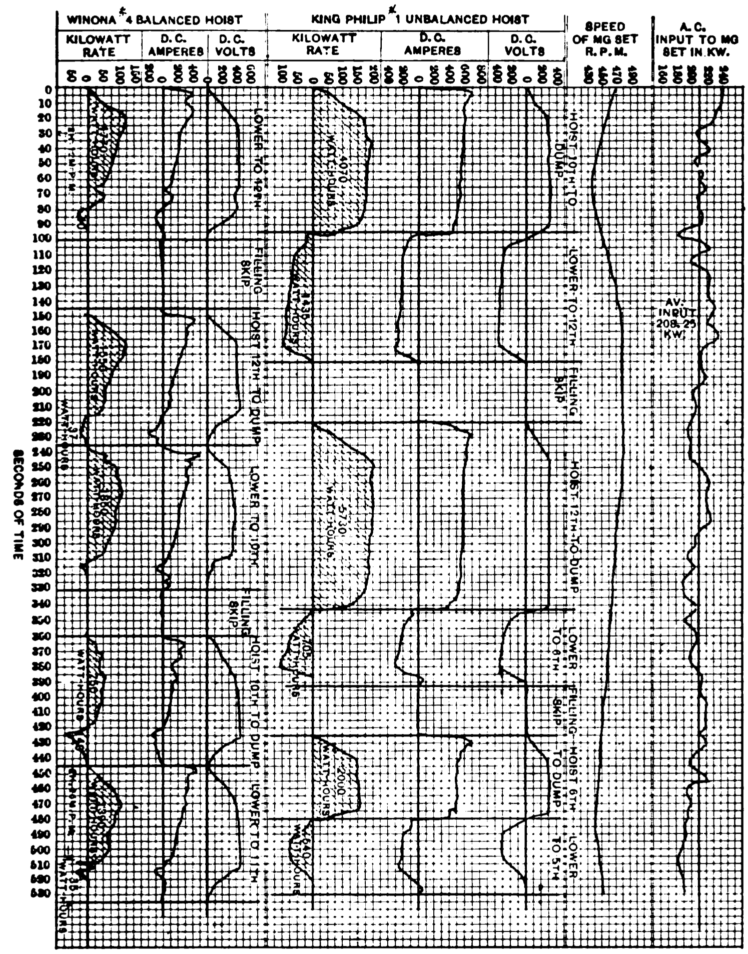

FIG. 2.—Operation of motor-generator set

output of the direct-current generator driving the Winona No 4 hoist for the same period.

Where electricity is used for hoisting, the main reason for using an Ilgner fly-wheel set is to take the peak loads off the power station. How well this is accomplished is shown by comparing the input curve of the diagram with the two curves of direct-current output. Incidentally this method utilizes the energy of a descending unbalanced skip, the motor acting as a generator and restoring energy in the flywheel. For the King Philip hoist, unbalanced, the amount thus restored is comparatively large, varying from 20 per cent to 35 per cent of the energy required to hoist the loaded skip from the corresponding level. This variation is due to variation in the loading of the skips. On the Winona hoist, balanced, the amount of energy thus restored is very small and occurs only when the motor is used as a brake at the close of the hoisting period.

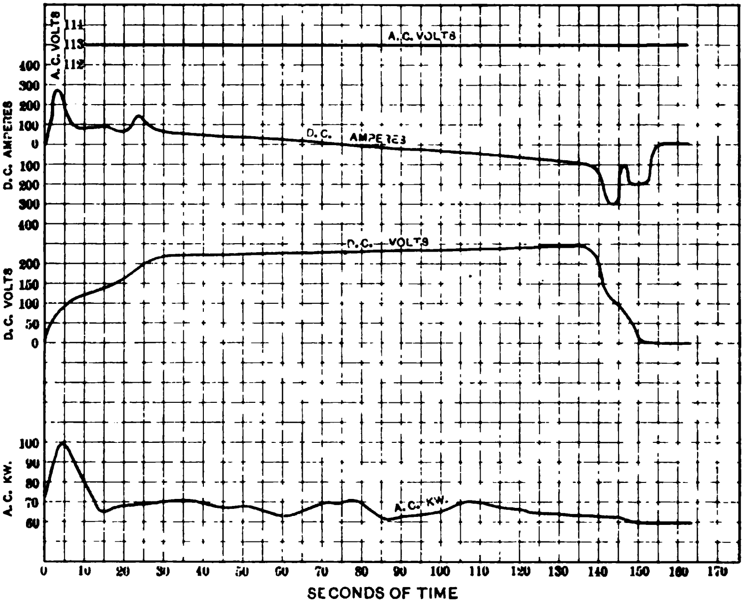

FIG. 3.—Restoration of energy

The restored energy for both cases is shown on the shaded areas below the line. An interesting example of this restoring action is shown (Fig. 3) on Winona No. 4 hoist, where men are being hoisted on the south skip. Energy is required at starting but the demand gradually decreases and at about the 8th level the weight of the descending north skip counterbalances the ascending skip. During the remainder of the hoisting period energy is being stored in the flywheel.

Where a double compartment shaft can be used and the skip and rope can be counterbalanced by duplicates in the other compartment, the counterbalancing skip being ready for a paying load on reaching the bottom, it is obviously not economy of power to use any other system of restoring the energy of the descending skip. The efficiency of any other system will be very low compared to the efficiency of the counterbalancing skip where the only losses are friction and air resistance.

Fig. 4 shows the current output of the King Philip generator when hoisting a full skip from the 12th level, and the energy restored to the set when lowering the same skip still full. This was done twice, as shown.

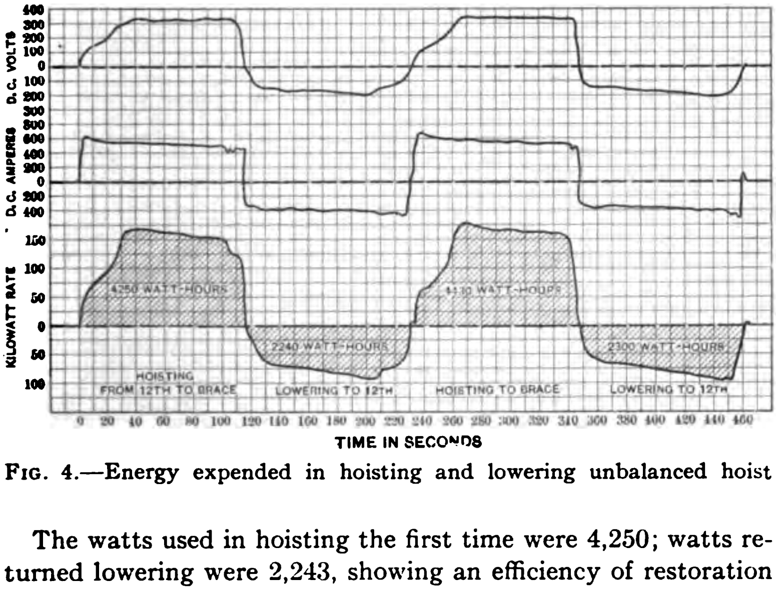

FIG. 4.—Energy expended in hoisting and lowering unbalanced hoist

The watts used in hoisting the first time were 4,250; watts returned lowering were 2,243, showing an efficiency of restoration of 52.8 per cent. The watts used hoisting the second time were 4,430; the number of watts returned lowering the second time was 2,300, showing an efficiency of restoration of 51.9 per cent.

Fig. 5 shows the decreasing speed of the motor generator set, after the power is shut off on Saturday nights. About three hours are required for the set to come to rest.

Fig. 6 shows the acceleration of the skip and the rope speed for the hoisting period.

The greatest disadvantage of the Ilgner system is a constant loss in windage and bearing friction of the motor-generator set

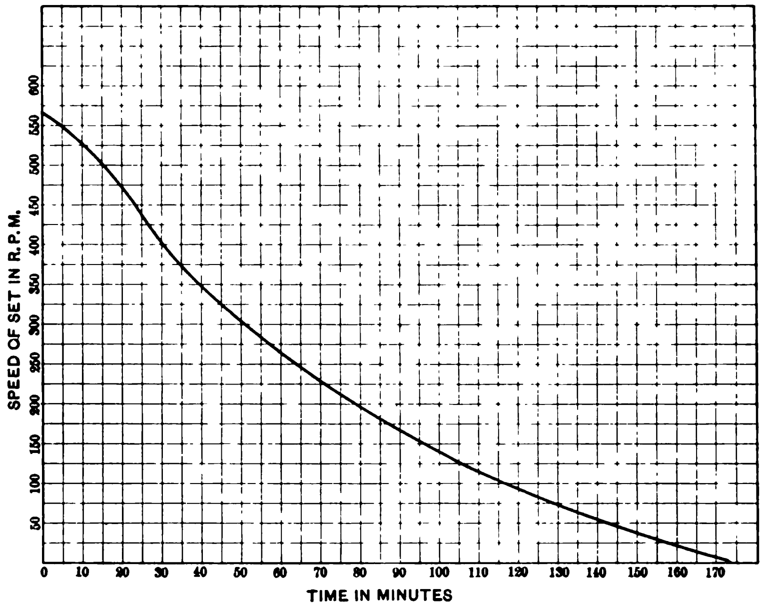

FIG. 5.—Retardation of motor-generator set

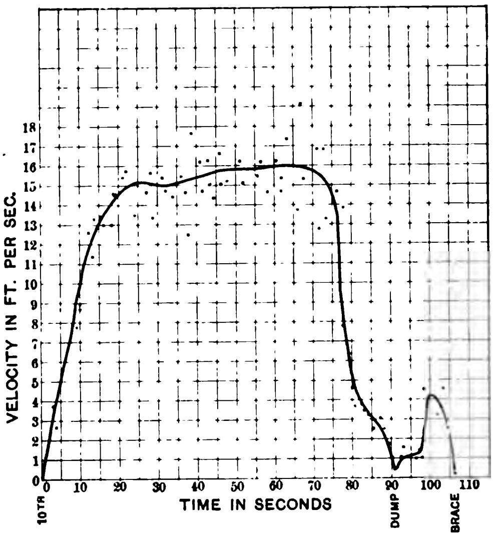

FIG. 6.—Velocities of hoisting

itself. Observations have shown this loss for the set at this plant to be very nearly 55 kw. This loss can be reduced materially by casing the flywheels. When the work done by the hoist is large enough to make the proportion of this constant loss small, an Ilgner flywheel set adds fuel saving to the saving of labor, etc., due to the centralization of the power plant.

The use of this system enables us to dispense with two boiler plants and their firemen. It would have been necessary, also to build larger boiler plants, with railroads and coal trestles to serve them. The hoists themselves handle the skips much better than the steam hoists, starting from rest very smoothly. The large amount of repair work necessary on a reciprocating engine is also done away with.

A paper read before the Philadelphia Section of the American Institute of Electrical Engineers, on March 14, 1910.

THE GENERATING SYSTEM OF AN ELECTRIC LIGHTING COMPANY

BY A. R. CHEYNEY

Under this head it is intended to touch briefly upon a few of the important considerations which may be of general interest relating to the production of electricity. The generating system here spoken of includes everything from the coal at the mine to the outgoing wires from the substations.

The main function of a lighting company is to sell electricity, and in order that it may meet with the success to which it is entitled, two facts must be kept in mind. The generating cost must be kept as low as possible, and the service must be supplied at a uniform pressure, and absolutely without interruption. Two elements are involved in the solution of the problem of cost and reliability; the physical, which follows certain fixed and unalterable laws; and, closely interwoven, the human element, as vital and as far reaching as the physical itself. This close relationship between things material and the human element is a condition that the operator has always with him, and it is most important that his conception of both be kept clear and separate.

Fig. 1 shows in graphic form some of the various details of a generating system and their relative interdependence. From the coal supply at the mine to the wires leaving the substation, one continuous, unbroken chain binds all the parts together The failure of a single link unless properly cared for, may mean the failure of all. Accident to any one of a certain class of the above composite parts may involve the system in difficulty almost instantly, as, for instance, failure of electrical machinery, underground cables, oil switches, etc. Other parts may fail

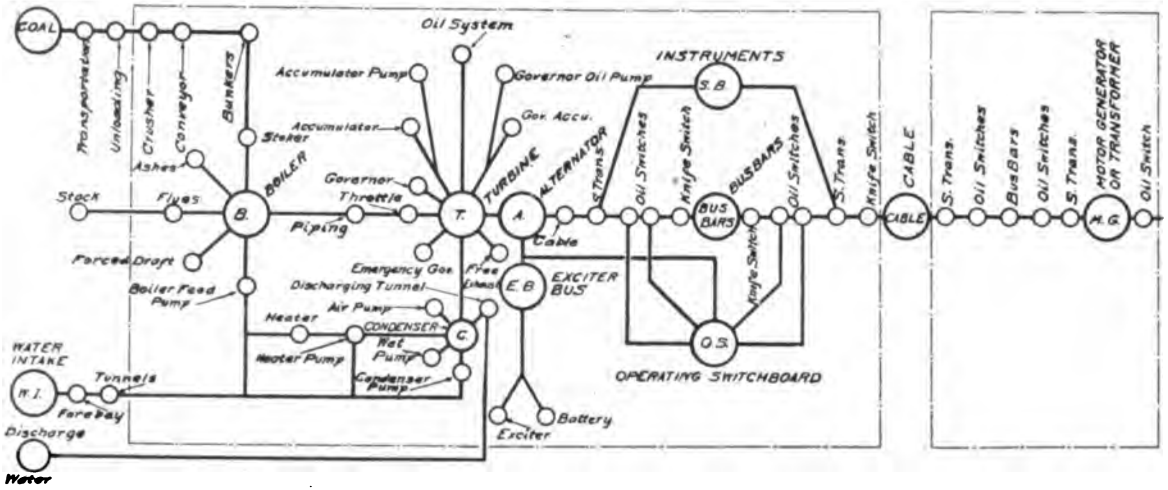

FIG. 1—Diagramatic scheme of connections of generating plant equipment.

and the system will continue to operate for a certain period, and before the danger point is reached repairs may be effected.

In any case, a break anywhere along the line must be immediately cared for. This, with large and heavy machinery, is a different proposition from the repairs to the small plant of a few years ago. Everything, including even many of the wrenches, has to be carried by the traveling crane, which, as a rule, has two hoists, in this instance one of 60 tons, and one of five tons for more rapid manipulation. As it requires a considerable length of time to have repair parts made up, in the case of our large units, it is necessary to keep on hand spare parts to a certain limited extent, at least, in order that the prolonged disablement of a main generating unit of large size may be avoided as far as possible.

If we consider the above diagram to be made out in duplicate or triplicate, properly cross connected, it will readily be seen that the stability of the system is greatly increased. This is what actually takes place in modern central station construction. Certain of the links, such as coal supply, water supply, main station bus bars, etc., as a rule, constitute single links and are depended upon for absolute freedom from trouble.

The best of our modern plants, operating under the most favorable conditions as to load factor, with steam turbines of the latest type, mechanical stokers and superheated steam, delivers about 12 per cent of the energy in the coal to the bus bars. From this must be subtracted the loss in transmission and transformation. The most efficient light known can actually make use of but about 10 per cent of this resultant energy within the range of the visible spectrum, so that we are actually converting into light but about one per cent of the energy in the coal. The efficiency of the electric motor is, of course, higher, in which case our total efficiency would reach possibly eight or even nine per cent.

The matter of load factor, as it affects the generating system, is so radically different in the cases of the gas plant and the electric plant that it is difficult to find enough in common to afford any comparisons. In the gas system, generators may be operated at maximum economy, storing the gas all the while until the demand is made for it. There is, unfortunately, no such thing as storing any small part, even, of the output of a modern central station, other than in the revolving energy of the wheels themselves.

Modern generating systems are all polyphase, and in our large cities the safe limiting voltage is fixed by the insulation resistance of the underground system. It is, of course, advantageous to have a voltage as high as possible, especially when the energy has to be transmitted to considerable distances. An underground cable that can safely carry 1,800 kw. at 6,000 volts is capable of carrying over 3,000 kw. at 11,000 volts. As the expense of the underground cable system is very heavy, this factor must be very carefully balanced against the other factor of the problem, that of absolute safety, if such a thing may be said to exist. Thus, various engineers and companies use different voltages. The Manhattan Company at 11,000 volts operates side by side with the New York Edison Company which uses 6,600 volts. The Commonwealth Company, of Chicago, operates at 9,000 volts, the Philadelphia Rapid Transit Company at 13,000 volts, and the Philadelphia Electric Company at 6,000 volts.

The elements which have most to do with the main station cost are fixed charges, maintenance expense, coal, and labor. Both the fixed and maintenance charges are practically established with the design and construction of the plant. The items of coal and labor, therefore, are the most important of those items which may be affected by proper or improper operating methods, and are the chief factors in determining the generating cost, which, in this case, is taken to include the total cost of the main and substation system. The thermal efficiency of a plant burning a high grade of coal does not differ greatly from that of a plant burning a lower grade, provided both plants are properly designed and operated. If, now, in one station we can deliver, coal to the fire room at $1.00 per ton and in another station it costs $3.00 per ton, uniform excellence of design being assumed, the second station cannot approach the first in generating cost.

While this cost does not by any means fix the selling cost, it is in all cases important, and, where energy is purchased in large blocks, one of the deciding factors. The relation of the generating to the selling cost is clearly shown in published reports of the Boston Edison Company, for the year ending June 30, 1909, filed with the Massachusetts Gas and Electric Commission. (*Electrical World*, September 30, 1909). This is probably a fair example of an average large central station system selling current for both lighting and power. The following table will illustrate the above relationship.

Item	Per cent of total cost
Manufacturing cost	24.60
Purchased electricity	0.02
Distribution cost	15.65
Office expenses, management, etc	15.65
Miscellaneous taxes, insurance fund charges	44.00
	100.00

Further information with regard to the above system might be of interest.

Kw-hr. generated during the year	90,877,123
Kw-hr. sold during the year	62,177,318
Ratio of energy sold to energy generated	68.5 per cent
Coal consumed	95,350 tons, or 2.35 lb. per kw-hr.

The total expense is 12.5 per cent of the total capitalization. The manufacturing cost including main and substations, which is 24.6 per cent of the total cost is subdivided as follows:

MANUFACTURING COST, MAIN AND SUBSTATIONS

Item	Per cent of total cost
Fuel	12.50
Rentals, real estate	0.80
Oil and waste	0.19
Wages at stations	6.18
Water	0.70
Station repairs	0.37
Steam plant repairs	2.11
Electrical plant repairs	1.74
	24.60

It must, of course, be understood that local conditions affect most materially the matter of relative costs. The possibility of reducing certain items of expense or of eliminating them altogether, such as office expense, metering and collecting, etc., has been carefully considered by central station men, and one solution is exemplified in the very low cost to street railway companies, which is given by the Commonwealth Edison Company, of Chicago, which has figured out that with careful engineering a lighting company can depend upon the increase of load factor brought about by a combination of lighting and railway loads to establish a profitable safe selling price below that at which a single plant for either lighting or railway purposes alone could generate it. The price given in the case of certain railway load carried by the Commonwealth Company, as published, is 0.5 cent per kw-hr. plus $15.00 per kw. of maximum demand during the year, sold at the main station bus-bars.

The design and construction of any system is one of the important factors in determining the generating cost. These elements also enter very materially into the question of reliability. It is impossible for a plant of inferior design or construction to compete with one well designed, and efforts made to overcome this constant drawback by more careful and systematic operating methods are always accompanied by increased cost and possibly by chance of interruption of service. Machinery should be installed with due regard to its probable life in service. Any defective or uneconomical machinery should be discarded. A shut-down in a large system is a dear price to pay for the relatively small saving caused by retaining such machinery.

One noticeable feature in the latest station practice would seem to be the introduction of the steam turbine, not only in the case of the main generating units of the plant, but in connection with auxiliary apparatus, such as boiler feed pumps etc. The added simplicity, great reduction in space required and also the fact that these small units combine the facility of handling of the motor-driven with the reliability of the steam-driven auxiliaries, and also that they are fairly economical in the use of steam, goes far towards recommending them for such purposes. They may be operated condensing or non-condensing as required. The steam curve of a certain 90-h.p., high-pressure turbine, using steam at 175 lb. pressure, shows, at full load, 34 lb. of steam per hour, at three-quarters load, 37½ lb., and at half load, 45 lb.

One item which should be carefully considered when any plant is projected is that there should be incorporated in its design provision for periodic testing, for measuring the steam taken by the auxiliaries, for instance, in more or less detail, for running boiler tests, etc. Without this provision, necessary changes in piping and connections in preparation for such a test involve such a considerable amount of labor and annoyance that it is quite probable that little actual testing will be carried on. In any event, the cost of conducting experimental investigations under such conditions will go far towards defeating the very purposes of the tests.

Testing may be made easy, convenient and practical. The fundamental measurements which are necessary are, of course, the weight of coal and water consumed, and the electrical measurement of the station output. The readings of the main output meters of the station should be carefully watched and the instruments regularly checked. In this connection it is important that, if possible, the instruments be checked with their respective series transformers in place. Thermometers should be installed at all important points such as in the steam lines, boiler feed lines, and in connection with the condenser equipment. The absence of proper installation for testing purposes, whether omitted for the sake of simplicity or otherwise, makes it impossible to obtain the best results.

In our modern stations we note that this matter is being very carefully considered, and provision made so that all such investigations may be conducted at a minimum of trouble and expense. The operation of a properly designed modern station thus becomes, in itself, a constant succession of tests. Regular and periodic records are kept covering the items, the information contained in these records being at times very valuable.

Several items incident to economical operation might here be mentioned. The amount of blow-off leakage should be weighed at stated intervals. The blowing down of boilers should also be carefully recorded and should find its place in the analysis of heat losses. Losses due to mechanical inefficiency of auxiliaries should be reduced wherever possible. These become a constant drain on the station, even though at times the excess of exhaust steam is necessary to heat the feed water. It is advisable, therefore, to use high efficiency auxiliaries, mostly steam driven, and, if more steam is needed at times of peak load, or even regularly during the day, to obtain it from other sources, for instance, the second-stage pressure of the steam turbine units may be made use of.

It should be observed that whatever steam is admitted to the heaters should be actually utilized therein. This means that the heaters themselves must be properly cared for and kept in an efficient condition. Exhaust piping should be carefully covered in order to prevent condensation before the steam is returned to the heaters. The condensation of the main steam lines should be known, and occasionally, if possible, it may be advisable to make a test to keep a check upon it. The firing of soft coal is best cared for by stokers, by which means regular and efficient combustion can be maintained, the smoke nuisance is eliminated, and a saving both of coal and of labor, is accomplished. Flue gas analysis is, of course, necessary. The best method of taking samples and of analyzing is still subject to a divergence of opinion. The method of obtaining an integrated sample over an eight hour run on a boiler, or three samples per 24 hours, seems to offer many advantages. The ashes should be carefully weighed and a regular analysis made to indicate the proportion of combustible matter thrown away unconsumed. Every effort should be made to reduce this waste to the minimum and herein is an opportunity for considerable saving in very many plants.

Careful attention must be paid to loading up of the main generating units, and the same applies to the substation machinery. It is frequently good practice to put the next incoming machine on the line rather early, in the case of a rising load, and to take it off early in the case of a load which is going down.

Load factors are more directly affected by the commercial than the engineering departments of the company, yet the question of load factor is vitally important in its effect on station cost. Sufficient men and machinery must be provided to care for the maximum possible load for the day. A thunder storm may raise the load by as much as 100 per cent or more. Boilers cannot be started up at a moments notice nor can auxiliaries or main generating units. It is, therefore, advantageous to install boilers that can be operated economically over wide ranges of load. The saving possible by thus reducing the banked fire losses is considerable. If boilers and other machinery be operated at 100 per cent over rating, it is evident that the machinery in commission could be reduced fully one half in very many instances.

As an example of the above, two specific cases were taken in one of which the boilers were operated so as to carry the peak load of the station at normal rating, and in the other case the boilers were pushed at 100 per cent over rating on the peaks, an additional boiler being carried along as a reserve. The figures representing the coal used under the above conditions are as follows:

CASE 1. Boilers at rating. Total coal burned 210 tons, of which 35 tons were used on banked fires, leaving 175 tons actually consumed in producing steam.

CASE 2. Total coal consumed 181 tons, of which banked fires consumed 11 tons, while 170 tons were used in producing steam. In this particular instance, therefore, a saving of 29 tons, or 13 per cent, in fuel is obtained by pushing the boilers as above stated.

One of the great advantages of certain stokers over hand-fired furnaces under large boilers is the fact that the stokers can continue to operate at heavy overloads for a considerable length of time, whereas, as a rule, firemen cannot be depended on under such conditions except for very limited periods.

To illustrate the load that can be safely carried on a good boiler and to show the advantage of being able to operate a boiler at 100 per cent over rating still more plainly; consider a standard 630-h.p. boiler having 6,300 sq. ft. of heating surface and evaporating 21,750 lb. of water from and at 212 deg. fahr. per hour, or 3.45 lb. per sq. ft. of heating surface per hour. Assuming 20 lb. of water per kw. of plant output, the boiler would carry, at normal rating, a station load of 1,087.5 kw., while at 100 per cent over rating, which, as tests have shown, is not at all impossible under proper conditions, one 630-h.p. boiler would carry a load of 2,175 kw. Figuring from the factors of evaporation, assuming the feed water was being supplied at 180 deg. fahr., and that the boiler was delivering saturated steam at 175 lb. pressure, at 100 per cent over rating, and taking 2,175 kw. as the starting point, we find that by shutting down temporarily on the feed water, or in other words, resorting to the procedure well-known to all engineers of carrying water high up to peak, and leaving the peak with water slightly lower than normal, we can get an output from this same boiler from the energy stored in its own drums in the form of highly heated water, of 19½ per cent additional, or a total of 2,599 kw. This is not given as advocating the practice above mentioned, although without doubt it has probably saved more than one plant from a shut-down. The practice may be a dangerous one in a large plant. The point is, if such an increase in boiler output can be obtained by this means, it is one of the factors to be considered in the designing of our new boilers.

It is hoped, however, that the necessity for this procedure may never exist when the ideal station boiler is designed. Very many tests have been made on boilers at over rating in which very high efficiencies have been reached over wide ranges of load. In one instance at hand, a water tube boiler was operated at from 130 per cent to 190 per cent of rating with a very slight drop in efficiency.

Two factors entering seriously into the problem of reliability are the necessity for an interrupted coal supply, and also an ample supply of water for the condensers and the boiler feed pumps without chance of interruption, at all seasons of the year, and under all river and tide conditions. The lack of proper water supply is one of the reasons why the culm banks of our state have not been put to further use. The amount of water necessary in a plant of 50,000 kw., assuming 20 lb. per kw. and, in summer, 50 lb. per lb. of steam condensed, would be 50,000 $\times 20 \times 50 = 50{,}000{,}000$ pounds of water per hour.

The variation in temperature of water used for condensing, due to change in seasons is considerable. Thus, not only is a very much larger amount of water necessary at certain seasons than at others, in order to obtain high vacua, but circulating pumps must be installed either in duplicate, or adapted to variable speeds, in order to care for this condition. The average temperature of the water taken from the Schuylkill River for the past year was as follows:

1909	Monthly average
January	37 deg. fahr.
February	40 " "
March	43 " "
April	54 " "
May	64 " "
June	74 " "
July	80 " "
August	79 " "
September	75 " "
October	64 " "
November	53 " "
December	38 " "

Highest temperature . . . . 84.4 deg. fahr. July 2, 1909
Lowest temperature . . . . 34.2 " " February 2, 1909

Every station should have worked out and kept in a conspicuous position—for instance, framed and hung over the desks of the chief operating men—a standard table of heat losses covering the best results that could reasonably be expected from the plant under the most favorable of conditions. This would then become an encouragement to endeavor to reach in practice the limits which theory has established. A plant operating without any detail knowledge of its heat expenditures works under a great handicap. Many of the items of heat expenditure are easily obtained. They are of very great assistance in reducing unnecessary plant losses. The following comparison between the results obtained in the large turbine station of the Commonwealth Company, of Chicago, and the reciprocating plant of the Interboro Rapid Transit Co., of New York, both of which sets of figures have been published at length and frequently quoted, is of interest.

	Commonwealth Co.	Interboro R. T. Co.
	Boiler Room Losses	
Refuse in ash pit	3.0	2.4
Rejected to stack	19.6	22.7
Radiation and unaccounted for	8.0	8.0
Banking fires	5.6	
	Engine Room Losses	
Rejected to condenser	48.1	60.1
Total boiler room losses	36.2	
Total turbine room losses	51.8	
Delivered to bus bars	12.0	10.3

We note in the turbine plant that the percentage of total heat rejected to the condenser is much lower than that in the reciprocating plant, the figures being 48.1 and 60.1 respectively. This would indicate, with equivalent boiler conditions, a greater mechanical efficiency for the turbine than for the reciprocating unit. This suggests the condensing equipment. It is extremely important that the condenser installed be of the highest possible efficiency and also that it be capable of producing a high vacuum at the time of peak load on the station in order that the boiler output may be reduced to the smallest amount possible at that time. The differences in temperatures between the exhaust of the main generating unit and the discharge water of the condenser should be as low as possible.

It frequently becomes necessary to depart slightly from conditions of maximum economy in order to give proper insurance of uninterrupted service. Under no conditions can we afford a general station shut-down. It is, therefore, generally necessary during the day and up until after the evening peak, say 11 o'clock at night, to have always available on the line an extra generator in the main station. This, in a turbine plant, is very easily accomplished by bringing up a machine to full speed, synchronizing and throwing it on the line. Closing the throttle valves then gives a machine as a motor ready for instant service merely by opening the steam valve. Steam saved by thus operating the turbine is considerable, as the remaining units may be kept at full load. It is, of course, necessary that the turbine should be allowed sufficient steam at certain intervals to keep it warm.

A first reserve unit in addition to those kept on the line, is always kept in readiness, as far as possible, with oil turned on and the condenser pump in operation ready for turning over of the main unit at a moment's notice. With regard to the substation machinery and apparatus, it is advisable that at times of heavy load this be operated well loaded rather than underloaded, thereby reducing the load at the main station as much as possible.

Another matter which has lately been claiming recognition is the regular and systematic keeping of temperature records of all electrical machinery, particularly that which is heavily loaded. One way of caring for this is to install maximum thermometers in all large machines and pieces of apparatus liable to overload, and to take from these regular weekly readings. These readings are tabulated in proper form and come to the headquarters of the operating department weekly with the inspection records. Apparatus which has been seriously overloaded and possibly not reported is then readily noted. It has been found that machines such as turbines, which have to be periodically cleaned by removing the revolving field in order to provide access to the air ducts of the armature iron which are apt to become choked up with dust and grease, are more safely operated if this record is kept, as the gradual rise in temperature due to such stoppages in the air ducts becomes evident week after week by increased values of the readings of the maximum thermometers. This dangerous condition otherwise might pass unnoticed. The method was first brought to my attention by the operating officials of one of the large New York systems.

In the matter of obtaining the lowest possible station cost consistent with reliability, I desire to call attention to a small matter which, however, may be the possible means of effecting a saving which is not always properly taken into account. Detailed costs are generally worked out in fractions of a cent per kw-hr. For certain reasons it is occasionally a good plan to work out all items of cost that pertain to the transportation, unloading, conveying, handling and firing of coal, including labor in the fire room, and ash disposal, also the maintenance of all apparatus involved in the above, including boilers, stokers, etc., as so many cents per ton of coal burned. In this way figures, each of which is directly proportional to the coal burned, will be given more meaning to the foreman and others, than if they are expressed in small fractions of a cent per kw-hr.

For instance, it is an easier matter to make a saving on repairs to boilers or in coal handling, or any other similar items, if we can tell the head of a boiler department that his cost is 15 cents per ton of coal, than if you tell him it is 0.025 cents per kw-hr· A man will work harder to bring this 15 cents down to 12 cents than he will to reduce a very small fraction by a microscopical amount. We will thus have cost per ton at the mine, transportation, lighterage, unloading, conveying, bunker expenses, labor on the fire room floor, repairs to boilers, furnaces, and to the ash conveying machinery, and also cost of ash removal, all expressed in cents per ton of coal consumed.

And right here it might be stated that one of the best means for obtaining economical station operation is to encourage every member of the working force to take care of his particular work in the most careful and economical manner by giving him a desire to do better work and by actually giving him enough information to see that his own work is important and is being kept account of, letting him see that any change in the efficiency of his department, small or large, becomes a matter of permanent record. He thus feels that he is a factor in production and is anxious to do his best. The above method commends itself, also, in that it has absolutely nothing to do with the selling cost and the unit of energy, and is therefore a safe figure to use.

Power factor is a matter which must be carefully watched by lighting companies supplying alternating current load. There seems a tendency in spite of careful engineering, for the power factors to grow lower. It then becomes necessary at certain stages to install synchronous apparatus in sufficient amount to counteract the evil. This synchronous apparatus should be installed at the substation where the power factor is particularly low. This is frequently made possible by the installation of synchronous motors driving arc light generators, which are naturally shut down during the time of day load when the power factor is low, and thus become an extremely convenient means of increasing the power factor. Trouble with low power factors exists in a more troublesome degree in summer than in winter. This makes the generating machinery operate at high temperatures. It therefore becomes very convenient to make use of the reserve turbine unit operated as a motor with over-excited field to reduce the current and temperature of the running machines.

Other corrections for poor power factor, outside of synchronous motors, are in the line of insuring proper voltage to motors and loading them up to the limit of safety. Low power factors are also possible by wrong connections, and in regard to the synchronous apparatus itself, it is very necessary that the substation operators be trained to run with a high power factor or leading current when required, as an under-excited synchronous motor is worse than none at all. When we consider that any load contracted for of a power factor of 50 per cent practically means a doubling of the capitalization per kilowatt involved the importance of good commercial engineering is very manifest.

The transmission system of our large companies is, in great part, underground, and it is necessary that it be as carefully installed and protected as possible. Short-circuits and high-potential surges may be encountered at any time and unexpectedly, and must be cared for. The use of choke coils in the main leads of large turbines is being urged in large 25-cycle installations on account of the necessity for protecting the switching apparatus. The short-circuits that can be obtained from present installations of turbine units in certain plants are enormous, and it is unsafe to rely upon any oil switch yet manufactured to open it. In such a case there seems to be very little choice; choke coils must be installed. On 60-cycle systems, however, the necessity for this protection is not quite so urgent, although it is quite possible that our large stations of this frequency may yet have to be thus equipped.

" The momentary short circuit current of an alternator bears to the permanent short circuit current the ratio

$$\frac{\text{armature self-inductance} + \text{armature reaction}}{\text{armature self-inductance}}$$

" In machines of high self-inductance and low armature reaction this increase of the momentary short circuit current . . . is moderate, but may reach enormous values in machines of low self-inductance and high armature reaction, as large low-frequency turbo-alternators." This is an inherent feature of the turbo-generator. " The momentary short-circuit current is from 40 to 50 times full-load current, which is a fact that in large turbine plants must be carefully considered in connection with the other parts of the system and most especially in connection with switches and circuit breakers."*

In several systems, the neutral of one or more machines is grounded either through a resistance or solid, thus allowing any grounded feeder to cut itself out of commission generally under overload rather than short circuit conditions which relieves the situation somewhat with regard to oil switches. Certain indicating devices have been worked out which show any unbalanced static condition in a cable system, locating the grounded feeder before a short circuit results, and giving the operator warning to immediately cut the feeder out of commission. For an excellent description of such a device see article in the TRANSACTIONS of the A. I. E. E., October 11, 1907, Volume XXVI, p. 1619, by Mr. Torchio.

The installation provided in the case of substations for the direct current districts will generally include a storage battery reserve sufficient to carry them temporarily over any chance loss of current for a sufficient length of time to enable the operators to get the revolving machinery into commission again. Alternating-current substations are generally provided with air-blast transformers, although if the voltage is high, of course, oil-cooled transformers will be used. These transformers may have dial heads for adjustment of primary voltage if desired. Automatic regulators in which the relation between the position of the primary and secondary coils is changed automatically by means of a motor, controlled by a relay operated by a compensating voltmeter attachment calibrated for the special line drop in question, are being installed in large numbers and are giving excellent satisfaction on these 2200-volt circuits of the alternating-current distribution system.

This induction regulator is essentially a transformer, in that, neglecting the slight loss in the regulator itself, the product of volts and amperes on the primary side is equal to the product of volts and amperes on the secondary. The primary is wound for full line voltage and acts as the exciting coil, being connected directly across the line. The secondary or stationary element carries full load current and is directly in series with the line. The flux set up by the current in the primary affects the secondary or series winding according to its direction and intensity. The neutral point is where the two coils are at right angles.

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* Steinmetz "Transient Phenomena", p. 201, and Proceedings of the N. E. L. A., 1909, p. 154.

Rotating the primary in either direction from the neutral impresses a voltage on the series winding which increases or decreases the line voltage as is desired. In order that the wave form may be preserved, both primary and secondary coils are designed with as many slots as possible, and, in order that the secondary may not, by the field set up by its own current, act as a choke coil, and thus lower the power factor of the regulator, the primary winding of these regulators is provided with a short circuited winding at right angles to the main winding. With the regulator on the neutral position this causes the primary to act as a short circuited secondary of a transformer so that the choking effect of the secondary flux is eliminated. The power factor of the regulator is fairly high, and as the capacity of the regulator itself is rarely more than 10 per cent of the circuit capacity its effect in reducing the power factor of a lighting load is but a fraction of one per cent.

Voltage schedules on the 2,200-volt circuits are made out by the department of distribution and forwarded to operating headquarters, giving the pressure to be maintained at the substation voltmeter with each change of load in amperes. These once in effect are not changed or departed from in any way until superseded by new schedules properly approved and forwarded to the substation. Each circuit panel carries this voltage schedule card in a card holder on the panel itself, so that it is always available for checking.

A slight use of the vector diagram will readily show that for circuits of variable power factor—for instance when the day load consists of motors giving a power factor of 70 per cent, and the night load which is mostly a lighting load, with a power factor of 95 per cent,—no one voltage schedule based on amperes alone will properly care for the voltage at the load center. In this case the voltmeter and relay control for the induction regulator must be compensated for the line characteristics. With substation voltmeters corrected by compensation for line constants, all the voltmeters in the stations will read practically alike, or the voltage at the consumers' premises, and the mental calculation of the operator in following schedules, which in a station of many circuits becomes practically impossible, is made unnecessary. The line e.m.f., of course, varies with each circuit.

The keeping of records is an important part of an operating system. The exact records to be kept and the details to be followed will necessarily vary with the size and type of the system involved. As the system grows, detail becomes more and more necessary and the blending of the reports of the different branches into one complete whole, which will give us exactly what we may require at some future time, and yet which will avoid repetition and unnecessary labor, becomes the subject of considerable thought. First in importance, perhaps, among the operating records comes the station log book. This is a daily entry of all the main facts concerning load, engines on line, boilers in service, being repaired, cleaned, etc., pumps and their operation and, in fact, covers the operation of the plant and system. Thus, the log book for a station of 5,000 kw. would be entirely inadequate in the case of a plant of 25,000 kw., and the operating records of a 100,000-kw. plant naturally would involve greater detail than those of a 25,000-kw. plant. The object in keeping the station log book is two-fold; for assistance in laying out plans for daily operation and future growth, and secondly, for keeping on record certain important facts which may be called for at any time. In small stations these records are kept by one man as a part only of his many and varied duties. As the system grows larger this work increases so rapidly that a man will have very little to do outside of what pertains directly to his log-keeping. About this time it also becomes necessary for the data to be given to the log-keeper, as he has no time to look it up. This will be taken care of probably by the regular reports of minor departments. With a still larger system, two separate log books will be kept, one for the mechanical and one for the electrical department. The entries in these books will then be made directly by the operating men themselves and will become records at first hand. Engineers and electrical foremen operating on successive shifts will sign the log of the preceding shift as well as that of their own to put themselves on record that they have made themselves familiar with the operating conditions under the previous shift. Reports in abstract will now be taken from two log books instead of one.

Of the office records of a generating system, next in importance to the log book comes the card index system covering in detail every piece of apparatus in the system with the date of installation, first cost, order number, and a complete description, including a name-plate, serial number, etc. so that information is at hand in case replacement or spare parts are desired. This not only applies to every engine, generator, exciter, battery, etc., but to every piece of machinery and apparatus in operation which is liable to have trouble and need repairs. It thus includes a record of all series and potential transformers, air blast transformers of alternating and direct current substations, rotary converters, motor generator sets, etc. Each large piece of apparatus bears a specific number which is entered on requisition, whenever necessary, in order that all expenses involved in connection with any piece of apparatus may be entered on record in connection with the card itself, so that at any time a system with proper records should be able to give the maintenance charge against any piece of apparatus desired, whether this is asked for yearly or after a period of years.

In order to weld the whole operating force, electrical and mechanical, main station and substations into one compact whole so that concerted action may be possible, instruction sheets specifically intended for one particular branch are distributed throughout the system. These are kept in binders provided for the purpose. Blue prints covering bus bar wiring of every station are sent to all stations for the same reason, as are also detailed prints giving the switchboard panels with every instrument, switch, etc., numbered, and covered by card in card index system as stated before. Each operator is then in a position to advise with regard to the disablement of any particular part of his apparatus by merely referring to a drawing and panel number. In this way it is frequently possible to save considerable time in making repairs and in getting reserve apparatus into commission. It also assists materially in instructing the operating force, broadening their knowledge and making them think for themselves.

In a large and complicated system it will generally happen that a miniature of the system covering every machine, bus bar, switch, cable, piece of machinery in both main and substation will be found necessary for the assistance of the main station operator. Apparatus in service and position of switches will be indicated by appropriate markings. This exemplifies the necessity for a central station operator on the main board or in close touch therewith.

Complete detailed drawings and card index should also be kept of the various piping systems, valves, etc., of the mechanical department of the generating station. All important valves of the plant should be numbered and each should also bear a tag with its number, and description of the valve. Reference to valves will always be made by numbers. Instruction sheets are also issued in this connection with special cuts covering, for instance, detail of step bearings, middle bearings, upper bearings, of turbines, etc., showing oil grooves and general construction. In a system involving a great complexity of piping, as is necessary in plants of a large size, too much care cannot be taken that the men are carefully drilled with regard to the location and exact function of every pipe and valve, giving them a better knowledge of the complete system rather than that of only the particular part of the same in their immediate vicinity. This system of blue prints and records gives all men a chance to offer suggestions, without which feature the best of operating systems is working under serious disadvantage. Piping systems in large stations are generally painted in special colors to better designate their specific function.

With growth comes a necessary division of responsibility which necessitates an organization that will work smoothly yet flexibly in order that proper care and attention may always be given to every detail. Slight defects are occasionally found in machinery or apparatus of the method of caring for the same. These may be of more or less importance, possibly not at all dangerous in themselves, but collectively they have an influence tending to lower the standard of the station equipment. To give good and reliable service, all machinery, switches, etc., must be kept in first class condition at all times. Therefore, to guard against omissions of inspection, or any possible oversight or infringement of regular operating rules, a careful system of inspection and checking is necessary. Every piece of apparatus and every special inspection, or regular overhauling of a piece of machinery, every emergency drill and test, is cared for under specific inspection number. These are grouped according to departments and according to periods of inspection. The main inspection sheet, carrying the list of inspections necessary, is grouped into as many columns as there are week ends in the month. All inspections made, therefore, during the above week are noted by special marks opposite their names, and the initials of the foreman, engineer, or assistant making the specific inspections are required opposite each item.

At the end of every week the complete list of inspections not made or machines or apparatus not in perfect condition, rules which have not been complied with, or any departure from regularity in test or otherwise, is abstracted from the weekly detailed inspection sheet and sent to the office of the operating head by the main department chiefs. The signing of this inspection card in itself constitutes an order to have such discrepancies corrected before the next succeeding week. No item is expected to appear on the inspection card for two consecutive weeks. The system of inspection is made absolute, and it therefore rests with the operating head whether he will accept conditions as they are, or insist upon them being corrected. The natural result of this system has been a higher ideal of excellence in both equipment and station conditions, and an increased spirit of confidence, which is essential for the best results.

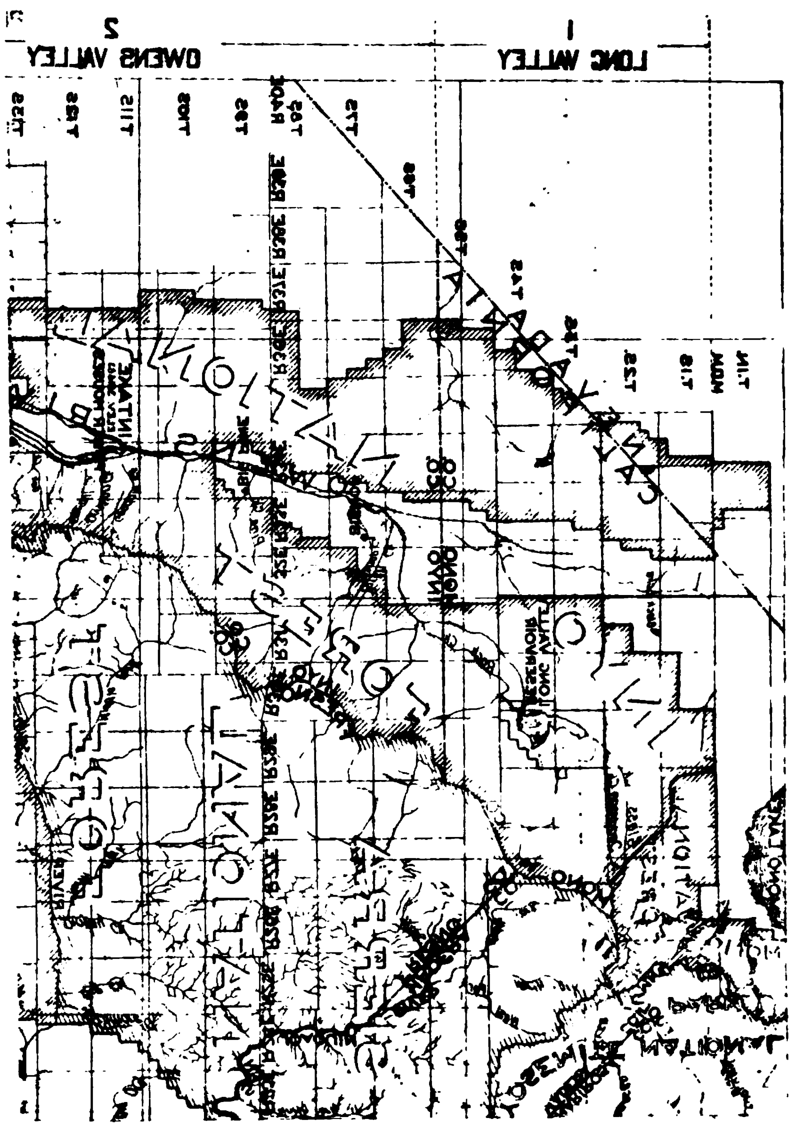
Another important point which assists in maintaining a high standard of reliability is the selecting, training, drilling and redrilling of the working force. It is not enough that the directing head be well assured that every man in his system knows his duty in times of trouble as well as when things are running smoothly, although this in itself is no slight undertaking, but he must be absolutely assured that each man will act as his best knowledge dictates under all conditions. A man can only get acquainted with accidents by experience. A majority of accidents due to the breaking down of apparatus never occurs after the first time. It will not be questioned, therefore, that the value of the operating man to the company increases directly with his length of service. There are, unfortunately, occasional accidents due to mistakes of the men themselves. As a rule these are not due to ignorance. A great majority of them are made by men who have been trained and who know better. There are times when a man's brain and hand do not act together. The elimination of this class of mistakes is a necessary step in the direction of good service. Mistakes can be made in construction and in design which may never appear excepting to a limited few, but an error in operation appears in ever widening circles, reaching possibly the remotest consumer on the company's lines.

As a fundamental requirement therefore, we will grant that our active operating men must be given reasonable hours, good pay, reasonable prospect of advancement, as the occasion may offer, and be relieved as far as possible from worry and annoyance of any kind. Without good organization throughout the whole generating system, this is impossible.

There are thrown every year in a certain substation system, 197,000 switches, a mistake in any one of which might perhaps cause local trouble. The quality of service given by large companies, however, shows that the errors here are comparatively few. They do, however, occur occasionally. In the main generating station of the same system there are thrown yearly some 52,000 switches. A mistake here is more far reaching in its effects than a corresponding mistake in any substation, as it may possibly involve the whole system. By exercising great care the number of mistakes of this latter kind are very few, possibly none at all being made which involve anything more than local trouble. To eliminate these few remaining errors, however, and to provide against unforeseen contingencies, a rule that every operation involving main station switching excepting in minor cases, must be checked by another operator or foreman whenever it is physically possible has given considerable ground for satisfaction.

Finally comes the choosing of the working force and the selection of the foreman, engineers and assistants. This, at first, might seem the easiest part of the whole. There are, however, very many points to be considered even in the selection of men in minor positions. It must always be borne in mind that the helper may one day be an engineer or a foreman or even more. In the choice of men for the various positions of authority, those must always be selected who have, together with other qualifications, the ability to handle men and the capacity for growth. At times the choice of a man to fill the larger positions is self-evident. In order, however, to avoid even the semblance of partiality or favoritism, it has occasionally been found a good plan to give each applicant an examination based on such attributes as a man in the coveted position should have. These will involve such points as honesty, ability to handle men, ability to achieve results, cool headedness, technical knowledge, mechanical ability and others. A sheet is prepared for each name, bearing in column form the various attributes, given, with their relative values, by the head of the department. An examining board, composed of assistants of experience, each of whom has a sheet for every applicant, places such values on each man's sheet as his own experience and knowledge of the man in question would seem to entitle him. Each name is completely marked before the second name is considered; so there can be no recollection, even unintentional, of what numbers the preceding man has obtained. The figures are then carefully added up in the office, and corresponding grades attached. It is a peculiar fact that it rarely happens there exists any real difference in opinion as to who is the best man for the position. The value of this method, of course, lies in the fact that it is absolutely impartial. Every man on the examining board must be trained in matters pertaining to the operation of stations and central station systems in order to make it effective. The use of veto power will rarely be found necessary.

Finally, equal in importance with preserverance, whole-hearted service and painstaking insistance on high standards on the part of every man in the department, is proper company organization and recognition of faithful and efficient accomplishment.



2
OWENS VALLEY
1
LONG VALLEY
MONO
INYO
LONG VALLEY RESERVOIR
CROWLEY LAKE
MONO LAKE

A paper presented before the Los Angeles Section of the American Institute of Electrical Engineers, March 22, 1910.

ELECTRIC POWER IN THE CONSTRUCTION OF THE LOS ANGELES AQUEDUCT

BY E. F. SCATTERGOOD

The Los Angeles aqueduct extends from the intake in Owens valley, about 12 miles north of the town of Independence, to the storage reservoirs at the head of the San Fernando valley, about 24 miles distant from the city of Los Angeles, from which point the city water department will take care of the distribution of the water. The length of the aqueduct proper is, therefore, 240 miles.

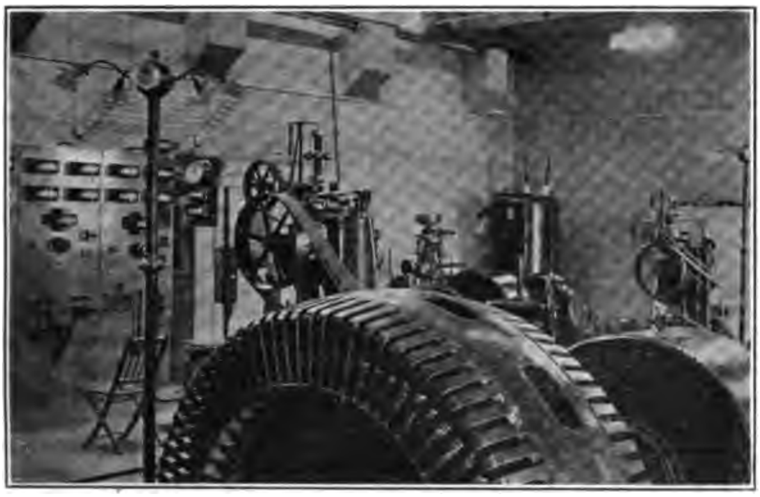
From the southern end north to the north portal of the Elizabeth lake tunnel, a distance of 35 miles, the work is heavy, being to a considerable extent composed of tunnels, including the Elizabeth lake tunnel, some 27,000 ft. in length, through granite rock. Preliminary estimates showed that in such sections the considerable amount of power required could be furnished much more cheaply, from a central generating plant and distributed by high tension transmission, than by small power generating units, either by steam or distillate engines at various points as required. This section is supplied with power purchased from the Southern California Edison Company, and delivered at one of its substations about four miles west of the aqueduct line and near the center of this section. From the Elizabeth lake tunnel to a point 55 miles further north, the aqueduct follows along the desert in the open, and estimates indicated that the conduit excavation, and concrete work of lining and cover, could be done more cheaply with the use of steam shovels and gas engines than by the erection of a temporary electrical generating and distributing system. From the Pinto hills north to the intake, a distance of 150 miles, there are alternate sections of the heavy tunnel work and of the lighter conduit work. In the Owens valley there are numerous creeks flowing down the eastern slope of the Sierra Nevada mountains offering excellent opportunities for power in sufficient quantities for construction work on the aqueduct; and estimates showed clearly that power could be developed at these creeks and transmitted along this 150 miles, and delivered to all points requiring power, in large or small amounts, at a very much lower cost than that for which it could be furnished in any other way.

It should be stated for the benefit of those who are not so familiar with the city's project, and who may read this paper, that the power referred to here is for construction purposes only, and should not be confused in any way with the large amount of electric power which may be developed along the line of the aqueduct when it is in operation, and which will total a peak load capacity of 120,000 h.p. delivered at step-down voltage in the city.

POWER SYSTEM

For the purpose of supplying power along the section of the aqueduct from the intake to the Pinto hills, hydroelectric plants were installed on Division and Cottonwood creeks. The Division creek plant is about three miles south from the aqueduct intake, and has a rated capacity of 600 kw. The works at the point of diversion at the creek cost $1,214. The penstock starting from this point, and extending down the slope 10,500 ft., consists of 6,291 ft. of 18-in. riveted pipe and 4,209 ft. of 15-in. lap-welded pipe, and cost, in place, $28,102. The effective head obtained is approximately 1,200 ft. The power house equipment consists of one tangential wheel direct connected to a 2200-volt, three-phase, 600-rev. per min. generator and a bank of transformers, stepping the voltage up to 33,000, each of which has a continuous overload capacity of 25 per cent above the 600-kw. rating. The power house is built of concrete in a substantial manner. This is also true of the second one to be described, as these plants are intended to become a part of the permanent aqueduct power system. The cost of the power house and equipment, including three cottages, etc., is $21,100, making a total cost of approximately $84.50 per kw., or $63 per h.p. rated capacity at the switchboard.

The Cottonwood power house is approximately 40 miles south from the Division creek plant. Its equipment consists of two tangential wheels, operated under 1,200 ft. effective head, each direct connected to a 750-kw. three-phase, 2200-volt, 600-rev. per min., generator, each of which in turn is connected to the 33,000-volt line through a separate bank of transformers. The works at the diversion point cost $3,964. The canyon for a distance of 3,750 ft. is so precipitous as to make a conduit or tunnel impracticable within reasonable cost, therefore, a 24-in., No. 12 gauge, riveted pipe was buried along the side of the canyon, at a cost of $9,352. From this point to the forebay, a distance of 7,042 ft., a covered concrete conduit, 30 in. by 20 in. inside section, was constructed on the mountain side at a cost of $11,228. The penstock, with 523 ft. of 24-in. pipe and 4,009 ft. of 22-in. pipe, or a total of 4,532 ft., cost $29,820. The power house and camp complete cost $49,638, making a total of $69.40 per kw., or $51.75 per h.p. of rated capacity at the switchboard, the plant having 25 per cent overload capacity.



Cottonwood power house—two 750-kw. generators—power all utilized for construction work

The transmission line is 151 miles long, and is made up of three No. 4 bare copper wires; two-part seven-inch porcelain insulators with iron thimbles, pins and bases; one wire on a 15-in. crossarm at the top of a 30-ft. pole, and two on a 6-ft. crossarm below, and poles spaced 180 ft. apart. The average cost of this line is $862.50 per mile. About one-fifth of this line is through rough mountainous country, and the wagon haul for the entire line an average of 12 to 15 miles. This line has since been extended from its southern end to the aqueduct cement plant, a distance of 17 miles, with No. 2 copper, at a cost of $1,050 per mile. The object of this extension is to deliver surplus power to the cement plant, with the advantage of supplementing the steam plant, thus saving fuel oil and making the entire system more flexible and reliable by running in parallel with two 750-kw. steam turbines at that point. Had the cement plant been contemplated originally, more copper might have been used along the whole line, and more generating capacity installed to advantage. As an interesting illustration of the value of synchronous condensers in connection with transmission of electric power, it may be stated that while delivering a distributed load of 1000 kw. between the intake and the Pinto hills, 400 to 420 kw. could be delivered at the cement plant, 125 miles from Cottonwood at 30,000 volts with 35,000 volts at Cottonwood when not in parallel with the steam turbines; and that 800 kw. can be delivered at the cement plant when running in parallel, by strengthening the field of the turbo-generators, with the same voltage drop and the same distributed load along the line.

Floating transformer station used in connection with suction dredge; Owens Valley

There are about 74 step-down transformers connected to this line in banks of two or three; most of these transformers are of

40 kw. capacity, the remainder are either 20-kw. or 80-kw. The greater number are of the out-door type, which have given excellent satisfaction, and are very much liked by the men in charge of work, because of the decreased expense and time of setting them up. Most of them have been shipped from the factory with the oil in them, as they are in boiler iron cases, made suitable for moving with the oil in place, thus avoiding the necessity for drying out of transformers at isolated places. The protection of this high-tension line against lightning and surge voltages is a combination of low-equivalent arresters at the Cottonwood power house and three sets of horn-gap arresters at other important places. The transformer stations are protected by air-insulated choke coils and fused horn-gap switches. The comparatively small insulators for the voltage used, while they have given no trouble whatever, do undoubtedly serve to give additional protection to apparatus along the line by affording relief from any excessive potential. No apparatus has been lost from lightning or surges during the eighteen months of its operation.

By including interest, placing a proper depreciation on the permanent power plant, and assuming a low value of return from the copper on the temporary line, and on the transformers constituting the substations, (the system to be in use but four years), it was estimated that the cost per kilowatt hour delivered at a step-down voltage, in large and small quantities as desired, would be approximately 1.15 cents. The indications are that this estimate will prove to have been conservative.

USES OF ELECTRIC POWER

Stating as briefly as possible the uses to which this power is put; there are in Owens valley about 20 miles of the aqueduct which can conveniently be built with dredges. Four electric shovels are in use for conduit excavation in the open country. One mill for regrinding tufa with the cement is located at Haiwee, 22 miles south of Cottonwood. Electric power is used at Haiwee, also for sluicing and other work connected with the building of the earthen dam. There are approximately 18 miles of rock tunnels and three miles of earth tunnels provided for by this power system. The typical tunnel equipment consists of one air compressor, driven by a 100-h.p., 440-volt, three-phase induction motor; one 80-kw. motor-generator set, providing 250-volt direct current for electric locomotives; lighting and other work inside the tunnels; other power for blowers, machine shop, hoists, pumping, etc., as the case may be, and for lighting camp. In case electric locomotives are not used, as in shorter tunnels, alternating current at 110 volts is used for lighting in the tunnels also.

Dredges. There are two suction dredges in operation in Owens valley, each equipped with a 12-inch centrifugal pump, driven by a 100-h.p., 440-volt induction motor; one 40-h.p. motor to run the cutter, one 40-h.p. motor to run the jetting pump for breaking down the bank over the cutter, and one 20-h.p. motor for operating various hoists. There is also one dipper dredge of one and one-half yards capacity, of the friction type, driven by one 100-h.p. induction motor. The step-down transformers in each case are mounted on a float, with the rack overhead supporting the choke coils and switch on which the taps from the transmission line land. The line being close by requires but one short span, and a crossarm is placed on the round cedar pole by clamping it with two bolts and a short piece on the back, as shown in the illustration, then pushing up at a safe distance from the lower arm. Connection is made with the line through long spiral springs of tempered brass and a brass clip at the end. These are put in place by means of a long pole from an insulating stand, or by climbing a short distance up the power poles, with the line switches at the transformers open, and the transmission line hot, which necessity requires, and which cannot result in

Dipper dredge in Owens Valley

personal harm when done by an experienced lineman, as is the case. The connection from the transformer float to the dredge is made by means of a three-conductor submarine armored cable. The cable is stored on a reel on a second float attached behind the dredge, with flexible connections to the dredge, so that the cable is automatically paid out, and when all out the flexible connections are detached and the cable wound up, then the reel float and the transformer float are towed up to the dredge together. This method has proved very satisfactory in avoiding abuse to the cable and in saving time and expense in moving.

Method of connecting portable substation to 33,000-volt transmission line

Electric Shovels. Electric shovels with three-quarter yard buckets, and 25-ft. booms, used for conduit excavation, are of the friction type, driven by one 75-h.p., 2200-volt induction motor. The step-down transformers are mounted permanently on sleds or trucks, with the racks supporting the choke coils and switches permanently fixed overhead, and with two 10-kw., 2200- to 440-volt transformers attached, supplying power for concrete mixers operated in connection with each shovel. The cable used is three conductor No. 10 with rubber insulation, rounded out with jute, taped with weather-proof braid and half round steel armor over all. This connects between the transformers and the shovel and between the temporary 440-volt line on the power poles (about 1000 ft. back from the transformers) and the mixers, and is giving excellent satisfaction. The considerable advantage experienced with the use of out-door type transformers in connection with dredges and shovels is very evident.

Electric Locomotives. Twelve three-ton electric locomotives rated at 1200 lb. draw-bar pull at six miles per hr. are in use in this section of the aqueduct. At each end of the Elizabeth tunnel, which is not supplied from this power system, there is one locomotive of this size and one six-ton locomotive. In that tunnel, which is approximately 90 sq. ft. in section when lined, the larger locomotive is preferred, making it possible to pull out 14 to 16 cars of muck at one time. The three-ton locomotives are of good size for the tunnels in the section under consideration, which are approximately 70 sq. ft. in finished section, and range from 2000 to 10,000 ft. in length where locomotives are used. The use of electric locomotives in these tunnels results in a reduction in cost of excavation and placing the concrete lining, which is a considerable percentage of their total cost. The actual cost of removing muck and delivering concrete is considerably less than it would be if done in other ways, especially by mules; but the greater reduction in cost is due to the practical condition of being able to get the muck away for the convenience and economic working of the miners in excavation, and allowing the placing of rock crushers and concrete mixers at a conveneint point outside of the tunnel for concrete work. Concreting is being done successfully and with perfect satisfaction to the engineers at a distance of 10,000 feet in one instance. This use of these machines makes it possible not only to reduce

Electric shovel on open conduit; Mojave Valley the cost where speed is not a consideration, but to very materially increase the speed, if desired.

Small Isolated Power. Experience with distillate engines in connection with concrete mixers and other small power has led the men in the field to plead for electric power; for example, several steam shovels are in use in this section for conduit excavation, and it was thought at first that the expense of stepping down the voltage, moving transformers, etc., for supplying two or three motors of 7½ to 10 h.p. each would not be justifiable but the division engineers now insist that the cost of maintaining and operating distillate engines under the conditions experienced along such work is in itself greater than the cost of supplying the electric power, including the charge made against

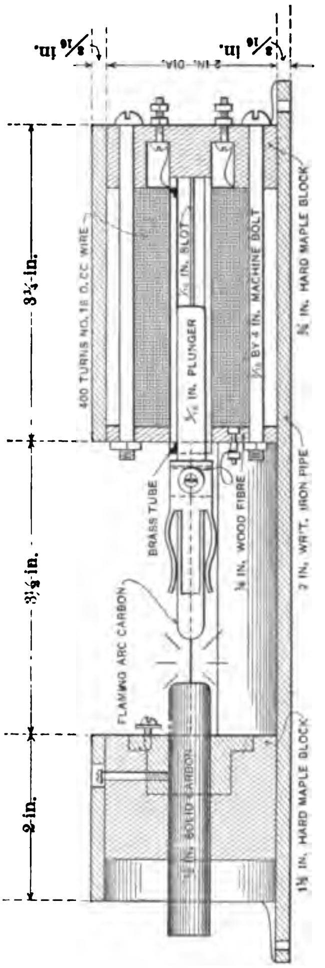
33,000-volt portable substation—outdoor type transformers them for the energy, as well as the equipment, beyond the transformers; and they further state that the interruptions which they have experienced in concrete work with distillate engines behind a single steam shovel, as compared with what they have experienced in concrete work with electric power behind an electric shovel, has cost them anywhere from $20 to $40 a day after the engines had been in use a few months and began to develop troubles under those conditions of operation; in other words, the saving is due to the consideration of reliability aside from actual cost of supplying power to the mixers. The cost for tunnel work is considerably reduced and the speed increased by electric lighting. The illustration herewith shows a type of home made cluster, which is giving excellent results at the headings.

Electric mine locomotive; Elizabeth Lake tunnel

PROTECTION AGAINST GASES

One of the long tunnels in another section runs through an oil district, and at times has developed considerable explosive gases. In order to protect the men against this danger, electric sparking devices have been installed, designed as shown in the illustration. They may be operated either by alternating or direct current. They are operated by direct current in this case by means of a switch outside of the tunnel, and as may be seen, are absolutely positive in their action and cannot fail if properly trimmed when the miners leave the tunnel. They have exploded gases several times, and in the form shown are usually found intact after the explosion; several of them being in use gives opportunity for further trials before entering the tunnel.

Lamp cluster used in tunnels and designed to reduce lamp breakage from blasting, etc., to a minimum.



Sparking device for exploding gas in tunnel

AMOUNT OF POWER REQUIRED

A good idea of the amount of power necessary to operate the equipment may be obtained by studying the following tabulation, which gives the total rated motor capacity, approximately 3470 h.p., of the various equipment attached to this system, and the total electrical horse power, approximately 2000 h.p., required at the switch board of the two power plants combined for supplying this system independent of the cement plant. The energy necessary for lighting machine shops and other small requirements is not tabulated, but is included in the power at the switchboard. In many instances power is used 24 hours each day, but in other cases during 16 or 8 hours per day; on an average about 16 hours per day. The amount stated as being required at the switchboard is taken from the heavy load periods during the day; in other words, the average peak load for that work. The average load during the 24 hours would be about 60 per cent of this.

MOTOR INSTALLATION INTAKE TO PINTO HILLS

2 suction dredges	400 h.p.
1 dipper dredge, 1½-yard dipper	100 "
4 electric shovels, ¾-yard dippers	300 "
Tufa regrinding mill	200 "
Haiwee dam, hydraulic work	100 "
8 air compressors, 500 cu. ft. each	800 "
8 motor generators, 80 kw. each	1000 "
7 rock crushers, 10 and 20 tons per hour each	140 "
28 concrete mixers, 6 and 10 cu. ft. per batch	280 "
7 blowers, 1350 cu. ft. per minute each	70 "
3 hoists	60 "
2 pumps	20 "
Total rated capacity of motors	3470 "

The average power used at each end of the Elizabeth tunnel, already described, is 88 kw. during the 24 hours, divided, as follows: 5½ kw. for lighting outside the tunnel; 35½ kw. for operating the motor-generator which supplies power for ventilation, electric locomotives, lighting the tunnel and a small amount of pumping from the tunnel; and 47 kw. for compressed air for drilling, machine shop, camp water supply, etc. The average peak is about double the average load.

TELEPHONE SYSTEM

The telephone system is considered not only one of the most profitable adjuncts to the aqueduct construction, but one which is essential to its economic construction at reasonable speed. It consists of approximately 260 miles of main line from the Los Angeles offices to the intake, built of two No. 10 copper wires strung on redwood poles, at a cost of $188 per mile. This line is divided in three sections by two exchanges, which more than doubles its efficiency. In addition to this there are local telephone systems in each of the various divisions along the work; some of these have as high as 26 telephones. Each local system may be temporarily connected with the main line by a switch in the division engineer's office, there being but one main line telephone on each division. As the telephone system is to be used by all classes of men, very few of them familiar with electrical work, it was though undesirable, if not wholly impossible, to operate it successfully with the line on the power poles. Estimates showed that by making the poles on the transmission line five feet shorter, the telephone line could be placed on separate redwood poles at an equal or slightly less cost, and this has been done. The telephone lines are in every case placed underground at crossings with high-tension electric lines.

A paper presented at the Charlotte meeting of the American Institute of Electrical Engineers, March 30, 1910.

ELECTRIC DRIVE IN TEXTILE MILLS

BY ALBERT MILMOW

It is the purpose of this paper to deal especially with the employment of electric power, derived from hydroelectric systems of distribution, for the operation of textile mills. It is impossible in a paper of this kind to go very fully into detail, and no attempt will be made to discuss the forms of drives, kind of motors or, in fact, any other technical details, since any one of the more important ones would require a special paper to do it justice.

This paper aims to treat the subject from a broad, general viewpoint, with particular reference to its commercial aspects, and especially in comparison with the old forms of steam drive.

The general branches of the subject which will be taken up are first cost, cost of operation, production as affected by balancing and speed, and general remarks.

First Cost

The references which follow will be to new mills especially equipped for electric drive, insofar as first cost is considered, and not to mills already equipped with steam power. The figures are based on a plant of 25,000 spindles on moderately fine work, which requires a power equipment of about 1000 h.p. The figures which follow are for everything included in a mill that is chargeable to the power plant:

Electric Drive

Group drive throughout, all 2300-volt motors. Power delivered at 2300 volts.

Transformer house and switchboard room	$1,000.00
Belting	1,300.00
Motor support	400.00

Shafting	$8,000.00
Boilers	1,200.00
Boiler setting	350.00
Boiler room	1,650.00
Reservoir	1,800.00
Piping	900.00
Motors	10,560.00
Transformers for low voltage motors, 2 to 5 kw	126.00
Transformers for lighting, 1 to 50 kw	383.00
Switches for motors	300.00
Switchboard	1,500.00
Wiring and installation, including lighting	4,000.00
Freight on electrical apparatus	428.00
	$33,897.00

MECHANICAL DRIVE

Boiler room Engine room Chimney	$16,000.00
Engine, 24-rope wheel, compound	17,500.00
Engine foundation	2,000.00
Boilers	6,000.00
Boiler setting	1,800.00
Smoke breeching	770.00
Condenser, pumps and heaters	2,520.00
Reservoir and crib	6,500.00
Steam power piping	6,000.00
Ropeway and extra sprinklers	2,000.00
Shafting and structural steel work	12,053.00
Rope	600.00
Belting, main drive and counters	1,300.00
Lighting generator, belted, and switchboard	1,000.00
Marine engine generator, 10 kw., and switchboard	1,000.00
Lighting wiring, 2-wire system	2,000.00
Total	$79,043.00

From the table it will be seen that the total cost of the power plant for steam drive would be $79 per h.p., while the cost for a similar electric equipment is $33.90 per h.p., or a saving of $45.10 per h.p. of plant capacity where the electric drive is used.

It is to be noted that all costs are included in these estimates, though it is quite usual for advocates of steam drive to take for its first cost only the costs of engines, boilers, piping, etc., neglecting such important items as building chimneys, belt-ways, condenser reservoirs and other items which are essential to steam drive, but which are not required where a mill is electrically driven. This difference in cost should enter into the cost of power, taking the interest and depreciation at 12 per cent, the lowest possible figure. However, it is obvious that if this same amount of money were expended in producing textile machinery the earnings would certainly exceed the 6 per cent included in this figure as an interest charge.

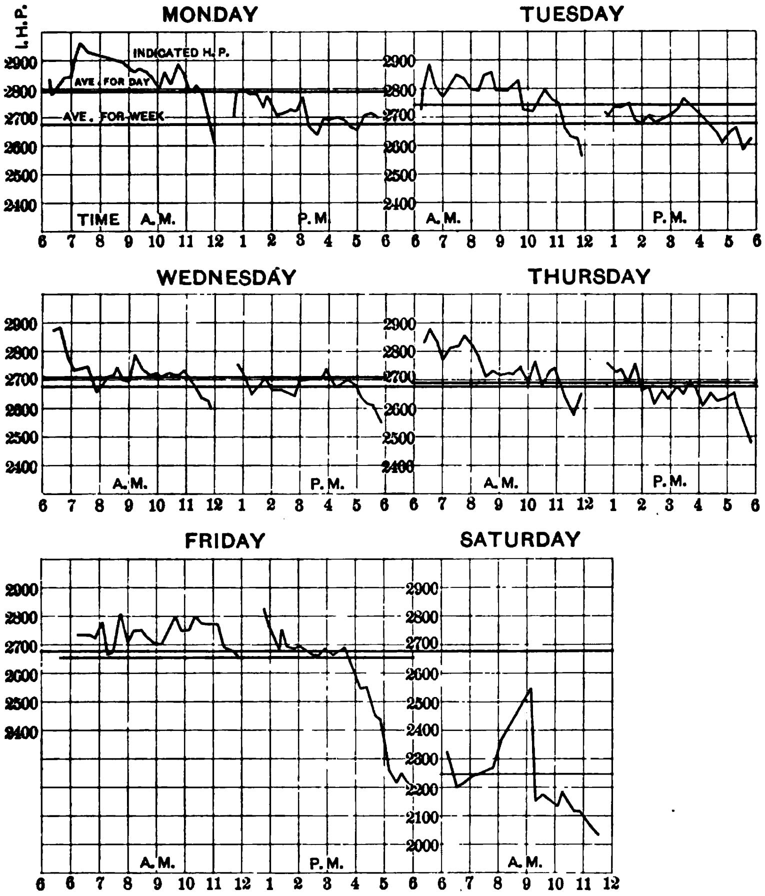


Fig. 1

Cost of Operation

The cost of steam power in a textile mill is very difficult to determine. Fig. 1 shows a series of engine indications made for a period of one week, at ten minute intervals. It will be noted that a very wide variation of power is shown and only a very thorough and detailed set of indications, as shown here, will give a fair average of the amount of power.

It is customary with advocates of steam drive to make certain large deductions in a purely arbitrary manner from the total cost, for the values of steam used in processes of manufacture other than for power, such as dye-house operation, heating and slashing, and then to divide the remainder by a factor obtained by taking one or more engine indications.

It will be seen from Fig. 1 that it is obviously erroneous to take any value for the total horse power of a mill other than an average taken approximately as shown; even this, to obtain perfectly accurate results, should extend over a long period, embracing all the seasons of the year, as there are many variable quantities involved, such as the temperature of the mill, which varies with the seasons, the humidity of the air, and even the nature of the cotton staple.

These factors cause an extreme variation of power during, say, a year's period of as much as 20 per cent, and this variation is very noticeable in a day's or a week's run, as will be seen by the variations of power as shown in Fig. 1 on that part of the curve corresponding to Monday.

On account of using the same boilers for power and for other purposes it is difficult to obtain accurate figures on the cost of dye-house, heating, and slasher operation in a steam-driven mill. Where boilers are used for making tests it is usual to use a large power boiler, which runs in an underloaded condition and hence inefficiently, and the steam is often carried in long systems of piping before it is utilized. In electrically driven mills it has been possible to segregate these costs. The cost of heating a 10,000 spindle mill is, for the climate of the Piedmont region, about $250 per year, and as this size mill will use about 500 h.p., the cost of heating may be taken to be 50 cents per h.p. per year. This figure is for a boiler of just sufficient capacity for the work. Similarly, the cost of slashing is found to be $1.40 per h.p per year, or a total of $1.90 per h.p. per year for heating and slashing. Of course, this figure varies with the class of work, but it applies to work using an average of about No. 30 yarn. The figure commonly taken in estimating steam horse power cost is about $4.00 per h.p. per year, which is entirely too high. For these reasons it is very difficult to determine any accurate cost of the steam power on the horse power-year basis.

In dealing with about seventy mills electrically driven, many of which have been converted from steam to electric drive, it is found that no two present identical conditions, and even when a mill is changed to electric drive, the opportunity of improving speeds, etc., is usually taken advantage of, and the mill is generally reorganized to an extent that precludes the possibility of a direct comparison.

It has been found, however, that where the machinery in a converted mill has been kept intact and the speed kept constant, and where accurate records of engine indications prior to the change have been kept (which is rarely done) a saving in the power required is effected, though most mills when making this change take the opportunity afforded of improving production in one or more ways and thus increase the power required. The manner of operating a mill is also important in determining the amount of power required. Some mill men force production to the highest point, while others are content to run at moderate speeds and production.

The varying cost of fuel, the quantity and varying temperature of condenser water, and the difficulty of obtaining accurate data make it impossible to arrive at any accurate conclusion regarding an average cost of steam-generated power in textile mills.

In electrically-driven mills the absolute horse power-hours and the indicated power can be determined at any time. An opportunity is given to check wastes and correct them, and a considerable amount of non-productive power is saved by the elimination of useless shafting.

Assuming the price of electricity to be $25 per h.p. per year for 11 hours per day, 306 days per year, and assuming a saving at equal production of 15 per cent in power, which I consider conservative, the cost at which steam power must be generated to equal the price of electric power will be $21.25. From this must be deducted the fixed charges on the difference in first cost, which we may take at 12 per cent on $45.10, or $5.41 per h.p. per year, leaving $15.84, plus $1.90 which will be required for the heating and slashing operations of the mill, or a total of $17.74 as the figure at which steam power must be generated to be equal in cost to electric power at $25 per h.p.; and in this figure there must be included the cost of all oil, waste, labor, fuel, ash removal, coal handling, superintendence and, most important of all, the item of repairs, which is frequently omitted entirely in making estimates of steam power cost. If it were possible to attain this figure with a steam drive, a power only evry inferior to electric drive would have then been obtained.

PRODUCTION

Hydroelectric power offers many advantages in operation, due to the readiness with which parts of a mill may be run so that the maximum possible output may be obtained. By reference to Fig. 1 it will be noted that a wide variation of power is shown, due, among other things, to the fact that it is unnecessary to run all of the departments all of the time.

In a mill which has perfect balance, each piece of machinery used in each process will deliver to the next succeeding department just the right amount of material to keep both sets of machinery operating at full output all the time, and so on until the completed article of manufacture is produced. This is a condition difficult to realize, as in actual service it is found that market conditions in nearly every case make change of product necessary, and in a mill which can be designed for only a limited range of work, any variation from this affects all the preparatory departments by giving them more work for coarser product or less for finer product.

In mills which are used exclusively for spinning, and which do no weaving, a part of the product is in the form of twisted yarns and part of it in single yarns; hence the twister department, which uses a great deal of power, is often called upon to its full extent and again is often entirely idle.

In equipping a mill for electric drive it is usual and proper to provide one or more motors for each process of the work so that in case the demand on that department is increased, it is possible to work over time on that particular department, where, on account of the inefficiency of the engine at light loads and often because of the very small part of its capacity that is required, it would be impossible to run with a steam drive; or if some department, such as the twisters, is not needed at all, the motor provided for it can be shut down entirely, saving all expense of its operation without affecting the operation of any other department or in any way affecting its speed.

These points are actually taken advantage of and practiced to a very great extent. In mills using automatic looms they are frequently left in operation at the noon hour, when they will run until some threads break, when the loom automatically stops itself and remains stopped until the weaver returns. Many of them continue in operation without interruption. In some cases looms are left in operation after shutting down time until the loom stops itself, which often does not occur until all the filling yarn is exhausted. These hours in the aggregate sum up a very respectable total in the course of the year.

The textile industry in the south is at a growing stage and few if any mills are left complete as first installed, especially among the larger mills. It is almost the usual thing to see a mill with one of its ends boarded up instead of closed with brick, thus proclaiming to the world the intention of its owners to extend it as soon as they can. In the days before electric power was available this necessitated a steam plant entirely too large for the first installation, so a plan was resorted to of installing one-half of an engine and operating this as a simple engine, with the ultimate intention of adding a cylinder for compounding when the mill should be increased. This arrangement necessitated the investment of a great deal of money in a steam plant to begin with, which to-day can be put into the manufacture of cotton goods, and resulted in very high costs for power when using only a simple engine. These conditions have too often proved a handicap which has prevented the mill men from realizing their hopes as soon as they might have done. With electric drive the system is perfectly flexible. Only the investment for the work actually installed is demanded at the outset, and the full output and efficiency are secured from the beginning.

An interesting application illustrating the flexibility of electric drive has recently been made and is being quite generally followed. In this case a mill was built with a capital of $100,000 and with an equipment of 5000 spindles for the production of yarns. It was the intention to operate this mill day and night and the promotion of the mill was based on this idea. It was found, however, that for the spinning frames, which require women and girls to operate them, sufficiently satisfactory labor could not be obtained to operate during the night run, so that the management found itself in a position of being able to offer to its stockholders a production based only on the actual money employed, or $100,000. Through their own initiative they then took advantage of the opportunity offered by electric drive and added to their equipment an amount of spinning machinery equal to that already installed. This operated with the rest of the equipment during the day time, and all preparatory machinery, for which only men are employed, is operated day and night, thus giving material to the double number of spinning frames during the day. This resulted in a production equal to that of a mill of 10,000 spindles costing $200,000, while the total cost of the mill was only $120,000. The addition of the extra spinning machinery cost $20,000, and the original cost of the mill was $100,000. This arrangement has, simply by the proper use of electric power, saved the mill an additional burden of investment of $80,000, the interest and also the depreciation on which would more than eliminate the entire power bill.

The old idea of building a mill amounted essentially to first building a steam plant and then building the mill to conform to it, as its shape and the arrangement of the machinery had to conform to the most convenient ways of running shafting. In an electrically driven mill the matter of power is secondary. The machinery is placed in the most convenient way for operation as a textile plant and the motors are installed afterwards.

It has been found that in practically every mill that has been converted from mechanical to electric drive, an increase in production has been obtained. This is almost always the case and it is not usually taken account of by investigators of power costs. Among the uninformed there is a quite general opinion that the converted mill takes to operate it electrically as much as or more power than it previously did with steam. On account of the increased production with the electric drive this is true in a great many cases; but in many other cases it is uncertain, as no accurate records of steam indications have been taken or kept. The explanation of this increase in power is simply that the production has been increased. At the time the motors are installed the speeds of the mill are readjusted and nearly always increased, the power is applied more directly to the work with less chance of slippage of belts and, above all, the speed with motor drive is much more constant.

Figs. 2 to 51 show a series of curves taken with a delicate recording tachometer. The longitudinal lines each represent 1 per cent of instantaneous variation, and approximately one-half inch in length of the diagram shows an interval of time of one second. All of these charts shown were taken in actual service, excepting Fig. 6, which was taken to prove the accuracy of the instrument with the best known constant speed drive—a direct-current shunt motor supplied with current from storage batteries.

Fig. 2 shows a chart from a 3000-h.p. cross-compound engine, taken directly from the main driving shaft.

Fig. 3 shows one from a 1000-h.p. cross-compound engine.

Figs. 4 and 5 are charts taken directly from the shafts of an 85-h.p. and a 125-h.p. motor, respectively.

Fig. 6 is taken from a known constant speed.

Figs. 7 and 8 are from water turbines in operation and under load.

Figs. 9 to 15 inclusive show speeds of a shaft directly driven from one large engine through rope drives, with the exception of Figs. 10 and 15 in which the shafts were driven from a second belt. Fig. 10 is the record of a shaft driven by a belt from the shaft recorded in Fig. 9, and Fig. 15 a shaft belt-driven from that of Fig. 14.

Figs. 16 to 20 show the same shafts driven by motors after the mill has been converted. Figs. 9 and 16, 10 and 17, 11 and 18, 12 and 19, 14 and 20, 15 and 21 represent steam and electric drives, respectively.

It will be seen from these records that a very material improvement in initial speed and transmitted speed has taken place. This mill was selected, among many others, as being representative of a large well equipped mill, and the steam drive is much worse in many of the mills charted.

Figs. 22 and 23 are of particular interest as showing the torsional spring in the shaft. This represents a line of shafting about 300 feet long such as is commonly found in weave rooms. Fig. 22 was taken at the driving end and Fig. 23 at the extreme other end, showing that where the original speed was excellent it was badly perturbed before reaching the end of the shaft.

Figs. 24 to 32 show speeds in a steam driven weave room. Fig. 27 is taken with the engine drive and the others are counter-belted to the shaft in Fig. 23 on one side, and to that in Fig. 32 on the other. It will be noted that the original speed, which was good, has been increasingly perturbed by belting, so that the greatest variation in every case is shown on the last shaft. Figs. 33 to 41 show speed records of the same shafts driven by two large motors. It will be noted that a considerable general improvement has taken place.

Figs. 42 to 44 show very badly perturbed speeds. These represent the three main line shafts on which the entire machinery of a large mill depends. This speed variation is caused by bad belting and excessive end play in the shafts, causing crowning and slackening of the belts alternately.

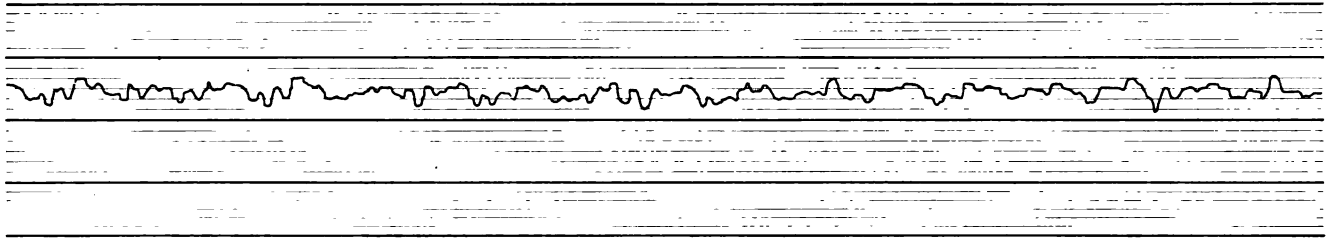


Fig. 2

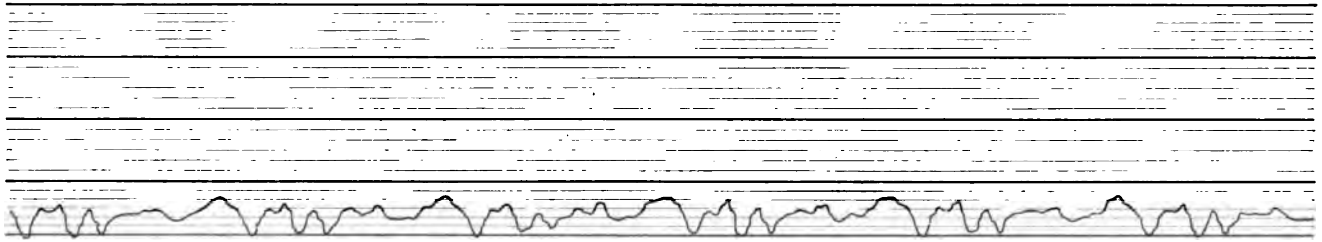


Fig. 3

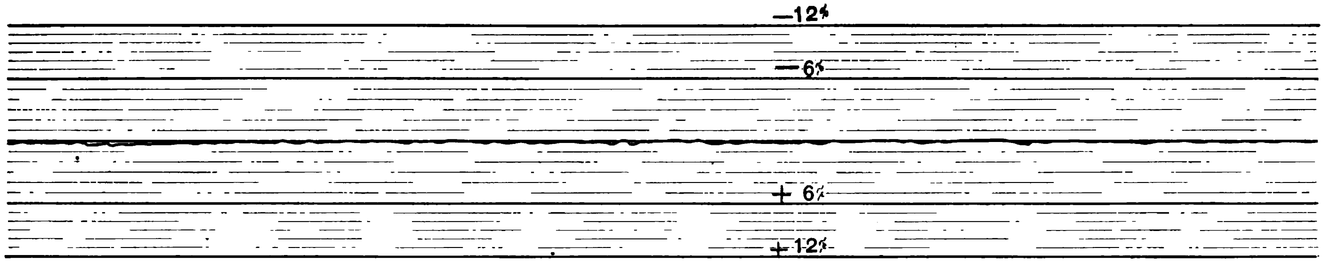


Fig. 4

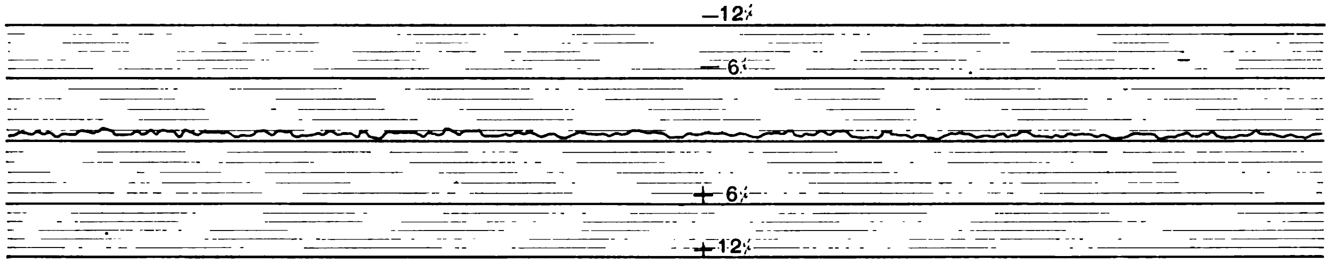


Fig. 5

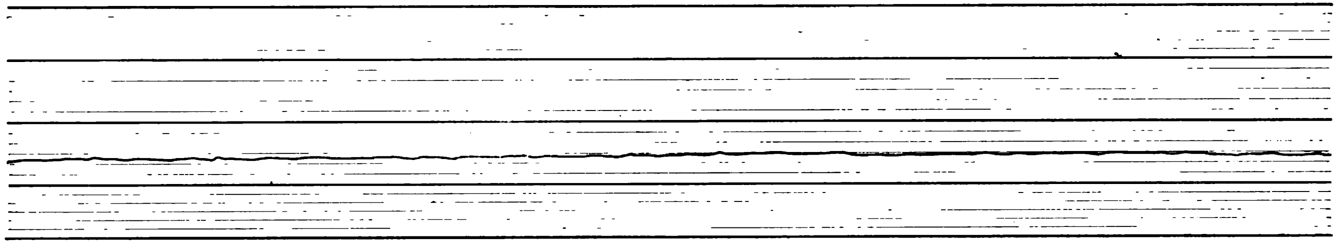


FIG. 6

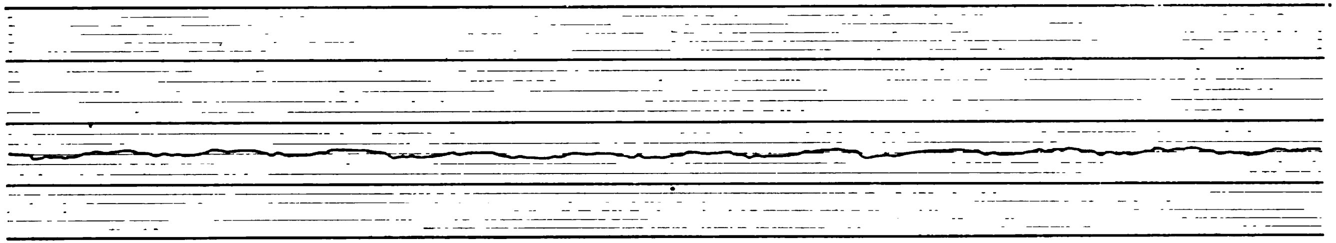


FIG. 7

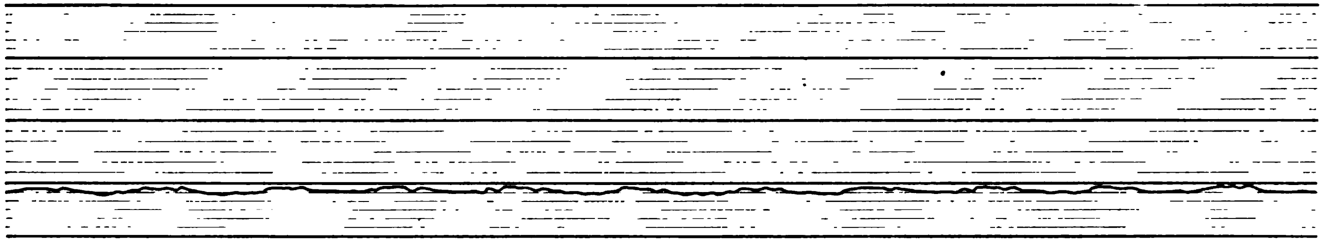


FIG. 8

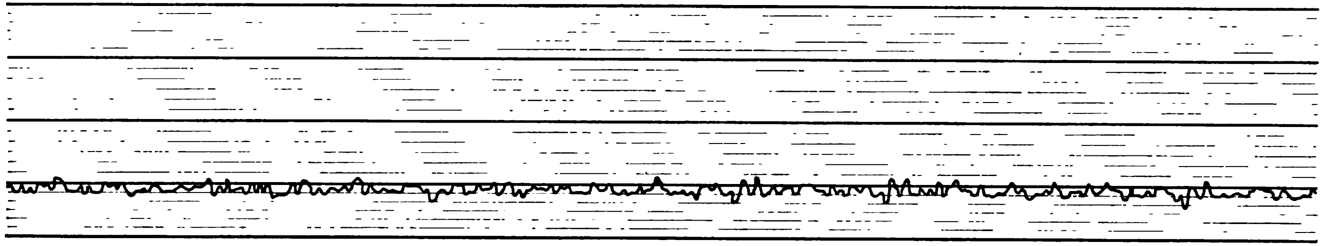


FIG. 9

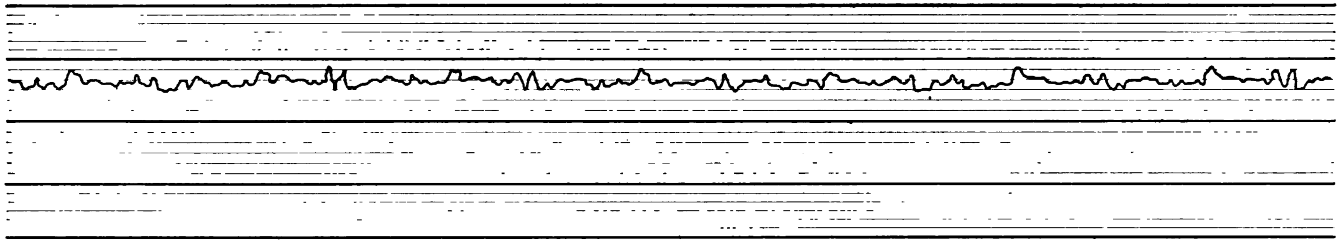


Fig. 10

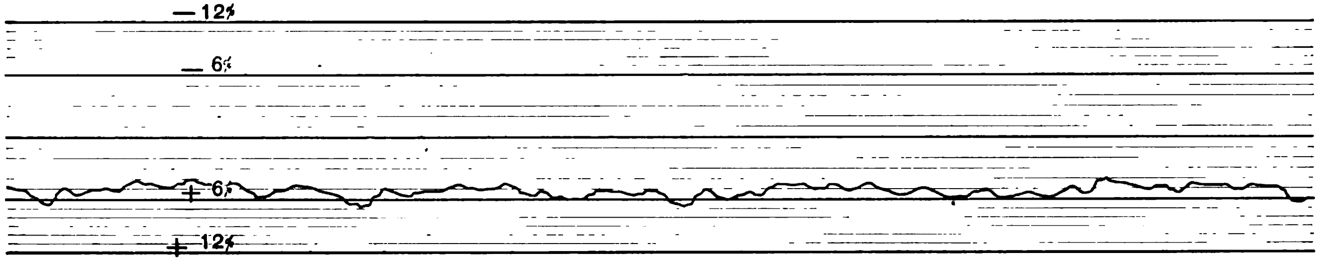


Fig. 11

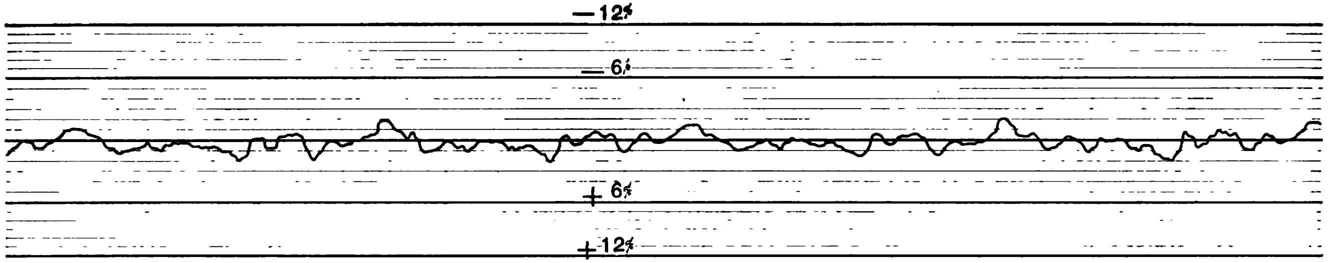


FIG. 12

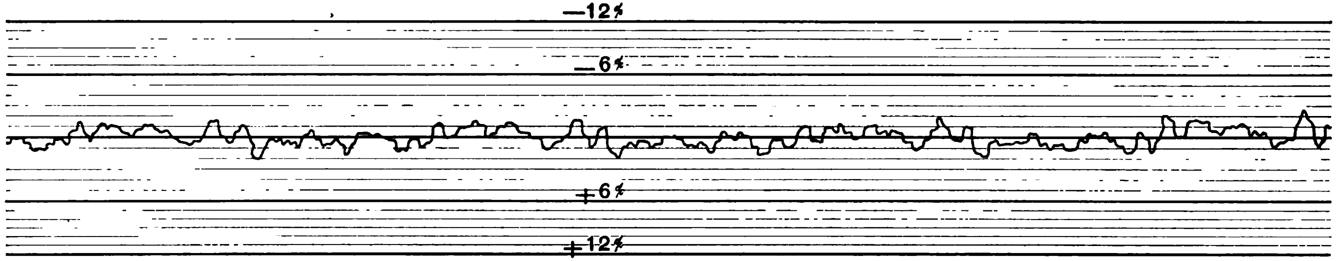


FIG. 13

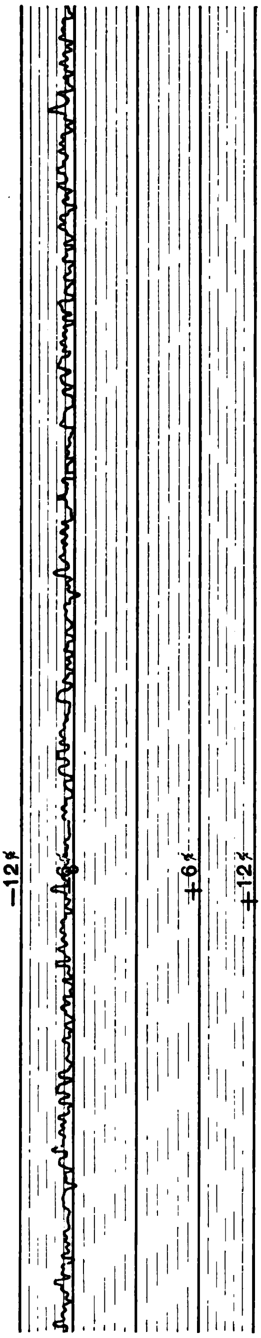


FIG. 14

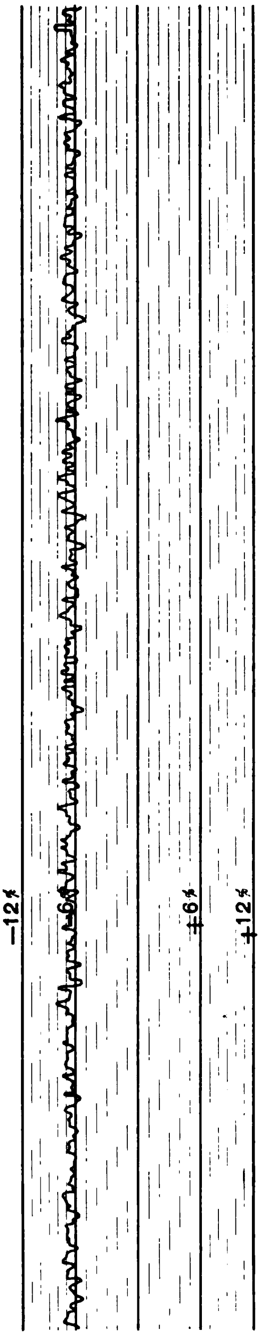


FIG. 15

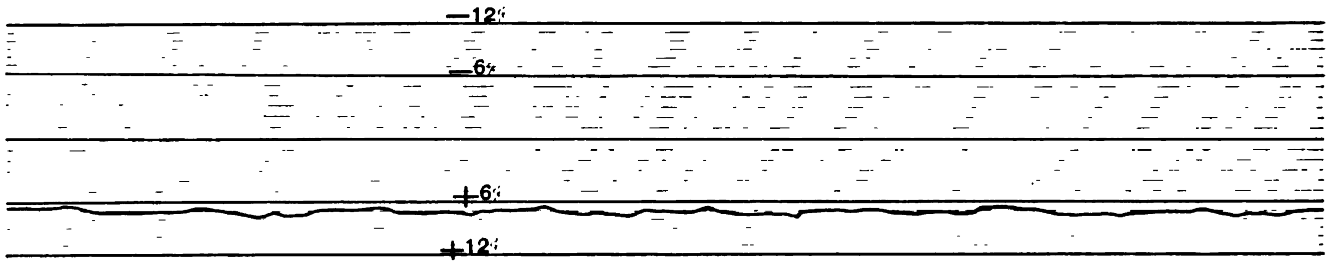


FIG. 16

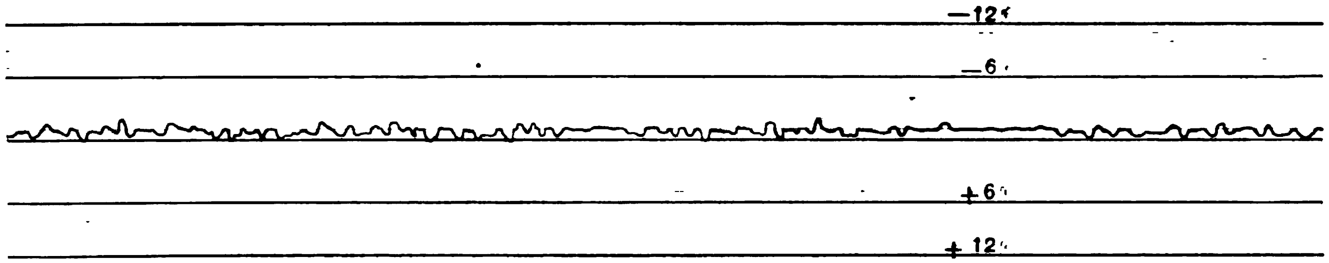


FIG. 17

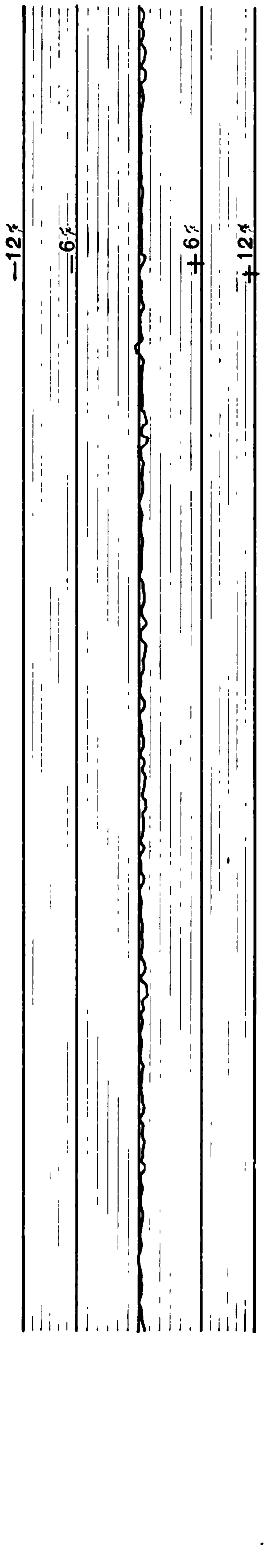


Fig. 18

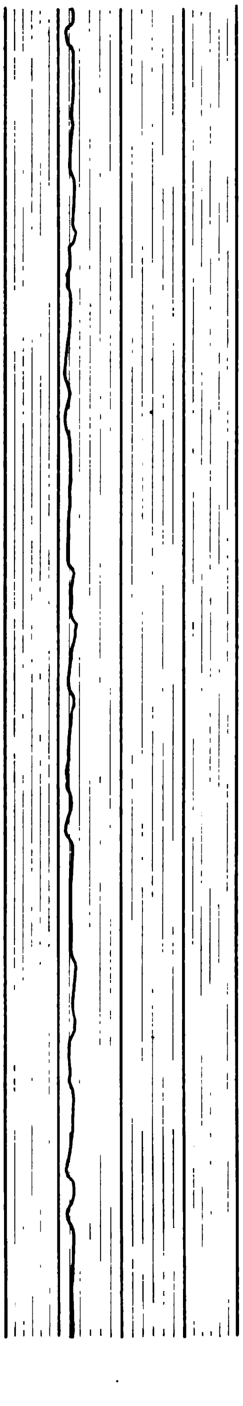


Fig. 19

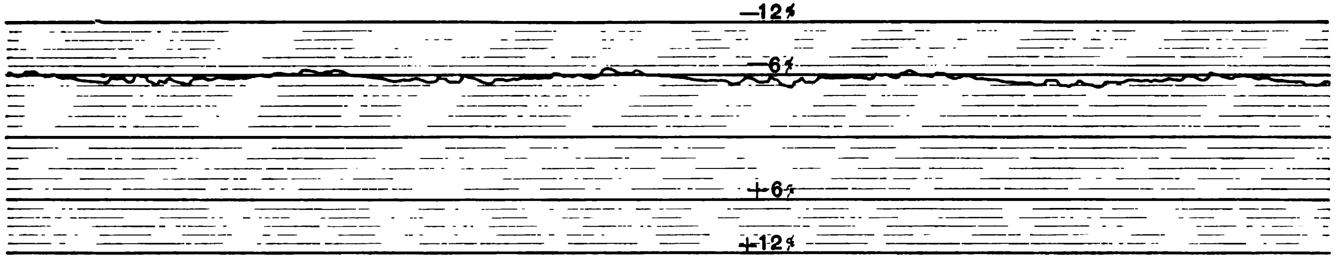


Fig. 20

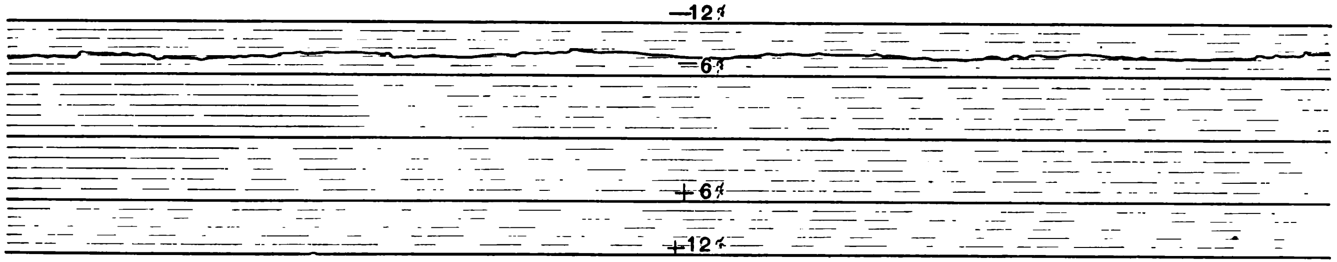


Fig. 21

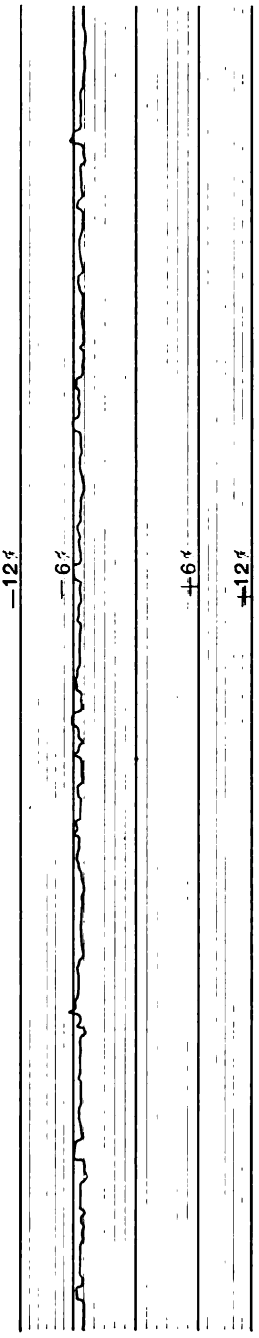


FIG. 22

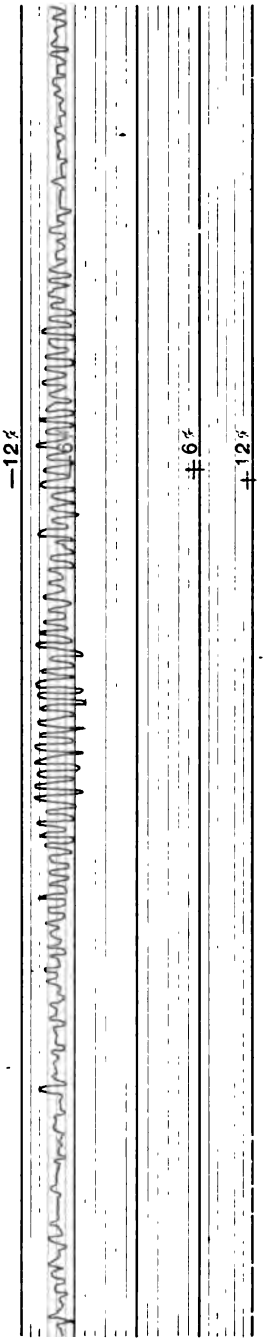


FIG. 23

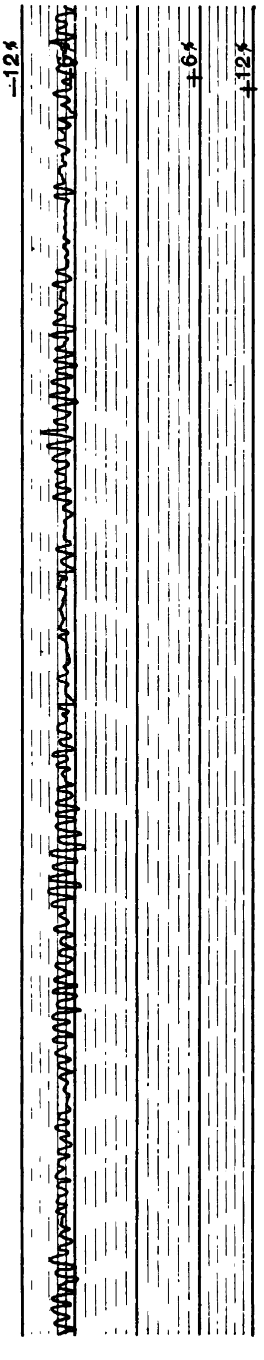


Fig. 24

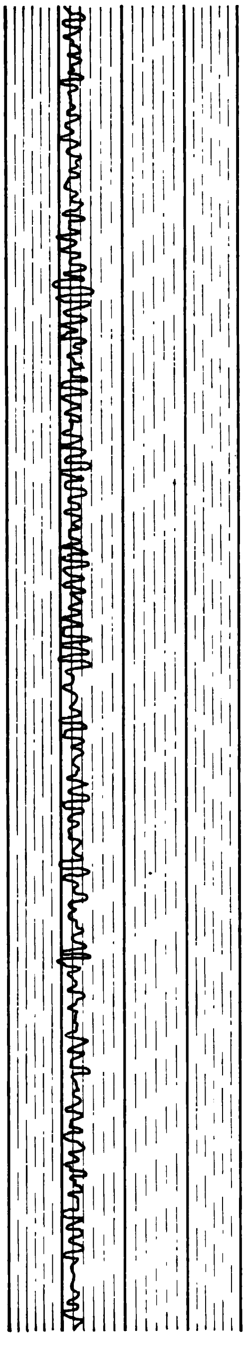


Fig. 25

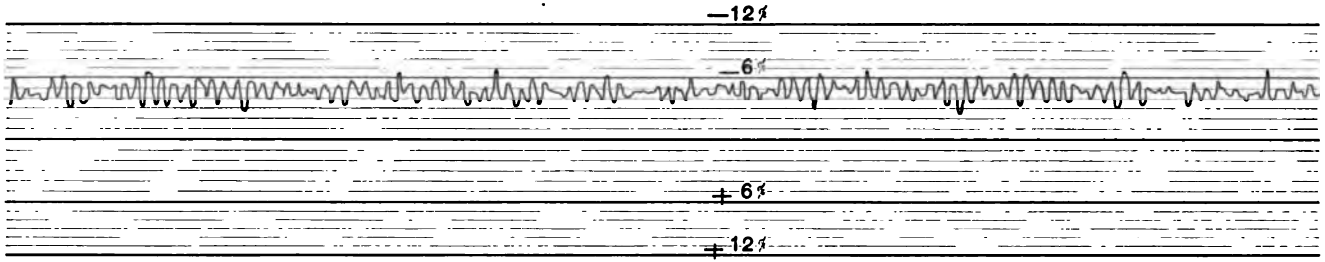


FIG. 26

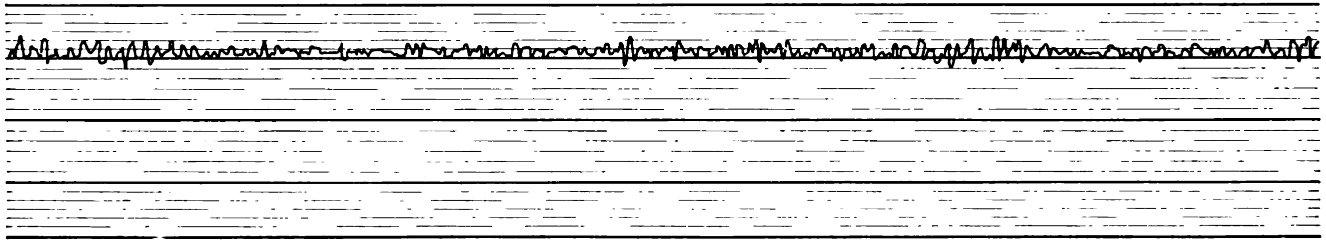


FIG. 27

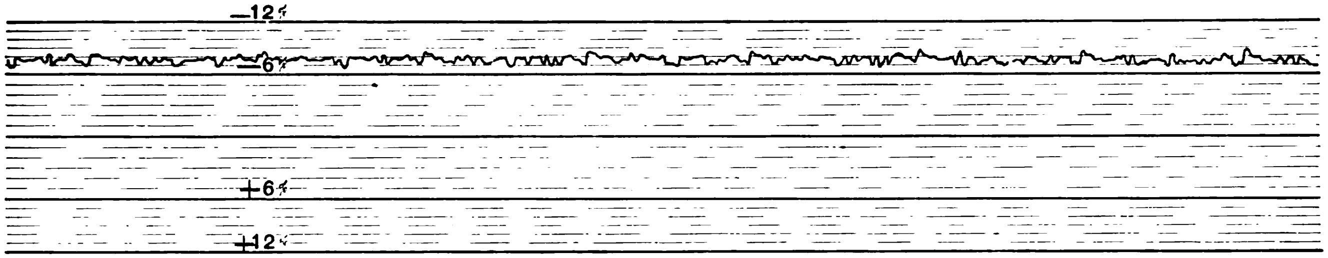


FIG. 28

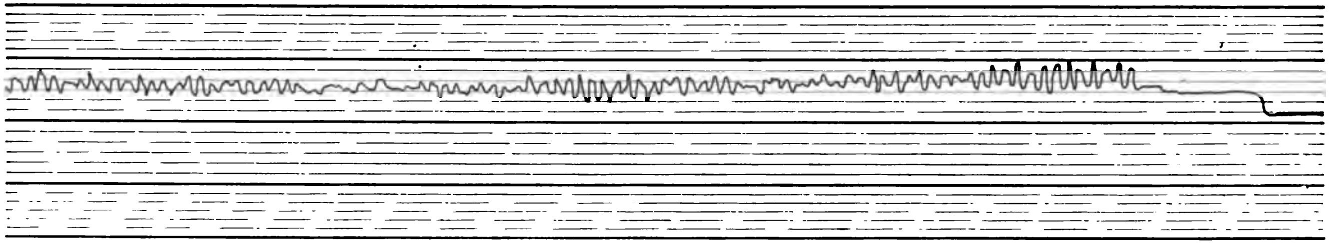


FIG. 29

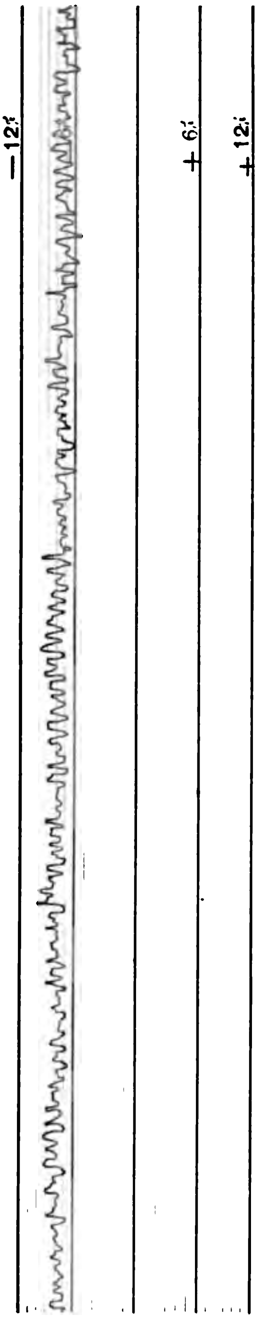


Fig 30

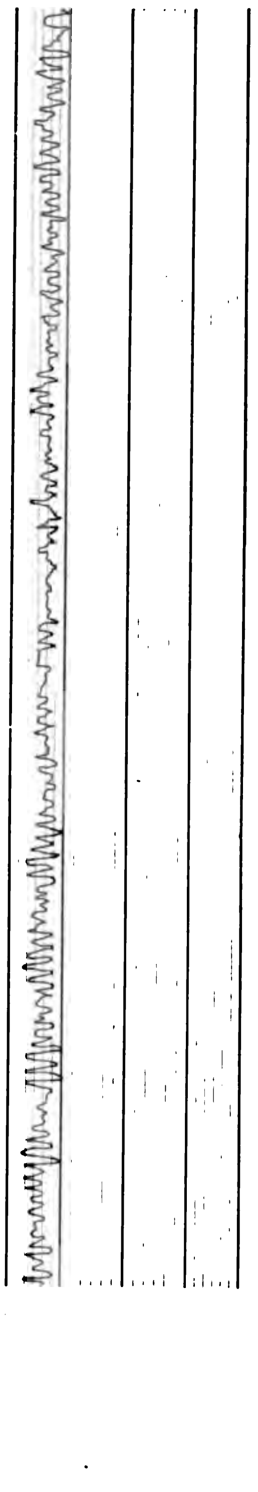


Fig. 31

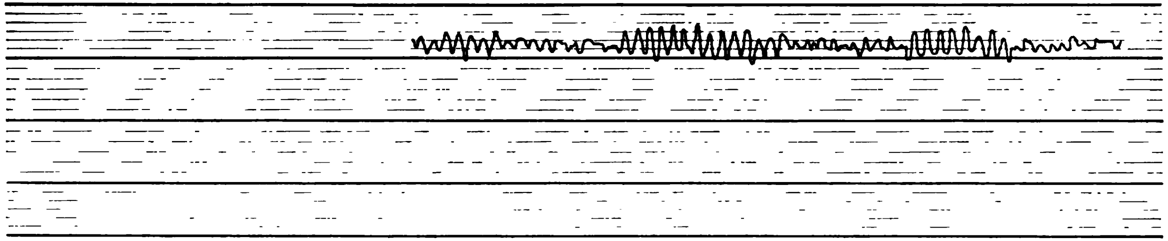


FIG 32

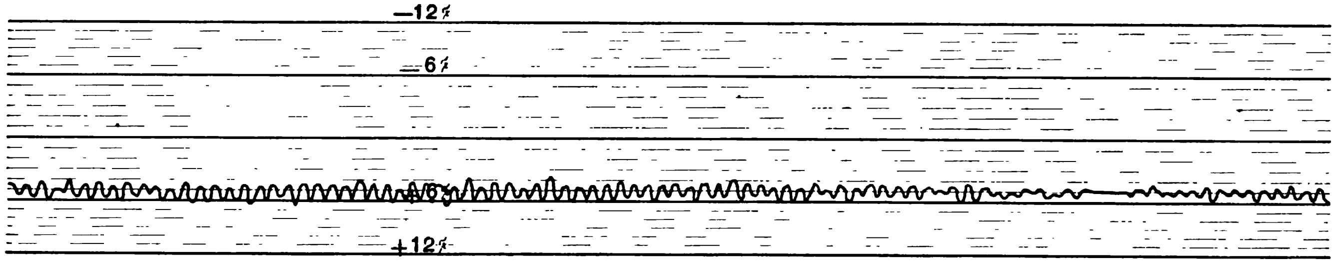


FIG. 33

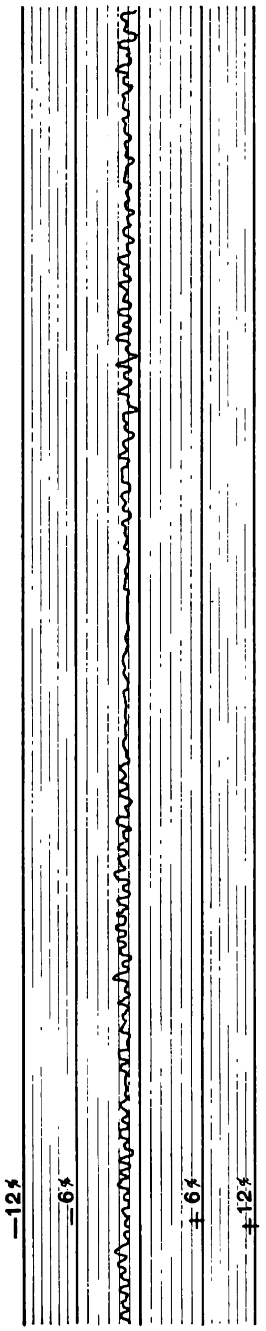


Fig. 34

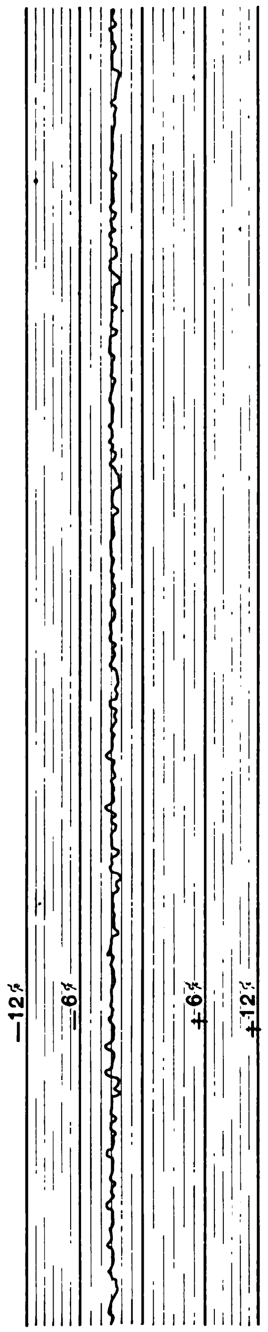


Fig. 35

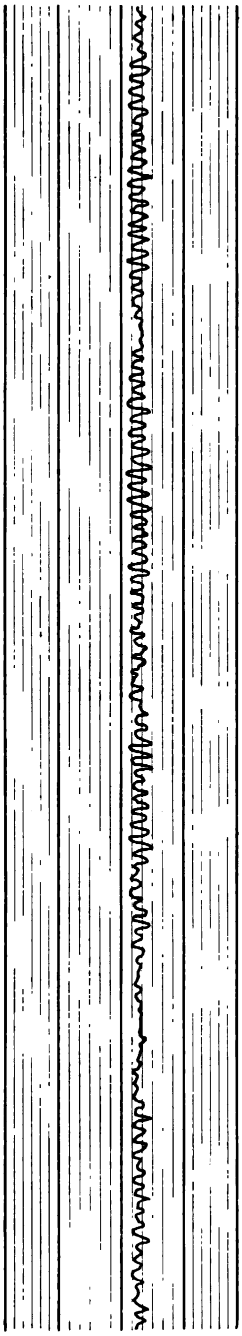


FIG. 36

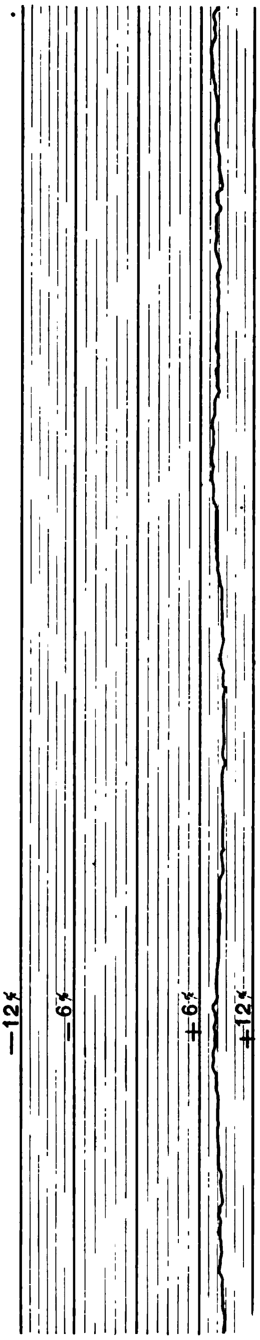


FIG. 37

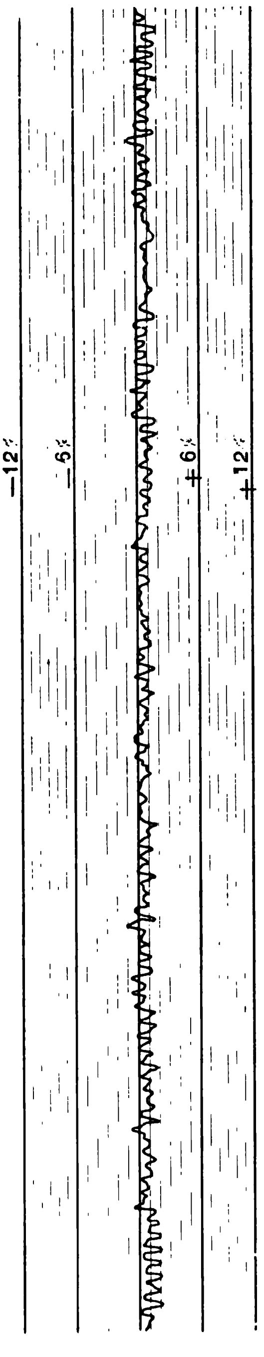


Fig. 38

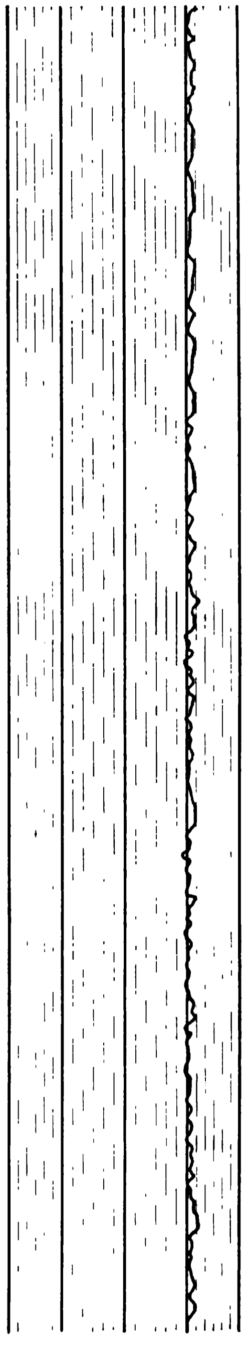


Fig. 39

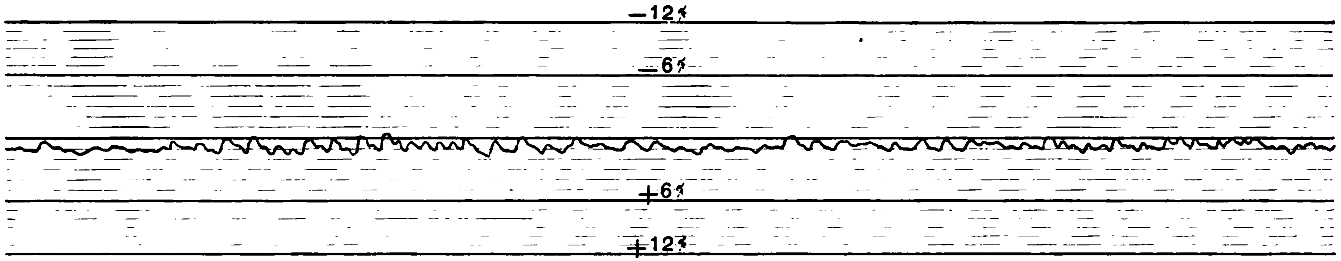


FIG. 40

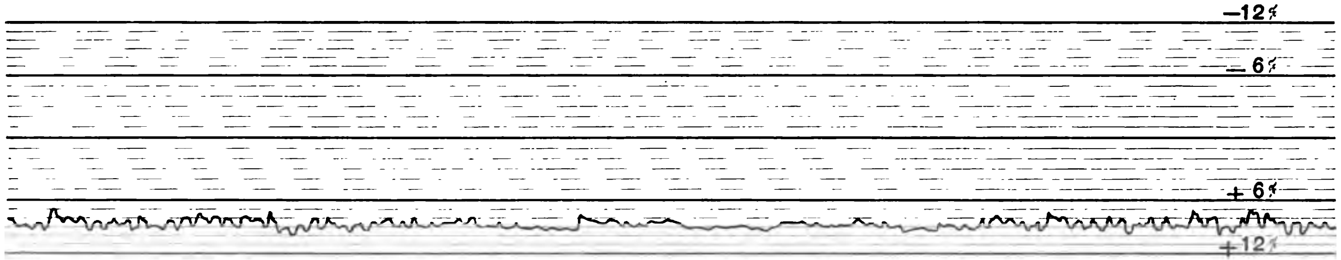


FIG. 41

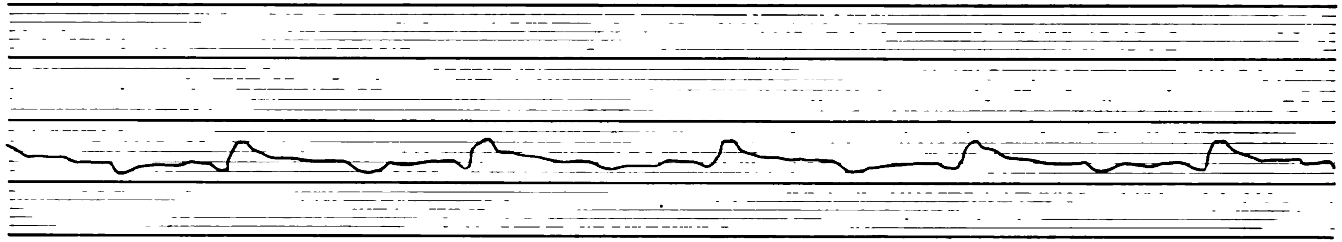


FIG. 42

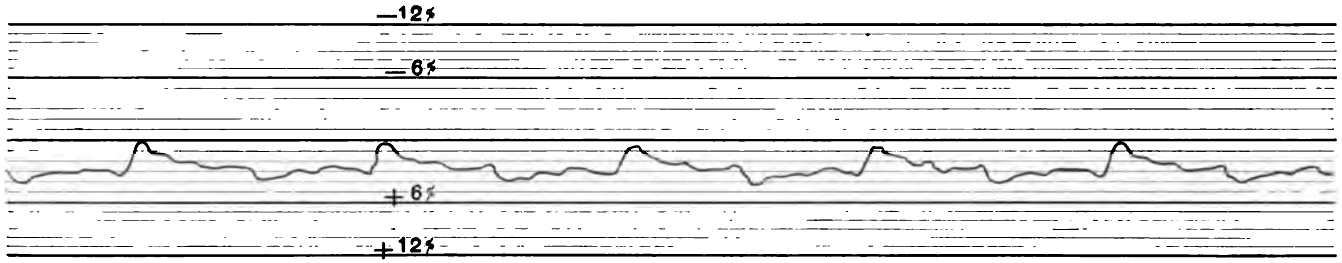


FIG. 43

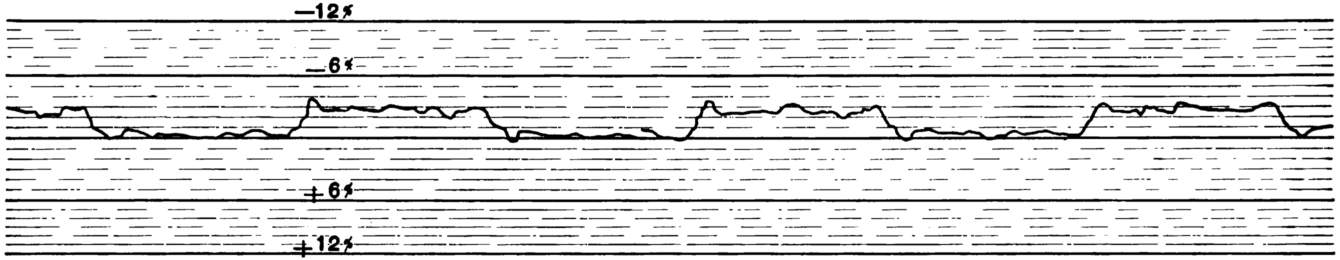


Fig. 44

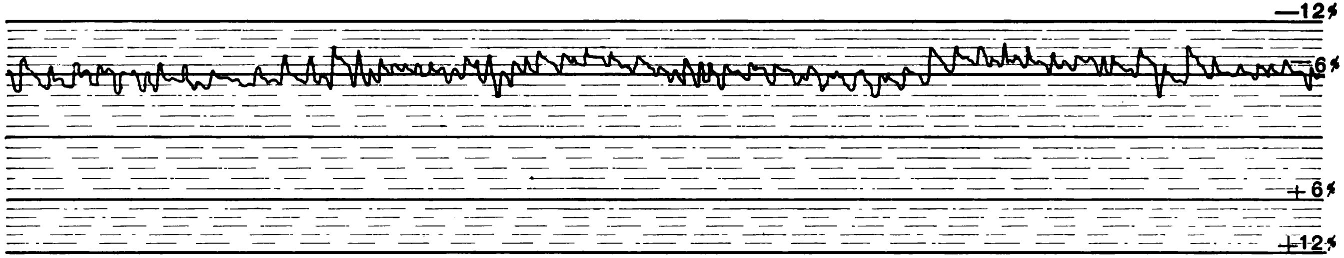


Fig. 45

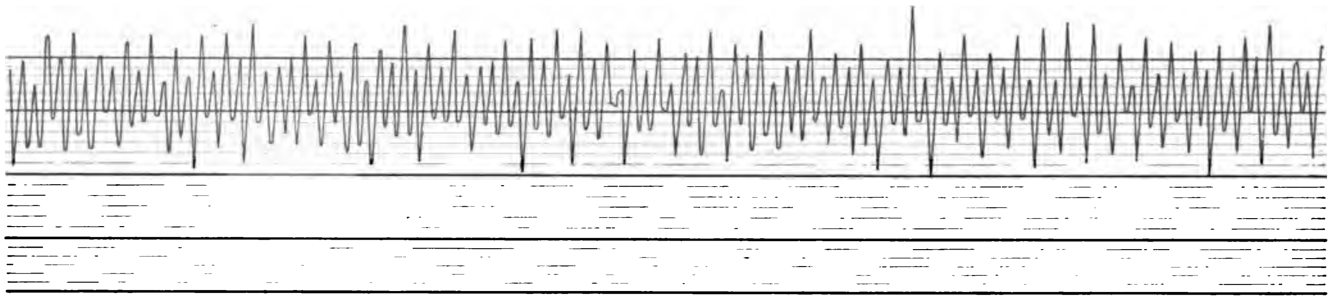


FIG. 46

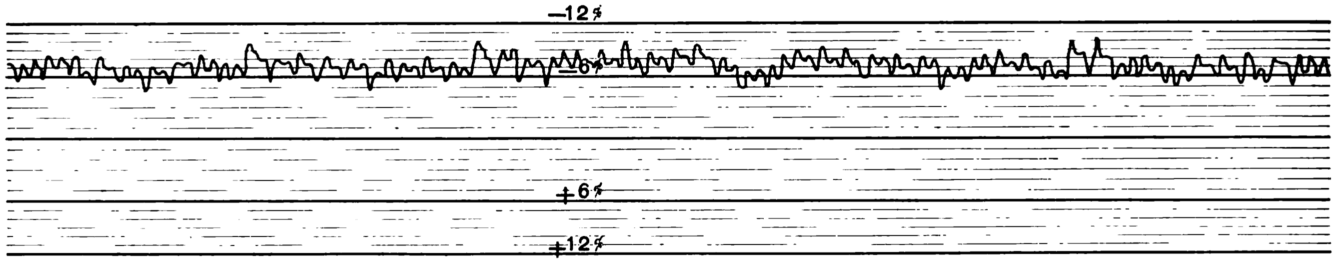


FIG. 47

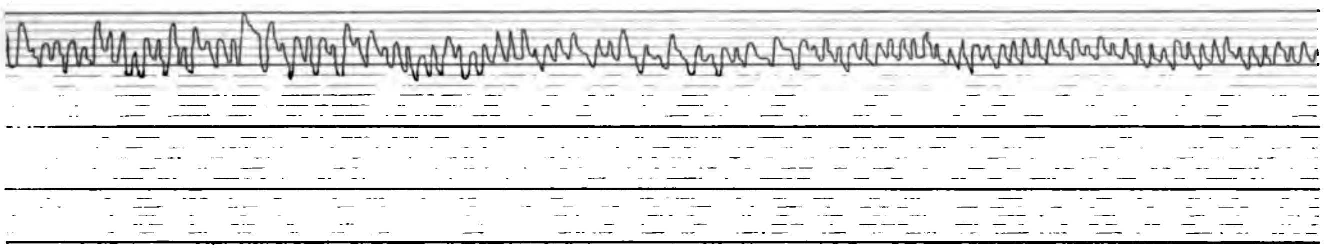


FIG. 48

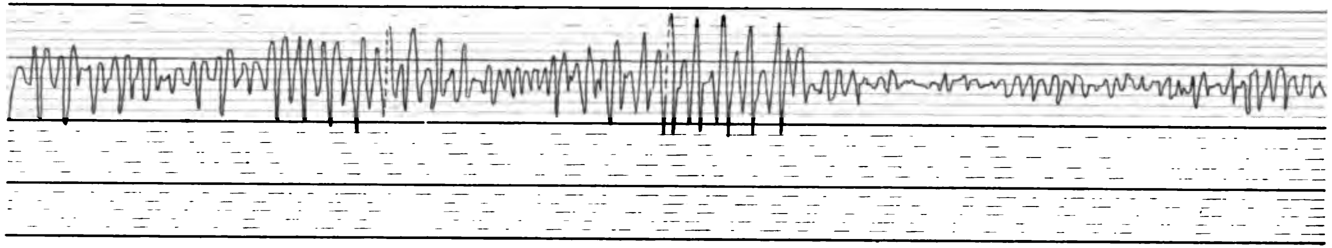


FIG. 49

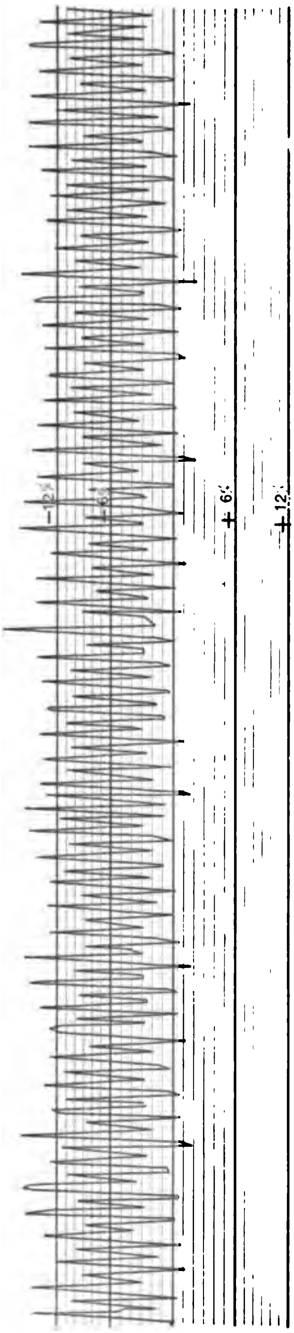


FIG. 50

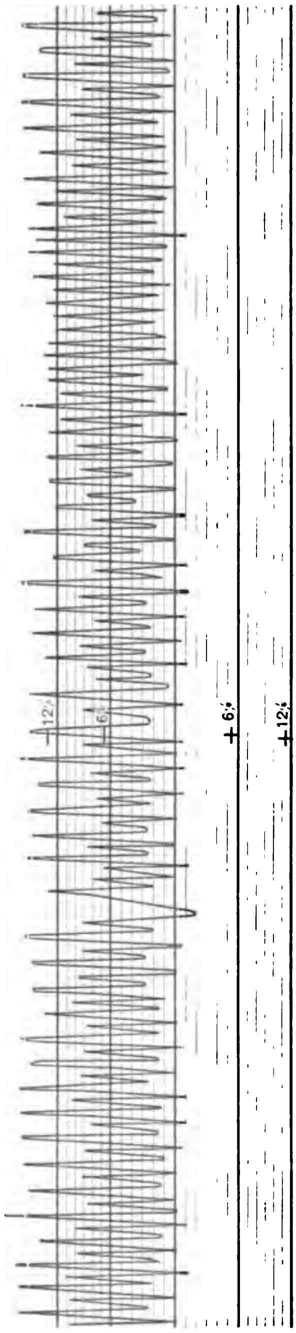


FIG. 51

These curves show the insufficiency of counted speeds where instantaneous variation is neglected. The highest point of the curve shows the maximum at which the work will run and all below that represents a loss of production. As a matter of interest the curves, Figs. 45 to 51, are shown. These illustrate an extremely bad speed condition of which the mill manager has been ignorant, and the mill has never been able to get out a good production.

In the territory of the larger hydroelectric systems the total number of mills operated consume a large amount of power. Each mill comprised in the group uses a relatively small proportion of the power furnished by the system. It is therefore possible to throw off or on many motors, or, indeed, many of the entire mills without disturbing the speed of the system. This is not the case in a mechanically driven mill, where even a small part of the machinery represents a good percentage of the total load of the engine.

In a converted mill, driven from a hydroelectric station, one of two results are always brought about. If the original production is maintained the amount of power necessary is reduced. This should not in all cases be regarded as of paramount importance, the most vital advantage being an increased product from the mill, which it has been shown can be obtained through electric drive. This has actually been obtained in nearly every case that has come under my observation.

In mills only very roughly converted, where surplus power is taken, and where the old uneconomical arrangement is left intact so that the steam drive may be used when the electric power is temporarily shut off, all carefully kept records show that an increase of production of from 2 to 10 per cent is obtained. In new mills especially constructed for electric drive the higher of these figures should obtain. This increase is brought about by two things. First, proper balancing of the work, and next, the application of motive power directly to the work it is to drive, and the fact that this motive power has a constant speed value, both instantaneously and continuously.

The importance of production may be shown in a broad, general way as follows: The value of a mill's product per annum is about equal to its capital stock. The cost of manufacture, with many variations for the class of work, may be taken proportionately about as follows:

Cotton, 60 per cent; power, 4 per cent; all other costs, 36 per cent, and the power cost, as a total is from 3 to 6 per cent of the total market value of the product. Thus, assuming the cost of a 5000 spindle mill as $100,000, its product in a year will be worth, roughly, $100,000 and its power bills say $5,000. If the product of this mill could be increased 10 per cent the gross value of this increase of product would be $10,000 of which the only cost would be cotton and power and some labor. The most costly operations of labor are paid by the day and effect no increase.

Allowing, however, for some increased labor cost we have as the total cost of this extra production:

Cotton, 60 per cent; power, 4 per cent, and labor, 3 per cent, or a total of 67 per cent and a net profit of $3,300 per year, or two-thirds of the total cost of the power, thus nearly eliminating the power bill. On account of the steadiness of the speed of the electric drive the machinery will suffer less deterioration than if run at even lower speeds with the steam drive.

It is very proper and very necessary to take all of these points into account as having a direct bearing on the cost of steam power.

GENERAL REMARKS

Fig. 52 shows the increase in power furnished to textile mills in the Piedmont region of North Carolina and South Carolina by the Southern Power Company. It will be seen from this that the increase was very slight during the years 1904, 1905 and 1906. In 1907 the mill managements in the territory where these lines existed having had the experience of their neighbors over the years previously referred to, began to appreciate the advantages and economies of the hydroelectric drive. It will be noted from this curve that during the year of 1909 and especially the last six months this increase has been greater than at any other time.

In hydroelectric systems of distribution to cotton mills it is found to be impracticable to place a sub-station for each consumer, especially to meet the conditions which we have in Piedmont Carolina, where several mills of small or moderate size are installed in one town. This is on account of the large first cost of a substation reducing from 100,000 volts, and also on account of the difficulty of running the high-tension mains through cities and towns. On account of the high cost of transmitting low secondary voltage any distance, both as to initial investment and in power loss, it was found necessary to adopt 2200-volt motors in mills where the general practice had been to use motors of 550, 400 and even as low as 220 volts.

At first considerable prejudice existed among the mill owners and the underwriters against the use of high voltage motors, but some years of experience have demonstrated their superiority in every way. The first cost is about equal to that of the lower voltage motors. Their efficiency is equal and the slip is also equal or somewhat less. With an equipment of 2200-volt motors power can be transmitted with an economical loss and reasonable first cost to a distance of approximately one and one-half miles from the central sub-station.

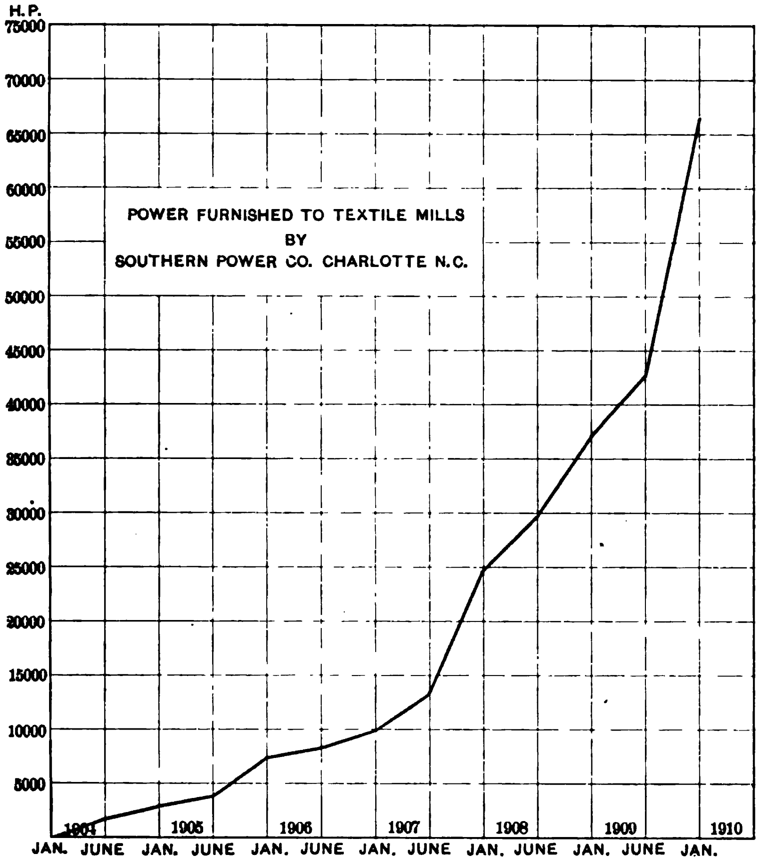


Fig. 52

In many of the older low voltage installations, for the sake of economy, open wire is run in the mill. The cost of installing it in conduit would be excessive on account of its size. And also on account of the size of the wires, and the very extensive system of feeders, it is only a matter of time until open wiring becomes disarranged, due to its being swept to remove the lint and dirt which it accumulates. Another serious feature of this system is the frequent and necessary employment of fuses to protect smaller branches.

Probably 90 per cent of the motors burned out in the mills under my charge have been burned out by the failure of one of the three fuses of the three-phase circuit, leaving the motor operating on a single phase, which eventually destroys it. On account of increases to the mill equipment, or bad initial calculations, the wiring loss in the mill often runs up to very high figures with the lower voltages. In one mill in my experience, with a 220-volt distribution about 500 feet long, the total wiring loss reaches 15 per cent, and this after the mill management had at a considerable cost added feeders from time to time as the mill has been enlarged.

In mills using 2200-volt motors, the wiring is run in iron or steel conduit and consists of three-wire insulated cable with lead sheaths. The loss in this system is reduced to practically nothing, the cost is low, and complete protection is afforded by means of automatic oil switches. The size of the wires is very small, and the whole system takes up less space in a mill and is no more conspicuous than water and sprinkler pipes. On account of grounding the conduit, the liability to accident is practically eliminated.

The manufacturers of standard motors now build 2200-volt motors in sizes of as low as 15 h.p., and where motors smaller than this are required, 2200 to 550-volt transformers are installed on the mill wall close to the motors and the secondary wire is run directly to the motors from them.

DISCUSSION ON "ELECTRIC DRIVE IN TEXTILE MILLS", CHARLOTTE, N. C., MARCH 30, 1910.

Mr. Milmow: In reference to the first cost of electric drives, we have taken the figure at $33 per horse power, which includes a great many things ordinarily not required in the electrical equipment of the mills. The $33 includes all the shafting and belting, fire protection, and reservoir, and other things of that kind. A new mill can be equipped, or an old mill converted, as a complete installation, as far as electric motors and wiring are concerned, for about $15 a horse power, maximum, and has been done as low as $12 per horse power. After several years of experience I can highly recommend the use of high voltage motors, and wish to say that we consider that the use of 550-volt motors handicaps a mill at the start and handicaps its future development. It requires more power, and introduces entirely unnecessary losses in the transforming of power, but the 2,200-volt motors, of which we have had a large number in use, have done their work and carried out their service with practically no repairs and with general satisfaction to everybody.

C. F. Scott: Aside from the particular points which are dwelt upon in this paper, I have been interested to note how many of the advantages which are brought out are those which are incidental. Although in this paper the cost of the power is the essential thing set forth, and although it is shown that the cost of electric power is less than that of steam power, yet the great advantage does not lie in the simple cost of the power, but in indirect elements; in the superiority of the motor, in its general convenience, flexibility, and adaptability, and in its constancy of speed. The power can be considered both from the quantity and quality standpoints and it is the quality standpoint which seems to me to be the strong one, and the important one, as is stated in this paper.

An interesting point is brought out in regard to the location and arrangement of the mill—in a steam-driven mill the steam plant must first be designed and the lines of shafting laid out as may be convenient for the engine. The building and arrangement of machinery is secondary to engine, shafting and belting. On the other hand, in the electrically-driven mill, the design can be made, not from the standpoint of power, but from the standpoint of the operations. The power becomes secondary, and the whole arrangement of the mill can be made most economical and most serviceable and efficient, so as to better serve its real purpose of economic production. The mill itself can be installed in any convenient place without reference to waterfalls or convenient proximity of condensing water, and the motor can be put up on the ceiling where it will take no room. Further this paper shows an increase in production by the gain in speed constancy. These indirect things make for better and larger production through the higher efficiency which can be gotten from the operation of the mill and the labor which is there employed.

In the study of a problem of this kind, we have a most excellent illustration of the advantages attained by taking a broad view of the situation. We find here, as in many other cases, that the indirect advantages in the use of electricity, may be of far greater value than simply the saving in the cost of power.

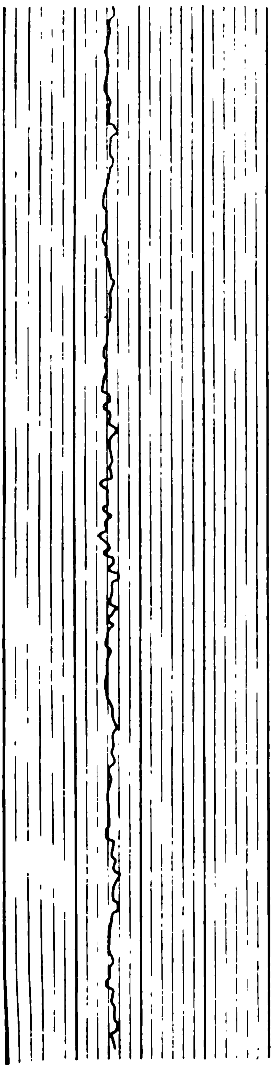
W. S. Lee: If you will refer to the chart on page 387, which represents a curve taken by indicating an engine every ten minutes for a period of one week, you will find a rather interesting condition of affairs. That is one of the best and most economical mills in the whole territory. You will note that on Monday morning the mill began with a very heavy load, something over 2900 h.p., and that this load ran fairly steady during the forenoon, but in the afternoon dropped off considerably. This same condition obtained on Tuesday. I call your special attention to the last few hours on Wednesday. I ask you also to note the last hour on Thursday, and the last hour and a half on Friday. These curves present a graphic picture which shows that the mill is not being operated up to the proper efficiency. The production of the mill was decreased, due to the fact that each department was not kept up to the highest standard of efficiency, as it did not work its full number of hours per day. This shows the importance of keeping a power curve, which will show what the mill is doing. A manager can tell from his power curve whether the mill is being run properly.

I do not know that I can explain this subject of speeds more thoroughly than is done by these curves. Speed means a great deal in output to cotton mills. Cotton mill machinery is built to operate automatically. If a thread or any part breaks it stops the machine automatically and it takes a certain time for the operator to get to this machine and get it started. Furthermore, the momentary variations in speed cause certain pulsations which, when magnified, produce a cadence throughout the mill. These pulsations very often break thread and stop the machine, which normally would not occur if the speed was more uniform.

I want to call your attention especially to the charts on page 418. These are from a mill with which we have a contract to furnish power; it is now operated by steam and has a speed variation of 16 per cent. If you will put an ordinary tachometer on the end of the shaft, and take speed for one minute, it will show good speed, but this does not show the variation up and down as shown by this curve on a large scale. The variation from the average speed is eight per cent below and eight per cent above.

Since the charts referred to on page 418 of Mr. Milmow's paper were taken, showing variation of this mill while being driven by steam, the mill has been electrically equipped and is now operating by electric power. Chart No. 1 shows a 60-h.p.

motor in this same mill driving cards; chart No. 2 shows a 60-h.p. motor on spinning frames; chart No. 3 shows an 85-h.p. motor on spinning frames. By observing these charts it will be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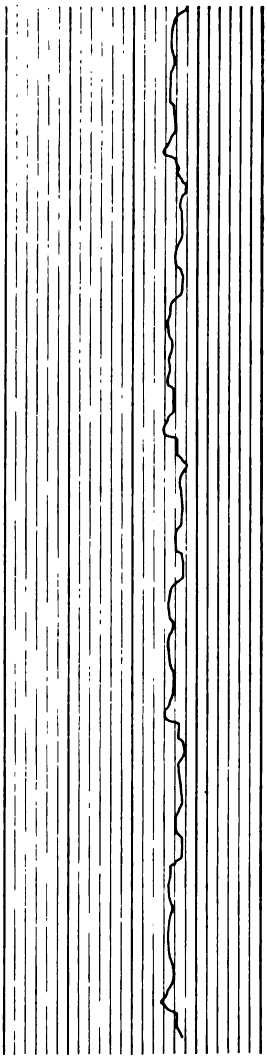
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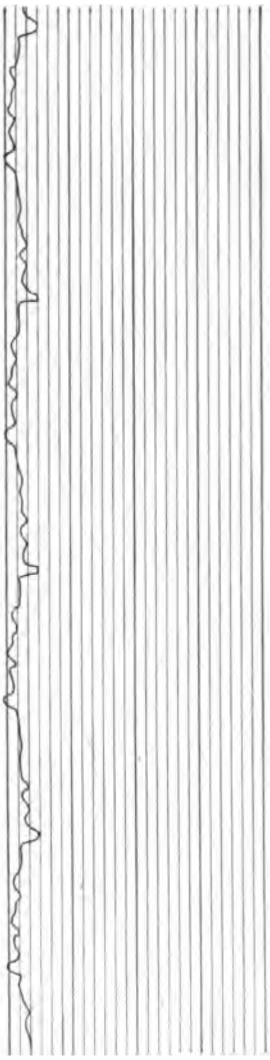

No. 3

noted that the extreme variation is from 2 per cent to 3 per cent, and most of the time less.

If you can use a power in the mill that will have only three per cent speed variation, you immediately move your average speed up six-and-a-half per cent higher than you had it before. If you move the speed up six-and-a-half per cent, we know more goods are made, and we know it takes more power to do it. The results of changing over a lot of these mills have been different in almost all cases. In some cases we have increased the amount of power, in other cases we have decreased it. Where we have increased the power consumption we have increased the production.

There is another matter to which I desire to call your attention, and that is in connection with extensions of the mills. All mills in this part of the country are built with the idea of increasing or extending them. I do not believe there has been one mill built down in this part of the country that its president and manager did not contemplate increasing its capacity. Now, if that is the case, it is impossible to lay out an economical or efficient steam plant that is susceptible to that variation. In the case of the electric drive, the mill manager can put in what he needs for his present purposes, and as the business increases and he extends the mill he can build on to it additional sections.

A. W. Henshaw: I think the curve given on page 421 is particularly interesting, as showing the very rapid increase in the application of electric power to textile mills in this part of the country.

The Census reports for the year 1900 show that the total power used in cotton mills in the United States was approximately 800,000 horse power, which had increased to approximately 1,000,000 horse power in 1905. This is an increase of 28 per cent. Deducting from that figure the power used in the states of North Carolina, South Carolina and Georgia, the amounts are 628,000 h.p. in 1900, and 700,000 h.p. in 1905, which is an increase of eleven per cent; whereas in North Carolina the power used in cotton mills had increased sixty per cent in these five years, and in South Carolina and Georgia one hundred per cent, showing that the great increase in the cotton industry has been recently in these southern states, a very marked condition as compared with the other states of the Union. I am speaking particularly of the total power used in cotton mills, whether supplied electrically or otherwise.

It is interesting to see also what a large percentage of that power is used in this particular section of the country as compared with the power used in all lines of manufacture. In South Carolina there were 156,000 h.p. used in cotton mills in 1905 out of a total of 221,000 h.p.—that is, seventy per cent of the power used in manufacturing in South Carolina was applied in cotton mills. In North Carolina there were 93,000 h.p. used in cotton mills, out of a total of 219,000 h.p., which is 42 per cent.

The amount which is applied by the use of electric motors has increased very rapidly, and is continuing to increase. The State of South Carolina has been far ahead of any of the other states in that respect. In 1905, approximately 19 per cent of the power used in cotton mills was applied by the electric drive, and in North Carolina only about two per cent. That there has been a very rapid increase since then is shown by the curve to which I have referred.

I believe that when we obtain the results of the census for 1910 we shall see a great increase, and that this particular section of the country will be far ahead of any other in the large amount of power supplied through the electric drive in cotton mills.

D. B. Rushmore: Mr. Milmow's paper is of interest in connection with the statements recently made that this country is passing from the position of an agricultural nation to that of an industrial one. The use of electricity for manufacturing purposes is old, but its rapid extension into all such lines is one of the phenomena of the present time.

In the paper under consideration we have an interesting comparison of the steam plant in a particular mill, and electricity taken from a large system—a comparison which must be made in detail in many different individual cases. In general, it is much more economical for the generation and distribution of electric power to be concentrated in the one large system and for the manufacturing industry to buy such power, rather than to generate it in a small plant of its own.

Mr. Milmow has brought out a large number of interesting points illustrating the advantages of electric drive. Many of these are applicable to other forms of industry, and this will be one of the valuable uses of his paper.

L. T. Robinson: I would inquire if Mr. Milmow will take a moment to explain how the speed curves were taken; that is, what sort of an instrument was employed in taking them, and what the time scale on the curves is? I would also call attention to the value, to all concerned in the industrial application of motors, of just such curves as those, shown on page 387. Perhaps he will carry his investigations further and obtain curves on individual machines. The opportunity is always there to use curve drawing instruments on individual motors to check operating conditions and to know if the motors are being run to their full capacity at all times.

Mr. Milmow: We obtained these curves by means of a tachometer specially constructed by Messrs. Schaeffer & Budenberg, applied to the shaft under test by means of a belt. We checked up all these measurements very closely, and one of our curves, Fig. 6, has been inserted there to show the accuracy of the instrument. We have checked the instrument a number of times to determine its accuracy. The instrument itself is rather expensive and cumbersome, and I do not think it would be feasible to apply it in general to industrial applications.

Mr. Robinson: What is the time scale?

Mr. Milmow: That is given in the paper, and is approximately one-half inch in length of the chart, equals one second. You can see that the wave variations are decidedly instantaneous ones.

A paper presented at the Charlotte meeting of the American Institute of Electrical Engineers, March 30, 1910.

GAS ENGINES IN CITY RAILWAY AND LIGHTING SERVICE

BY E. D. LATTA, JR.

It is not the object of this paper to present the subject of internal combustion engines from a scientific point of view, or to report on results obtained from tests made under the most favorable conditions with apparatus and facilities only to be found in an experimental laboratory, but to consider the subject under the following heads:

First, to give a description of the apparatus and equipment in a small but thoroughly appointed central station, viz: that of the Charlotte Electric Railway Company, using gas engines for prime movers, and supplying current for street railway purposes, electric lighting, and motors in small units.

Second, to give from the daily operating reports, some figures from which can be formed an idea of the reliability, efficiency, and adaptability of the plant under conditions which are relatively as severe as can well be imposed upon any plant, whether large or small. The extremely variable nature of a railway load and its rapid fluctuations caused by a system of few cars with comparatively large individual requirements, is so directly antagonistic to the fine degree of regulation and the continuity of operation demanded by good lighting service, that the handling of such conditions in a creditable manner should receive due consideration as a factor of no small importance.

Third, to give some data on the subject of producer gas manufacture, which to the engineer versed in the principles of fuel combustion may seem obvious and even crude, but which to operators and those investigating the operation of producer gas plants may be of value, in that it can be acquired only by experience and by tedious reference to the works of many authors on the subject of fuel combustion.

Lastly, to offer a few remarks on the adaptability and advisability of gas engines for certain kinds of work.

The period covered by this paper, viz., twelve months, dates from the first of January, 1909, when the plant had been in operation for about six months, and could be considered as being fairly well under way. Much has been learned during the year just passed, and each day gives new experience for the operators. Therefore, while we feel satisfied and even gratified with the record to date, still we feel it is reasonable to expect an improvement over results of the present year, brought about by eliminating some of the petty troubles which experience has taught how to overcome, and thereby attaining a more uniform efficiency of operation.

Description of the Plant

The engine room equipment consists of two 810-b.h.p. horizontal twin-tandem, double-acting four-stroke cycle gas engines and one 60-h.p. single tandem exciter engine, in general similar to the large engines. The 540-kw., three-phase, 60-cycle, 2300-volt alternators, are direct and rigidly connected to the crank shafts of the main engines, and a 40-kw. direct-current generator is direct connected to the exciter engine. In addition to this apparatus there is an induction motor-driven exciter set of the same capacity as the engine exciter, a 300-kw. and a 500-kw. rotary converter, and the usual switchboard equipment.

The producer apparatus is contained in a building about one hundred feet from the power house, and consists of two 1000-h.p. units of twin generator down-draught producers, having a continuous overload capacity of 50 per cent. Each unit consists of two 9-ft. generators, 16 ft. high, having a fuel space 7 ft. in diameter by 8 ft. high above the grate bars, which are of arched fire-clay tile. The generators are connected at the bottom by openings, lined with fire brick, containing water-cooled gate valves, to an economizer or vertical boiler of 100 h.p. rating. From the top of the boilers a 16-in. pipe leads to the bottom of the wet scrubber and from the top of the wet scrubber to the exhauster, or through a by-pass around the exhauster to the dry scrubber. A 60,000-cu. ft. holder receives the gas from the producers and delivers it to the engines. (See cut of producer on page 494.)

To describe the engine more in detail, the cylinders are 24-in.

bore by 36-in. stroke; the fly-wheels are 16 ft. in diameter and weigh 34,000 lb. The entire engine occupies a floor space of 18 ft. by 44 ft. and together with the alternator weighs 500,000 lb. All parts of the engine that come in contact with the hot gases are water-jacketed, including cylinders, pistons, piston rods, mixing chamber, valves and valve seats, and the exhaust pipe down to the floor level. The jacket water from the various parts of the engine empties from separate pipes into open funnels, which enables the operator to determine at all times the temperature of the different parts of the engine.

The ignition is low tension make-and-break, with two igniters to each end of each cylinder. The ignition current is supplied by one of three batteries of five cells each, and requires about 10 volts. This current passes through a separate kicking coil to each igniter, and a pivoted armature at the end of each coil indicates when the igniter is working properly.

The valves are the poppet type and are actuated by bell-cranks which are lifted by cams on the cam-shafts which are geared to the crank shaft and run at half speed. While there are some mechanical objections to the use of cams on account of difficulty of lubrication, still they are supposed to have a decided advantage over eccentrics, which impart a harmonic motion to the valve. By the use of cams with properly designed contours, quick opening and quick closing of the valves is obtained, and there is a relatively long period during which the valve is wide open.

Intake and exhaust valves are located on top and bottom, respectively, of a compartment bolted to the side of the cylinder which acts as a mixing chamber at one time, and explosion chamber at another part of the cycle.

The governors are of the Jahns type, in which the centrifugal force of the weights revolving in a horizontal plane is resisted by the direct pressure of coiled springs, the weights turning on rollers in a constant oil bath which practically eliminates friction. The governor is driven by a belt from the cam-shaft, and carries no load other than that required to revolve itself. The cut-off valve shaft is driven by bevel gears from the cam-shaft through a hunting gear, which is raised or lowered by the governor, and thus advances or retards the motion of the cut-off shaft with regard to the cam-shaft. The cut-off shaft by means of cams serves all cut-off valves. A cut-off latch hook, engaging the cam of the cut-off shaft, releases the cut-off valve by means of a floating lever connected to the inlet valve and latch which lifts the cut-off valve stem until the latch is disengaged. A dashpot on this valve stem permits the valve to close without jar.

The governing is done with a uniform mixture, the amount of which admitted to each cylinder is controlled by the governor through the agency of the cut-off valve gear. Each cylinder has its own separate mixing chamber and mixing valve which regulates the proportion of gas and air, and a disturbance such as a back-fire does not foul the gas going to other cylinders, this feature is a great advantage when close regulation is desired.

A plunger in the face of the fly-wheel works in and out radially against a coiled spring. In case of excessive speed of the fly-wheel, centrifugal force drives the plunger out beyond its normal position and opens a switch in the igniter circuit, thus shutting down the engine and preventing racing in case of the governor belt breaking or the governor otherwise losing control of the engine. This device is tested at regular intervals by depressing the governor, and is found invariably to operate within five or six revolutions above normal speed.

The problem of piston packing which for many years was one of the greatest difficulties in the way of building double acting engines has been solved in a fairly satisfactory manner by the use of metallic packing contained in packing cases. The packing cases each contain five rings of special cast iron made in segments, with overlapping joints, the segments being held in place against the piston rod by a 3/16-in. garter spring drawn around the circumference. The packing case is bolted to the cylinder head by means of a flange, between which and the cylinder head is a ground joint. About once in three months each packing case is removed and supplied with clean packing. The packing removed is then thoroughly cleaned when convenient and put aside for use at another time. If a high grade cylinder oil is used and the packing is regularly cleaned, the troubles from this source are practically eliminated.

The pistons are about 24 in. long and each has six slots in which are cast iron piston rings. The clearance between rings and slots is 12/1000 in. This clearance should be very carefully determined for different engines, as it depends principally upon the kind of gas used, and the nature of the lubricating oil. If the clearance is too small and the gas is not clean or the oil is inferior, the rings will become carbonized and stick in the slots. On the other hand, if the clearance is too great, a hammering action will take place between the rings and slots, and both will become badly battered in a short time. The joints in the rings are staggered and all joints are made at the bottom of the piston. The clearance between the bottom of the piston and the cylinder wall is very small, 11/1000 in. so as to reduce to a minimum the slippage past the piston.

Three cross-heads, one between the cylinders and one at the outer end of each cylinder, carry all the weight of piston and piston rod, relieving the cylinder walls and maintaining the piston rod in alignment.

The lubrication of the main bearings is accomplished by a flushing system of oil operated by turbine pumps, attached to the engine, which carry the oil from the engine through a filter to an elevated tank whence it returns by gravity.

The cylinders are lubricated by multiple pumps positively driven from the cam-shaft, the plungers of these pumps being so timed as to inject oil on the piston at the end of each power stroke.

Two air tanks each 5 ft. in diameter and 10 ft. long, located in the basement of the engine room, are kept charged with air at 150 lb. pressure for starting the engines. This air is delivered to the engine by two distributing valves driven by the cam-shafts, and so timed that air is admitted to each cylinder at the beginning of its power stroke. The compressed air is supplied by two compound steam pumps controlled by automatic governors, the pumps being located in the producer house.

During the summer months about 15 gallons of water, at an initial temperature of 80 degrees fahr., is required per horse power-hour for cooling, the temperature of discharge being about 120 degrees. During the winter months 10 gallons of water per horse power-hour at 60 degrees is sufficient, and it is discharged at about 100 degrees. The difference in the amount of water required in summer and winter is apparently due to the fact that the heat lost by radiation is much greater in winter. Even in the coldest weather that has been experienced since the plant has been in operation no other heat has been required for heating the building, and the temperature has not been found uncomfortable at any time.

The jacket water after being discharged from the engine flows by gravity to a hot well (see Fig. 1) of the cooling system, from which it is drawn by an electrically driven centrifugal pump of 50,000 gallons per hour capacity, against 15 lb. pressure, and forced through sprays into a basin in the middle of which is a cold well. From the cold well it is taken by a two-stage turbine pump of 15,000 gallons per hour capacity against 30 lb. pressure, and returned to the engine. These pumps are driven by the

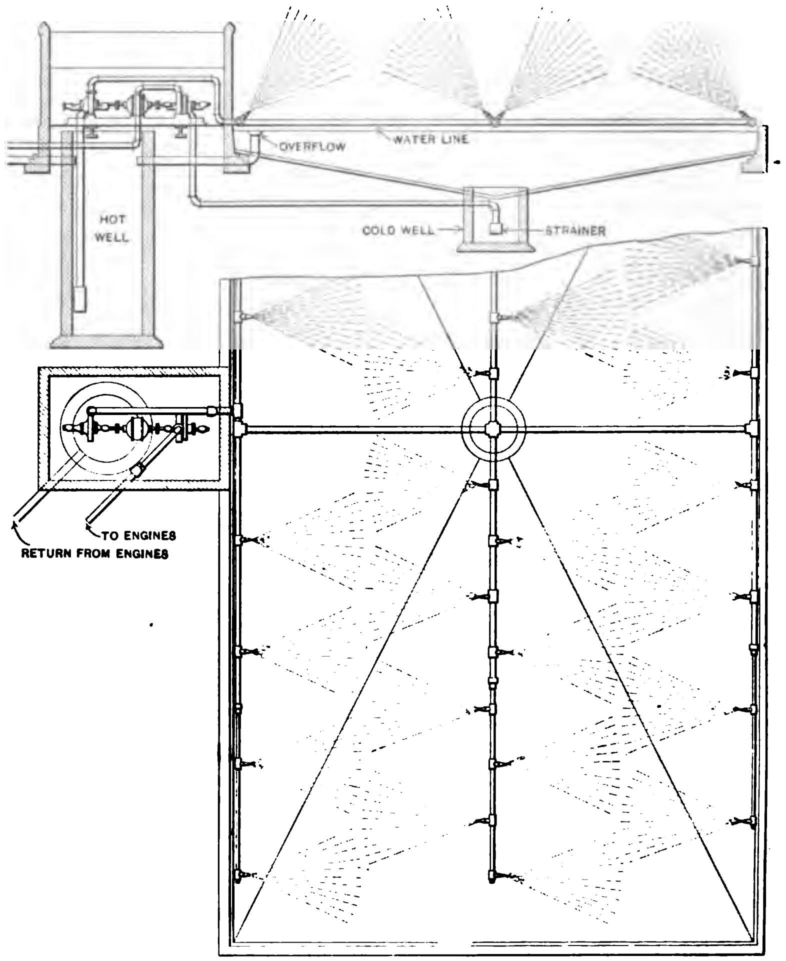


FIG. 1—Cooling system for jacket water of gas engine plant

same motor. As the capacity of the single-stage or hot-well pump is three times as great as that of the cold-well pump it follows that an excess of water is sprayed into the basin over that taken out of the cold well; this excess water overflows and returns to the hot well whence it is again pumped through the sprays. In this way all the water passes through the sprays three times to each time it is used in the engine and ample cooling is obtained, the water in the cold well is reduced to a temperature slightly below that of the atmosphere. The loss in water by evaporation to attain this degree of cooling is about 10 per cent, although in windy weather there is a slight additional loss occasioned by the blowing away of the spray.

Unlike a steam engine cutting off at 20 per cent to 25 per cent of its stroke for most efficient operation, permitting the steam to expand during the remainder of the stroke, a gas engine's most economical point of operation is attained when a full charge of the gas and air mixture is admitted to the cylinders. This condition is due to the following causes:

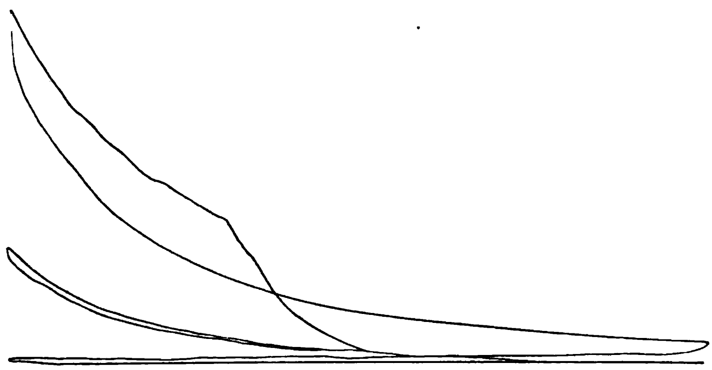
First, the combustion of gas is so rapid, that almost complete combustion takes place before the piston has moved but a little distance away from the end of the cylinder. The initial expansion therefore takes place at practically constant volume, the excessively high temperature of the gas burning in a restricted area causes an extremely rapid transfer of heat in the early part of the stroke, and consequently a loss of expansive ability.

Second, it has been found by experiment that inflammable gases ignited in the presence of oxygen, at constant volume, reach almost instantly a maximum temperature and consequently maximum pressure, and fall within a small fraction of a second (about 1/10 second) to a point far below the maximum, after which the pressure remains constant provided there is no transfer of heat. As one-quarter second is required for the full travel of the piston in one of these engines, it is clear that this rapid decline in pressure takes place before the piston has reached the middle point of its stroke. Both of these conditions largely reduce the expansive work of the gas.

Third, the percentage of inflammable gas contained in a charge of the mixture is small (about 12 per cent), the balance of the charge consisting principally of nitrogen and a small amount of carbonic acid gas, both of which are inert and absorb heat from the combustible constituents. It therefore requires a relatively large intake of the mixture to contain a sufficient amount of active gas to produce a given amount of power.

Under the foregoing conditions it follows that if a gas engine were rated at its most economical load, it would have no overload capacity whatever, but to obviate this condition it is customary to arbitrarily rate a gas engine at 87 per cent of its ultimate continuous capacity, which rating permits of an overload of 15 per cent. In the case of these engines, which are rated at 810 b.h.p. we have frequently carried a load of 700 kw. which is equal to 1010 b.h.p., or nearly 25 per cent overload, for a considerable length of time, and a momentary load of 800 kw. or 42 per cent over load without reducing the speed to a point that caused any trouble. While it would appear from these figures that the engines are somewhat under rated, for continuous operating the 15 per cent overload is as much as should be put upon them. The load of 700 kw., although it does not reduce the speed materially, gradually heats up the engine, with the result that after a few hours operation preignitions occur; also the high pressures in the cylinders strain the packing and cause gas to blow through.

There are three classes of disturbances that take place frequently in these engines, as is the case with all gas engines, viz: preignition, back-fires, and muffler explosions. The first of these is caused by the use of gas over rich in hydrogen, which ignites very readily under high compression without other application of heat; also by particles of carbon or other solid matter which become lodged in the cylinder and become incandescent under the temperature of compression, or when any of the water-cooled parts of the engine are insufficiently cooled by using too little water, or water at too high temperature. Preignition means that the gas becomes ignited during the compression stroke and the burning gas instead of being relieved by the forward motion of the piston as is the case in a power stroke, continues to be compressed until the piston reaches the end of its travel, with the result that back pressure of an extremely high degree is developed



INDICATOR CARD No. 1—Preignition

which momentarily tends to reduce the speed of the engine. Indicator card No. 1, taken at time of preignition, is shown herewith.

A back-fire occurs when the gas admitted to the cylinder is ignited on the suction stroke, but can also be caused by a leaky inlet valve, in which case the gas in the inlet pipe is ignited during the explosion stroke. Ordinarily a back-fire is caused when gas of a too lean nature is used, so that the gas burns very slowly and continues to burn in the exhaust stroke. A part of the gas still burning in the clearance space ignites the incoming charge. Also if there are any pockets or small passages, such as the water-cooled pipe leading to the indicator cock, the gas in the passage or pocket is cooled to a point where it does not ignite readily. It becomes heated and ignites in the latter part of the pressure stroke, and continues to burn until the succeeding intake stroke when the incoming charge is ignited. The result of a back-fire is only the loss of the next power stroke, and usually a mis-fire at the second succeeding power stroke caused by the burning gas blowing back into the intake pipe and fouling the gas contained in it. Back-fires were at first very common with these engines and were caused by a short section of water-cooled pipe leading to the indicator cocks, these pipes were removed, and a different type of indicator cock supplied. In the new type, the valve of the indicator cock seats directly against the outside of the cylinder wall and there is, therefore, no pocket to retain the gas, and back-fires very seldom occur. Indicator card No. 2 shows the result of a back-fire.

INDICATOR CARD No. 2—Back-fire

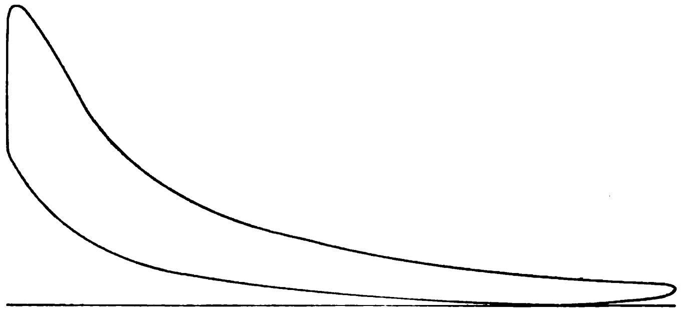
The disturbance caused by preignitions and back-fires is only momentary, and even when the engines are operating in parallel very little effect can be noticed.

A muffler explosion is caused after a mis-fire, when an unburned charge of gas and air passes into the exhaust pipe and is ignited by the exhaust from the power stroke of another cylinder. It has no effect upon the operation of the engine, but makes a noise similar to that of a preignition or back-fire.

Mis-fires seldom occur except following a back-fire as explained above. The double system of ignition practically obviates the possibility of this trouble.

Indicator card No. 3. is a typical gas engine card. It was taken, as were Nos. 1 and 2, with a 150-lb. spring. The compression is 135 lb. and the explosion pressure 267 1/2 lb. The mean effective pressure, as taken with a planimeter, is 53.625 lb. per sq. in., which would develop 311 h.p. per stroke in this one cylinder. As there are two cylinders acting during each stroke, the total indicated horse power of the engine at the moment the card was taken should have been 622 i.h.p. The load observed on the wattmeter at this moment, however, was rising, and was something over 600 kw.

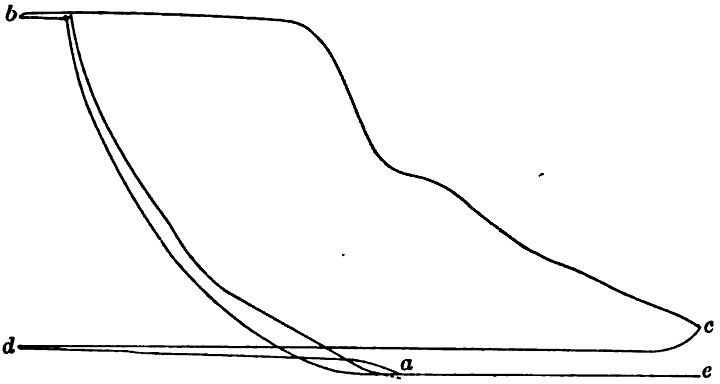
Card No. 4 is taken at light load with a 16-lb. spring; one complete cycle and part of another is shown on the card as follows: *a* to *b* last half of compression stroke, *b* to *c* combustion or power stroke, *c* to *d* exhaust stroke, *d* to *a* to *c* suction stroke, *e* to *a* to *b* compression stroke. At *b* the pencil was lifted. At *a* on the suction stroke the cut-off valve at the inlet closes, and the vacuum increases to a point below the range of the indicator, also at *b* the pressure reaches the other extreme limit of the indicator where it remains until expansion reduces the pressure to a point within the range of the light spring. A card taken with a light spring, as in this case, is of value in that it shows more distinctly than cards taken with a heavier spring the opening of the exhaust valve, and any wear of the cam operating the exhaust valve would be clearly shown by the toe of the card.



INDICATOR CARD No. 3—150-lb. spring; compression 135 lb; explosion pressure 267.5 lb.; mean effective pressure 53.625 lb.

Improper action of a gas engine is not shown nearly as clearly by the indicator card as it is in the case of a steam engine. For instance, the exhaust valve of a gas engine might be leaking and the only indication of the trouble would be low compression, yet the low compression might be caused also by badly worn piston rings or by packing in bad condition. The principal value of the indicator card is in adjusting the proportion of air and gas to give the most effective mixture, and for properly timing the ignition.

To adjust the mixture it is desirable to put a steady load upon the engine, preferably that produced by a water box, and then indicate the engine and adjust the mixing valve until the card shows the maximum explosion pressure for a given compression, which is the condition existing when sufficient air for complete combustion is admitted with the gas, without excess. When once adjusted for gas of a certain quality it is not necessary to change the mixing valve again.



INDICATOR CARD No. 4—16-lb. spring

The indicator is most frequently used for timing the ignition, which can be done with precision in no other way. This becomes necessary at regular intervals on account of wear, both mechanical and electrolytic, of the igniter contacts. From time to time the igniters have to be taken out, cleaned, and the contact points smoothed up, and in replacing the igniter after this overhauling, cards are taken from this cylinder, and the tappet rods which control the make-and-break movement are adjusted so that the card shows proper ignition.

The diagram herewith, Fig. 2, shows the various events of valves and ignition during one cycle, or two revolutions of the fly-wheel. It will be noted that the valves open a number of degrees before the dead center, and close 10 degrees after passing the dead center, while the periods of suction, compression, combustion and exhaust begin and end exactly at the centers. The reason for this apparent discrepancy is that the movement of valves is so very rapid, that a certain time element is required to accommodate the slower movement of the gas. The points indicated as valve openings and valve closings on the diagram, represent the points at which the valves begin to open and are completely closed. As the opening and closing of the valves require an appreciable length of time, the actual period during which the valves are wide open more nearly coincides with the period of travel of the piston. It will be understood that the cut-off valve is released independently of the inlet valve closing, and may occur at any point of the suction stroke, depending upon the load.

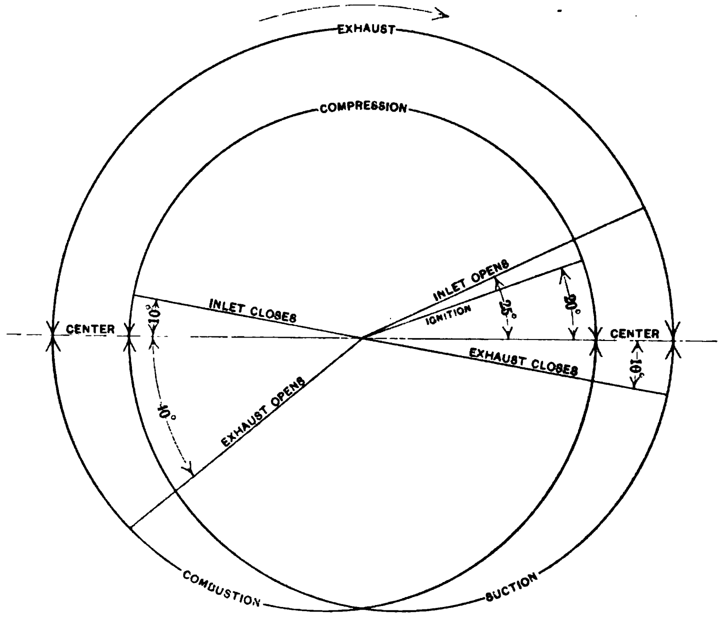


FIG. 2—Valve diagram of four-cycle gas engine

While the ignition is shown to take place at a point 20 degrees ahead of the end of the compression stroke, this location of the ignition is only approximately correct, for, as explained above, the position is located in practice by means of the indicator, and it may vary slightly with the quality of the gas and proportion of mixture. The ignition is timed to occur 20 degrees before reaching the end of the stroke, so that sufficient time will be given for the flame propagation before beginning the power stroke. The ignition of these engines takes place in a combustion chamber just off the end of the cylinder. When the gas in the combustion chamber becomes thoroughly ignited, it bursts out into the clearance space of the cylinder, practically at the time the piston is at the end of its travel, the molecules of gas are compressed to the highest degree, and the flame from the combustion chamber ignites it almost instantly. The flame propagation about the igniters is in spherical form, the surface of the sphere increasing as the square of the time elapsing after ignition. In the combustion chamber, therefore, the time required for the entire volume to become ignited is appreciable. The gas in the cylinder, however, is ignited by the flame from the combustion chamber and from the indicator cards it seems to be practically instantaneous.

To develop full power on the engine it is necessary that cylinders and pistons should be perfectly tight, for not only is power lost by leakage past the piston and through leaky valves on the power stroke, but poor compression of the gases will mean slow ignition and a considerable loss in initial pressure. In order that ignition should be rapid, the molecules of gas must be closely pressed together so that the initial pressure will be high, and if timed so as to reach the maximum point just as the piston starts to move forward, the full power of the gas will be developed.

Plant Performance

Under this head, considering the class of service, we regard reliability as being of paramount importance, and we believe the record, taken from the engineer's daily log, of shut-downs caused by gas and engine troubles only, will be considered extremely creditable when allowance is made for the severe conditions of operation, and the fact that the plant was only in its first full year of existence. Electrical troubles have been decidedly more annoying than engine troubles, but such of these as have no bearing whatever upon the engine or gas operation will not be mentioned inasmuch as they are irrelevant.

From the daily reports we find, as follows :

Jan. 1—Exciter spark plug out of order	**5 min.**
Jan. 31—Exciter trouble	**5 min.**
Feb. No trouble.	
Mar. No trouble.	

April 12—Plant shut down caused by suction of engine drawing water from the gasometer over into gas main, causing water trap and shutting off gas supply	45 min.
April 27—Same trouble	30 min.
At the first occurrence it was not known exactly what the source of this water was, and it was attributed to condensation from the gas, but after the second occurrence the trouble was located, and corrected by raising the inner walls of the gasometer, and making the lift necessary to draw the water over the top greater than the suction from the engine could accomplish.	
May—No trouble.	
June 18—Shut down at one o'clock a.m. caused by belt on oil pump breaking; the other engine was undergoing some slight repairs and was not in condition to start	15 min.
July 23—Shut down on account of igniter wire from battery to engine becoming grounded in conduit. This trouble, although located promptly, could not be repaired without great delay, therefore wire had to be run across engine room floor and old wire cut out	45 min.
July 30—Shut down caused by operation of safety stop on engine, opening igniter circuit	12 min.
Aug.—No trouble.	
Sept.—No trouble.	
Oct.—No trouble.	
Nov.—Shut down caused by unusual overload occurring when only one engine was in operation	8 min.
Dec.—No trouble.	
Total interruption of service due to gas and engine troubles	2 hr. 45 min.

In considering these figures it should be borne in mind that the plant operates 24 hours per day and every day in the year.

Other troubles have occurred while both engines were operating, making it necessary to carry the entire load, or the principal part of it, on one engine, but while these occasions caused annoyance, they were handled without serious inconvenience to service.

Second in importance to reliability we regard character of operation, viz: speed regulation, and ability to operate successfully in parallel, the former being a function of the engine only, while the latter involves both engine and alternator.

The manufacturers guarantee as to speed is, that from 25 per cent to full load, the engine will govern within a maximum variation of 2 per cent. This condition is met as regards the mean speed on steady loads. When, however, a heavy load is suddenly thrown on the engine, or removed from it, a momentary swing of not exceeding 2 per cent below or above mean speed for the given load occurs, which is due to overreaching of the governor. While this swing in speed is not excessive, and is found to an equal or even greater extent in high-class reciprocating steam engines, it is rather remarkable that it is not far worse than the above figure in a four-cycle gas engine; for at the moment the load on the engine is changing, the governor has no control whatever upon the charge of gas next to be ignited, since the amount of this charge was regulated in the suction stroke which preceded the compression stroke. For example, assume that the engine is operating at three-quarter load, and the governor by means of the cut-off valves is regulating the amount of gas per charge accordingly; just as one crank reaches dead center and ignition has taken place prior to a power stroke, an additional load is thrown on the engine, making a total load equal to the full capacity of the engine; the cylinder for the next power stroke just ignited is charged with gas for three-quarter load, the cylinder on the other side of the engine is midway of the compression stroke, and is therefore beyond the influence of the governor, and the cylinder on the same side of the engine as the one just ignited is just completing its suction stroke and has been cut off at 75 per cent of the stroke, rendering it, also, out of reach of the governor. We have therefore three impulses of power strokes of three-quarter value before a full load charge of gas can be admitted to the engine, during which time the fly-wheel has turned 270 degrees, and it would be expected that the governor would continue to drop and overreach before corrected by the increased speed from full power strokes. This natural tendency to over-reach on the part of the governor, is reduced to a minimum however by the nice adjustment between the fly-wheel inertia and damping of the governor.

It is generally supposed that the turning moment or angular velocity of a gas engine is uneven and characterized by periodic variations with each impulse, due to the fact that the initial cylinder pressures are extremely high as compared to those of steam engines. This would no doubt be the case with a single-tandem, four-cycle gas engine, but with the twin-tandem engines having four double acting cylinders, eight impulses are given to the fly-wheel in two revolutions or one complete cycle. Therefore, as the cranks of the two sides are quartering, an impulse is imparted to the fly-wheel every 90 degrees, or two impulses per stroke. The impulses thus over-lapping tend to smooth out the variations that otherwise would occur, and permit of a far lighter fly-wheel than could be used with a single-tandem engine. The lighter fly-wheel is less sluggish and consequently promotes good parallel operation, but it is not too light to afford sufficient inertia to practically absorb the variations in crank effort.

We have been convinced of the correctness of this statement by observing the behavior of the alternators at various times when they were running in synchronism, with the engine cranks in almost every possible relation. No difference can be discerned in the action of the switchboard instruments, whether the cranks are in step or in any other possible position.

While the parallel operation of this engine would not be considered good in comparison with steam turbines operating at high speed, with alternators having from two to four field poles, it nevertheless compares favorably with the best type of reciprocating steam engines with alternators having the same number of field poles, viz., sixty, which of course means that the variations in electrical degrees will be thirty times as great per degree of angular variation as would be the case in a turbine of the same capacity, which would operate at 3600 revolutions per minute.

The temperatures of the alternators above room temperatures, so far as can be observed with the constantly varying load, do not indicate an excessive synchronizing current, and there has never been any tendency on the part of the synchronous converters to fall out of step. The smaller converter running from one engine or from both in parallel, shows no signs of hunting, neither does the 500-kw. converter when running from both engines in parallel. It, however, hunts slightly when running on only one engine. This is probably due to the fact that this converter is practically of the same capacity as the one alternator, and the fly-wheel effect of its rotor is too great to permit its conforming to the variations of speed which are greater for a given load with one engine operating alone than when both are in parallel.

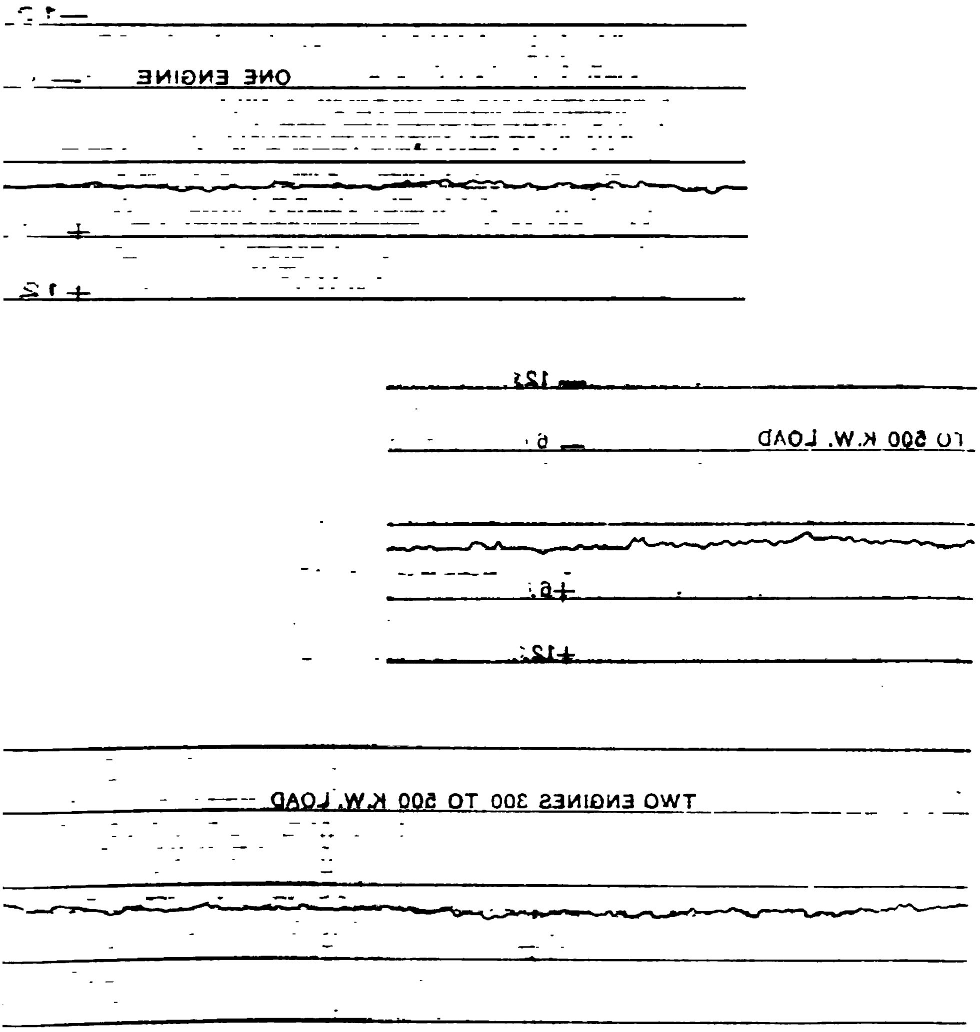
There is a slight periodic swing between the pointers of the wattmeters when the engines are operating in parallel; this is no doubt accentuated by the extreme sensitiveness of the meters, which have 325-degree scales, and by the pendulum motion of the pointers which is common in instruments of this kind. The same swing appears on the ammeters, but to a much less extent. The engines divide the load very equally, and by adjusting the governors they can be made to divide the load in any proportion that may be desired.

Below are shown four speed curves taken with an extremely sensitive graphic recording speed indicator. Each ½ in. of length represents approximately a time interval of one second, and the spaces between lines represent variations of one per cent.

The first record was taken from an engine with no load, and the second was taken from one engine with the load varying from 300 to 500 kw.

The third record was taken from one engine in parallel with the other engine under a total load ranging from 300 to 500 kw.

The fourth record is taken from one of the two engines in



Speed curves showing regulation of [illegible]

parallel, with a load of 300 to 500 kw., and a load of 600 kw. thrown on and off.

COST OF OPERATION AND REPAIRS

The figures given below covering the cost of operation and repairs speak for themselves, and there is little further to be said except to call attention to the extremely low load factor which is the controlling condition. The poor load factor is due principally to two conditions; first, the prevailing load for twenty hours per day is easily within the range of one unit, but the wide limits of variation make it necessary to operate the second engine on an average of ten hours per day; and second, from 12 o'clock night until 6 a.m one engine operates on practically no load at all.

We do not claim high economy for this plant, and can hardly expect it under the circumstances, and while we hope in future to effect a slight reduction in coal consumption by a more consistent and economical operation of the producers, we cannot expect a material improvement in operating cost under the load conditions that obtain.

We estimate that with an increase in the load factor of 25 per cent the additional output could be produced for an amount not exceeding 10 per cent of the present cost, because a higher economy of coal would result from a higher load factor, with practically no increase in labor, water, oil, or other of the larger items that go to make up the total cost.

In the matter of cost of repairs, also, we expect a reduction rather than an increase in the near future. The largest item in the total cost of repair parts is the cost of an entire new equipment of exhaust valves, which amounts to about half of the total. These exhaust valves were put in, not on account of wear and tear, or breakage of the original ones, but on account of their inferior design, which caused them to continually work loose from the stem, which was connected by a flange and stud-bolts. The new type has proved entirely satisfactory.

Four pistons have been taken out and fitted with new rings, the original rings having become broken when water leaks occurred in the cylinders due to defects in the castings of the piston water compartments. Broken rings almost invariably result from water leaks in a cylinder. In this case, new parts were furnished by the manufacturers without charge, and the labor was furnished principally from the operating force.

Considerable annoyance, though only slight expense, has been occasioned by the backing off of the packing glands around the valve stems, caused by vibration, and a consequent breaking of the exhaust valve casing. This trouble could have been avoided in the beginning, as it has been since, by tapping set screws into the packing glands to prevent their working loose.

The least serious trouble that has been encountered, but one of the most annoying, on account of its occurring at most inopportune times, is the breaking of the wedge adjusting bolts in either the crank or cross head bearings. We have had about six of these break, but the trouble has each time been promptly located, and quickly repaired without further damage resulting.

OPERATING FIGURES

	Engine hours	Kw.-hours	Coal	Coal per kw.-hour	Engine hours	Load factor*
Jan.	1140	304400	570199	1.873	36.8	0.445
Feb.	1060	278800	521190	1.869	37.8	0.438
March	1019	273600	531310	1.942	32.9	0.447
April	1032	256607	501145	1.954	34.4	0.414
May	902	248400	466935	1.879	29.1	0.459
June	872	257300	486804	1.892	29.0	0.492
July	913	275100	528452	1.920	29.5	0.502
August	1111	284900	556959	1.954	36.0	0.427
September	938	276800	533844	1.928	31.3	0.492
October	1102	302000	585037	1.939	35.5	0.457
November	1086	270700	534937	1.975	36.2	0.415
December	1228	327300	627469	1.917	39.6	0.430
Totals	12403	3355907	6444281		34.0 average	0.450 average

$$\text{* Load Factor} = \frac{\text{Output}}{\text{Engine hours} \times \text{capacity of one engine}}$$

In addition to the coal, 260,292 lb. of coke were used in starting producers, of which amount 122,371 lb. were reclaimed, leaving the total net amount used 137,921 lb., equal in cost to 192,000 lb. of coal.

We have, therefore, for the total coal consumption 6,444,281 lb. + 192,000 = 6,636,281 lb.

$$\frac{6,636,281}{3,355,907} = 1.97 = \text{lb. of coal per kw-hr.}$$

Assuming 85 per cent efficiency for alternators at 45 per cent load we have

$$\frac{197}{133}\times 85 = 1.275 \text{ lb. of coal per b.h.p-hr.}$$

COST OF CURRENT

Cost of coal per kw-hr.	0.349	cts.
Cost of power house labor per kw-hr.	0.170	"
Cost of producer labor per kw-hr.	0.131	"
Oil for power house	0.065	"
Oil for producer	0.005	"
Waste and sundries, power house	0.012	"
Waste and sundries, producer house	0.003	"
Repair parts for engines	0.046	"
Repair parts for producers	0.007	"
Machine shop work, engines	0.016	"
Machine shop work, producers	0.007	"
Excelsior for producers	0.003	"
Water, both departments	0.071	"
Total cost of current at switch board per kw.-hr.	0.885	"

POWER CONSUMED BY AUXILIARIES

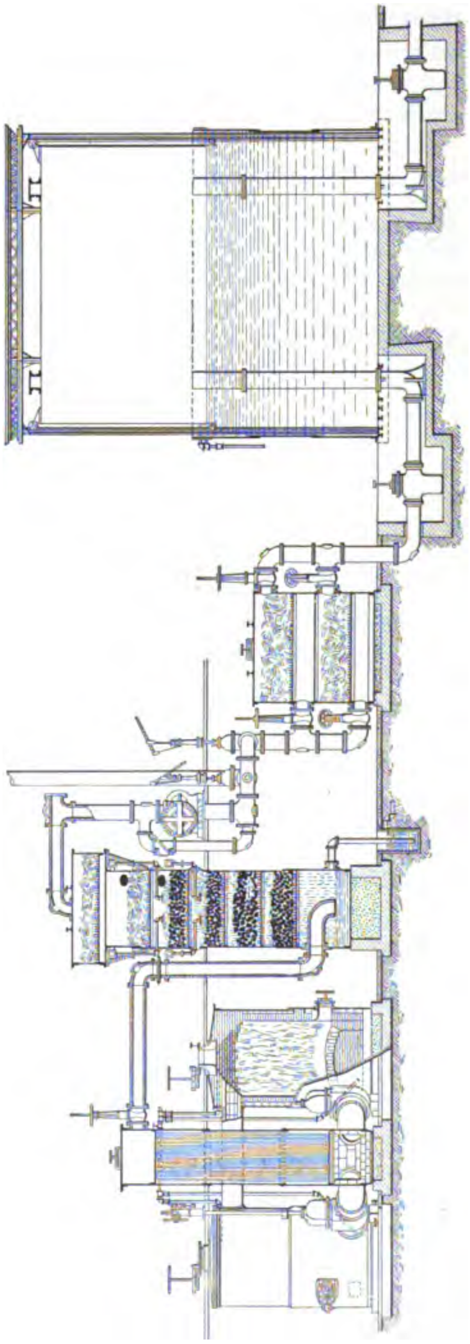
Cooling water pump, kilowatts per kw-hr.	0.0095
Station lighting " " "	0.0116
Motor driven exciter " " "	0.0688
Total kilowatts per kw-hr.	0.0909

The items of interest, depreciation, taxes, etc., are not included, for the reason that they would be quite unfair to the plant, on account of the fact that it was designed for three 810-h.p. units, while only two have been installed.

Buildings, producers, gas holders, piping, etc., are all installed complete for the full ultimate capacity. Therefore a relatively small additional expenditure for one engine generator and foundation would increase the capacity of the plant by 50 per cent, while the foregoing items of interest, depreciation, etc. would be increased but 18 per cent per unit of capacity installed.

PRODUCER OPERATION

In starting a producer the generators are charged to a depth of five feet with 72-hour coke, requiring about 6000 lb. to each generator, or a total of 12,000 lb. The exhauster is then started, and the coke ignited. The gas made during the first 40 minutes is too inferior to be of any use in the engine, and it is therefore



Gas generating system

blown out through the purge stack and wasted, instead of being admitted to the holder. As the coke in the generators burns and becomes hot, coal is charged at the top in small quantities and at frequent intervals. If coal is charged too rapidly, particularly in the early stages of the fire, it tends to coke, with the result that the draught will be unequally distributed over the fuel bed, finding its way down through holes and localizing the heat to such an extent that the excessive temperature causes clinker to form, thus reducing the capacity of the generator and shortening by several days the time that the set can be run without shutting down for cleaning. When the fuel bed has attained a sufficiently high temperature, the purge stack is closed, and the gas is admitted to the holder. Steam is introduced at the top of the charging doors and, together with the air, is drawn in by the exhauster, passing down through the generator, forming a mixed gas. The carbon of the incandescent fuel combines with the oxygen in the air and steam, forming carbonic oxide gas and free hydrogen, the principal valuable constituents of producer gas.

At intervals of 20 to 30 minutes, up and down steam runs are made in the generators in the following manner: The by-pass around the exhauster is opened, the charging doors of the generators closed, and steam is admitted beneath the grate bars of one generator, the gate valve of which is closed, for about thirty seconds. This steam passes up through the generator, moistens the ash, breaks up the fuel bed and cools the fuel at the point where clinker is forming, and which is not reached by the top steam before decomposition takes place. This steam leaves the generator through a connection at the top, passing over into the top of the second generator, down through the fuel bed and out through the other apparatus to the holder as a fixed gas. The direction of the steam is reversed on the next run, so that the generators are alternately treated in the same manner.

The hot gas leaves the generators at a temperature of about 1200 degrees cent. and passes out through a brick-lined nozzle and water-cooled gate valve into the lower compartment of the vertical economizer, which is also brick-lined. A large part of the sensible heat of the gas is given off and goes to make steam which is used in the generators and for running the exhauster. From the top of the economizer the gas passes, at a reduced temperature, to the bottom of the wet scrubber where it is water sealed, and passing up through the wet scrubber, it works its way through several layers of coke over which water is sprayed from above. During its passage through the coke and water most of the dust and lampblack in the gas is removed, and its temperature is reduced to that of the atmosphere. In the top of the wet scrubber a thick layer of excelsior removes part of the moisture and most of the remaining lampblack. From the wet scrubber the gas goes through the exhauster, then to the dry scrubber, where two more layers of excelsior thoroughly dry it, thence it passes to the holder, a clean, dry, cool gas.

It is very important that the gas should be reduced to atmospheric temperature in the wet scrubber by the use of a sufficient amount of cool water. About four to six gallons per horse power-hour is required, depending upon the temperature of the water and that of the atmosphere. If the gas is allowed to leave the wet scrubber hot, a large amount of water is entrained in the gas and carried in suspension over to the engines. The moisture in the gas is converted into steam by the heat of combustion in the engine, and the latent heat of the steam is absorbed from the burning gas, causing a total loss of this amount of heat to the engine, since the products of combustion are exhausted at a temperature far above that of condensation.

The use of a large holder, such as the one installed in this plant (60,000 cu. ft.) is of great value in operation. It takes up the variations in load and allows the producer to be operated at an even rate; also, if the gas varies in quality over short intervals, which is unavoidable, the gases above and below the mean value are thoroughly mixed and a gas of uniform quality is supplied to the engines.

A strip of metal on one of the guides of the holder, and insulated from it, is divided into ten parts, each representing about two feet lift of the holder. Each section is connected to one of ten lamps arranged vertically on the charging floor of the producer house. A roller on the lift of the holder makes contact with these strips, and lights a lamp in the producer house corresponding to the height of the lift. By means of this tell-tale the output of the producer is regulated. If the holder begins to fall, due to a continued heavy demand by the engines, the speed of the exhauster is increased, and the charging of coal is varied accordingly.

It may be of interest to describe here a rather serious difficulty which was encountered in this plant, and the way in which it was remedied.

A short time after the plant was put into operation, it was found that some of the tubes of the economizers were leaking. The tubes were rolled and the leaks stopped, but in a short time they were found to be leaking again. They were again rolled, but continued to leak, and when finally too thin to be any longer rolled they were taken out and replaced with new tubes. The old tubes when taken out were cut into sections and split open, and it was found that they were badly pitted throughout their entire length, although the pitting was worse at the upper end; weighing the tubes disclosed the fact that they had lost nearly 25 per cent of their original weight. After much surmising, the cause of the pitting of these tubes is believed to be as follows:

In the usual design of plants of this kind, with two or more sets of apparatus, the various sets are absolutely independent of each other as far as the wet scrubbers, and as the gas is water-sealed in the wet scrubbers it is impossible for gas from one set to pass over into another. In this plant, however, in order to increase the flexibility of operation, the two economizers were connected together at the top by a horizontal header, and each one was cut off from the header by a gate valve. These gate valves coming in contact with gas at fairly high temperature expand and contract, and cannot be kept perfectly tight. During steam runs, when the generators were under pressure, leakage of these valves permitted hot gas to pass from the economizer in operation to the one shut down, and after passing down through this economizer to escape through the open generators. It was found that the economizer not in use sweated profusely on account of the difference in temperature of the room and the water in the economizer, keeping the tubes continually wet. This moisture, combining with the hot gas leaking through the apparatus, undoubtedly formed a strong acid and attacked the tubes. Since arriving at this conclusion, each time a producer is shut down the gates of the valves are thoroughly cleaned, the tubes are cleaned with a wire brush, the tube ends and tube sheet are painted with one coat of graphite paint, and the manholes at top and bottom of the economizers are left open, so that a circulation of air prevents sweating. Since adopting these measures, there have been no more leaky tubes, and it is believed that the trouble has been effectually remedied.

At another time an annoying occurrence was the development of numerous hot spots on the shells of the generators; these hot spots were caused by defects in the linings. The brick of the linings were laid with fire clay mortar joints, and the space between brick and shell was grouted with fire clay grout. The jarring occasioned by the heavy barring necessary to remove clinker, broke the bond of the joints and the grout behind the brick becoming pulverized, sifted out when the cleaning doors were open. To correct this trouble holes were tapped in the shell, and fire clay grout forced in at various places under about twenty pounds pressure. As the brick of the linings had thoroughly settled when this was done, no further recurrence of the trouble has been experienced. Had the brick been dipped in fire clay grout and laid brick to brick, and the space between the brick and shell been rammed with a mixture of fire clay grout and shredded asbestos, as is the practice with other gas generating apparatus, the trouble would probably not have occurred.

It is found to be an advantage after cleaning a generator to wash the surface of the brick exposed to the fuel with fire clay grout, as the grout tends to form a cleavage plane between clinker and brick and greatly facilitates its removal. When cleaning the generators, it is not desirable to remove all the clinker, for in doing so a part of the brick would be chipped off each time, and greatly reduce the life of the lining. About one or two inches of clinker adhering to the brick is allowed to remain, and this coating affords great protection to the surface of the lining.

THEORY OF PRODUCER GAS MANUFACTURE AND COMBUSTION

The chemical reactions that take place in the producer generators are practically as follows:

Air passing down over the green coal as it becomes heated by the incandescent coke in the generator, supplies oxygen for combustion of the carbon, and the intense heat produced drives off first the hydrocarbons, which are extremely volatile, in the form of vapor which when condensed becomes tar. This tarry vapor is drawn down through the hot fuel, and most of it burned to lampblack, which is later removed by the wet scrubbers, and the tar, which is most objectionable, is disposed of in a very simple and satisfactory manner. The remaining hydrocarbons are retained as fixed gases in the form of marsh gas or methane, CH_4 and olefiant gas, C_2H_4. These gases are both high in heat value and are extremely valuable, but are obtainable in very small quantities.

The fixed carbon of the coal combines with oxygen from the air or steam admitted, and forms carbonic oxide, CO, and carbonic acid gas. The former, considering the quantity in which it is obtainable, is a most desirable gas; the latter contains no heat and is of no value whatever.

There are two ways in which carbonic oxide gas may be formed. When carbon is burned in oxygen present in insufficient quantity to afford complete combustion, a permanent gas is formed which passes out of the apparatus without further reaction. Since this is a simple and direct process, it would seem most natural and probable that the carbonic oxide is formed in this way. As a matter of fact, however, it has been pretty well established that the principal part if not all of the carbon monoxide gas is formed by a double reaction in the following manner: The air and steam supplied to the producer affords ample oxygen for complete combustion of the carbon in the coal at or near the surface of the fuel. As the complete combustion of carbon gives off heat at the rate of 14,647 B.t.u. per pound, the heat liberated raises the carbonic acid gas (CO_2) formed, to an intensely high temperature, and the hot gas passing down through the already incandescent fuel raises its temperature still higher, driving off carbon vapor, with each volume of which, one volume of carbonic acid gas combines to form two volumes of carbon monoxide. The combination absorbs the same amount of heat that would be given off if an equal weight of carbon monoxide were burned to form carbonic acid gas, *viz.*, 4,383 B.t.u. per pound. Since the molecular weight of carbon is 12 and that of oxygen 16, the product of combustion of one pound of carbon is $3\frac{2}{3}$ lb. of CO_2. In the second reaction, the $3\frac{2}{3}$ lb. of CO_2 combines with one pound of carbon, making $4\frac{2}{3}$ lb. of carbon monoxide (CO) of which 2 lb. consists of carbon and $2\frac{2}{3}$ lb. of oxygen. From the pound of carbon burned to form $3\frac{2}{3}$ lb. of CO_2 there was liberated and given to the producer 14,647 B.t.u., and in the reduction of $3\frac{2}{3}$ lb. of CO_2 to $4\frac{2}{3}$ lb. of CO an amount of heat equal to $2\frac{1}{3} \times 4383 = 10{,}227$ B.t.u. per each pound of carbon burned was absorbed from the producer, leaving a net gain to the producer of 4,420 B.t.u. per pound of carbon converted into carbon oxide. This is exactly the same as if a pound of carbon was burned directly to carbon monoxide.

If there was air alone admitted to the producer it can be readily seen that there would be a continual gain in heat to the generator with each pound of coal fired, and while high heat is conducive to a large production of carbon monoxide gas, and is desirable, an excessive heat will fuse the impurities of the coal and form clinker, closing the gas passages through the producer, increasing the vacuum for a given output, and reducing its capacity to such an extent that it becomes necessary to shut it down and remove the clinker. While the production of a certain amount of clinker is unavoidable, the cleaning of a producer entails loss of fuel and expense of labor, and should be postponed as long as possible.

It therefore becomes necessary to control the temperature of the fire, and this constitutes a fine point in producer operation, for only experience can guide the operator, and for the best results good judgment is absolutely necessary.

To cool the fire, steam is admitted at the charging doors together with the air, in an amount depending upon load conditions. First of all, the temperature of the fire must be kept below that which would cause rapid fusing of the impurities. If the design of the engine is such that it will utilize a gas rich in hydrogen, without preignition, the steam may be increased to a point that will reduce the production of carbon monoxide, and increase the carbonic acid, while the loss in heat by the production of carbonic acid gas will be more than compensated for by the high heat value of the hydrogen. The amount of steam cannot be increased indefinitely even if the engines would permit it, for the action of an excess of steam on the fire will cool the fire to such a degree that instead of being decomposed, it will pass through the generator in the form of live steam which is condensed in the holder and carried to the engine in the form of entrained moisture, the effect of which has already been explained. In general, we may say that the amount of steam to be used depends upon the rate of combustion, that is, it must be in proportion to the load, and the proportion depends upon the amount of hydrogen that the engine utilizes without preignition.

The effect of steam upon the fire is as follows: Steam entering at the charging doors and coming in contact with the hot fuel is disassociated into its constituent parts, *viz.*, oxygen and hydrogen. The action of the oxygen from the steam is identical with that of the oxygen in the air, and by combination with the carbon produces heat. Since hydrogen burning in oxygen to form water liberates heat in the amount of 62,032 B.t.u. per pound; conversely, when hydrogen is disassociated from oxygen, an absorption of heat in the same amount takes place. However, as the hydrogen and oxygen are introduced into the generator in the form of steam and as one pound of hydrogen combines with 8 pounds of oxygen to form 9 pounds of steam the latent heat of which from 70 degrees is 1,064 B.t.u. per pound, the net heat absorbed from the producer is $62,032 - 9 \times 1064 = 52,456$ B.t.u. per each pound of hydrogen liberated,—hence the cooling action of steam.

To demonstrate this effect by figures, the molecular weight of carbon is 12, that of oxygen 16, and that of hydrogen 1. Six pounds of carbon, therefore, will combine with eight pounds of oxygen to form 14 pounds of carbon monoxide, from which the heat evolved is $6 \times 4420 = 26,520$ B.t.u., and one pound of hydrogen will be liberated, absorbing 52,456 B.t.u. The loss of heat, therefore, to the generator will be $52,456 - 26,520 = 25,936$ B.t.u. for each 9 pounds, or $\frac{25,936}{9} = 2,882$ B.t.u. per pound of steam supplied.

Hydrogen gas is very valuable within the limits that permit its use, and it is inexpensive to manufacture. The amount of water required is negligible, and the heat required to convert the water into steam is taken from the gas after leaving the generator, and if not utilized in the economizer would be wasted in the scrubber. Its heat of combustion is very high, and although this heat is borrowed from the generator, it is heat that is liberated in the production of carbon monoxide, and like the heat of the gas, if not absorbed by the hydrogen it would finally be wasted by radiation and in heating the water of the scrubber.

In order that the operator may efficiently perform the duties of his position it is necessary that he should have a clear idea as to the nature and extent of the various losses that occur from the coal pile to the switchboard. For this purpose, actual figures, though not necessarily more than approximately correct, afford the best demonstration.

Taking for example the coal which has been used throughout the operation of this plant, a high grade of Pocahontas coal, we obtain from the United States Geological Survey the following analysis:

Proximate analysis	Per cent	Final analysis	Per cent
Moisture	1.90	Carbon	85.87
Volatile carbon	18.08	Hydrogen	4.65
Fixed carbon	77.03	Oxygen	4.64
Sulphur	0.67	Nitrogen	1.19
Phosphorus	0.008	Sulphur	0.67
Ash	2.312	Phosphorus	0.008
		Ash	2.972
Total	100.0		100.0

Heat value, calculated, 15,039 B.t.u.
Heat value, by calorimeter, 15,344 B.t.u.
This calculated value is checked approximately as follows:

Carbon	85.87 × 14647 =	12577 B.t.u.
Hydrogen	4.65 × 62032 =	2884 "
Total		15461 "
Deducting latent heat of evap.	0.0465 × 9 × 1064 =	445 "
Net heat value		15016 "

At the end of a run on one producer covering a period of 19 days during which time 293,000 lb. of coal was converted, the residual removed in cleaning the generators was carefully weighed, and found to be as follows:

Clinker from generators	13328 lb.
Ashes and lampblack from generators	3221 "
Ashes and lampblack from economizers	168 "
Total	16717 "

and in addition 5,351 lb. of good coke, suitable for use again. The 16,717 lb. of waste material is 5.7 per cent of the total coal converted, and while the analysis of the coal shows only about 3 per cent of sulphur, phosphorus and ash, the balance of weight, *viz.*, 2.7 per cent is no doubt supplied by oxygen with which some of these impurities combine at the high temperature of fusion.

From this coal we assume the gas to have the following analysis by volume, *viz.*

Carbon monoxide CO	20.3
Hydrogen H	11.6
Methane CH_4	1.2
Olefiant Gas C_2H_4	0.3
Carbonic acid CO_2	8.2
Nitrogen N	58.4
Total	100.0

While this is by no means a high grade gas from the above coal, the analysis is assumed purely for the sake of explanation, although it is believed to be a fair average of the gas produced in the plant.

From the above analysis of gas is computed the following table:

TABLE OF GAS AND AIR FOR COMPLETE COMBUSTION

Symbol gas constituent	Per cent by vol.	Weight in one cu. ft. of gas	Per cent by weight	B.t.u. per cu. ft.	B.t.u. one cu. ft. gas	Air in pounds for complete combustion			Products of combustion		Dilutant Nitrogen	Carbon and hydrogen	
						Oxygen	Air	Nitrogen	Pounds CO_2	Pounds H_2O		C pounds	H pounds
CO	20.3	0.015868	21.67	343	69	0.009068	0.039430	0.030362	0.024936	—	—	0.006800	—
H	11.6	0.000648	0.89	347	40	0.005184	0.022540	0.017356	—	0.005832	—	—	0.000648
CH_4	1.2	0.000536	0.73	1072	13	0.001072	0.004661	0.003589	0.001474	—	—	0.000402	—
	—	—	—	—	—	0.001072	0.004661	0.003589	—	0.001206	—	—	0.000134
C_2H_4	0.3	0.000234	0.32	1711	5	0.000534	0.002321	0.001787	0.000734	—	—	0.000201	—
						0.000264	0.001150	0.000886	—	0.000297	—	—	0.000033
CO_2	8.2	0.010122	13.82	—	—	—	—	—	—	—	—	0.002760	—
N	58.4	0.045815	62.57	—	—	—	—	—	—	—	0.045815	—	—
	—	—	—	—	—	—	—	0.057569	—	—	0.057569	—	—
Total......	100.0	0.073223	100.0	—	127	0.017194	0.074763	—	0.027144	0.007335	0.103384	0.010163	0.000815

Air required per cu. ft. of gas for perfect mixture 0.9259 cu. ft.
Air required per pound of gas for perfect mixture 1.0213 pounds.
B.t.u. lost by latent heat of evaporation 0.007335 × 1064 = 7.80 B.t.u. per cu. ft. of gas.
Net heat value of gas 127.0 − 7.80 = 119.2 B.t.u.

Assuming that 72,710 cu. ft. of the above gas will be required by one 810 b.h.p. engine operating for one hour at full load, we then have:

Constituents of gas	Weight in 1 cu. ft.		Weight in 72710 cu. ft.		Heat units	
	C.	H.	C.	H.	Lost in producer	Retained in gas
CO............	0.006800		493.55		2,181,491	5,047,535
H..............		0.000648		47.12		2,922,947
CH_4............	0.000402		29.22			427,985
		0.000134		9.74		604,192
C_2H_4...........	0.000201		14.68			215,018
		0.000032		2.32		143,914
CO_2............	0.002760		200.67		2,939,213	
N..............	inert					
Total......			738.12	59.18	5,120,704	9,361,591

Dividing the amount of carbon by the percentage contained in the coal we get $\frac{738.12}{85.87}$ = 859 lb. of coal required for 72,710 cu. ft. gas.

In this coal there appears 4.65 per cent of hydrogen of which 4.44 per cent is apparently in the form of hydrocarbons, the hydrogen of which undergoes no reaction in the producer. The balance, 0.21 per cent, is in the form of moisture, and will be classed with hydrogen obtained from steam.

Therefore we have $859 \times 0.0444 = 38.14$ lb. of hydrogen in hydrocarbons and $59.18 - 38.14 = 21.04$ lb. of hydrogen derived from steam, the heat value of which $21.04 \times 62.032 =$ 1,305,153 B.t.u. is absorbed from the producer and should be deducted from the total amount under head of "heat lost." We have, therefore, for the net results,

Heat lost in producer, 5,120,704 – 1,305,153 =	3,815,551	B.t.u.
Heat retained in gas........................	9,361,591	"
Total heat of combustion of 859 lb. of coal..	13,177,142	"

showing a loss of 28.9 per cent in the producer.

It would seem that the analysis of gas assumed is unfair to the producer, for the relatively small amount of hydrogen (less than 0.40 per cent by weight) introduced into the producer in the form of steam, would indicate that the producer was being operated at high temperature, and therefore a large amount of carbon monoxide would be formed and a correspondingly smaller amount of carbonic acid than the quantities given in the analysis, resulting in a gas of higher heat value and a higher degree of efficiency for the producer.

From 859 lb. of coal consumed, 810 b.h.p. for one hour were produced, from which the coal consumption is $\frac{859}{810} = 1.05$ lb. of coal per b.h.p-hr. This is about in line with the 1.275 lb. of coal per b.h.p-hr. at 45 per cent load factor, which was the average consumption of the plant under discussion for the past year.

From the table we find that one cu. ft. of gas requires 0.926 cu. ft. of air for complete combustion, and therefore 72,710 cu. ft. of gas will require 72,710×926 = 67,402 cu. ft. of air, making a total mixture of 72,710+67,402 = 140,112 cu. ft.

The displacement of the piston in one power stroke is 9,574.464 cu. in. = 5.54 cu. ft., and as there are 28,800 power strokes per hour, the total displacement per hour is 28,800×5.54 = 159,952 cu. ft. If the full load capacity of the engine is 87 per cent of its ultimate capacity, then 159,952×0.87 = 139,158 cu. ft. is the full load displacement per hour, and the suction efficiency of the engine would be $\frac{140{,}112}{139{,}158}$ or a trifle over 100 per cent. As this is not possible it is evident, if the figures are correct, that the assumption of 72,710 cu. ft. of gas at 127.0 B.t.u. per cu. ft. is a little more than required to develop 810 b.h.p.-hr. at the full load rating of the engine, provided the engine is properly rated. However, as the error is small, we will continue in the original assumption as to quantity and value of gas and derive from the above figures the following approximate heat balance:

Heat lost in producer and auxiliaries	**3,815,551 B.t.u.**	**28.9 per cent**
Heat lost in engine friction at 84 per cent mechanical efficiency $\frac{1980000 \times 154}{772}$	**394,977 "**	**2.9 "**
67437 lb. of water raised 40 degrees, specific heat 1.013:67437×40×1.013 =	**2,734,000 "**	**20.8 "**
Latent heat of evaporation 532.62 lb. steam at 1064 B.t.u. per pound	**566,707 "**	**4.3 "**
Lost in radiation and exhaust	**3,588,446 "**	**27.3 "**
Total losses	**11,099,681 "**	**84.2 "**
Heat effective in engine $\frac{1980000 \times 810}{772}$	**2,077,461 "**	**15.8 "**
Total heat of combustion	**13,177,142 "**	**100.0 "**

Since the specific heat of the products of combustion is not known for temperatures as high as exist in the exhaust, it is impossible to compute the heat lost in this direction, and therefore the heat lost by radiation and by exhaust can only be arrived at by elimination.

The specific heat of the products of combustion containing 15 per cent CO_2 is given as 0.323 for 100 degrees fahr., and it is known that the specific heat of all gases increases considerably with increased temperatures. If the amount of heat, *viz.*, 3,588,446 B.t.u. as derived by our heat balance is correct and the temperature of exhaust 800 degrees above atmospheric, which is approximately true, there being $72710 \times 0.148{,}123 =$ 10,761 lb. of gas delivered from the exhaust, the specific heat (neglecting loss by radiation of engine) would have to be $\frac{3588446}{10761 \times 800} = 0.413$, as compared to water, which would seem to be a reasonable value.

In Conclusion. That the gas engine has a wide field of usefulness is no longer disputed, but whether it is adapted to conditions of operation such as are met in the plant described is very questionable, unless it be in connection with a storage battery. Other factors however than the conditions of load, as in this case, often enter into the question, and bring influence to bear upon the adoption of a system seemingly unsuitable for the conditions in hand.

The economy of the gas engine has long been conceded, and its reliability at the present time has been proved without a shadow of doubt. An engine in the Edgar Thompson Works of the U. S. Steel Corporation has operated continuously night and day for six months with the total loss of only three hours time; and other records that would do credit to any class of prime mover are to be had in numbers.

When a source of power at low price but uncertain continuity is available, a gas engine and producer will prove a most perfect relay, provided the character of service will warrant the cost of reserve power.

With the holder full of gas and the exhauster of the producer stopped, the fires in the generators will smoulder with almost inappreciable stand-by loss. The engine may be started and put under load in less than two minutes, and the producer can be brought up to working condition before the gas in the holder is exhausted.

Again, when natural or blast furnace gas is available, or when location renders the cost of fuel high, the gas engine has no competitor. Fuel can be utilized in the producer that is absolutely unfit to be burned under a boiler, but even where conditions are more favorable to steam, the gas engine makes a most respectable showing.

DISCUSSION ON "GAS ENGINES IN CITY RAILWAY AND LIGHTING SERVICE", CHARLOTTE, N. C., MARCH 30, 1910.

H. K. English: I have been greatly interested in Mr. Latta's paper on Gas Engines. The record given of plant performance showing a total shut-down of but two hours and forty-five minutes for the year is indeed an enviable one. Also, I consider the data given on operating costs of particular value, as it bears the stamp of "real life" instead of being an engineering estimate, which at best is often only a "wise guess".

It is to be regretted, however, that the items of interest and depreciation have been omitted. Figures on cost of generating power, with these items omitted, are very misleading, this being particularly true of a gas engine plant where installation costs vary widely and little is known regarding such costs. If Mr. Latta would give some figures on installation costs of the plant under consideration, it would add greatly to the value of the other data given.

I would also like to ask Mr. Latta how often he finds it necessary to shut down his gas generators for cleaning, and how long a generator is out of service during this cleaning process.

F. D. Gatchell: Referring to the paragraph of this paper dealing with the piston rod packing, I would like to state that while it is true that the piston rod packings are removed occasionally to be cleaned and adjusted, this is becoming more and more infrequent owing to a better knowledge of how to adjust and assemble this packing before placing it on the piston rod and also to a much better system of lubrication. When these engines were first placed in operation considerable trouble was experienced by the blowing out and leaking of the packing, and if this condition was allowed to go on for any length of time the garter springs holding the segments in place were soon distorted owing to the high temperature of the gas blowing through. This made the packing segments warp and not fit the rod properly. We have overcome these troubles very effectively, however, first, by careful study of the lubricating conditions, and second, by a different method of applying the garter springs. After a series of experiments with different kinds and quantities of oil, we believe that we have hit upon a combination which effectively fits this practice. This is borne out by the fact that we have several sets of packing on these engines which have been in continuous operation for several months, one set having been in service for over ten months without cleaning. This is very desirable for these engines as there are eight sets of piston rod packing on each engine to be kept up.

The method we have adopted in regard to installation of the garter springs which hold the segments of packing together, is that instead of using the continuous spring all the way around the packing as formerly, to divide the spring into short sections connected together with links of solid wire. Each piece of spring takes care of one segment of packing and the joints are bridged by the solid wire. It can readily be seen that as the packing nearly always begins to blow at the joints between the segments, these solid pieces of wire will not be affected by the heat as readily as the springs, and do not stretch, allowing the packing segments to get out of place. We are confident that this simple method of installing these springs has reduced our packing trouble considerably and from indications in the operation of this packing, as used now, it should run several months without adjusting or cleaning.

Referring to the paragraph on page 444 which states that there is a slight periodic swing between the pointers of the wattmeters; it may be of interest to state that since this paper has been written we have discovered that one of the wattmeters was improperly connected and after removing this trouble the so-called periodic swing has been reduced to a marked degree, so that it is hardly perceptible, which would indicate that the fluctuation was principally an instrument trouble rather than one caused by cross currents between the alternators running in parallel.

E. D. Latta, Jr.: If I may be permitted to add a few remarks by way of discussion of my own paper, I should like to call attention to recent experiments made at the University of Illinois on the subject of the occluded gases in coal. These experiments show that when coal is freshly mined a considerable amount of gas exudes from it and simultaneously an absorption of oxygen from the air takes place. The gas escapes rapidly from the coal when first exposed to air, but the rate of escape gradually decreases until at the end of about two months it has practically ceased. Similarly the absorption of oxygen decreases with the time of exposure but to a much less degree, for the experiments indicated that after two years exposure the coal still showed a marked avidity for oxygen, and it is probable that this condition continues indefinitely.

This slow oxidation of coal may account in part for the difference between railroad weights and the weights of coal as fired, for nearly all consumers of coal who carry a large stock on hand, find it necessary to add a certain percentage to the weights of coal as fired in order to balance with the railroad weights.

The gas which escapes from the coal, when freshly mined, consists largely of hydrocarbons in the form of marsh gas, CH_4 which is well known to be the cause of nearly all coal mine disasters. If the analysis of the coal referred to in this paper were made, or samples taken within two months after the coal was mined, it is probable that a subsequent loss of hydrogen in the form of marsh gas occurred, and that the coal as fired did not contain the heat units that the analysis showed. Assuming a possible loss to the coal of 2 per cent of hydrogen subsequent to the analysis, the total higher heat value of the coal per pound would be 14,220 B.t.u. which is more nearly the commercially accepted value of good bituminous coal. The engine efficiency would then become 17 per cent instead of 15.8 per cent and the loss of heat attributed to the producer would be materially reduced, for instead of obtaining 4.44 per cent of hydrogen from the hydrocarbons in the coal, there would be found only 2.44 per cent or 20.95 lb. of hydrogen from 859 lb. of coal. The balance of 38.22 lb. of hydrogen would therefore have to be supplied by the introduction of 344 lb. of steam, in the disassociation of which there would be 2,370,863 B.t.u. absorbed from the producer, reducing the total heat units lost in the producer to 5,120,704 —2,370,869 = 2,749,841 B.t.u., or 20.7 per cent. This figure would show for the producer about the efficiency that is claimed for it by its manufacturers.

A paper presented at the Charlotte meeting of the American Institute of Electrical Engineers, March 30, 1910.

ON THE MODIFICATIONS IN HERING'S LAWS OF FURNACE ELECTRODES INTRODUCED BY INCLUDING VARIATIONS IN ELECTRIC AND THERMAL RESISTIVITY

BY A. E. KENNELLY

At the meeting of the American Electrochemical Society in October 1909, a paper was read by Mr. Carl Hering on " Laws of Electrode Losses in Electric Furnaces ". At least seven interesting and important laws of electrode losses were enunciated and demonstrated in that paper, of which, however, only the two following need here be considered:

a. The combined loss through the cold end of an electrode is equivalent to the sum of the loss by heat conduction alone, (when there is no current) and half the $I^2 R$ loss.

b. This combined loss will be least when the loss by heat conduction alone is made equal to half the $I^2 R$ loss; the total loss will then be equal to the $I^2 R$ loss, and no heat will be conducted from the interior of the furnace.

In the discussion upon the paper the question was raised as to how far the temperature variation in electric and thermal resistivities of the electrodes modified these laws, since these resistivities might be considerably different at the hot and cold ends. This paper is devoted to a consideration of that question from an arithmetical point of view.

We will assume that both the electric and thermal resistivities are known at the hot end, as well as at the cold end of the electrode, from physical data for the electrode material at the furnace temperature and at the external air temperature. We will also assume that both resistivities change uniformly according to a straight-line law from the known value at the cold end to the known value at the hot end. Thus, in Fig. 1, OX represents the length of an electrode, whose cold end O has a certain resistivity—either electric or thermal—represented by the ordinate OA, and whose hot end X has a corresponding resistivity represented to the same scale by the ordinate XB. We now assume that at any point P along the electrode, the resistivity considered has a value PQ, the point Q being found on the straight line AB. This assumption would be entirely justified if the resistivity followed the temperature according to a straight-line law, and also if the temperature increased uniformly along the electrode when at work. But in the working condition, the gradient of temperature is greater near the cold end than near the hot end. If only on this account, the actual resistivity curve probably deviates to one side or the other of the straight line AB. In assuming, therefore, straight-line laws of resistivities from one end of the electrode to the other, we arrive at only a first approximation to the true solution of the problem, although we greatly simplify the solution. Nevertheless, the first-approximation solution which we shall develop is probably sufficiently close for ordinary practical purposes, especially as our data concerning the temperature variation of the resistivities is still very meagre. Moreover, since the results indicate that the first-approximation effect of the change in resistivities is relatively small, the necessity for seeking a second approximation becomes yet smaller.

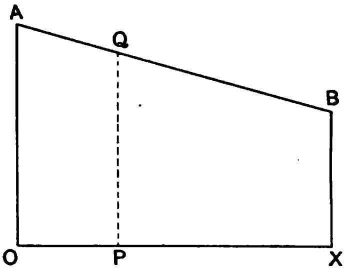


FIG. 1.—Diagram representing the assumed type of straight-line law in linear resistivities

In Fig. 2, OX represents a prismatic electrode with a length OX of X cm., and a uniform cross-sectional area of s cm^2, commencing at the cold end O, the temperature of which is taken as 0 degrees cent., and terminating at the hot end X, the temperature of which is taken as T degrees cent. The electrode is assumed to be perfectly insulated at the sides, both electrically and thermally, by the surrounding furnace wall. If the temperature of the cold end should differ materially from 0 degrees cent. it suffices to reckon this temperature as 0 degrees and to deduct from the furnace temperature T a corresponding amount, so as to maintain the correct difference of temperature between the ends.

In the following demonstration C. G. S. units are employed throughout.

Let t_x = the temperature at any point of the electrode distant x cm. from O. (degrees cent.)

ϕ_x = The flow of heat through a cross-section of electrode distant x cm. from O, and reckoned as positive when in the direction $O\,X$ (abwatts).

I = the current strength passing through the electrode (absamperes).

$\rho_x = \rho_0\,(1+a\,x)$ = the electric resistivity of the electrode at a point distant x cm. from O; where ρ_0 is the resistivity at the cold end, and $\rho_0\,(1+a\,X)$ is the resistivity at the hot end (absohm-cm.).

$\sigma_x = \sigma_0\,(1+b\,x)$ = the thermal resistivity of the electrode at a point distant x cm. from O; where σ_0 is the resistivity at the cold end, and $\sigma_0\,(1+b\,X)$ is the resistivity at the hot end. (thermal absohm-cm.).*

The differential increase in heat flow occurring in the element dx is

$$d\phi_x = I^2\,\frac{\rho_x}{s}\,dx = I^2\,\frac{\rho_0}{s}\,(1+a\,x)\,dx \qquad \text{abwatts (1)}$$

$$\therefore \frac{d\phi_x}{dx} = I^2\,\frac{\rho_0}{s}\,(1+a\,x) \qquad \text{abwatts/cm. (2)}$$

---

* A unit cube of material of thermal resistivity σ absohm-cm. will permit a thermal flow of $1/\sigma$ abwatts, or ergs per second, when a difference of temperature of 1 degree cent. is maintained between a pair of opposite faces. The constants a and b may be either both positive, or both negative, or of opposite signs.

Also

$$\phi_x = -\frac{s}{\sigma_x}\cdot\frac{dt_x}{dx} = -\frac{s}{\sigma_0\,(1+b\,x)}\cdot\frac{dt_x}{dx} \qquad \text{abwatts} \quad (3)$$

where the negative sign indicates that the flow of heat has a direction opposite to the positive direction of temperature gradient.

$$\therefore\ \frac{d\,t_x}{dx} = -\phi_x\,\frac{\sigma_0}{s}\,(1+b\,x) \qquad \text{degrees cent. per cm.} \quad (4)$$

Differentiating with respect to x, we have:

$$\frac{d^2\,t_x}{dx^2} = -\frac{d\phi_x}{dx}\cdot\frac{\sigma_0}{s}\,(1+b\,x) - \phi_x\,\frac{\sigma_0}{s}\,b$$

degrees cent. per cm. per cm (5)

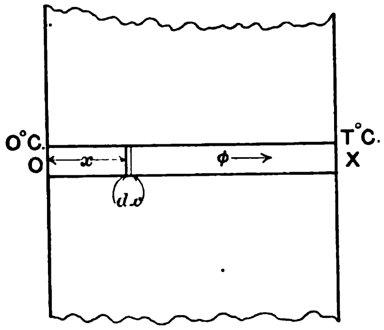


FIG. 2.—Electrode of uniform cross-section insulated both electrically and thermally in furnace wall

Substituting in (5) the value of $\frac{d\phi_x}{dx}$ in (2),

$$\frac{d^2t_x}{dx^2} = -I^2\,\frac{\rho_0\,\sigma_0}{s^2}\,(1+ax+bx+abx^2) - \phi_x\,\frac{\sigma_0}{s}\,b$$

degrees cent. per cm. per cm. (6)

Differentiating again with respect to x,

$$\frac{d^3t_x}{dx^3} = -I^2\,\frac{\rho_0\,\sigma_0}{s^2}\,(a+b+2abx) - I^2\,\frac{\rho_0\,\sigma_0}{s^2}\,(b+abx)$$

degrees cent. per cm. per cm. per cm. (7)

$$= -I^2 \frac{\rho_0 \sigma_0}{s^2}(a+2b+3abx)$$

degrees cent. per cm. per cm. per cm. (8)

This is the fundamental differential equation connecting temperature with distance along the electrode. Integrating with respect to x, we have:

$$\frac{d^2t_x}{dx^2} = -I^2\frac{\rho_0\sigma_0}{s^2}\left\{(a+2b)x+\frac{3ab}{2}x^2\right\}+A$$

degrees cent. per cm. per cm. (9)

$$\frac{dt_x}{dx} = -I^2\frac{\rho_0\sigma_0}{s^2}\left\{\left(\frac{a+2b}{2}\right)x^2+\frac{ab}{2}x^3\right\}+Ax+B$$

degrees cent. per cm. (10)

$$t_x = -I^2\frac{\rho_0\sigma_0}{s^2}\left\{\left(\frac{a+2b}{6}\right)x^3+\frac{ab}{8}x^4\right\}+\frac{A}{2}x^2+Bx$$

degrees cent. (11)

where A and B are integration constants to be determined from the terminal conditions. No new integration constant appears in (11) because $t_0 = 0$, by assumption.

In order to determine B, we may substitute X for x in (11), in which case $t_x = T$ degrees cent. This gives:

$$T = -I^2\frac{\rho_0\sigma_0}{s^2}\left\{\left(\frac{a+2b}{6}\right)X^3+\frac{ab}{8}X^4\right\}+\frac{A}{2}X^2+BX$$

degrees cent. (12)

from which,

$$B = \frac{T}{X}-\frac{A}{2}X+I^2\frac{\rho_0\sigma_0}{s^2}\left\{\left(\frac{a+2b}{6}\right)X^2+\frac{ab}{8}X^3\right\}$$

degrees cent. per cm. (13)

substituting this value of B in (10), we obtain:

$$\frac{dt_x}{dx} = \frac{T}{X}-\frac{A}{2}(X-2x)+I^2\frac{\rho_0\sigma_0}{s^2}\left\{\left(\frac{a+2b}{6}\right)(X^2-3x^2)\right.$$

$$\left.+\frac{ab}{8}(X^3-4x^3)\right\}$$

degrees cent. per cm. (14)

Using this result in (3), we have:

$$-\phi_x = \frac{1}{1+b\,x}\left[\frac{s}{\sigma_0}\cdot\frac{T}{X} - \frac{As}{2\sigma_0}(X-2\,x)\right.$$

$$\left. + I^2\,\frac{\rho_0}{s}\left\{\left(\frac{a+2\,b}{6}\right)(X^2-3\,x^2) + \frac{a\,b}{8}\,(X^3-4\,x^3)\right\}\right] \qquad \text{abwatts (15)}$$

There remains the constant A to be determined from the known conditions of thermal flow. This constant A, which appears in (9) as a rate of change of temperature gradient, may be conveniently expressed as the sum of two parts, or

$$A = A_1 + A_2 \qquad \text{degrees cent. per cm. per cm. (16)}$$

where A_1 depends only on the furnace heat-flow, or the flow of heat which would take place through the electrode in the absence of electric current, and A_2 depends only on the joulean heat-flow, or the flow of heat which would take place in the electrode with the electric current acting, but with no furnace heat, or a temperature 0 degrees cent. at both ends.

The total furnace flow will be obtained by dividing the difference of temperature, or thermomotive force, by the total thermal resistance of the electrode $\mathcal{R}$, which is

$$\mathcal{R} = \int_0^X \frac{\sigma_x}{s}\,dx = \frac{\sigma_0}{s}\int_0^X (1+b\,x)\,dx = \frac{\sigma_0}{s}\,X(1+b\,\frac{X}{2}) \qquad \text{thermal absohms (17)}$$

This means that the thermal resistance of the electrode, with a thermal resistivity varying in the manner assumed, is the same as that of an electrode having the same dimensions and a constant resistivity, equal to the arithmetical mean resistivity of the first. The furnace flow is thus:

$$-\phi_{x\,(I\,=\,0)} = \frac{Ts}{\sigma_0\,X\,(1+b\mathrm{v})} \qquad \text{abwatts (18)}$$

where $\mathrm{v} = X/2$

Putting $I = 0$ in (15) we obtain:

$$\frac{Ts}{\sigma_0 \, X(1+b\text{v})} = \frac{Ts}{\sigma_0 \, X(1+bx)} - \frac{A_1 \, s \, (\text{v}-x)}{\sigma_0 \, (1+bx)} \quad \text{abwatts} \quad (19)$$

from which

$$A_1 = \frac{T}{X} \left(\frac{b}{1+b\text{v}} \right) \quad \text{degrees cent. per cm. per cm.} \quad (20)$$

The total joulean heat flow will be the integral of the $I^2 R$ loss in the electrode. The total electric resistance R is:

$$R = \int_0^X \frac{\rho_x}{s} \, dx = \frac{\rho_0}{s} \int_0^X (1+a\,x) \, dx = \frac{\rho_0}{s} \, X \left(1+a\frac{X}{2} \right) \quad \text{absohms} \quad (21)$$

That is, the total resistance of the electrode with an electric resistivity varying in the manner assumed, is the same as that of an electrode having the same dimensions, and a constant resistivity equal to the arithmetical mean resistivity of the first. The total joulean flow is then, with $T = 0$:

$$-\phi_0 + \phi_X = I^2 \frac{\rho_0}{s} X \, (1+a\,\text{v}) \quad \text{abwatts} \quad (22)$$

In (15), first put $T = 0$; $x = 0$; and then $T = 0$, $x = X$.

$$-\phi_0 = -A_2 \frac{s\,\text{v}}{\sigma_0} + I^2 \frac{\rho_0}{s} \left\{ \left(\frac{a+2\,b}{6} \right) X^2 + \frac{a\,b}{8} X^3 \right\} \quad \text{abwatts} \quad (23)$$

$$\phi_X = -A_2 \frac{s\,\text{v}}{\sigma_0 \, (1+bX)} + \frac{I^2 \rho_0}{s \, (1+bX)} \left\{ \left(\frac{a+2\,b}{6} \right) 2\,X + \frac{3\,a\,b}{8} X^3 \right\} \quad \text{abwatts} \quad (24)$$

Adding (23) to (24) and equating to (22), we obtain:

$$A_2 = \frac{I^2 \rho_0 \sigma_0}{s^2 \, (1+b\text{v})} \left\{ \frac{bX^2 \, (4a+8b+3abX)}{24} - 1 \right\} \quad \text{degrees cent. per cm. per cm.} \quad (25)$$

Substituting the above values for A and B in (11) and (15):

$$t_x = \frac{Tx}{X}\left(\frac{2+bx}{2+bX}\right)+I^2\frac{\rho_0\sigma_0 x}{s^2}\left[\left\{\left(\frac{a+2b}{6}\right)(X^2)^2x-+\frac{ab}{8}(X^3-x^3)\right\}\right.$$

$$\left.-\frac{X-x}{2(1+b\,\mathrm{v})}\left\{\frac{bX^2(4a+8b+3abX)}{24}-1\right\}\right]$$

degrees cent. (26)

and

$$-\phi_x = \frac{T}{X}\,\frac{s}{\sigma_0}\left(\frac{1}{1+b\mathrm{v}}\right)$$

$$+\frac{I^2\rho_0}{s(1+bx)}\left[\left\{\left(\frac{a+2b}{6}\right)(X^2-3x^2)+\frac{ab}{8}(X^3-4x^3)\right\}\right.$$

$$\left.-\left(\frac{\mathrm{v}-x}{1+b\mathrm{v}}\right)\left\{\frac{bX^2(4a+8b+3abX)}{24}-1\right\}\right] \quad \text{abwatts (27)}$$

Consequently, substituting $x = X$ and $x = 0$ successively, we obtain after rearranging the terms:

$$-\phi_X = \frac{T}{X}\,\frac{s}{\sigma_0(1+b\,\mathrm{v})}-\frac{I^2\rho_0\mathrm{v}}{s(1+b\,\mathrm{v})}\left\{1+X\left(\frac{2a+b}{3}\right)+X^2\frac{ab}{4}\right\}$$

abwatts (28)

$$-\phi_0 = \frac{T}{X}\,\frac{s}{\sigma_0(1+b\,\mathrm{v})}+\frac{I^2\rho_0\mathrm{v}}{s(1+b\,\mathrm{v})}\left\{1+X\left(\frac{a+2b}{3}\right)+X^2\frac{ab}{4}\right\}$$

abwatts (29)

Equations (26) to (29) contain the complete solution of the problem under the assigned conditions. If we assume constant resistivities, or $a = b = 0$, they become:

$$t_x = T\frac{x}{X}+I^2\frac{\rho_0\sigma_0}{s^2}x\left(\frac{X-x}{2}\right) \quad \text{degrees cent. (30)}$$

$$-\phi_x = \frac{T}{X}\cdot\frac{s}{\sigma_0}+I^2\frac{\rho_0}{s}(\mathrm{v}-x) \quad \text{abwatts (31)}$$

$$-\phi_X = \frac{T}{X}\cdot\frac{s}{\sigma_0}-I^2\frac{\rho_0\mathrm{v}}{s} \quad \text{abwatts (32)}$$

$$-\phi_0 = \frac{T}{X} \cdot \frac{s}{\sigma_0} + I^2 \frac{\rho_0 \, \mathrm{v}}{s} \qquad \text{abwatts (33)}$$

which correspond completely to the formulas given in Mr. Hering's paper. That is, the total heat flow at the cold end is the sum of the furnace flow and half the joulean flow.

If we retain a in formulas (26) to (29), but put $b = 0$; *i e*, assume constant thermal resistivity, we obtain:

$$t_x = T \frac{x}{X} + I^2 \frac{\rho_0 \, \sigma_0}{s^2} x \left\{ \frac{a}{6} (X^2 - x^2) + \frac{X-x}{2} \right\} \qquad \text{degrees cent. (34)}$$

$$-\phi_x = \frac{T}{X} \frac{s}{\sigma_0} + I^2 \frac{\rho_0}{s} \left\{ \frac{a}{6} (X^2 - 3\,x^2) + (\mathrm{v} - x) \right\} \qquad \text{abwatts (35)}$$

$$-\phi_X = \frac{T}{X} \frac{s}{\sigma_0} - I^2 \frac{\rho_0}{s} \mathrm{v} \, (1 + \frac{2}{3} a \, X) \qquad \text{abwatts (36)}$$

$$-\phi_0 \doteq \frac{T}{X} \frac{s}{\sigma_0} + I^2 \frac{\rho_0}{s} \mathrm{v} \left(1 + \frac{a}{3} X\right) \qquad \text{abwatts (37)}$$

Similarly, if we retain b in formulas (26) to (29), but put $a = 0$; *i.e.*, assume constant electric resistivity, we obtain:

$$t_x = T \frac{x}{X} \left(\frac{2 + b\,x}{2 + b\,X}\right) + I^2 \frac{\rho_0 \, \sigma_0}{s^2} x \left\{ \frac{b}{3} (X^2 - x^3) \right.$$
$$\left. - \frac{X - x}{2\,(1 + b\,\mathrm{v})} \left(\frac{b^2}{3} X^2 - 1\right) \right\} \qquad \text{degrees cent. (38)}$$

$$-\phi_x = \frac{T}{X} \frac{s}{\sigma_0} \left(\frac{1}{1 + b\,\mathrm{v}}\right) + I^2 \frac{\rho_0}{s\,(1 + b\,x)} \left\{ \frac{b}{3} (X^2 - 3\,x^2) \right.$$
$$\left. - \left(\frac{\mathrm{v} - x}{1 + b\,\mathrm{v}}\right) \left(\frac{b^2}{3} X^2 - 1\right) \right\} \qquad \text{abwatts (39)}$$

$$-\phi_X = \frac{T}{X} \frac{s}{\sigma_0 (1 + b\,\mathrm{v})} - \frac{I^2 \rho_0 \, \mathrm{v}}{s\,(1 + b\,\mathrm{v})} \left(1 + X \frac{b}{3}\right) \qquad \text{abwatts (40)}$$

$$-\phi_0 = \frac{T}{X} \frac{s}{\sigma_0 (1 + b\,\mathrm{v})} + \frac{I^2 \rho_0 \, \mathrm{v}}{s\,(1 + b\,\mathrm{v})} \left(1 + X \frac{2\,b}{3}\right) \qquad \text{abwatts (41)}$$

Formulas (36) and (37) show that with the electric resistivity alone varying, the joulean heat does not divide equally between the two ends of the electrode. The part escaping through the furnace end is such as would be produced in an electrode of uniform resistivity equal to that actually found at distance $X/3$ cm. from X; while the part escaping through the external end is such as would be produced in an electrode of uniform resistivity equal to that actually found at distance $X/3$ cm. from O. With a essentially negative in carbon, the joulean flow through the furnace end would be less than that through the external end.

Formulas (28) and (29) may also be obtained in a different way, as follows: Referring to Fig. 2, the joulean power developed in the element $d\,x$ is defined by equation (1). This power divides into two current elements, one $d\phi_x$ escaping through the furnace end, and the other $-d\phi_0$, escaping through the outer end. This division may be expressed:

$$d\phi = -d\phi_0 + d\phi_x \qquad \text{abwatts (42)}$$

The division is effected in inverse proportion to the thermal resistances on each side of the element dx. The thermal resistance $\mathcal{R}_0$ between O and x is:

$$\mathcal{R}_0 = \frac{\sigma_0}{s}\,x\left(1+\frac{b}{2}\,x\right) \qquad \text{thermal absohms (43)}$$

The thermal resistance $\mathcal{R}_x$, between x and X is:

$$\mathcal{R}_x = \frac{\sigma_0}{s}\left\{(X-x)+\frac{b}{2}\,(X^2-x^2)\right\} \qquad \text{thermal absohms (44)}$$

The total thermal resistance $\mathcal{R} = \mathcal{R}_0 + \mathcal{R}_x$ from O to X is expressed by (17). The divisional currents are therefore:

$$-d\phi_0 = d\phi\,\frac{\mathcal{R}_x}{\mathcal{R}} = d\phi\,\frac{(X-x)+\frac{b}{2}\,(X^2-x^2)}{X\,(1+b\,\text{v})} \qquad \text{abwatts (45)}$$

$$= \frac{I^2\rho_0(1+ax)\left\{(X-x)+\frac{b}{2}\,(X^2-x^2)\right\}dx}{sX\,(1+b\,\text{v})} \qquad \text{abwatts (46)}$$

$$d\phi_{\mathrm{x}} = d\phi \frac{\mathcal{R}_0}{\mathcal{R}} = d\phi \frac{x\left(1+\frac{b}{2}x\right)}{X\,(1+b\,\mathrm{v})} \qquad \text{abwatts (47)}$$

$$= \frac{I^2\rho_0(1+ax)\left\{x\left(1+\frac{b}{2}\,x\right)\right\}dx}{sX\,(1+b\mathrm{v})} \qquad \text{abwatts (48)}$$

Integrating (46) and (48) from $x = 0$ to $x = X$, we find the total currents $-\phi_0$ and ϕ_{x}, as expressed in (28) and (29) respectively, after taking the furnace flow into account as in (18).

NUMERICAL EXAMPLE No. 1, WITH CONSTANT THERMAL RESISTIVITY, OR $b = 0$

We may take as an example a graphite electrode of length $X = 50$ cms. and of uniform cross-section $s = 100$ sq. cm., terminating in a furnace with a temperature elevation of $T = 1600$ degrees cent. Let us first assume that both the electric and thermal resistivities of this electrode are uniform throughout its length ($a = b = 0$). We may take the electric resistivity as $\rho = 0.85 \times 10^6$ absohm-cm.* (0.00085 ohm across a block 1 cm. cube, or 0.000333 ohm across a block 1 inch cube), and the thermal resistivity as $\sigma = 2.5 \times 10^{-7}$ thermal absohm-cms. (1 degree cent. across a block 1 cm. cube would transmit $1/(2.5 \times 10^{-7})$ abwatts of thermal flow, *i e.*, 1/2.5 watts; or $1/(2.5 \times 4.19)$ gm. calories per sec.)

The steady current strength which will be consistent with the minimum waste of heat in this electrode will be, by (33) $I = 245.6$ absamperes (2456 amperes), representing a current density of 24.56 amperes per sq. cm. The electric resistance of the electrode will be 0.425×10^6 absohms (0.425×10^{-3} ohm), the drop of potential in the electrode 1.044×10^8 abvolts (1.044 volts) and the joulean power expended $I^2 R = 2.560 \times 10^{10}$ abwatts (2560 watts).

The thermal conditions of the electrode are represented in Fig. 3, where abscissas along OX represent distances, and ordinates the temperature to the right-hand scale in degrees cent. The thermal current strength is indicated in watts to the left-hand scale. The straight line OT indicates the temperature at different points along the electrode, in the steady state, when

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* The thermal and electric resistivities used in this example are borrowed from Mr. Hering's October paper.

no electric current flows, but the furnace temperature is independently maintained. The parabola $O\,P\,X$ indicates the temperature which would be reached, in the steady state, at each point of the electrode, if the furnace were cold but full

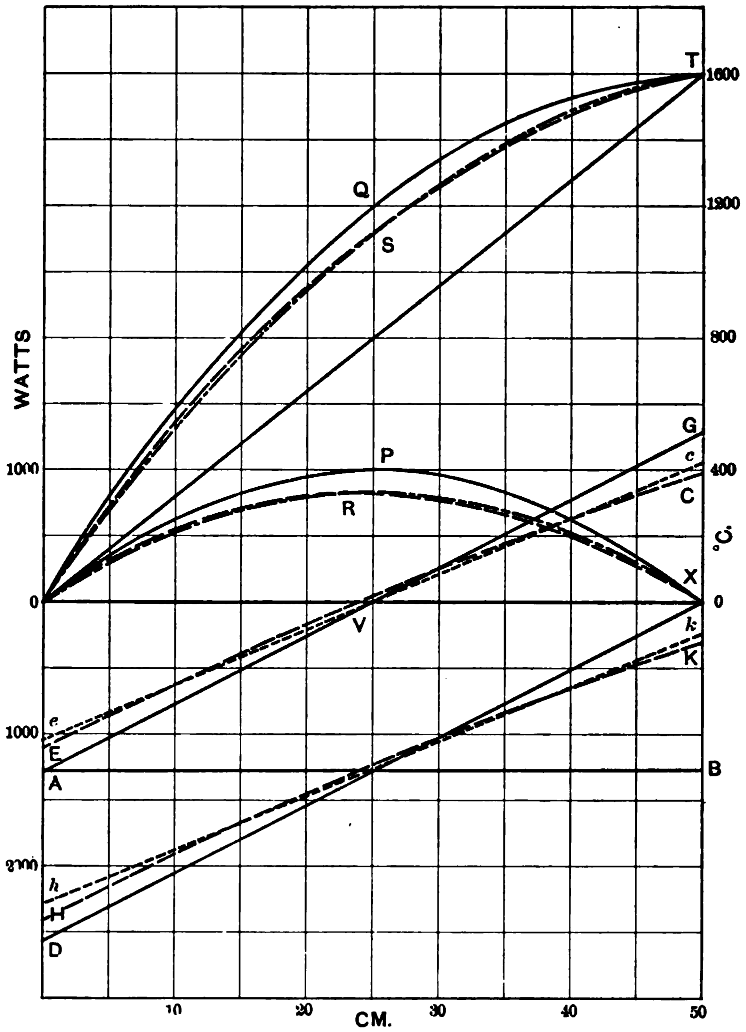

FIG. 3.—Thermal chart for electrode of uniform thermal resistivity

electric current were maintained. Thus, the middle point P of the electrode would attain a temperature elevation of 399.5 degrees cent.; while the two extremities O and X would have no temperature elevation.

Under working conditions the above two thermal states would be superposed, and the temperature at each point of the electrode is shown by the curve *O Q T*, which is the parabola *O P X* superposed on the straight line *O T*.

Again, the furnace temperature elevation of 1600 degrees cent. working through the thermal resistance of the electrode (1.25×10^{-7} thermal absohms), would determine a thermal current flow of $1600/1.25 \times 10^{-7} = 1.28 \times 10^{10}$ abwatts or 1280 watts, which is constant at all points along the electrode, as indicated by the horizontal straight line *A B*. Again with the furnace cold, and the electrode active, there would be no thermal current at the middle point *V*; but there would be a positive, or furnace-directed thermal current at all points between *V* and *X*, together with a negative, or outwardly-directed, thermal current at all points between *O* and *V*. This condition is represented by the straight line *A V G*, with 1280 thermal watts escaping from each end. In the working condition, the above thermal currents are superposed and the total current is represented by the straight line *D X*, with no current in either direction at the furnace end, but with 2560 thermal watts leaving the outer end *O*. All this is in accordance with the principles enunciated in Mr. Hering's paper.

Let us next assume that at the furnace end, owing to the influence of the temperature elevation of 1600 degrees cent., the electric resistivity of the graphite electrode is only 64 per cent of its value at the outer end; or $\rho_X = 0.544 \times 10^6$ absohm-cm., also that the resistivity falls uniformly from *O* to *X* as expressed by the relation $a = -0.0072$, or $\rho_x = 0.85 \times 10^6\ (1 - 0.0072\,x)$ absohm-cm. Then if the thermal resistivity remains constant, ($b = 0$) we find by formula (34) that the furnace temperature gradient *O T* Fig. 3 remains unchanged; but the curve of joulean temperature gradient *O R X* is no longer a parabola, but a cubic, which reaches its maximum (330 degrees) at *R*, about 23 cm. from *O*, the two sides *O R* and *X R* being dissymmetrical. The total temperature gradient in the working state is the broken line *O S T*, and is the sum of the broken line *O R X* and the straight line *O T*.

Again, the furnace thermal current through the electrode is shown at *A B*, 1280 watts as before; but the joulean current is the broken line *E C*, with 973 watts flowing out of the furnace end, and 1127 watts from the outer end. The total thermal current in the working state is indicated by the broken curved line *H K*, with 307 watts escaping from the furnace, and 2407 watts escaping at the outer end.

If instead of using the correction formulas (34) and (35), we assume a constant electric resistivity at the mean value between ρ_0 and ρ_x, or $\rho = 0.697 \times 10^6$ absohm-cm. ($a = b = 0$), then the furnace gradient *O T* remains unchanged; but the joulean gradient becomes a new parabola, represented by the dotted line *O R X*, reaching its maximum of 328.7 degrees cent. at the middle point *V* of the electrode. The total temperature gradient is then the dotted line *O S T*, which differs only very slightly from the broken line *O S T* of the correction formula. Again, the joulean thermal current is indicated by the dotted straight line *e c*, intersecting *O X* in *V*. The flow out of each end of the electrode is 1050 watts. The total thermal current in the working state is indicated by the straight line *h k* with 230 watts escaping from the furnace, and 2330 watts from the outer end.

It is evident that with the electrode dimensions, the range of temperature elevation, and the resistivity here assumed, the corrected formula only changes the thermal current by 77 watts at each end.

NUMERICAL EXAMPLE NO. 2, WITH BOTH RESISTIVITIES VARIABLE

We may next consider a case in which both the electric and thermal resistivities vary. This is represented in Fig. 4. The electrode dimensions, furnace temperature elevation, and electric current strength, are all taken as in the preceding case; but we assume $\rho_x = 0.85 \times 10^6 (1 - 0.0072\, x)$ absohm-cm. and $\sigma_x = 2.5 \times 10^{-7} (1 + 0.01\, x)$ thermal absohm-cm., which make at the furnace end the electric resistivity 36 per cent less, and the thermal resistivity 50 per cent greater, than their respective values at the outer end *O*. Computing the distribution of temperature and thermal current by the correction-formulas (26) and (27) we obtain the broken lines of Fig. 4. The furnace gradient is *O U T*, no longer a straight line, the drop of thermal potential (temperature) being greater toward the furnace end where the resistivity is greater. The joulean gradient is the broken curve *O R X*, which, being a cubic, is not symmetrical, and which reaches a maximum of 405 degrees cent. about 26 cm. from *O*. The total gradient in the working state is shown at *O S T*.

The furnace thermal current *A B*, Fig. 4, is 1025 watts, uniform at all points, and directed towards *O*. The joulean thermal current is indicated by the broken curved line *E c*, that leaving the furnace at *X* being 910 watts, and that leaving the outer end *O* being 1206 watts. The total thermal current is given by

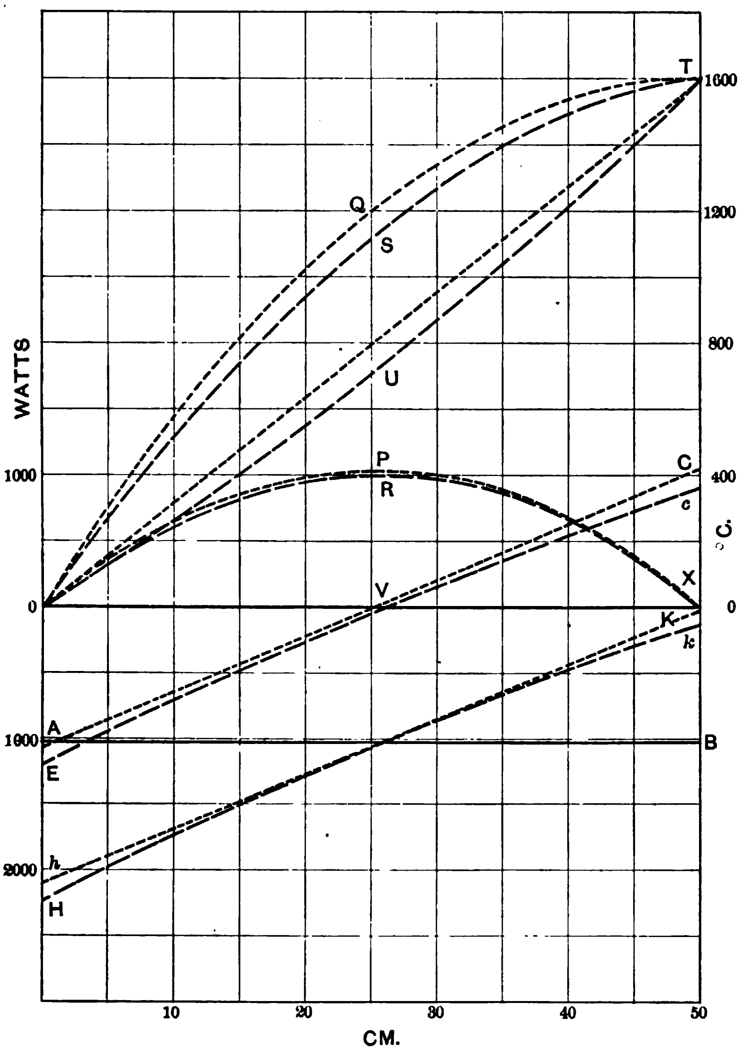

FIG. 4.—Thermal chart for electrode having variation in both electrical and thermal resistivities

the broken line *H k*, 115 watts leaving the furnace at *X*, and 2231 watts leaving the outer end at 0.

If instead of using the correction formulas, we take the simple formulas (30) and (31) of constant resistivities, and the arithmetical mean of each, we have $a = b = 0$, $\rho = 0.697 \times 10^6$ absohm-cm., $\sigma = 3.125 \times 10^7$ thermal absohm-cm. We then obtain the dotted lines of Fig. 4. The furnace gradient becomes the straight line *O T*. The joulean gradient is the parabola *O P X* with its maximum of 411.0 degrees cent. The total gradient in the working state is *O Q T*.

The furnace thermal current *A B* is uniform at 1025 watts, as in the corrected case. The joulean thermal current is the straight line *A C*, with 1050 watts escaping from each end. The total thermal current in the working state is the dotted straight line *h K*, with 25 watts leaving the furnace at *X*, and 2075 watts leaving the open end at *O*.

The errors due to taking mean resistivities are therefore, in this case, 140 watts at the furnace end, and 156 watts at the outer end. The magnitude of this error tends, in general, to increase with the length of the electrode, the electric current density, the magnitudes of the resistivities, their range of variation, and the furnace temperature elevation. Considering the present imperfection of our knowledge concerning electrode resistivities, it will ordinarily not be worth while to take the extra time necessary for working out the correction-formulas. In most cases the mean resistivities, as used in Mr. Hering's paper, will give satisfactory results.

If we examine formula (29) and consider what cross-section of electrode will minimize the total escape of heat from the outer end, we differentiate (29) with respect to *s*, and equate to zero in the usual way. This requires that the first term of (29); *i e.*, the furnace flow, shall be equal to the second compound term, or joulean flow. Consequently, in the general case when both resistivities vary, the minimum heat-waste is found when the joulean flow through the external end is equal to the furnace flow. This is the same relation as was stated in Mr. Hering's paper. Whereas, however, the joulean flow through the outer end was pointed out in that paper to be half the total joulean flow with constant resistivities, it is not, in general, half the joulean flow when either one or both of the resistivities can vary.

Within the assumptions to which the above inquiry has been confined, Mr. Hering's first two laws may be amended as follows, to meet the conditions of variable thermal and electrical resistivity.

a. The combined loss through the cold end of an electrode is equivalent to the sum of the loss by heat conduction alone (when there is no current) and approximately half the $I^2 R$ loss, the exact fraction depending on the temperature coefficients of the resistivities. With constant resistivities, the fraction will be one-half.

b. The above combined loss will be least when the loss by heat conduction alone is equal to the joulean loss through the cold end. The total loss will then be approximately equal to the total joulean loss and very little heat will flow into or out of the furnace. With constant resistivities, this resultant furnace flow will be nil.

LIST OF SYMBOLS EMPLOYED

a = the distance coefficient of electric resistivity (1/cm.).

b = the distance coefficient of thermal resistivity (1/cm.).

$A = A_1 + A_2$, an integration constant (degrees cent. per cm. per cm.).

B = an integration constant (degrees cent. per cm.).

I = current strength through electrode (absamperes).

ϕ_x = thermal current in direction OX, through a cross section of the electrode, at distance x cm. from the outer end (abwatts).

$\mathcal{R} = \mathcal{R}_0 + \mathcal{R}_x$ = thermal resistance of the electrode (thermal absohms).

R = electric resistance of the electrode (absohms).

ρ = electric resistivity (absohm-cm.).

σ = thermal resistivity (thermal absohm-cm.).

ρ_x = electric resistivity at distance x cm. from outer end (absohm-cm.).

σ_x = thermal resistivity at distance x cm. from outer end (thermal absohm-cm.).

s = cross-sectional area of electrode (sq. cm.).

T = temperature-elevation of furnace over outer end (degrees cent.).

t_x = temperature-elevation of any point on the electrode x cm. from and above the outer end. (degrees cent.).

v = $X/2$ (cm.).

x = distance from outer end to a point on the electrode (cm.).

X = length of the electrode (cm.).

DISCUSSION ON "MODIFICATION IN HERING'S LAW OF FURNACE ELECTODES," CHARLOTTE, N. C., MARCH 30, 1910.

Carl Hering: In this very able and interesting paper Dr. Kennelly has made a contribution to our useful knowledge on this subject, which is of considerable value to us as engineers, as he demonstrates that certain correction factors in these simple laws of electrode properties, may be neglected in practical work, or if they are to be included then how to allow for them.

This is of special importance because serious doubt was thrown on the usefulness and reliability of these simple laws by criticism from certain academical quarters on the ground that the premises on which they were based did not include an academically rigid consideration of the temperature variations of the physical constants (which by the way would at present be impossible because they are not yet known). None of these academic critics however did or were able to show quantitatively that the alleged error was really large; they condemned the results of this investigation in a wholesale manner, merely because the assumed simplified premises were not academically exact; although I believe none denied that the results were rigidly correct under those assumed premises.

Dr. Kennelly in this paper has therefore come to the rescue of these new laws by showing with the same tools which the academician is so fond of, that the approximation under more exact premises, is very close, thereby assuring the engineer who is designing furnaces that he may feel safe to use the laws as based on the simple conditions, and that he can safely ignore the academic opposition to them.

His paper affords a very good illustration of how the mathematical physicist can perform services of great value to the practical engineer by solving the more intricate mathematical problems and giving the conclusions in simplified and well digested form for direct application to practice. This, in my opinion is putting mathematics to its proper use, namely, as a tool to produce a useful result, as distinguished from a mere form of entertainment of those physicists who are more interested in mathematical intricasies and gymnastics than in useful practical results.

Some of Dr. Kennelly's results confirm in a more positive way the more general deduction made in the original paper, that as the curve representing the losses is very flat at its minimum point, no great error would be committed, as far as this loss is concerned, by any possible and much greater errors in the cross section due to neglecting the minor factors like the temperature corrections, provided only that the results are somewhere near this minimum point; the simpler formulas enable us to get near this point.

One of his conclusions, namely, to the effect that the conditions for a minimum electrode loss and those for no flow at the furnace end, are no longer identical (though still approximately so) when the temperature variations are taken into consideration, has since been confirmed by an entirely different method, and therefore appears to be correct even without his simplifying premise of a straight line heat gradient in the electrode by the ingenious use of which he has succeeded in getting sufficiently accurate results in a case in which the rigidly correct solution becomes extremely complicated. Even when the rigid solution is effected on the basis of straight line laws of variation of the resistivities, it is still only an approximation because it is known that these variations do not follow such regular laws; for graphite for instance the resistivity first falls and then rises again hence the variation even reverses; while for carbon we know it could not fall according to a straight line law because such a line would when prolonged, give a zero and even a negative resistivity which of course would be absurd.

At first thought it seemed that there might be a mathematical inconsistency in assuming as he does, that the heat gradient in the electrode during normal operation, is a straight inclined line, when it is known that this line must be horizontal at the hot end in order to produce the condition of no flow at the furnace end, and really is a parabola. But is seems that this approximate assumption is made only in so far as it concerns the values of the temperature coefficients of the resistivities, and no farther. If so, it is not an inconsistency, but merely means a a slight error in the form of a small per cent of an already small per cent, and therefore can safely be neglected. When an assumption of such a nature serves to greatly simplify an otherwise extremely complex mathematical result, (which another investigator abandoned when he found it too complicated to integrate) it affords another good illustration of the skillful use of mathematics as a tool to arrive at results for use in practice.

I take pleasure in strongly endorsing Dr. Kennelly's use of thermal resistivities (instead of conductivities) and thermomotive forces. I have long used these quantities in my regular work, and would like to have used them in my papers, but I feared that it would meet with disfavor among many who seem to prefer to waste time and brain energy using the more orthodox methods than to reduce these personal losses to a minimum by using quicker and more direct, though unorthodox methods and tools.

President Stillwell: The opportunity for utilizing electric furnaces exists only where cheap power is available. In the case of these southern rivers, which have so widely variable flow, the problem of the utilization of the power developed always raises, not only the question of cost of development, but also the possibilities of finding a market for the power. At Niagara, the company which financed the original development was greatly disappointed by the slowness with which the market developed. It took a long time to convince the people who used steam power in Buffalo that electric power could be substituted to advantage. At that time there was naturally very much greater doubt of the continuity and certainty of transmission than there is today. The result was that at Niagara a number of electrochemical industries were actually developed as a result of the fact that power there could be obtained in large quantities at low cost, and today about two-thirds of the power which is produced by the Niagara Falls Power Company is used in electro-chemical processes, very few of which existed when this power was first made available and attention directed to it.

In certain sections of the south, with its great and comparatively undeveloped mineral resources, there are also water powers in excess of present requirements for existing industrial uses, and we have thought that by directing the attention of the southern members of the Institute in these papers to certain important fundamental facts relating to the design of electric furnaces, some impetus might be given towards bringing the metallurgist and the engineer together in this section to the advantage of the community.

I was told recently that the U. S. Steel Company, in the old factory of the Washburn & Moen Company, at Worcester, is using a very large electric furnace for the production of steel, and that notwithstanding the high cost of power at that point, the improved quality of the steel, the almost absolute immunity from those constituents, such as phosphorus and sulphur, which are harmful in steel for most of its uses, justified this comparatively expensive method of refining the metal.

A paper presented at the Charlotte meeting of the American Institute of Electrical Engineers, March 30, 1910.

THE PROPORTIONING OF ELECTRODES FOR FURNACES

BY CARL HERING

Introductory. The usual rules for proportioning electrodes for electric furnaces have been based on such factors as allowable current densities, least practicable resistance (hence shortness and large section), lowest heat conduction, the summation of losses due to the electric resistance and to the heat conduction to get the total, etc.

Believing that these laws were not based on correct principles, and were therefore unsatisfactory and perhaps even misleading, and as apparently no one had made a thorough investigation of this subject based on unquestioned fundamental laws, the writer some time ago made a careful study of the true principles underlying the proper proportioning of electrodes, based on indisputable physical laws. The results of this analysis showed that our former rules were not only entirely inadequate, but were in part quite incorrect and led to entirely wrong conclusions. And as the value of the annual loss of energy in such electrodes is very large, the matter of the correct proportioning is of considerable commercial importance as well as of interest to the engineer. This analytical investigation was then supplemented with an experimental one in which the necessary physical constants and the behavior of different electrode materials were determined.

The purpose of the present paper is to give a general review of these investigations from the standpoint of the engineer who is concerned with the proper design and operation of furnaces, and to discuss more particularly the practical bearing of the results of the experimental part, including the proper proportioning of the electrodes, the selection of the best material, the calculation of the losses, the indications of the faults in existing constructions and their remedies, etc.

Some parts of these investigations have been published or are being published elsewhere, to which those interested are referred. The present paper will include only a general summary of these and will discuss more particularly the experimentally determined data not included in the other papers.

Fundamental principles. The fundamental principle of the present analysis of the electrode problem, is that the heat gradient at the hot end should be zero; that is, the line representing it should be horizontal at that end. This means that no heat will then traverse through the hot end, either one way or the other; hence no heat from the furnace or its products is lost through the electrode, and the product can therefore not be "chilled" by the electrode as has often been found to be the case with improperly proportioned electrodes. Such an electrode is a perfect heat insulator, better even than the walls.

This zero gradient can be obtained only by having the temperature of the hot end of the electrode equal to that of the furnace. In the present method this is done by so proportioning the electrode that the current through it will raise the temperature of the hot end to this furnace temperature.

Although the writer's first recommendation of this fundamental principle was met with scepticism and even ridicule, it is now believed to be generally accepted as the correct one. One's first impression, that this would consume much energy, is found to be incorrect; the explanation is briefly, that as the heat near the hot end has no easy means of escape, (for as it cannot get into the furnace it must all flow out at the cold terminal) it will rapidly accumulate, so that a small amount of energy will soon produce a high temperature. Under simplifying assumptions, (and approximately under all conditions*) this state of temperature equilibrium, is found to be also the condition of minimum total loss of energy in the electrode.

Although this way of operating an electrode is quite the contrary to that dictated by prior practice, which was based on the lowest practicable resistance, it turns out to be the most economical, even though it may involve an intentional increase of the resistance loss; it is the total loss which should be considered, as the watts of heat lost either from the furnace or in the electrodes cost the same.

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*Metal. & Chem. Engineering, April, 1910, p. 188.

Another advantage is that the whole interior of the furnace then becomes useful, because a furnace in which there was a chilling action around the electrodes, by a mere change of proportions of the electrodes, based on this principle, can then have its capacity increased to that of its full interior size.

It furthermore means that all the heat escaping at the cold end is then the $I^2 R$ heat. Or inversely, if all the heat escaping at the cold end is the total $I^2 R$ heat, and neither more or less, then the temperature of the inner end will be that of the furnace, and there will be no loss of furnace heat and therefore no chilling.

It is evident that this condition can be reached regardless of how good or bad a heat conductor the electrode material is; even with such a very good heat conductor as copper. Hence, even without any further analysis, this shows the fallacy of the oft repeated and generally accepted statement that a good heat conducting electrode material necessarily chills the furnace, and is therefore objectionable. It will at once be seen that electrodes of good heat conducting materials must simply be made smaller in section than others.

Besides this fundamental principle there are a number of other features in which the writer's conclusions differ very radically from our former practice. The second one is in the determination of the total loss of energy in an electrode. According to the usual former practice, as shown in even very recent papers, the total loss was assumed to be the sum of that due to heat conduction alone and that generated in the electrode itself by the current. The writer found that this also was a fallacy and was not founded on a correct analysis. The true total is the sum of the conduction heat and only half the $I^2 R$ heat, under the simplest condition of constant conductivities and no loss of heat to the walls. This has since been confirmed by others also and is now, it seems, generally accepted. Under the more complicated conditions of varying conductivities, it is claimed by some to be only approximately true, but in any case it is much more nearly correct than the older method.

It is easily seen why it should be so. The heat conducted from the furnace when there is no current, flows over the whole length of the electrode, hence the drop of temperature is proportional to the total flow; but the $I^2 R$ heat is generated throughout the whole length, hence is equivalent to the whole of it entering at the middle and flowing over only half the length, or to half of it flowing over the whole length. Hence as far as the drop of temperature between the ends is concerned, only half of that corresponding to the $I^2 R$ heat must be added to that due to conduction alone.

A third point of difference, and one which is still adhered to tenaciously by some, concerns the current density. This was formerly the basis of electrode design and is still considered so by some writers. The present investigation, however, has shown this to be a fallacy also. It has shown that the current density does not enter as a fundamental factor which determines the proportions. Even more than that; to base the proportions on current densities may even mislead one into using entirely incorrect proportions with unnecessarily large electrodes and losses of energy, accompanied by a false assurance that it is the best that can be done. It may have been found that when certain current densities were exceeded, troubles arose, but in the writer's opinion the mistake made was in attributing them to the current densities instead of to the length; it can be shown that the same current density will cause the electrode to become too hot or too cold, depending upon the length of the electrode. And conversely, for a given length a fixed current density prescribed by rule of thumb may be either much too high or much too low. Current density cannot therefore be a determining factor; it is no more a factor in the proportioning of electrodes than it is in calculating transmission lines, and should be abandoned the same as it was in the latter case years ago.

Since the writer pointed this out, a crude attempt has been made to defend the older practice by claiming rather vaguely that in some way the current density should be modified with the length. This is " beating around the bush " and would be an unnecessarily awkward and roundabout method, even if definite rules which are directly applicable had been given by the defender of that method, which was not the case.

The writer's conclusions are that current densities need not be considered at all as a determining factor, not any more so, and perhaps even less so, than in the calculation of transmission lines. He has operated electrodes very successfully and with the greatest possible economy of power at heretofore unheard-of current densities; and he knows of cases in which far lower current densities were concluded (erroneously) by furnace engineers to have been too high.

The fourth point of difference in the present method is in the resistance. The writer has found that the usual rule, to make it as low as practicable, is a mistake. It can be shown that the resistance for the most economical operation is not at all a matter of choice. It is determined by the conditions of the problem and is fixed by the temperature, current and material; it is different for different materials; hence to try to make the resistances the same for different materials is improper designing.

This investigation, of course, applies to the electrode proper, or what might be termed the essential electrode, or the chief part of an electrode, namely the part which passes through the walls, and in which the coöperation of the two heat flows is the governing feature. Any additional parts within the furnace or projecting beyond the outside of the walls, are not theoretically essential parts even though they may be very necessary in practice; such parts are evidently determined by entirely different conditions and considerations and must be treated apart from that portion which is absolutely necessary to lead the current from the outside to the inside of the furnace. To attempt to combine the various parts of such a longer electrode and to treat them as one in an analysis for finding out the laws governing the proportions, would either be impossible or would at least lead to endless complications rather than to a simplification.

Hence throughout the present paper the proportions of the electrode and particularly the length, refer to this essential part passing through the wall; the prolongations at either or both ends, if any, (as for instance the part embraced by the metallic terminal, or the extra part allowed for feeding) must be determined separately, being governed by entirely different considerations. When the metallic terminal surrounding the outside end is close against the wall and relatively short as compared with the part within the walls, it would probably be sufficient for most practical purposes to consider the electrode proper as ending at the middle of this terminal. And unless the cooling water is very close to the electrode, and the heat resistance between the electrode and cooling water is very low, the temperature at the virtual end of the essential part of the electrode will be higher, and perhaps considerably higher, than the cooling water, hence the drop of temperature in the electrode proper will be less; it will be shown below that the hotter the outside terminal, the smaller the loss in the electrode.

This shows the fifth point of difference from our former views. Instead of trying to keep the outside terminals as cool as practicable, we ought to try so to design them as to let them get as hot as practicable, even to the extent of heating them with a blast lamp, when such heat is cheaper than electric heat. This will economize power, provided of course that the electric heat comes from the electrode proper and not from a poor terminal contact. The section of the electrode, however, becomes larger by raising the outside temperature.

A sixth point of difference from former practice which is brought out by this analysis is that instead of tending to make electrodes large, we should on the contrary try to make them small, as they can then be just as efficient; and there may even be other advantages also, besides economy of material, terminals, etc., in doing so.

Another complete departure from former methods is in the abandoning of the conductivities of the materials as factors in calculating electrodes and electrode losses. The writer found that the desirable qualities of electrodes do not depend on either the electric or the thermal conductivity alone, but on certain relations between the two. The analysis shows that our former deep-rooted conviction that a high heat conductivity is a bad feature for an electrode, is entirely wrong. The fact is, that it may be a good or a bad quality, depending upon the electrical conductivity. Neither alone is a criterion or a measure of excellence, and to consider them so misleads us.

In the writer's method of designing electrodes both qualities have been abandoned entirely as a basis of proportioning, and they have been replaced by two new qualities which are true and correct measures of excellence of those materials when they are used for electrode purposes; moreover they greatly simplify the calculations. Apparently the only objection to them is that they are not yet found in that form in tables of physical properties; they are however easily calculated from the conductivities, if the latter are known. That they are new and unfamiliar quantities will, it is believed, not be considered an objection by those who will take the time to understand their meaning.

These two new measures of electrode qualities are the " electrode voltage " and the " specific cross-section ", these specific names having been given them in order to distinguish them clearly from other quantities. They are both measures of physical properties, quite as much so as conductivities, specific heats, specific gravities, etc., and are constants for the particular materials; that is, they are independent of the dimensions. The former concerns the power loss and the latter the size. The lower their values are the better is the material for electrodes. They will be further discussed below.

ANALYTICAL

In an analytical investigation to determine the theoretical relations or laws in a complicated case involving many variable factors, especially in an entirely new field, the writer has followed, and is entirely in accord with, the teachings of such able authorities as Thomson (Lord Kelvin) and Taite, and doubtless of others also; namely, that it is best to solve such a problem first under the simplest possible conditions or premises, as a first approximation, and afterward to consider the refinements (if necessary) as a second or even third approximation. An attempt at the start to solve the complete problem with all its numerous less important refinements, as advocated by some of the writer's critics, would be more likely to obscure and lead us away from those simple and instructive approximate relations, which are often so valuable to the constructing engineer, than to lead us toward them and to point them out to us. A minor factor which might be absolutely negligible in practical calculations may give rise to very great complications in strictly correct algebraic expressions of a desired relation, thereby completely obscuring the more useful approximate one.

Hence in the present investigation, after a number of trials, it was found best first to eliminate all but the main or essential factors by limiting the premises to the simplest conditions. This made it possible to determine the fundamental relations or laws of electrodes, which prove to be very interesting and useful. By proceeding in this way, it was found that most, and perhaps all, of the more important corrections due to the minor factors, like the variations of the conductivities with temperature, could be combined into two experimentally determined coefficients or constants, and by the use of these in the original formulas, all the important, and perhaps even also the unimportant corrections can readily be included. A method was then devised by the writer for determining these constants experimentally, and was carried out by him; the results will be given below. This combination method is believed to be a simpler and more practical way of solving the complete problem with all its intricacies, than the purely analytical one, which even if it were completed, could not be used in practice until certain extended experimental determinations had been made, as no one has yet made them. As the present method of using the simplest possible formulas and embodying all the correction factors in two experimentally determined constants, seems to be not only simple, but even more accurate and reliable than the other more complicated method would be, it is believed that the necessity for the other solution and for the long series of experimental determinations, which it is based upon, no longer exists.

The premises of the present simplified analysis are: that the cross-section is uniform; that the two conductivities have the same values over the whole length; that the electrode is heat insulated except at its ends; also that the Thomson effect, the skin effect, and other similar minor factors are neglected. Under these premises the following relations are rigid and exact, and may therefore be called the laws of electrode losses.

Laws of electrode losses:

a. The combined loss through the cold end of an electrode is equivalent to the sum of the loss by heat conduction alone (when there is no current) and half the $I^2 R$ loss.

b. This combined loss will be least when the loss by heat conduction alone is made equal to half the $I^2 R$ loss; the total loss will then be equal to the $I^2 R$ loss, and no heat will be conducted from the interior of the furnace.

c. This minimum loss is dependent only on the material, current and temperature, but not on the absolute dimensions; it merely fixes the relation of the cross-section to the length, but leaves a choice of either; hence

d. For economy of electrode material the length should be made as short as practical considerations permit.

e. For each material there is a definite minimum loss of electrode voltage which depends only on the temperature and is independent of the dimensions or the normal current for which the furnace is designed; hence

f. The best possible electrode efficiency for any material may be determined from the total voltage of the furnace and this minimum voltage due to the material and the temperature, and is independent of the dimensions.

g. The temperatures indicated by the heat gradient of the combined flow are equal to the sums of those of the individual flows.

The proof of these laws is given in a paper by the writer on

" Laws of Electrode Losses in Electric Furnaces ",* and need not be repeated here.

The starting point is the fundamental principle, first announced by the writer a year ago as the proper one, namely, that no heat should leave or enter the furnace through the electrode or in other words, that the heat generated by the electrical resistance shall raise the temperature of the hot end to that of the furnace, it is shown that under the given conditions this is also the condition of least total loss.

Watts, a measure of flow of heat. Before giving the formulas the writer desires to explain that it is quite correct, and it simplifies such calculations greatly, to represent and measure a flow of heat in terms of the electric unit watts, instead of in calories per second. A watt is just as correct a measure of a flow or current of heat (calories per second), as an ampere is for measuring a flow of electric current in coulombs per second. Heat is energy, and a rate of flow of heat per second is power, hence it is measurable in units of power like watts. Since the writer called attention to this, others have endeavored to improve matters by calling this unit " watt seconds per second ", but this cumbersome name is entirely unnecessary and obscures rather than simplifies our conceptions. It is evident that watts × seconds ÷ seconds = watts. When the heat conductivity of a material is given as 10 watts for an inch cube, it simply means that with one degree cent. difference of temperature between two parallel sides, and perfect heat insulation on the other four, the same amount of energy will flow through as heat, say into water at the cold end, as would enter the water from a coil of resistance wire in which 10 watts were being set free.

In the following, therefore, all flows of heat will be represented in watts, and it is recommended that in future all thermal constants pertaining to electrodes be given in terms of watts instead of calories per second. The conversion factors are: gram calories per second $\times$ 4.18617 = watts, and watts$\times$0.238882 = gram calories per second.

Formulas. The following formulas are the same whether inches or centimetres are used, provided they are employed consistently throughout, including all those constants which are based on dimensions, and which of course will be different; those like the electrode voltage or watts per ampere are, of course, the same in both systems. All the formulas in this paper are in

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*Trans. Amer. Electrochem. Soc. Vol. 16, p. 265.

erms of actual units and may therefore be used directly in practice. They refer to one electrode.

Let S = cross-section in square inches;
L = length in inches (the essential length);
I = current in amperes;
W = watts generated electrically in the electrode;
H = heat flow in watts which would flow if there were no current;
h = heat flow in watts which enters the hot end from the furnace;
X = total heat flow in watts leaving the cold end;
T = temperature drop in centigrade degrees between the hot and cold ends;
r = electrical resistivity in ohm, inch cube units;
k = thermal conductivity in watt, inch cube units;
e = electrode voltage in volts;
E = total voltage between the two ends, or the watts per ampere;
s = specific cross-section in square inches;
S' = section in square inches per ampere per inch of length (or in sq. cm. per ampere per cm. length if the other quantities are in terms of centimetres).

In general, the flow of heat in watts at the cold end is

$$X = H + W \div 2 \tag{1}$$

and entering at the hot end

$$h = H - W \div 2 \tag{2}$$

in which

$$H = k\,T\,S \div L \tag{3}$$

and

$$W = r\,I^2\,L \div S \tag{4}$$

The total flow out of the cold end will be a minimum when

$$H = W \div 2$$

Representing this minimum flow by $m\,X$, then

$$m\,X = 2\,H = W = I\sqrt{2\,k\,r\,T} = I\,e\sqrt{T} \qquad (5)$$

this it will be seen does not contain either S or L, which means that this is the same for all dimensions; it includes the condition however that the ratio of the section to the length is

$$S \div L = I\sqrt{r \div 2\,k\,T} \qquad (6)$$

which means that either the length or the section may be made anything one desires, provided only that the ratio is equal to the above. As the length is usually fixed by other conditions this formula is best written

$$S = I\,L\sqrt{r \div 2\,k\,T} \qquad (7)$$

The electrode voltage is

$$e = \sqrt{2\,k\,r} \qquad (8)$$

and the total voltage is

$$E = \sqrt{2\,k\,r\,T} = e\sqrt{T} \qquad (9)$$

both of which are seen to be independent of the dimensions or the current, the electrode voltage being even independent of everything except the properties of the material, and hence itself a physical constant. This means that for every material there is a fixed and definite voltage for one degree which voltage is the same no matter what the size of the electrode or the normal current, provided only that it is correctly proportioned so that no heat flows through the hot end.

Conversely, the total voltage E being known, a convenient way is at hand of finding out whether the hot-end temperature of the electrode is that of the furnace or not, as this voltage might be measured without much difficulty during the operation of the furnace; if the measured voltage is found to be less, the electrode is chilling the furnace, if greater, the electrode is getting hotter within the wall than it is in the furnace.

The electrode voltage is that physical constant which is a true measure of the loss of power in an electrode. When multiplied by the square root of the temperature drop and by the current, as shown in (5), it gives the minimum loss in watts which can possibly be obtained with that material, for that current and temperature. Hence if its value is known, it is not necessary to know the two conductivities in order to calculate this loss of power.

The quantity E is measured directly in the experimental determinations described later; hence it is known for each temperature and material. Substituting its value (9) in equation (5) gives

$$m\,X = I\,E \tag{10}$$

That is, the minimum loss in watts may be determined directly by multiplying this value of E by the current; hence the voltage E may be called the " watts per ampere ".

This shows the simplified method suggested by the writer, for calculating these minimum losses. It consists in tabulating for each material the values of E for different temperatures, as obtained directly by experiment (by the method described below); then for any given case, in which of course the current and temperature are given, one needs merely to multiply the corresponding value of E by this current to get the result. This is so simple that it can often be done mentally. The values of the conductivities need therefore not be known.

Returning to formula (7), if I, L and T are made unity, that is, for 1 ampere, 1 in. length and 1 degree cent. of temperature, the resulting cross-section, now represented by s, becomes

$$s = \sqrt{r \div 2\,k} \tag{11}$$

This the writer proposes to call the " specific section ", because it is a physical property of the material, as its value, like that of the electrode voltage, depends only on the relations of other physical properties. It is a true measure of the size of an electrode, of course always under the condition that the electrode operates as was specified. This quantity therefore is the mate to the electrode voltage and determines the size just as the latter determines the loss.

Now let S' be another quantity so that

$$S' = s \div \sqrt{T} = \sqrt{r \div 2\,k\,T} \tag{12}$$

It will then be seen that in the same way and for the same purpose as was described above for E as compared with e, it is possible to determine by direct measurement (by the method described below) the values of this quantity S' for various temperatures and for each material. When these values are tabulated it again becomes an extremely simple matter to calculate the proper cross-section, because

$$S = I\,L\,S' \tag{13}$$

that is, one needs merely to multiply this value of S' from the tables by the current and the length to get the actual cross-section. This quantity S' is therefore here termed the " section per ampere per inch of length ". Hence this calculation is also reduced to a surprisingly simple one, provided these tabulated values are at hand. Such a set of values of both S' and E is given below in Table II.

When S' is not known, then

$$S = I\,L\,s \div \sqrt{T} \tag{14}$$

It will be seen that again the two conductivities drop out and need therefore not be known. In the absence of these tables the values of e and s should be used. If they too are unknown the mean conductivities must be resorted to. If in turn these electrode means are not known and the conductivities at the specified temperature are known, the mean values must first be determined from them. If these conductivities vary greatly with the temperature, a closer approximation could be obtained by taking into consideration the mutual effects of these variations on each other and on the mean, as described later in the discussion of the experimental results.

In this connection the writer desires again to call attention to the fact on which particular stress was laid in his first published description of his method, and which fact has been entirely ignored by the critics, that the curve of the combined losses is quite flat at its minimum point. This means that a considerable error can be made in the cross-section without affecting the power loss appreciably; for instance in a certain case an error of 10 to 20 per cent in the cross-section near the minimum point produced an error of only 1 to 3 per cent in the loss. Hence great accuracy in determining the values of these conductivities is not required for engineering purposes, even though to the physicist these slight variations produce great complications in the algebraic analysis. The degree of complication produced by a factor in a rigid mathematical analysis is no measure of its real importance.

Another reason why great accuracy in the values of these conductivities is not necessary for engineering purposes is that they both occur under the square root sign in the formulas used for electrodes (5) and (6); hence if one of them, as for instance the thermal conductivity which is the one least best known, is four times too great, the result will be only twice too great.

Various other relations exist between these old and new quantities which at times are of interest and use. They are easily deduced and are therefore merely summarized here.

$$e = I \div W\sqrt{T} \tag{15}$$

$$e = r \div s \tag{16}$$

$$s = e \div 2\,k \tag{17}$$

Mean values and equivalent electrodes. All the above is based on the premise that the temperature variations of the physical constants may be neglected; this so greatly simplifies the formulas and relations that the numerous useful and interesting results given above, are obtained. They would certainly not have been brought to light from the extremely complicated relations which result when the temperature variations are introduced algebraically. This is the reason why the writer prefers the method of studying a new problem by means of simplified assumptions first, leaving the corrections due to small variations to be introduced afterward as a second or third approximation, if indeed such accuracy is necessary in calculations of furnaces which unlike dynamos, transformers and other electrical apparatus, cannot possibly be built or operated under very exact specifications. Hence great accuracy in the present investigation is merely of academic rather than of engineering interest.

In the complete form of the method as described by the writer in the original paper on this subject and repeated here, the variations of the conductivities are taken care of very effectively and no doubt more effectively than by intricate calculations, by determining the constants under the very same conditions under which they are to be used. This point was also overlooked by the critics. It embodies the desired correction factors in the constants themselves, hence they need no further attention. Even if the values at specific temperatures are known, which is not the case for carbon and graphite, the writer doubts very much whether the final results calculated from them by means of the more involved and decidedly more complicated algebraic relations, would prove to be as close to the actual as they are when determined by the present extremely simple method.

In the present method the values of the conductivities and other deduced factors obtained as will be described, are the means peculiar to electrode conditions. What they really represent are the values of another or *equivalent electrode* the conductivities and other properties of which are the same as these mean values, and are constant from end to end, that is, they are independent of the different temperatures along the electrode.

Such an equivalent electrode will as a whole operate in exactly the same way, and hence, as far as the flows of heat at the two ends are concerned, it is theoretically identical. It differs however in the shape of that part of the temperature gradient which is intermediate between these two end points. Hence, whenever this intermediate heat gradient is concerned and only then, one must consider the nature of the temperature variations. This will be shown below in the discussion of the experimental results.

A brief summary of the discussion which has taken place concerning this and other features of the writer's method, will be given at the end of this paper.

EXPERIMENTAL

Most engineering calculations of structural work are based on the physical properties of materials often called " constants " even though their values vary somewhat; the proper designing of electrodes is no exception. When not done in this way it becomes a process of more or less skillful guessing which ought not to be called engineering. Until these constants are determined, calculations based on them of course cannot be made. At the time when the present investigation was begun some of the necessary physical properties were either not known at all, or known only very vaguely and indefinitely; this refers chiefly to the heat conductivities. No particular need for them had existed, but since it had become possible to calculate electrodes on a rational basis, the need of these constants was felt. The writer therefore undertook a determination of them for graphite, carbon, iron and copper. The tests were made in the well equipped Electrical Testing Laboratories in New York City.

The method used was the one suggested in his recent paper on " A New Method of Measuring Mean Thermal and Electrical Conductivities of Furnace Electrodes."* It is based on the same fundamental principles and formulas as those of this analysis. Briefly it consists in effect in operating a pair of electrodes under conditions approximating as nearly as possible those under which they should (according to this analysis) be operated in practice, namely that the electrodes shall not chill the furnace; or more scientifically speaking, that the heat gradient at the furnace end shall be zero, represented by a horizontal temperature line, in which case there will be no flow of heat into or out of the furnace through the hot end of the electrode.

While thus operating, the current, voltage and cold temperatures are carefully measured for various furnace temperatures. The heat flow is by this method measured electrically in terms of watts before it is heat, thereby avoiding the necessarily cumbersome and often inaccurate measurements of flows of heat in the form of heat. From the data obtained the mean thermal and electrical conductivities or resistivities and several even more important constants are calculated by the formulas given, which are practically the same as those in which they are afterwards used to calculate other electrodes. Further details are given in the above mentioned paper.

The method therefore amounts to measuring the constants of an electrode under actual operating conditions, and when these conditions are what they should be in practice. Hence it is very direct and does not involve any questionable process of determining the constants under one set of conditions and applying them to entirely different ones. The only important difference between the conditions of the test and those of the subsequent application of the constants, is in the dimensions of the electrodes. These constants are specific quantities; that is they are reduced to values per inch or centimetre units, hence they apply equally well to large or small electrodes, if minor effects, such as the differences in the ratio of the surface to the volume, are

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*Trans. Amer. Electrochem. Soc. Vol. 16, p. 317.

neglected. If further proof of this is necessary, it has been furnished by Dr. E. F. Northrup, who in an unpublished article has demonstrated that even under the complex conditions of the operation of electrodes, it is strictly correct to apply the constants obtained by this method to electrodes of different lengths or cross sections or both, provided that the temperature conditions at the ends are the same, and that the heat insulation is also relatively the same.*

The constants given by this test are the ***mean*** values for the electrode *as a whole* and when operating under the proper conditions. The conductivities thus obtained are not necessarily the arithmetic means of those at the ends or even the averages taken at equally spaced distances. They are means peculiar to operating electrodes, and their relations to the end values or to the mean of the values at equally spaced distances, are different for different materials. For this reason the writer has proposed the term " electrode mean " to designate them. They are the correct mean values to be used in the formulas determined by the present analysis, and as it would be difficult to calculate them accurately from values like those given in the usual tables, for different specified temperatures (if such values existed for electrode materials which they apparently do not), they are best determined experimentally by a direct method like the one described, if indeed it is not also an easier and more reliable method than those formerly used; it gives the proper mean values directly, while the other methods do not. While great accuracy in these constants is seldom if ever necessary in practice for calculating electrodes, it is desirable, to use them in an investigation like the present, in which comparisons and other deductions are to be made and in which the behavior of electrodes is to be studied.

The reasons why these mean values are peculiar to electrodes, will be best seen below.

This phase of the subject is discussed more in detail in an article published elsewhere.† It will be sufficient to say here that these means depend upon the distribution of the heat in the electrodes; that is, on the temperature curve. This is different for different materials and depends on the joint coöperation of both the electric and the thermal conductivities, because each affects the other. These means are in fact the values of an equivalent electrode which as a whole would operate exactly

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*Trans. Amer. Electrochem. Soc. Vol. 17, 1910, p 215 bottom.

†Metal. & Chem. Engineering, March, 1910, p. 128.

like the original one, as explained above. Hence in the present method these differences in the temperature curves are eliminated as far as the action of the electrode as a whole is concerned; they need be considered only in connection with the relations between the electrode and the surrounding furnace wall.

The details of the determination of these constants are described in a paper to be read before the American Electrochemical Society at its Spring meeting*. The purpose here is to compare and discuss the results, and to endeavor to point out what they teach us. It will be sufficient to say here that the tests were made with care; the results, as far as they go, are believed to be reliable and even more accurate than is required for most practical purposes. Sets of measurements were made for each of several temperatures for each material, and the final result of each run is an average of a number of very closely agreeing sets of readings. The furnace temperatures were kept constant for periods of about 10 to 30 min. to within about 1 per cent and generally considerably less, it being an important feature of this test to reach the stable state of temperature.

The iron and copper electrodes were run to as near their melting points as practicable. The iron had unfortunately been injured slightly by an accidental excessive temperature prior to the last test, near its melting point, hence the values at the highest temperature are not as closely accurate and reliable as the others, but they are probably not far wrong. The same was the case with the highest temperature values for graphite. Allowances for these have been made in the curves. Less care was taken with the lower temperature values as they were of less importance.

Above about 900 degrees cent. the graphite and carbon electrodes began to be affected presumably by the gases in the granular insulating material, (magnesite), probably by the CO from the incompletely calcined carbonate. The results beyond that point were therefore thrown out, and those near it may not be quite correct.

The full lines in the accompanying curve sheets represent the ranges over which the results were actually measured; the dotted lines are exterpolated and therefore are only probable values. These exterpolated values were added here with some hesitancy as the writer is well aware of the possible danger in relying on the extensions of formulas and curves beyond the actual measured ranges. In the present case however the several curves for each

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*Trans. Am. Electrochem. Soc., Vol. 17, 1910, p. 151.

material are linked by fixed relations, hence it is not like simply prolonging individual curves; an incorrect extension of one curve will be likely to show on the others, and perhaps in an exaggerated form. For this reason the extension of each one aids in determining the extensions of some of the others. They are therefore probably more nearly correct than mere unguided and independent extensions would be; in fact it seems likely that these fixed relations are far better guides for these extensions than the curvatures of the known parts of individual curves.

In all these curves the exterpolated values were checked at 2000 degrees cent. and 1400 degrees cent. by these relations, and whatever differences were found were distributed over the curves where they corresponded best with the curvatures of the known parts. A second approximation was thus obtained and this was again adjusted, and so on until a final agreement was reached. This care was taken because at present there exist no reliable data concerning these mean values for those temperatures, and it was thought that the exterpolated values were at least better than none at all, as they were not likely to be far wrong. They are offered here merely for what they are worth and nothing more. The tests for determining these constants become tedious for the higher temperatures on account of the oxidation or other forms of deterioration of the carbon and graphite, and the melting of the metals. It may therefore be some time before the tests are repeated for those temperatures. Until then these exterpolated values may perhaps be of some service. Attention may here again be called to the fact pointed out above, that the curve of minimum loss is rather flat at the minimum point, hence quite a large error in the correct proportions will give rise to only a small one in the energy loss; close accuracy in the constants is therefore not necessary.

There may, of course, be radical changes in these physical constants at the melting points of the metals, and at some points at which carbon may change its condition. These cannot be predicted. The present extensions are all based on a regular continuation of the measured relations.

Although all the electrodes were very nearly $\frac{5}{8}$ in. in diameter they differed slightly, hence for comparing them more correctly with each other, the results have here all been reduced to a diameter exactly of $\frac{5}{8}$ in. For the same reason they have also all been reduced to a constant cold terminal temperature of

100 degrees cent. by adding or subtracting the required amount to both temperatures. The error involved in doing this is no doubt absolutely negligible for the present purposes. The data were obtained from electrodes 8 in. long measured between the furnace end and the furnace side of the water-cooled terminal.

When the method described in this paper is used for calculating electrodes, the important physical constants in these determinations are the electrode voltage and the specific section described above, and others related to them (E and S'). The two conductivities are then eliminated as separate quantities and need not be considered. They have nevertheless been included in the following curve sheets as matters of interest and of use in studying the subject. The original measured data, namely the current and volts have also been added, after reducing the former as described; they lead to interesting and valuable deductions.

As the current densities in some of these runs were extraordinarily high, it may be of interest to add here that the electrodes behaved very well, so well in fact that the writer would not hesitate to use such extreme current densities in regular practice under the proper conditions. The results prove his contention, which has been disputed by others, that the current density is absolutely no factor in the determination of the proportions of electrodes. As the curves for the values of the current densities would be exactly like those for the current, they have not been repeated on the curve-sheets.

Experimental data. The experimental results and the deductions calculated from the data are given in the accompanying Table I which explains itself; the exterpolated data are given in italics so as to distinguish them from the others.

In order to compare and study these data more readily, they have been plotted in Figs 1 to 11. In Figs. 1 to 4 the properties are compared for each of the materials, while in Figs. 5 to 9 the materials are compared under each of the properties. In Figs. 10 and 11 the two most important of these properties are compared; they were omitted from the other sheets for the sake of clearness.

In all the curves the scales give their actual values and not merely relative ones; hence as these scales are very different for the different materials, it is not proper to compare with each other the curves of the same property for the different materials without making due allowance for the different scales; they may be compared directly only as far as percentage differences ar

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'd directly only as far as percentage differences ar concerned. In the second group, Figs. 5 to 9 all the results of one kind are reduced to the same scales, and may therefore be correctly compared quantitatively.

All these data refer to electrodes when operating under the condition that the hot end is raised by the current to the exact furnace temperature, and when the electrode, therefore, does not abstract any heat from the furnace. The values of all the specific properties (resistivities, conductivities, electrode voltages and specific sections) are the means under electrode conditions for the electrode as a whole; that is, they are the values of an equivalent electrode which as a whole will operate like the original one, but in which these properties have the same values throughout its entire length. The values for the currents, watts and current densities apply of course only to the particular size of the electrode tested and will be different for electrodes of other dimensions. The voltages, however, apply also to any other sizes of electrodes and to any other currents, provided only that the electrode is properly proportioned and is operated under the normal specified conditions and with the normal current.

Besides the actual numerical values of the various quantities, the point of special interest in this set of curves is whether the specific properties (that is, the properties per unit conditions) are sufficiently near to constant to be assumed so in ordinary practice, and also whether they rise with the temperature or fall, as this makes a difference in their behavior.

Carbon. Fig. 1. The current curve rises rapidly and nearly in proportion to the temperature. This means that changes in the current will produce nearly proportionate changes in the hot-end temperatures, hence variations in current affect the losses considerably, and a current which is considerably greater than the normal for which the electrode was designed, will tend greatly to overheat the electrode within the walls.

The watts increase nearly according to a diagonal line, as with all the other materials tested, except that for carbon there is a more pronounced deviation at low temperatures, which is also seen in some of the other curves, indicating that the properties of carbon follow somewhat different laws at the lower than at the higher temperature ; or perhaps, that at the higher temperatures, they follow laws similar to those which other materials follow at the lower ones.

The electrical resistivity diminishes, at first more rapidly, then less so, tending to become more nearly constant. A decreasing resistivity means that as the current heats the electrode, the heat generated per inch will become less and less at the hot end and relatively greater at the cold end, than it was

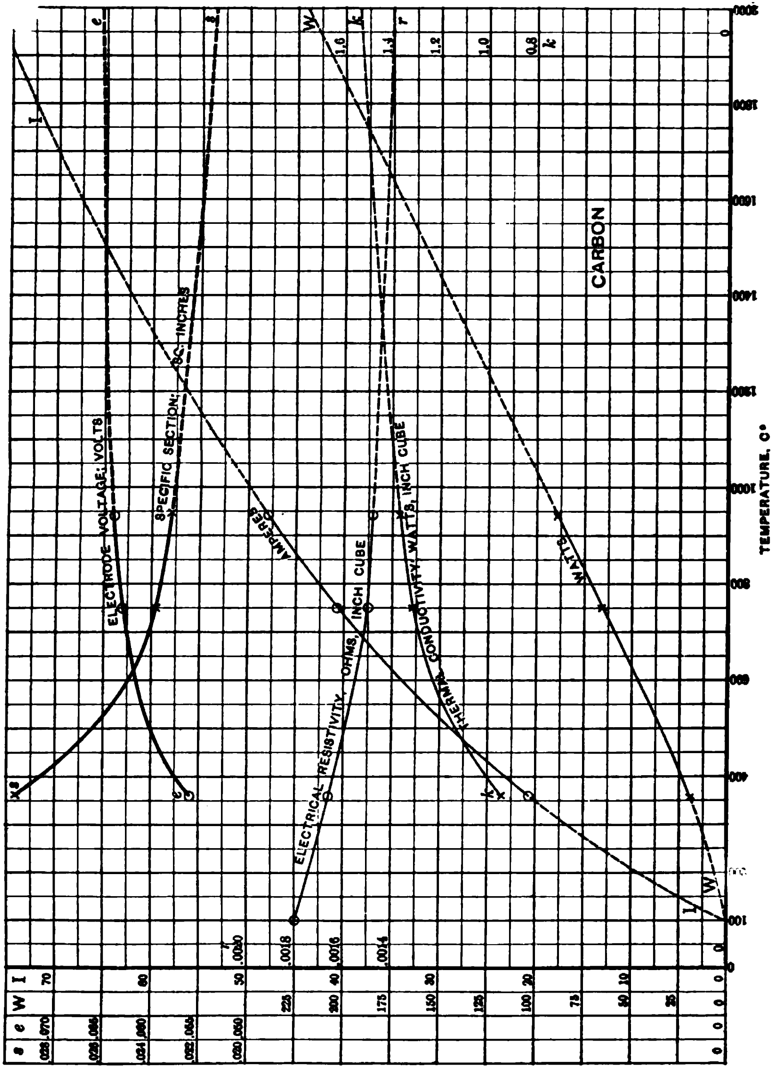

FIG. 1.—Electrode properties of carbon

before; hence the colder half will be heated more rapidly. This in turn signifies that the heat gradient will tend to approach a horizontal line from the hot end to near the cold one, and will then drop suddenly. Or in popular terms, the furnace heat will follow the electrode deeper into the walls. This seems to be one of the causes of the burning of the furnace wall in high-

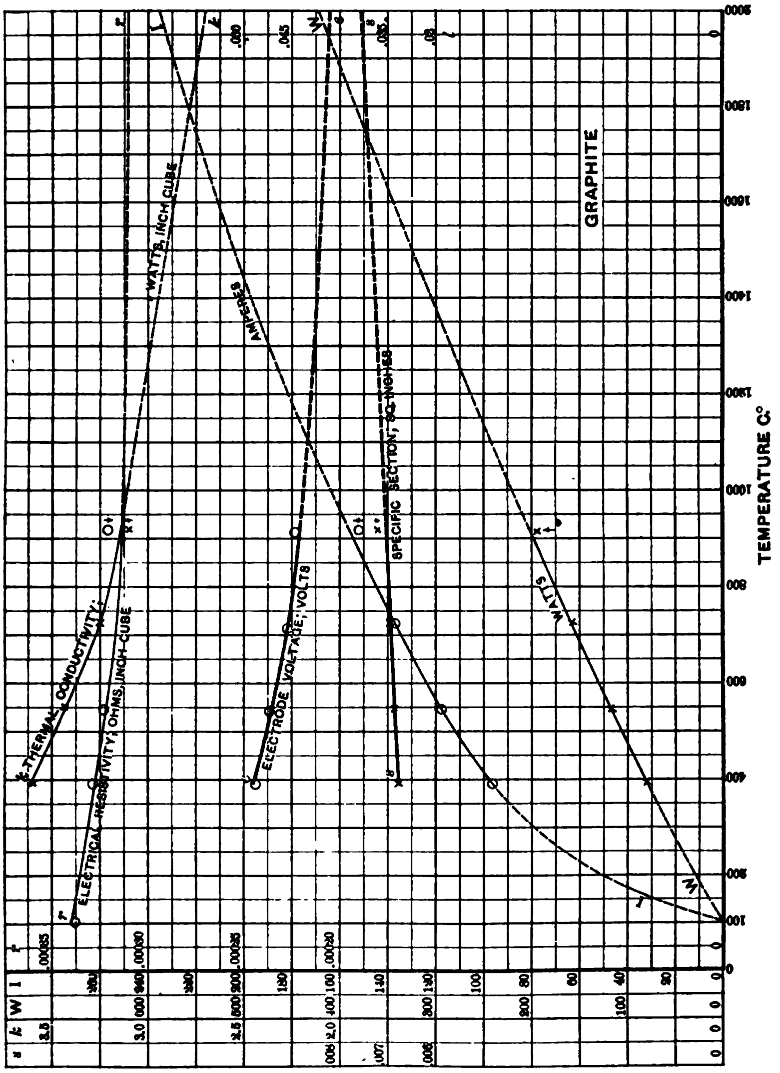

Fig. 2.—Electrode properties of graphite

temperature furnaces in which carbon electrodes are used. A falling resistivity is therefore an undesirable quality for electrodes.

A rapidly rising one would be far better; this is the case with iron.

The thermal conductivity increases (it does not decrease as has been claimed by others) at first more rapidly, then less so, also tending to become more nearly constant. The surprisingly high values for the mean thermal conductivities are no doubt explained by the fact that the electrical resistivity falls quite appreciably with an increase of temperature. This in an electrode means that the larger half of the heat generated in the electrodes will be produced in the colder half, hence nearer the outlet, as explained above; it therefore has a shorter distance to travel in order to get out. The mean effective thermal conductivity calculated from the heat which flows out and from the dimensions of the electrode. will therefore be increased, and will even be larger than an average of that taken at equally spaced points. But the value obtained in these tests is the real one which is wanted, as it is the one which applies to the electrode as a whole; it is the value which an electrode of uniform conductivities would have, which, as a whole, would operate like this one. This unequal distribution of heat in electrodes will be discussed by the writer more in detail in an article to be published elsewhere.* The difficulty in calculating the mean from individual values lies in not knowing the heat distribution, that is, the temperature curve; also in the fact that these individual values for different temperatures have not yet been determined. The writer for these reasons recommended the present method as the more direct one by which to get the final results in the form in which they are wanted.

A rising thermal conductivity is an undesirable feature for electrode materials, as it tends to force the higher temperatures nearer to the colder end. Carbon unfortunately combines this feature with a falling resistivity, both of which conduce to the same undesirable result.

The curves for carbon furthermore show that the electrode voltage, which is a true measure of the power loss, also increases with the temperature, but the rate is slower and slower, tending to constancy. It will be shown later that there are reasons to believe that it may even reverse again and fall at still higher temperatures. The loss in carbon electrodes therefore increases not only with the temperature, but also per degree of temperature; at least for these ranges. The chief conclusion, as far as our present knowledge goes, is that probably no great error would

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*Metal. & Chem. Engineering, March 1910, p. 128.

be made by assuming this important quality to be practically a constant, namely about 0.065 volt.

The specific section, which is a true measure of the size of an electrode, decreases rapidly at first and then more slowly, showing that carbon electrodes become relatively smaller for the higher temperatures; they are even smaller per degree at the higher temperatures. This is a good feature, and especially so for carbon because such electrodes are much larger than those of other materials, as will be seen later.

The electrode voltage and the specific section, are properties of the material, just as the specific resistance is, and if their values are constant or virtually so, calculations are simplified. The curves show that for most purposes in practice they may be assumed to be virtually constant for the higher values of this range of temperature.

The curves of the total voltages and of the actual size of the electrodes, being the ones which are the most important in practice, have for clearness been drawn apart from the others and will be discussed below in connection with Figs. 10 and 11.

The comparison of the quantitative values of the properties of carbon with those of other materials, is best made later in connection with Figs. 5 to 9.

Graphite. Fig. 2. The current curve rises more rapidly at first than for carbon, and in this respect graphite apparently possesses properties more like those of the metals. After this rise at the lower temperatures, it seems to approach more nearly to a straight line. The inclination of the latter part is less than for carbon, which indicates that for the same proportionate change in current the change of temperature produced thereby will be greater for graphite. From this it would appear to follow that a graphite electrode is more sensitive to changes of current than is one of carbon.

The curve of watts is practically a diagonal line, which shows that the watts lost in a given electrode will increase very nearly in proportion with the temperature drop, due to the current.

The mean electrical resistivity decreases slightly at first, and then seems to tend to constancy, at about 0.00031 in inch units (0.00081 in cm. units). It varies considerably less than for carbon, therefore the heat generated in the electrode will show a tendency to be more evenly distributed along the length, although the greater half of the $I^2 R$ heat is as in carbon, generated in the colder half of the electrode. Hence graphite stands between carbon and the metals.

A comparison of these mean values with those obtained by others when the whole rod is at the same temperature is of interest. It shows that these mean values are higher than the arithmetical means between the two extremes. This appears to be due to the fact that owing to a more rapidly decreasing thermal conductivity, the heat is forced back toward the hot end by the changes in thermal conductivity, more than it is forced to the cold end by the changes in the electrical conductivity. The result is that the average between the extreme temperatures would be greater than the actual; hence the mean resistivity found in these tests should be greater, which is the fact, if these data are correct. This places graphite among the metals in this desirable quality of forcing the heat back to the hot end.

The curve for the thermal conductivity shows that it falls as has already been stated. In this feature graphite differs decidedly from carbon (for which this curve rises) and is like the metals. The thermal conductivity falls more rapidly at first and then displays a tendency to become more nearly constant. Its rather high value is due partly to the falling electrical resistivity, as was explained above for carbon. It will be seen below that this brings its mean value even above that of iron, which has a rapidly rising resistivity.

The electrode voltage falls slightly, but seems to tend to what for all practical purposes may be assumed to be constant at about 0.040 to 0.045 volts. As this is a measure of the loss, it follows that the loss per degree diminishes slightly with the temperature instead of increasing, as it does with carbon. Graphite, therefore, is relatively to the temperature, more economical of power at higher temperatures than it is at the lower ones. This is due to the somewhat rapidly falling thermal conductivity.

The specific section is practically a horizontal line, and consequently may be assumed to be constant at about 0.0070 in square inches. This means that the size of the electrode relatively to the temperature is practically the same at high and at low temperatures; it does not decrease per degree, as with carbon, but even at the higher temperatures it is still much smaller. These comparisons are best seen below in other sets of curves.

Iron. Fig. 3. The current curve shows a marked peculiarity in that it is practically a horizontal line, differing radically in this respect from carbon and graphite. This is due no doubt to the very rapidly rising resistivity. As the hot end becomes hotter the resistance rises so rapidly that it cuts down the current again. Such an electrode is therefore nearly self-regulating for a constant current. A slight increase of current causes a very great rise in temperature. This fact was not fully realized during the progress of the test, in which the current was at one time raised too high, which apparently melted or perhaps even volatilized the hot end; this occurred before the run at the highest reading, hence the values obtained for the last point are not as good as the others, and were given less weight. After the test bar had been removed it was found that it had been melted at the hottest point and had even partly disappeared. This must have happened before the last run was taken, as that was still below the melting temperature. Anyone who repeats this test should be very careful to increase the current but very little at a time, and should not try to hasten the time of reaching the steady state by a temporary excessive current.

This peculiar property of iron, to change greatly in temperature with slight increases of current, also interfered with the intention to avoid the region of the recalescent point, about 700 degrees cent., as it was to be expected that the electrical and thermal conductivities might also take part in the peculiar physical pranks which iron plays at that temperature. It is doubtless due to this recalescent point that the curves are not as regular as are those of the other materials. They have a noticeable hump at about 700 degrees cent. But notwithstanding these disturbing factors, the general trend of the curves enables instructive results to be deduced.

In the exterpolated (dotted) parts of these curves, it has been assumed that the laws of variations continue to be about the same. It is not unlikely, however, that with materials which melt, like metals, as distinguished from carbon and graphite, there may be decided changes of these physical properties at the melting point. This can be determined only by experiment, and tests with molten columns the cross-section of which must remain constant, become difficult. Moreover, unless they were made on a large scale they would be seriously interfered with by the so-called " pinch effect ", which would break the column unless it was very securely confined. Under the circumstances the exterpolated values may be of at least temporary use until someone has made the actual tests. But it should be remembered that they are nothing more than exterpolations.

The curve of watts is as usual virtually a diagonal

The electrical resistivity rises greatly, and roughly in a straight line with only an indication that the rate probably falls at higher

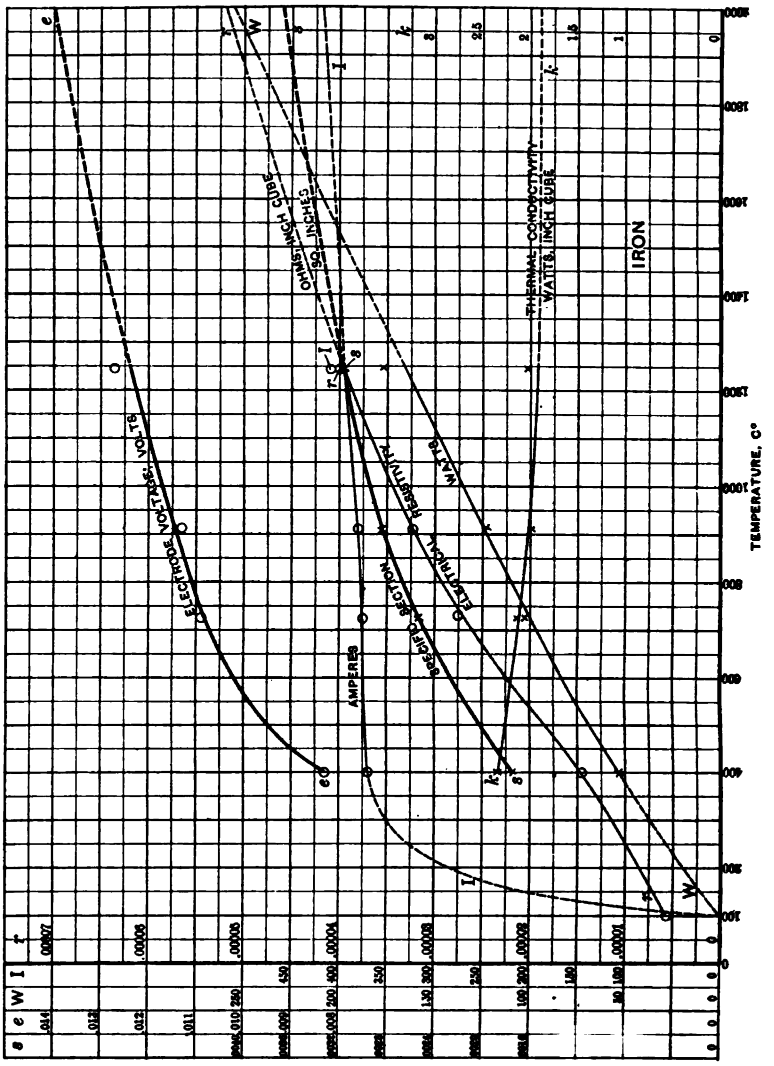

Fig. 3.—Electrode properties of iron

temperatures. This rapidly increasing resistivity is a very desirable feature for electrodes, as it forces the heat back to the hot end, as was explained above.

The thermal conductivity falls, which is also a desirable feature. It is of interest to note that for iron both conductivities vary in the desirable way, while for graphite only one does (the other however being nearly constant), and for carbon, they both vary in the undesirable way. Although the thermal conductivity of iron falls, the amount is but slight and it may be assumed

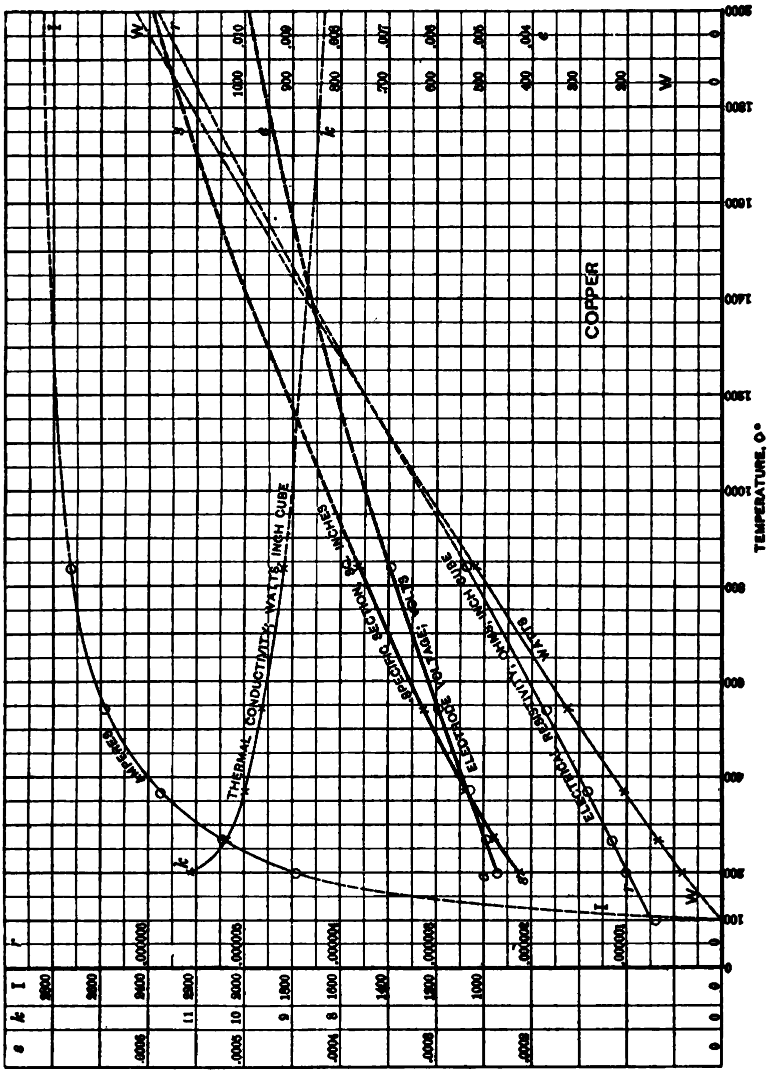

Fig. 4.—Electrode properties of copper

to be practically constant at about 1.9 to 2.0 in watts, inch cube units.

It will be noticed that the mean thermal conductivity is less than that of graphite. This may not agree with comparisons of the usual constants at specified temperatures; the explanation of the difference unquestionably lies in the fact that the heat is forced to the hot end more in iron than in graphite, as has been explained. The greater part of the heat having to travel a greater distance to get out, an iron electrode is rendered equivalent to one having a lower conductivity than the iron has at those temperatures.

Owing to this combined falling conductivity and rising resistivity, it seems that the temperature curve for iron must fall quite rapidly at the hot end and then approach the horizontal for the greater part of the length. This confines the high temperatures to the end near the furnace where they belong. It moreover has a tendency to make the temperature gradient in the electrode more like that in the walls, which signifies that little or no heat passes from one to the other. But one of the most important results is that when there is an excessive current, which tends to heat the electrode within the walls to a higher temperature than that of the furnace, this high temperature point will be very near the furnace, far nearer than it would be for carbon, for instance.

The electrode voltage rises quite decidedly. This means that iron electrodes are relatively less economical in power at the higher than at the lower temperatures; there are no indications of a constancy of the value of this property within these ranges.

The specific section also rises at about the same rate, showing that the size also becomes less favorable at the higher temperatures.

The test bars were cold rolled, mild steel.

Copper. Fig. 4. The tests with the copper electrodes were the best of the series. This was due partly to the fact that the currents, being very large, were better adapted to the output of the dynamo; partly to the fact that copper had a thermal conductivity so very much better than that of the surrounding heat insulating material, that the proportion of the loss to the surroundings was least; and lastly, because it was the last test of the set and the writer was enabled to embody the experience gained in testing the other materials.

The current curve rises extremely rapidly at first and then apparently tends rapidly toward the horizontal; it seems to be similar in shape to the one for iron at lower temperatures. It therefore appears that this shape may perhaps be characteristic of the metals. The last point was very near the melting point. hence the exterpolated values are based on the possibly incorrect assumption that no radical changes take place in these properties at the melting point.

The curve of watts is again practically a diagonal.

The electrical resistivity rises very rapidly and in virtually a straight line; copper resembles iron in this property, and the resistivity rises even slightly more rapidly in percentage. What was said about iron in this respect applies therefore also to copper. The heat will again be forced to the hot end.

The thermal conductivity also falls, as in the case of iron, only to a greater degree. This and the rising resistivity should make copper a very suitable electrode material for the temperatures for which it could be used.

The electrode voltage rises in almost a straight line proportion. So does the specific section. It is therefore like iron in these respects.

Comparisons. In all the above curve sheets the scales were chosen as large as the space permitted, hence they are all different. In order to compare the different materials with each other quantitatively all the curves for each property have been redrawn to uniform scales in Figs. 5–9.

Current. Fig. 5. These curves explain themselves. They show that at about 1500 degrees cent. a graphite electrode will carry over 3 times as much current as will one of carbon of the same size; iron will carry over twice as much as graphite or nearly seven times as much as carbon; and copper is enormously better than any of the others, its current capacity being about 45 times that of carbon or 14 times that of graphite. With what losses these electrodes carry these currents will appear later.

The curves also show a tendency to become horizontal. The actual numerical values refer to ⅝-in. round electrodes and to no others, although relatively the currents would always have the same ratios.

Current densities. The cross-sections in all the test rods being the same, these curves also represent the relative values of the current densities. The actual values are given in Table I. Some of them will be seen to be exceedingly high.

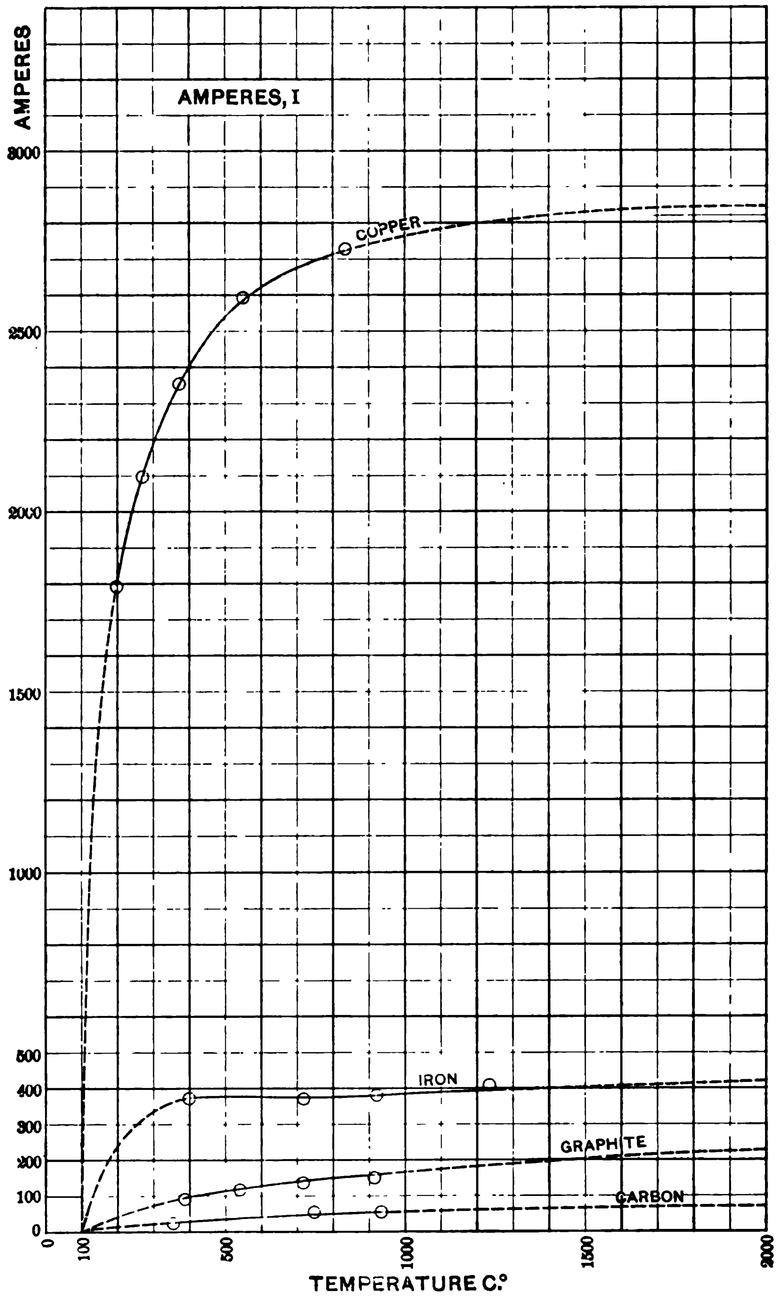

Fig. 5.—Current for different materials

Watts. Fig. 6. The curves for all four materials are seen to be nearly diagonal lines, indicating that the watts increase nearly in proportion to the temperature required. In order to show how little they differ from the true diagonals, the latter have been added as thin lines to the last points. The difference is greatest with carbon. It can be shown that in so far as the real curve differs from the exact diagonal, in so far does the thermal conductivity vary from a horizontal line, that is, from constancy; if these curves approach the diagonal more nearly for the higher temperatures, as they seem to, it means that the thermal conductivities approach constancy for those higher temperatures.

Moreover if the bend is above the diagonal as it is for copper, graphite and iron, it signifies that the thermal conductivity falls, while if below, as for carbon, it rises. Furthermore, it can be shown that the thermal conductivity is proportional to the tangent of the angle which the diagonal to any point makes with the horizontal.

Further than this, the curves should not be compared, as they might mislead. Quantitatively they refer only to those particular electrodes ⅜ in. in diameter, and to no other size. While the watts lost for copper are very much greater than for carbon, the current delivered was also far greater, and the relative loss was far less than for carbon. This is shown better in the later curves.

Electrical resistivity. Fig. 7. These curves show strikingly the quantitative relations, it being nearly impossible to show copper and carbon on the same sheet. A low electrical resistivity is a desirable quality in electrodes, both in economy of power and in the economy of materials. It shows why copper is so very much better than carbon, when it is possible to use it. Iron is near copper, and graphite is much nearer the metals than carbon. A rising resistivity is a good feature while a falling one is a bad one.

An interesting point is that the line for carbon falls rapidly, that for graphite also falls but very slightly, while those for the metals rise. Their relative inclinations make it appear as if they tended to meet at some very high temperature in a common point somewhat below graphite, at which point they would all have the same resistivity. At 1400 degrees cent., the relative values are about: copper 1, iron 10, graphite 72, carbon, 340.

Thermal conductivity. Fig. 8. The thermal conductivities differ far less than the electrical resistivities; moreover the usual order is here reversed, graphite being now next to copper. They again all seem to tend to meet in a point, this time iron being the more central one. The relative values at 1400 degrees cent. are about: copper 1, graphite 0.34, iron 0.22, carbon 0.17. It may be repeated here that a falling thermal conductivity is a good feature and a rising one is a bad one; also that a high thermal conductivity reduces the size of an electrode but increases the loss; hence it is a good or a bad quality depending upon which of the two economies one desires. There are other properties which are better measures of excellence of an electrode material; they will be discussed below.

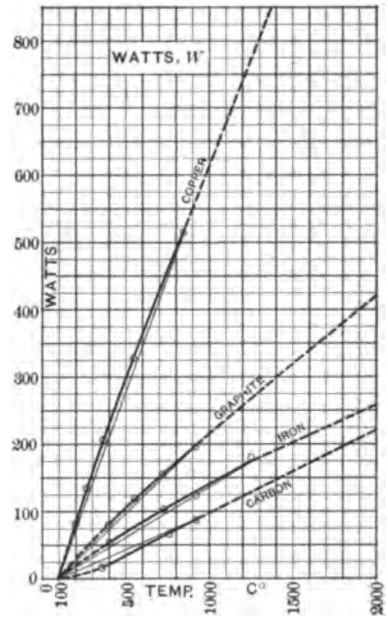

Fig. 6.—Watts for different materials

Electrode voltage. Fig. 9. This is the specific property which is a true measure of the minimum watts lost in an electrode, when it is properly proportioned. Its significance has been described above.

The curves are shown in thin lines. They all show a tendency to rise except for graphite which alone possesses the good property of a falling curve. As all these specific quantities seem to tend to meet at some very high temperature, it may be that carbon which is the only exception, will also fall again at higher temperatures, as indicated.

Iron is now nearly as good as copper and much better than graphite, although the difference seems to grow less at higher temperatures. The lines for graphite and carbon depart at first, but then remain nearly parallel. The relative values at about 1400 degrees, are about: copper 1, iron 1.5, graphite 5, carbon 7.5.

Specific section. Fig. 9. This is the specific property which is a true measure of the size of an electrode, when properly proportioned. Its significance has been described above. The curves are shown in heavy lines. They all tend to rise except for carbon; and again they seem to tend to meet. Copper as usual makes the best showing, and graphite is nearer the metals in this respect than it was for the electrode voltage. Carbon is far from the others, showing that such electrodes must be made very much larger. For about 1400 degrees cent. the relative values are about: copper 1, iron 6.6, graphite 14.6, carbon 45.

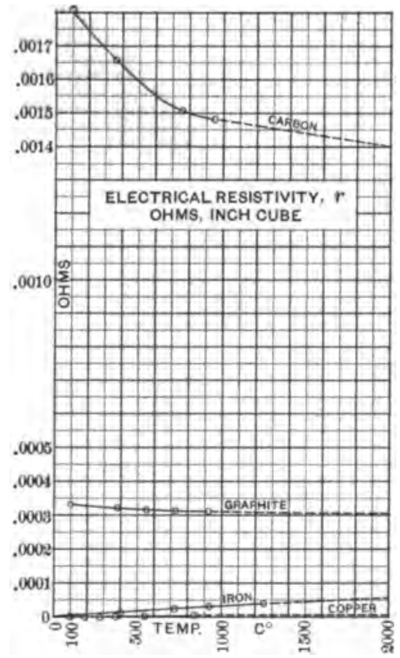

FIG. 7.—Mean electrical resistivities for different materials

These two qualities have been drawn on the same sheet to facilitate comparisons. Carbon electrodes are seen to be both large and wasteful of power, those of graphite are much smaller and while they consume less power, the difference is not as great as that in the sizes. Copper is best in both respects, and iron comes next in both qualities, being also better in both than graphite, particularly in the economy of power.

Actual losses and sizes. Figs. 10 and 11. The electrode voltage and the specific section are the two physical constants which the writer suggests using instead of those formerly employed. Like most other physical constants they vary somewhat with the temperature, though some of them only very slightly; but they nevertheless belong correctly under the heading of physical constants, which can for many calculations be assumed to be constant, or have the differences allowed for, just as is done with resistivities in ordinary electrical conductors.

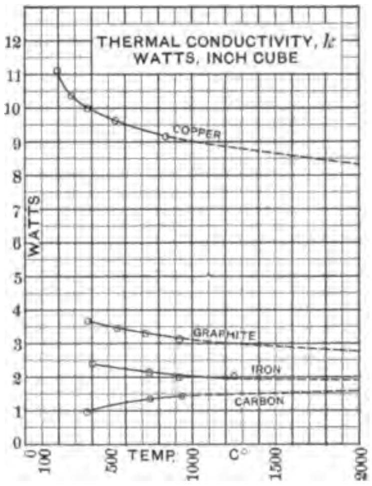

FIG. 8.—Mean thermal conductivities for different materials

But as was explained above, the usually required calculations may be considerably simplified and reduced to a mere simple multiplication, by using instead a tabulated set of numbers. These are no longer " constants " in the usual sense of the term, because from their very nature they must have greatly different values for different temperature ranges, although for some materials and ranges the curves representing them are very nearly straight lines.

If, therefore, the designer has such a table of values at hand, he will no doubt prefer those values to using the physical constants. These two sets of figures give the watts per ampere, and the square inches of section per ampere per inch of length, for each temperature. Hence to find the minimum loss in watts for any given material and temperature (the cold terminal temperature being 100 degrees cent.) one merely multiplies the corresponding number of " watts per ampere " from the table, by the current in amperes, while to find the proper section in square inches it is necessary only to multiply the corresponding " section per ampere per inch length " by the current and the length in inches. The calculations are so simple that they may in many cases be made mentally. These values are given in Table II and are shown graphically in Figs. 10 and 11.

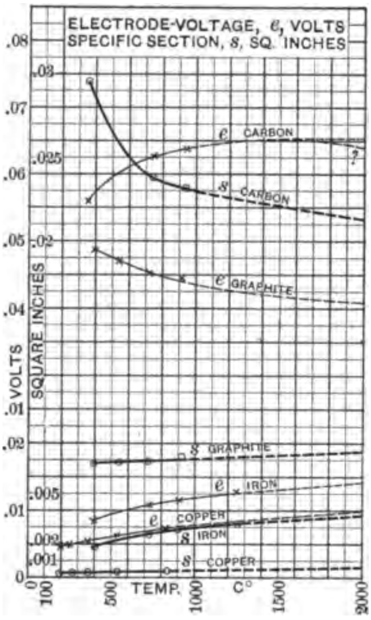

FIG. 9.—Electrode voltages and specific sections

As shown above, the watts per ampere are in fact merely the voltages (in volts) between the two ends of an electrode when operating under the condition in which there is no loss of furnace heat. Hence these are not deduced figures, but are actually measured during the test, (being half the measured voltages of the two electrodes), while the figures for the sections per ampere

TABLE II
CONSTANTS FOR CALCULATING ELECTRODES

Temperature		*E* Watts per ampere				S^1 Square inches per ampere per inch length				S^1 Square centimetres per ampere per cm. length			
Cent. degrees	Fahr. degrees	Carbon	Graphite	Iron	Copper	Carbon	Graphite	Iron	Copper	Carbon	Graphite	Iron	Copper
400	752	1.00	0.85	0.145	0.095	0.00165	0.00040	0.000103	0.000016	0.0042	0.00100	0.00026	0.000041
600	1112	1.38	1.04	0.225	0.140	0.00114	0.00031	0.000102	0.000015	0.0029	0.00078	0.00026	0.000037
800	1472	1.68	1.19	0.295	0.184	0.00090	0.00027	0.000101	0.000014	0.0023	0.00068	0.00026	0.000036
1000	1832	1.93	1.32	0.350	0.226	0.00076	0.00024	0.000098	0.000014	0.0020	0.00061	0.00025	0.000036
1200	2192	2.15	1.43	0.410	0.270	0.00069	0.00022	0.000094	0.000014	0.0018	0.00056	.00024	0.000035
1400	2552	2.36	1.52	0.460	0.310	0.00062	0.00020	0.000092	0.000014	0.0016	0.00051	0.00023	0.000035
1600	2912	2.53	1.62	0.510	0.351	0.00057	0.00019	0.000089	0.000014	0.0014	0.00048	0.00023	0.000035
1800	3272	2.68	1.71	0.565	0.391	0.00053	0.00018	0.000087	0.000014	0.0013	0.00046	0.00022	0.000035
2000	3632	2.83	1.79	0.610	0.430	0.00049	0.00017	0.000085	0.000014	0.0012	0.00044	0.00021	0.000035

per inch length are merely the cross sections of the test rods divided by the length of the electrode (half the length of the double ones used in the test) and by the current.

It will be seen therefore that it is not at all necessary to determine or even to consider either the electrical or the thermal conductivity in electrode problems, if these simple data are at hand. And the writer's conclusions therefore are, that as little or no reliable data of any kind exists for the higher temperatures, and must therefore be ascertained, it is much simpler to determine and use these two new factors, instead of determining and using the mean conductivities. It is also infinitely simpler than the former method of determining the conductivities at each of various temperatures and then by means of more or less complicated and approximate formulas calculating the final results, with the uncertainty involved in all approximate algebraic deductions in which we do not always know how much the originally small, allowed errors may be magnified during the algebraic processes.

The writer's present method goes directly from the experimental result to the desired application in practice, without involving any assumptions other than that the *relative* distribution of the heat in the electrode for any given material and end temperatures, is the same for all cross-sections and lengths, (which is believed to be exactly correct under the assumption of no heat loss to the walls), and that the relative heat loss to the walls, whatever it may be, is approximately independent of the lengths and sections, (which is known to be not exactly true but probably sufficiently so for all practical purposes).

It should be noticed that no assumption is made that the heat loss to the walls is the same for all materials; on the contrary it will be different, perhaps appreciably so because, as was seen above, some materials (like carbon) have the property of forcing the high temperature toward the cold end, while others (like iron) force it back to the hot end. For this reason the temperature gradients will be quite different in the two cases, and the loss to the walls, if it is large enough to be considered at all, will therefore be different for different materials; but in the present method this difference is taken care of in the tabular data, and needs no further consideration.

The curves for these two final quantities are given apart from the others in Figs. 10 and 11. In Fig. 10 they have been drawn to different scales so that they are nearly superimposed, thus enabling their relative inclinations or percentage values to be compared better with each other, while in Fig. 11 they have all been drawn to the same scale, so that they may be compared quantitatively.

In Fig. 10 it will be seen that the curves *E*, which measure the minimum loss, or the watts per ampere, all have a family resemblance, except in the case of graphite; in fact with slight changes in the scales, those for iron, copper and carbon may nearly coincide, except at their lower temperature values, and this difference may be due to the experimental determinations which were not carried out quite as carefully at the lower temperatures for carbon and iron, as for copper. Even graphite might perhaps be brought into line by a change in the horizontal scale, which would mean that the temperature would have to be multiplied by a coefficient, or have a different exponent.

This family resemblance, and the fact that all these curves must have a zero and an infinite value, of course suggest the possibility of a common formula for all, differing only in its coefficients. But this is beyond the purpose of the present paper; the results obtained in this interesting direction will be made the subject of another discussion.*

The marked difference of the graphite curve means that the losses in graphite electrodes do not grow as rapidly with the temperature as they do for all the other materials. This, of course, is a very good quality, especially for high temperature furnaces. For all the others the relative increase of this loss is about the same. It is of interest to note that copper and carbon, the two extremes in all other comparisons, are here very nearly alike in their percentage variations.

A comparison of these same curves *E* in Fig. 11, (the heavy line curves) shows the quantitative relations of the actual losses per ampere. The much greater loss for carbon is quite striking; but of course there are many cases in which metals are excluded by the very nature of the furnace. Consequently, tempting as it may be, the good quality of the metals cannot be taken advantage of. The relative values at 1400 degrees cent. are about: copper 1, iron 1.5, graphite 5, carbon 7.5; the same, of course, as for the electrode voltage.

The loss for carbon is seen to be 1.55 times that for graphite. This is interesting in view of the claims that have been made that graphite is more wasteful of power than is carbon, even ten times as bad. Hence either the experimental data on which that

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*Trans. Am. Electrochem. Soc., Vol. 17, p. 171.

result was based were in error, or the method of deducing the result from them was incorrect; or else the curves change very radically at the higher temperatures, which seems hardly likely. If the present exterpolations are correct, this difference in favor of graphite becomes even greater at the higher temperatures.

Returning to Fig. 10, the thin line curves S' (the section per ampere and per inch) will also be seen to have a family resemblance, and as they also must have values for zero (100 degrees in this case) and infinity, the possibility of a general equation differing only in coefficients or exponents, suggests itself for this relation also.

If equations can be deduced for both S' and E, it will be possible to calculate both the conductivities from them, as one is proportional to the product, and the other to the quotient, of the conductivities. The coefficients for S' and E are, of course, determined experimentally, as in the present case, and the conductivities will therefore be functions of these coefficients.

The exception in the S' curves is iron, but in general the two metals are similar to each other, as are the two non-metals, the two pairs differing somewhat.

Comparing them quantitatively in Fig. 11, the family resemblance is again apparent, the curves being evidently asymptotic to both ordinates, care being taken to deduct the 100 degrees cent. for the cold terminal temperature.

Carbon electrodes are again shown to be far larger than the others. The relative values at 1400 degrees are about: copper 1, iron 6.6, graphite 14.6, carbon 45, the same as for the specific sections. In this feature graphite is more like the metals and differs more from carbon than in the losses. The section for carbon will be about 3 times that for graphite. This difference in size, however, seems to diminish for higher temperatures, if the present exterpolations are correct.

Comparing both these important factors, it will be seen that graphite is better than carbon in both loss and size, especially in size. Copper is best in both and carbon worse in both, while iron is closer to copper in both than it is to graphite.

This final comparison is shown in a practical way in Fig. 12, in which the sizes and losses in electrodes of the different materials are drawn to scale for a given case, in which the current is assumed to be 10,000 amperes and the end temperatures 1400 degrees cent. and 100 degrees cent.

In the first set, to the left, the length is made the same for all, namely 10 in., hence the sections will be different, and in the proportions of 1, 6.6, 14.5, and 45, the same as above given. The actual sizes in square inches are: copper 1.38, iron 9.16,

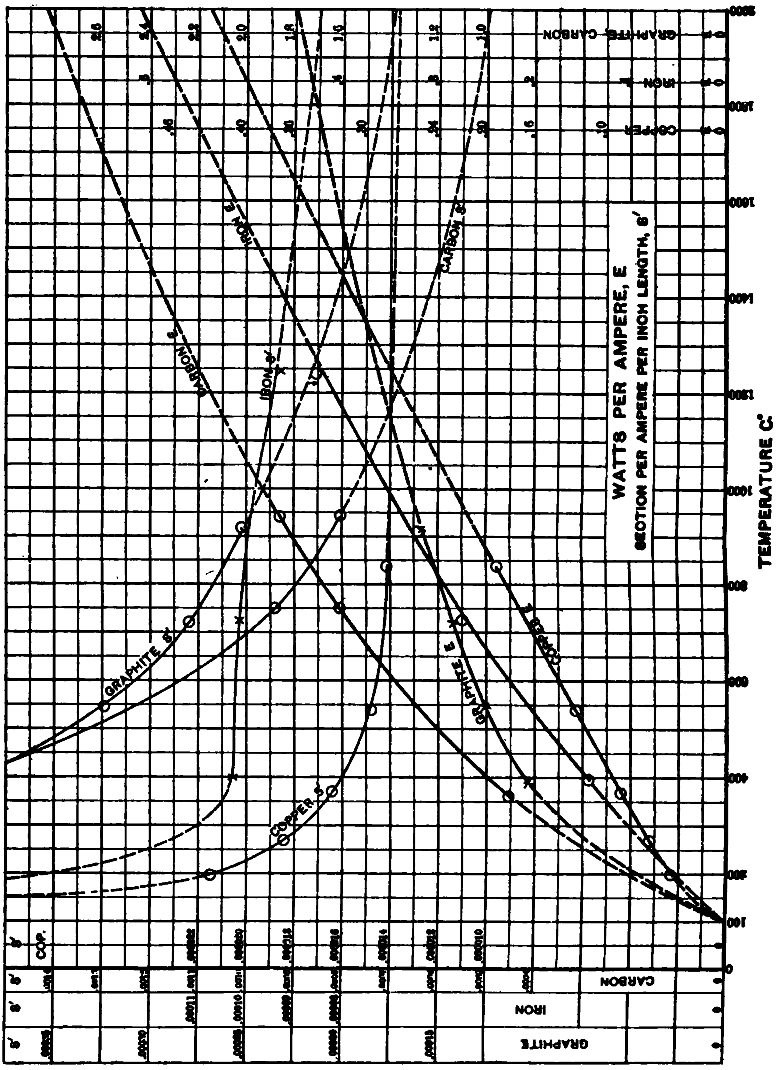

FIG. 10.—Losses and sizes; superimposed

graphite 20.1, carbon 62. It will be seen that the proportions for carbon are practically impossible.

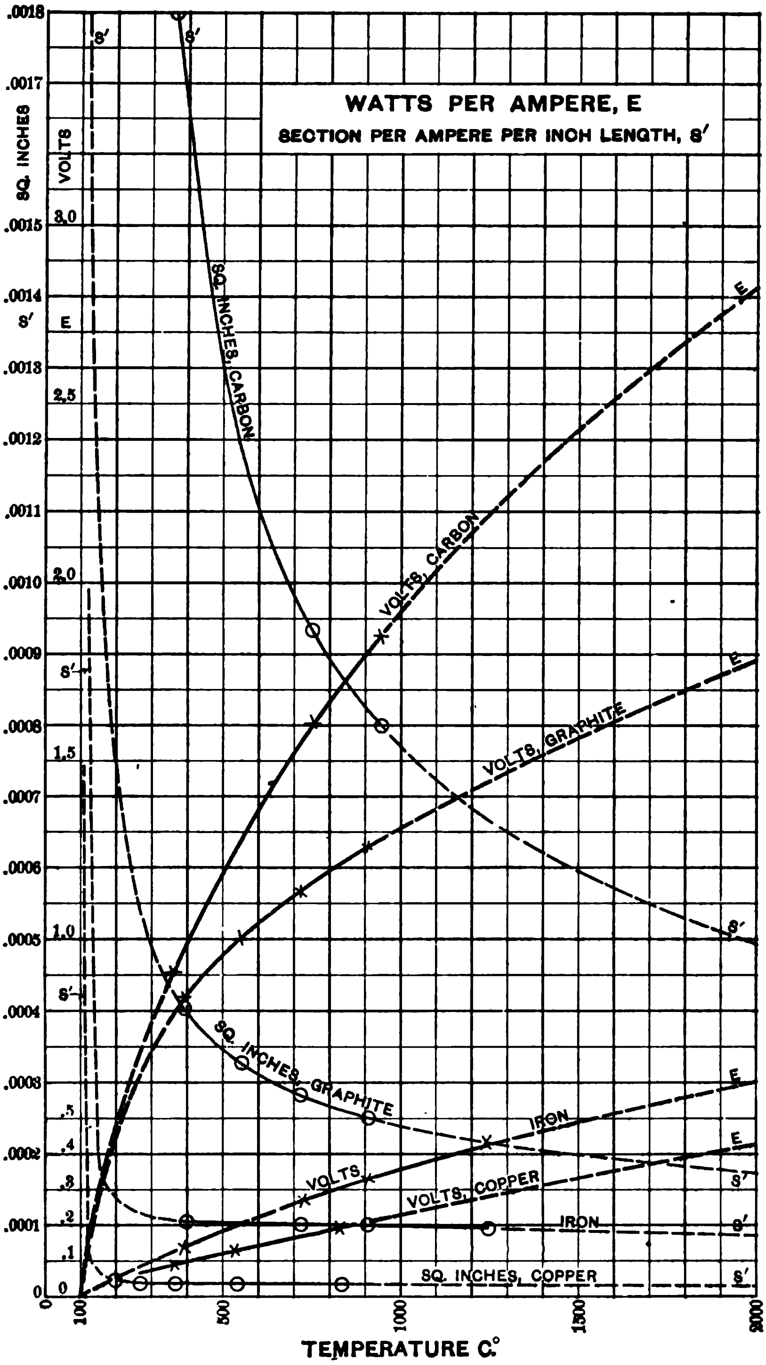

FIG. 11.—Losses and sizes; same scale

In the second set, to the right, the cross-section is made the same, the lengths being then different. They are in inches: 10, 1.51, 0.69, 0.22, dividing which by 10 gives their relative values based on copper. That for carbon is again impossible, as are also those for graphite, and perhaps iron.

The losses in kilowatts per electrode are indicated by the lengths of the heavy black lines, which of course apply equally well to either of the two sizes for the same materials. They are in kilowatts, about: 23.6, 15.2, 4.6 and 3.1, or in the ratio of 7.5, 5.0, 1.5 and 1.

When the ratio of the section to the length is a constant, as in this case, the length increases more rapidly than the diameter. Hence to give the carbon electrode a suitable shape for handling, it must be made still larger, and considerably so. In comparing practical electrodes this feature should be considered, and it will increase still more the difference between the sizes of the carbon and the others. When finally the volumes are figured out, the differences will be found to be very great. But even when thus correctly proportioned the losses will still be much greater for carbon, as they are the same for all sizes, provided the relation of the section to the length is the same.

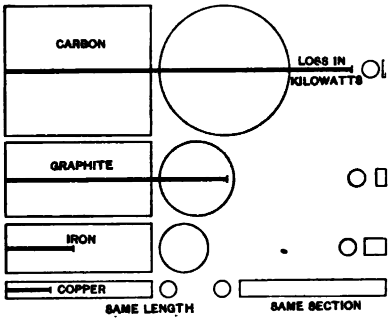

FIG. 12.—Comparison of sizes and losses

It is evidently not proper, as has been claimed, to lengthen the carbon electrode of the section shown, so as to give it a better shape, and to think that this merely means a small sacrifice in efficiency. Such a lengthening will evidently result in developing a high temperature within the walls, higher and perhaps much higher even than the furnace temperature. This would be likely to burn out the furnace wall, which would be fatal to successful operation. If it is made smaller and shorter the proportions will be still worse, as is seen in the upper right hand illustration. Consequently there seems nothing left to do but to make it much larger and longer.

This brings out another wrong deduction which has been made by others, based on the former incorrect rules. Suppose the carbon electrode in this Fig. 12 had been made with the same section but 20 in. long; it is evident from the results of the present analysis that a high temperature point, higher than that of the furnace, and probably very much so, would develop at a point somewhere between the furnace, and a point 10 in. from the cold end, because 10 in. is the correct length for that section. This would burn out the walls. The conclusion drawn from our former ideas was that the current density was too high, when the fact is that the electrode was too long for that section. The current density had nothing to do with the failure, because if the electrode had been made half as long instead of as long again, it would have been too cold and would have chilled the furnace, although the current densities were the same. Furthermore if the electrode had been made half the section and length shown in Fig. 12, it would have operated properly even though the current density had thereby been doubled. The current density, therefore, was not the cause of failure; it has often been made responsible for faults which were really due entirely to errors in the length.

SUMMARY

The final results of this rather lengthy investigation are briefly as follows, as far as they interest the designer.

The underlying feature is that the electrode shall not chill the furnace, nor develop a high temperature point within the walls at which the temperature is greater than in the furnace. Hence the hot-end temperature should be as nearly as practicable equal to that of the furnace.

The current and furnace temperature are always given in the specifications. The material and either the length or the section (but not both) may also be specified, but preferably all three should be left to the designer. The voltage and loss cannot be specified, as they are determined by the current, temperature and material.

The length (that is, the essential length, not including additions to either or both ends for other purposes than to get the energy through the walls) may be determined solely by the thickness of the furnace walls; but as this affects the cross-section, some latitude should be left in case the corresponding section is found to be too large or too small to be practicable.

The section in square inches is then determined at once by multiplying the proper temperature value of S' from Table II by the current in amperes and by the length in inches (formula 13). If this is too large or too small to be practicable, the length may be changed and the section may be re-determined. The quotient of the section divided by the length is a constant for any specified conditions, (numerically equal to S' from the table multiplied by the current) hence they may both be increased or decreased in the same proportion.

Should this table of values not be available and the specific section be known, formula (14) should be used for calculating the section. If this is also not known, then use the conductivities in formula (7). Great accuracy is not necessary when one is near the correct result, as an error in section near that point produces a relatively much smaller error in the loss.

The loss in the electrode in watts is entirely independent of the section or length adopted, provided only that their quotient is approximately as above. It is calculated in watts by multiplying the corresponding temperature value of E in Table II by the current (formula 10). If this table is not available, we may use the electrode voltage in the last part of formula (5). If this is not available either, then use the conductivities in the preceding expression of formula (5). This loss is for one electrode and it is the least possible under those conditions.

When the current for a furnace varies appreciably, the calculations must of course, be made for some assumed normal value, remembering that whenever it is less than that, the electrode will chill the furnace more or less; and whenever it is greater the electrode will get hotter within the walls, and in both cases the total loss will be greater.

In operating a furnace, if the electrode is found to chill the product, it is either too short, or too large in section. If on the other hand it is found to produce excessive temperatures within the walls, it is too long or of too small section. The current density is not a determining factor.

The hotter the outside terminal is allowed to get, the smaller the loss, but the larger the section or shorter the electrode.

When the proportions turn out to be large in section and short in length (as for instance with carbon for large currents as in Fig. 12) the relative proportions may be improved by increasing both length and section. On the other hand, if the electrode is abnormally long and small in section (as for instance with iron or copper and small currents) then if the section cannot be made smaller, there seems to be nothing left to do except to sacrifice some of the loss by making the electrode shorter and it will then chill the furnace more or less.

The additional lengths of the electrode necessary for the terminals, for feeding, or for the distribution of the current in the inside, must be calculated separately, as they are determined by entirely different laws and conditions; the above refers only to the essential part which is necessary to get the current into and out of the furnace as well as possible. The above length must therefore never include the long external part outside the furnace, for feeding purposes. Such a part radiates heat to the air and therefore follows entirely different laws of proportions. A redeeming feature of such a case is that the outside temperature used to determine the proportions of the essential part, may be allowed to be very high, probably limited chiefly by oxidation thereby reducing the total loss which has been increased by the long external part.

Summary of previous discussions. The description of this new way of attacking the problem of the proportioning of electrodes, given by the writer briefly in May, 1909, and more in detail in October 1909, has given rise to long discussions and attacks. Some of the purely technical parts were of interest and value and will be summarzied briefly below. The rest of the discussion is of no general interest as it consisted of the usual unsubstantiated claims of priority made by those who suddenly found that they had known it long ago but had not given their knowledge to others or used it themselves. It contained also the assertions of those who claimed, after the method was described, that it was obvious though this had not occurred to them before; also the statements of those who maintained that on account of some academic minutia it was obviously fundamentally incorrect, although they could not substantiate their claims with actual figures; and the assertions of others who thought that the results were of no value because the necessary physical properties of the materials were then not yet known; etc.

One of the parts of the discussions which was of value referred to the magnitude of one of the corrections to which reference was made in the original paper, due to the simplified premises. This correction referred to the effect of the variation of the conductivities with temperature, and therefore is in the nature of a refinement or second approximation. Another important part was an ingenious graphical method devised by Dr. A. E. Kennelly,* for representing and studying the relations of the quantities involved.

Concerning the temperature correction, Dr. Kennelly has shown in a very able paper† that under certain approximate premises, this correction is zero when the electrical resistivity varies according to a straight line law (the thermal one being constant). The correct mean value then is the arithmetic mean between the two extrême values at the two end temperatures. Also that the same is true when the thermal resistivity alone varies in this way. Also that when both vary in this way, the total loss is least when half of the heat flow at the cold end is joulean heat and the other half is conducted from the furnace; the remainder of the joulean heat is assumed to flow toward the furnace, thereby tending approximately to balance the furnace flow, hence a "very little heat will flow into or out of the furnace." This means that the condition of no loss of furnace heat under those approximate premises, is only a close approximation to the condition of minimum loss, instead of being identical, as it is with constant conductivities.

Dr. E. F. Roeber‡ has attempted the complicated mathematical solution of the case when both conductivities vary according to a straight line law, and has carried it up to, but not including the integration. Although this unfinished formula is probably too complicated for use in practice by engineers, it shows that for given materials at stated temperatures the correction factor is merely the numerical coefficient, and that the relations between the variable factors remain the same. Dr. Roeber also finds that when the electrical conductivity is constant and the thermal conductivity alone varies by a straight line law, this complicated formula reduces to the simple original one in the writer's paper. This indicates that it is largely the variation of the electrical conductivity which gives rise to a correction

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*Trans. Am. Electrochem. Soc., Vol. 16, p. 297.

†A paper "On the Modifications in Hering's Laws of Furnace Electrodes Introduced by Including Variations in Electric and Thermal Resistivities" published elsewhere in this volume.

‡ "Electrode Losses in Electric Furnaces," Trans. Am. Electrochem. Soc. Vol. 16, p. 363. See formula (5) p. 367.

factor, a fact which the writer has since shown in another paper in a different way.

Dr. H. C. Richards* gives a very interesting solution of the integration for the complete case when both conductivities vary by straight line laws, and gives the first two terms of the series of coefficients. This enables the correction factors to be determined, when the conductivities and their variation with temperature are known. By means of this interesting solution it was shown by the writer† that even for very great variations in the conductivities, the corrections on which some of the critics based their unsubstantiated claims that the writer's approximate formulas were very incorrect and even " fundamentally wrong ", were in fact quite negligible in practice.

The writer takes this opportunity to express his appreciation of these able mathematical solutions by Dr. Kennelly, Dr. Richards, and Dr. Roeber, which show that differences between the writer's simple first approximation of the complete problem and the second approximation, are not great, and in part do not exist at all. Their work was done before the present experimental determinations had been undertaken, and before some of the simplifications described in the present paper had been made.

Those who, on the other hand, attempted to belittle and discredit the results of this investigation, brought up minor points which were either based on an incomplete reading of the original paper and are answered in the present paper, or were based on academic points which it is believed the practical engineer can safely neglect or allow for, as he does in most other construction work. The present investigation was made from the standpoint of the engineer and not from that of the academician or the mathematical physicist whose enlargement of negligible minutia is apt to obscure the main practical issues; nevertheless the analytical part of this investigation is undoubtedly rigidly exact under the specified simple conditions.

It is suggested that critics who endeavor to tear down and destroy the work of others by hastily made and unsubstantiated assertions, which may prove later to have been unwarranted or incorrect, might do some thing which is really of value, by devoting their efforts to improvements and further developments instead of to mere destruction. Before tearing down a structure built by others, one should be very sure first that it is

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* Trans. Am. Electrochem. Soc. Vol. 16, p. 304.

† *Ibid*, p. 310.

a dangerous one; if one thinks he can build a better one, then let both stand; the fittest will survive in the end without the need of the hand of the destroyer.

As to the usual crop of claimants of priority after something has been disclosed, the practice of secreting information of benefit to fellow engineers, until someone else has taken the trouble to publish it, and then of claiming priority and expecting recognition, is not in accordance with a high standard of professional ethics, and is believed to be more apt to discredit the claimant than to do him credit. Unpublished ideas are of no benefit to the profession at large; it is the one who takes the trouble to publish them, that aids his colleagues.

DISCUSSION ON "PROPORTIONING ELECTRODES FOR FURNACES", CHARLOTTE, N. C., MARCH 30, 1910.

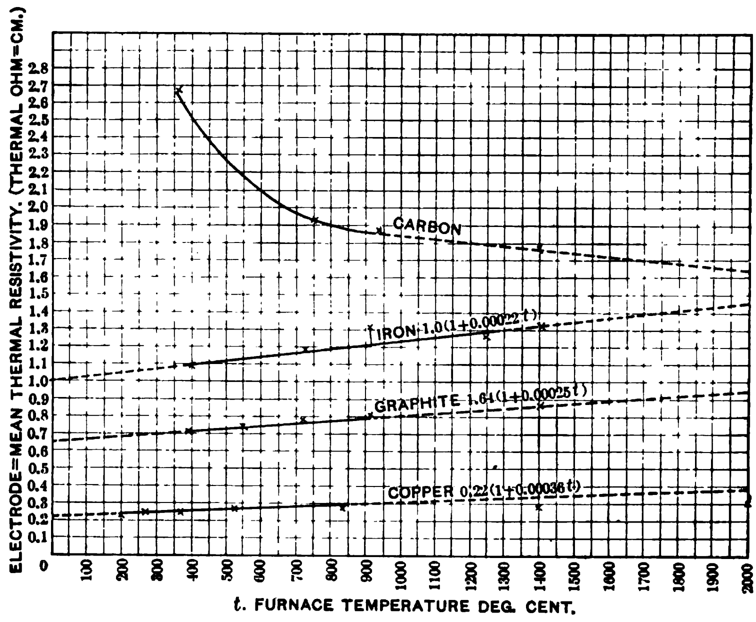
A. E. Kennelly: Mr. Hering's paper is of much importance both from the practical and theoretical standpoints. In its practical aspect, it gives the results of a number of experimental observations on the behavior of electrodes under furnace conditions. It expresses the outcome of these results in tables for easy reference. The numerical bases of these tables are two experimentally determined constants for each electrode material, —the "electrode-voltage" e, and the "specific section" s. As pointed out in the paper, the "electrode-voltage" e is $\sqrt{2}$ multiplied by the square root of the ratio of the electric to the thermal resistivity; while the "specific section" is $1/\sqrt{2}$ multiplied by the geometric mean of the electric and thermal resistivities. The term "electrode-*voltage*" can only be regarded as an abbreviation for the unwieldy phrase "*voltage* drop in the electrode per square root of the temperature drop." Similarly, the term "specific *section*" can only be regarded as an abbreviation for the unwieldy phrase—"cross-*section* times square root of temperature-drop, per ampere, per unit length of electrode." It is evident that these two phrases are too cumbersome for practical use; and that brief names are necessary, even at some sacrifice in verbal precision.

The advantage of the method of measuring these fundamental constants described in the paper is that whatever errors or defects may be included in the process, the measurements are made under furnace conditions; so that, for practical purposes, the data so obtained are likely to be more directly applicable than corresponding more rigidly accurate data, secured by physical laboratory methods.

Whatever refinements in the design of uniform electrodes that are uniform in material and cross-section, may be found necessary to meet outstanding sources of discrepancy, such as terminal contact-resistance, lateral escape of heat into furnace walls, disintegration of material, and the like, there can be no doubt that Mr. Hering's paper contains the essential engineering theory of electrode design.

It is a remarkable result of the investigation contained in the paper that copper is superior to iron, graphite, and carbon, as an electrode material, so far as concerns minimizing loss by waste of heat. One would naturally suppose at first thought, that copper would be the worst material of all for this purpose.

In its theoretical aspect, the paper also contains much that is new and valuable. Very little has hitherto been determined concerning the thermal conductivity and resistivity of electrode materials at high temperatures, so that the new data are very welcome. The values obtained are "electrode-means", as that term is defined in the paper on page 301, and are subject to the limitations involved by that definition. Nevertheless, since it has been doubtful heretofore as to whether the thermal conductivity of electrodes increased or diminished at high temperatures, these pioneer data represent a long step towards enlightenment. If even the sign of the temperature variation has been in doubt, we need not cavil at any lack of numerical precision in the newly determined thermal temperature-coefficients. In Figs. 1, 2, 3, 4, and 8 of the paper, the electrode-mean thermal conductivities of copper, iron, graphite and carbon are plotted graphically. None of these curves carry any clear graphical self-interpretation. The corresponding numerical values of the electrode-mean thermal conductivity *k* in what may



be called "thermal mhos per cm." are given in the column fifth from the end in Table I. If we plot the reciprocals of these values, or the electrode-mean thermal-resistivity in "thermal-ohm cm." as ordinates, against the furnace temperature as abscissas, we obtain the graphs of the accompanying illustration. It will be seen that the electrode-mean thermal resistivity of carbon appears to fall with temperature in much the same general manner that its electrical resistivity falls. On the other hand iron, graphite, and copper, appear from the results in the paper to follow roughly straight-line laws of increase in thermal resistivity with temperature. Their thermal resistivity follows the course of their electric resistivity in this respect. But whereas in the case of copper, for instance, the electric resistivity at

2,000 deg. cent. appears in the table as approximately nine times the electric resistivity at 0 deg. cent., the electrode-mean thermal resistivity of copper is only about 76 per cent greater at 2000 deg. cent. than at 0 deg. cent. This means probably that the inferred full thermal resistivity is about 150 per cent greater at 2000 deg. cent. than at 0 deg. cent. In other words the temperature-coefficient of increase in thermal resistivity, either in electrode-mean or in full, is apparently much less than the temperature-coefficient of electrical resistivity.

It is to be observed that whereas the electrode-mean electric resistivity of graphite, as given in Fig. 7, slightly falls off with temperature, faintly following carbon, the mean thermal resistivity steadily rises with temperature like iron and copper. This latter result is confirmed by some observations published by Mr. Hansen on page 351 of Vol. XVI of the Trans. Am. Electrochemical Society (1909) for the thermal conductivity of graphite between the limits of 37 deg. cent. and 600 deg. cent.

In the case of iron, we know that the electric resistivity undergoes marked and sudden variations in the neighborhood of the recalescent temperature, a property that is utilized in various forms of "ballast resistance." This disturbance is suggested by the bend in the curve of mean electrical resistivity for iron, on Mr. Hering's Fig. 3, in the neighborhood of 400 deg. cent. A corresponding deviation does not manifest itself in the thermal resistivity results for iron, if we exclude a particular deviation near 900 deg. cent. This is an experimental question that ought to be further investigated. If there is no discontinuity in the thermal resistivity of iron near recalescence, while there is a discontinuity in the electric resistivity, the fact has an important bearing on the theory of electric conduction in metals.

The temperature-coefficients of electrode-mean thermal resistivity in iron, graphite and copper appear from Mr. Hering's table to be respectively about 0.022, 0.025, and 0.036 per cent per degree cent. from and at 0 deg. cent. Consequently we may estimate, as a first approximation, that the full thermal-resistivity temperature-coefficient would be double the above values of 0.044, 0.05 and 0.072 respectively. This is merely equivalent to assuming that, as a first approximation the electrode-mean thermal resistivity is the arithmetical mean of the thermal resistivities at the hot and cold end of the electrode.

If my own paper, accompanying Mr. Hering's paper, had been written with these new constants available, the only alterations in the numerical examples would have been the substitution of $a = -0.0032$ for $a = -0.0072$, the distance coefficient of electric resistivity, and the substitution of $b = 0.016$ for $b = 0.01$, the distance coefficient of thermal resistivity. That is, one of these coefficients would have been reduced, and the other increased. The resulting numerical effect would have been comparatively small; but the general effect would have been to show still less deviation from the deductions of Mr. Hering's original formulas than the numerical examples actually present.

Summing up then the results of Mr. Hering's investigation from the above standpoint, we may say that with the exception of carbon, all of the materials tested showed at least substantially straight-line laws of resistivity, both electric and thermal, all the coefficients being positive, except the electric resistivity coefficient of graphite.

E. F. Northrup: Engineering problems may be classed, roughly, into those which aim to produce a material result for the first time, as building a Brooklyn bridge, and those which would repeat engineering accomplishments with better economy.

Mr. Hering's problem belongs to the latter class. He sees that there is an important engineering question to answer, which is this: How, with data which can be obtained practically, shall the material of furnace electrodes be selected; and having this, how shall it be proportioned so that, with the furnace temperatures required, the electrodes shall not chill the furnace charge while the power wasted shall be the least possible.

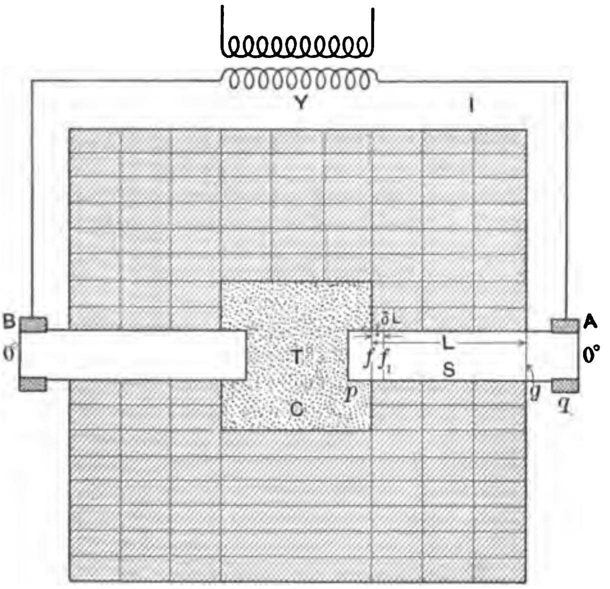
It is not a problem for elegant mathematical exposition, based upon assumptions that thermal and electric coefficients vary as idealistic functions of the temperature. It is an engineering problem and its solutions, to be of use, must have a form which designing engineers can use.

The solutions in Mr. Hering's present paper are set forth in no uncertain or vague manner and are so simple in form that a tyro may apply them in practice. Mr. Hering has introduced for the first time, the conceptions of two new specific quantities which attach to all furnace electrodes. One he calls the " electrode voltage ", e, the other the " specific section ", S. He points out by reference to actual experiments and theoretical considerations, how these two specific quantities may be determined precisely by experiments upon small test electrodes, and then be used for the calculation of actual large electrodes. When these specific properties of electrode materials, gotten for various furnace temperatures, are once completely determined and tabulated they will have a like value to the designer of electric furnaces that the specific heat of steam has to the designer of engine boilers.

The subject is important, much has been written upon it, and the mathematical point of view has been ably presented by several who are masters in this form of treatment. So much material has been given us that the important crucial results obtained may still remain obscure to some readers amidst the wealth of material that has been presented. These facts are made an excuse for presenting my way of looking at what appears to me the essential aspects of this interesting subject.

In the accompanying figure the two furnace electrodes A and B together with the charge, C, in the interior of the furnace complete the circuit from the transformer secondary, Y. It is assumed in what follows, that the furnace has been operated until steady conditions obtain—that is, until the heat supplied to the charge, *C*, equals the heat lost from the charge, so that the temperature of the central zone of the furnace charge is constant and has the required value, *T* degrees. It may be premised also, that the thermal conductivity of the electrodes is greater than the thermal conductivity of the furnace walls.

Now conceive that, for a brief time, the electric current is shut off. If this time, when there is no current, is taken sufficiently brief we can consider the interior of the furnace as containing an infinite quantity of heat as compared with the small quantity which will escape in a brief interval. But in this interval some heat will flow through the furnace walls and some through the electrodes. That which goes through the electrodes, per unit of section, will exceed that which goes through the walls per unit of section, because of the assumed greater thermal conductivity of the electrode material. The heat which flows through the walls must be supplied by electric power to the charge in the interior of the furnace. To reduce this supplied power to the least possible amount involves questions which relate to the design of the containing walls of the furnace and these questions have no connection with the problem of electrode losses.



Only the heat which goes through the electrodes is an electrode loss, which it is our problem to make as small as possible. The electrode, to which the analysis should be applied, is not the physical electrode, extending from *p* to *q* (see illustration) but that portion of the electrode *f* to *g* which extends the ditance L, through the furnace wall. Of course there will be losses in the exposed portion of the electrode (which should be as short as possible) and losses in the contact resistances where the current enters; but these losses require separate consideration, and in no wise affect the problem of the choice of material and the proportioning of the electrode within the furnace wall. The electrode, then, to which this and the other treatments given should in strictness apply, is that portion which extends from the interior to the exterior surface of the furnace wall.

The treatment of the problem would be unmanageable unless it were assumed that the heat which flows through the electrode all moves parallel to its axis. This assumption is thought to be justified for any engineering requirements for two reasons; First, because, when steady conditions obtain, the temperature gradient from the interior to the exterior of the furnace wall is roughly the same as the temperature gradient along the electrode itself. Second, because it is a well known physical fact, that a surface of separation between two unlike substances, especially if the surface is covered with a thin layer of air, offers a great resistance to heat flow. This premised, and being guided by Mr. Hering's analysis, we can reason as follows. The heat-flow in watts which would pass through the electrode from f to g, when the current is momentarily stopped, would be,

$$H = K T \tag{1}$$

where T is the temperature difference taken over the length L between the points f and g *at a very brief instant after the current is stopped*, and K is the actual thermal conductance of this portion of the electrode at the same moment.

Now, start the current flowing, which has been stopped but a brief instant. At the moment that the current is started let the ohmic resistance of the electrode between the points f and g be R, and, with the current I actually supplied, let the voltage drop between f and g be E. Then the watts developed electrically in this portion of the electrode will be

$$W = \frac{E^2}{R} \tag{2}$$

This heat is assumed to escape by way of the ends of the electrode only. As its development takes place along the length of the electrode, and is distributed in some unknown manner, it will have to traverse, to escape from the ends of the electrode, a length which is less than L. Suppose when this flow of electric heat is taking place the *effective* thermal conductance of the electrode is K'. By the cooling jacket the end, g, of the electrode is supposed to be kept at the same temperature, but the heat supplied electrically will tend to modify the temperature of the hot end at a point very near this end so that the temperature at a point f_1, distance δL from f will become, in a brief instant after the current is started $T \pm \delta T$.

Then the electric heat which flows out of the ends of the electrode will be $K' \ (T \pm \delta T)$, and this must equal the heat supplied, if we assume that the current is maintained steady until steady conditions of temperature are acquired. Hence,

$$\frac{E^2}{R} = K' \ (T \pm \delta T) \tag{3}$$

Now when all the heat (the current being on) which escapes from the cold end is electric heat, no heat will be escaping through the electrodes from the furnace and the loss of furnace heat will therefore be zero. Now fasten the attention on the point f_1, distant toward the cold end of the electrode from f a very small distance δL. If the voltage E is adjusted so that the temperature at the point f_1, is $T - \delta T$, there will be between f and f_1, a temperature gradient toward the cold end, $-\frac{\delta T}{\delta L}$, and some furnace heat will escape from the furnace. If on the other hand E is adjusted so that the temperature at the point f_1, is $T + \delta T$, there will be between f_1 and f a temperature gradient $+\frac{\delta T}{\delta L}$ and some electric heat will flow into the furnace. But this would mean that the furnace had not reached its final temperature which is contrary to the assumed condition of a steady furnace temperature, T. Hence, for no furnace heat to flow into or from the furnace, we should adjust the voltage E, until there is no temperature gradient over the small length δL. That is $\delta T = 0$, and we have from equation 3 for the condition of minimum loss of furnace heat,

$$E = \sqrt{R K'} \sqrt{T} \tag{4}$$

If the product $R K'$ can be shown not to involve the linear dimensions of the electrode, then it is a specific property of the material of which the electrode is made. To do this write,

$$R = \frac{L}{S} \ [\rho_m]_T \text{ and } K' = \frac{S}{L} \ [\sigma_m \ a]_T$$

Then

$$R K' = [a \ \rho_m \ \sigma_m]_T$$

The exact interpretation of these three relations is very important. The first means that the ohmic resistance of an electrode, when hot at one end and cold at the other, will increase with its length, decrease with its cross-section, and be dependent upon the *average specific* resistance of the material which maintains when the fall of temperature from one end of the electrode to the other is T degrees, the temperature of the hot end being the same as the temperature designated by T in equation 4.

The second means, that the *effective* thermal conductance of an electrode, when heated by an electric current until the temperature of its hot end is T, and when all the heat developed must escape through the cold end, increases with its cross-section, diminishes with its length, and increases with the quantities a and σ_m. The quantity a, depends for its value upon where the center of gravity of the watts developed is located along the axis of the electrode. If this center of gravity is located at the middle point of the axis $a = 2$, if located nearer the hot end a is less than 2, if nearer the cold end a is greater than 2. K' also depends upon the mean specific conductance of the material. This is a constant for an electrode of any size and any particular material when its terminal temperatures are fixed and are produced by an electric current in the electrode. With this understood we have by substituting the value of $R\,K'$ in equation 4,

$$E = \sqrt{a\,\rho_m\,\sigma_m}\,\sqrt{T} = e\sqrt{T} \tag{5}$$

where $e = \sqrt{a\,\rho_m\,\sigma_m}$ is the " electrode voltage " in volts.

It should be noted here that the smaller is a, that is the nearer to the hot end is the center of gravity of the electric heat supplied to the electrode, the smaller is the electrode voltage required for minimum heat loss. In iron, a would be less than 2, in carbon, a would be greater than 2.

The minimum power consumed is

$$P_m = I\,E = I\,e\sqrt{T} \tag{6}$$

Again from (4), writing $E = I\,R$

we get $I^2 R = K'\,T$ or $I^2 \dfrac{L\,\rho_m}{S} = \dfrac{S\,a\,\sigma_m}{L}\,T$,

which gives

$$S = I\,L\sqrt{\frac{\rho_m}{a\,\sigma_m}}\cdot\frac{1}{\sqrt{T}} = I\,L\,s\,\frac{1}{\sqrt{T}} \tag{7}$$

Equation (7) is the same as Mr. Hering's equation (7) p. 295, except that the quantity a replaces the factor 2. a will equal 2 only when the center of gravity of the watts supplied to the electrode is at the middle point of the axis and there is no furnace heat flowing. This will be the case generally only when the thermal conductivity and the electric resistivity are constants. The quantity $s = \sqrt{\left[\frac{\rho_m}{a\,\sigma_m}\right]_T}$ is what Mr. Hering calls the "specific cross-section". It is independent of the linear dimensions of the electrode but is dependent upon its material and upon the terminal temperatures being assigned at the time its value is determined. Its value will also be different if determined in any non-electrical way other than by the method described by Mr. Hering.

The two equations of Mr. Hering (modified here by substituting a for the factor 2).

$$P_m = I\sqrt{a\,\rho_m\,\sigma_m}\,\sqrt{T} = I\,e\,\sqrt{T} \tag{8}$$

and

$$S = I\,L\sqrt{\frac{\rho_m}{a\,\sigma_m}}\,.\,\frac{1}{\sqrt{T}} = I\,L\,s\,\frac{1}{\sqrt{T}} \tag{9}$$

the first of which enables the minimum power loss to be calculated and the second the proper electrode section for minimum power loss, I conceive to be the most important theoretical contribution to this subject.

Equations (8) and (9) would be useless if the quantities e and S could not be obtained by experiment. But fortunately, Mr. Hering has pointed out, and demonstrated by actual tests, that they can be so obtained, *and with far more ease and precision* than their components thermal conductivity, electrical resistivity and the center of gravity factor.

The analytical and mathematical treatments, that others have given to this problem, are certainly interesting and valuable in enabling the problem to be studied from very varied points of view. But the following aspects of these mathematical modes of treatment certainly should not go unmentioned. If the thermal and electric conductivities are assumed constant, then the most elemental physical considerations will lead to a solution without any application of the calculus. Such solution, however, is only roughly approximate. If these quantities are assumed to vary as a linear function of the distance along the electrode, then the solution of the differential equation, based upon this assumption, shows that the temperature gradient is not linear and hence the original assumption can only roughly represent the physical facts—probably no more closely than the assumption of constant specific qualities. If the conductivities are assumed to vary as linear or more complicated functions of the temperature, the integrations are at best formidable and generally impossible. An unintegrated differential equation is at the best nothing more than a formal statement, put into mathematical form, of an unsolved problem.

Respecting this view of the mathematical analysis of physical problems Fourier remarks, (§13, The Analytical Theory of Heat), " The numerical interpretation of the results of analysis is necessary, and it is a degree of perfection which it would be very important to give to every application of analysis to the natural sciences. So long as it is not obtained, the solutions may be said to remain incomplete and useless, and the truth which it is proposed to discover is no less hidden in the formulae of analysis than it was in the physical problem itself."

But suppose one does succeed in writing down and integrating the differential equations which express the conditions of the flow of heat in an electrode. These equations must involve the thermal conductivity varying as a function of the temperature. To obtain, then from the integrated equations numerical results one must know the thermal conductivity of such materials as carbon, graphite, iron, etc., at temperatures from, say, 100 to 2000 deg. cent. These variable " constants " are unknown and to determine them by experiment is *a far more difficult and uncertain undertaking* than it is to measure directly at various temperatures what we want to know; namely, Mr. Hering's electrode voltage, *e*, and specific section *s*.

It seems to me that there lies here an important line of investigation, which shall give us the values of *e* and *s*, at temperatures up to the highest employed in electric furnaces of all the electrode materials which are likely to be used in these furnaces. Mr. Hering worked with thermo couples to measure his temperatures and did not get up very high. His experimental investigation should be continued, using test pieces of greater ratio of diameter to length, larger currents and higher temperatures than he used. These high temperatures might be quite accurately measured by placing reliance on Steffan's law, that the total radiation from a black body is proportional to the fourth power of the absolute temperature. The radiation could be measured with a form of surface bolometer which the writer has designed and experimented with. This, after being calibrated at moderate temperatures with a thermo couple, could be relied upon to give accurate results at the highest temperatures. A series of values $E = e\sqrt{T}$, and $S' = s\frac{1}{\sqrt{T}}$ could be found thus and tabulated for temperatures exceeding 1500 deg. cent. These constants given by Mr. Hering in table II page 322, are exterpolated values above 950 deg. cent. This was the highest actual steady temperature which he measured, but a platinum-platinum rhodium couple used in connection with a potentiometer could have been used without its destruction to 1500 deg. cent. Beyond this temperature the radiation principle would have to be used, and the results which it would give would be as accurate as the higher temperatures of the furnaces are known, as these can only be determined in the same way.

The writer hopes that this more extended investigation may be deemed worth while and he would give it as his opinion, based upon considerable experience in making high temperature determinations, that results of an accuracy entirely satisfactory from an engineering standpoint could be readily obtained in the ways suggested. Such an investigation might be carried out with much propriety at the National Bureau of Standards.

A paper presented at the Charlotte meeting of the American Institute of Electrical Engineers, March 31, 1910.

PARALLEL OPERATION OF HYDROELECTRIC PLANTS

BY W. S. LEE

It is the purpose of this paper to sum up in a general way some of the advantages to be gained by operating a sytem of hydroelectric plants connected in parallel so as to exchange power from one plant or territory to another. The disadvantages of this system, which are almost all transmission operating conditions, have been purposely omitted, in the hope that some member may at a future meeting treat this phase of the subject, giving a solution of the problems involved. The deductions, although drawn from conditions existing on the southern Appalachian slopes, will in most cases apply to other localities.

It seems best to first consider some of the topographical features of this locality. The Appalachian mountains, in which many large streams have their sources, run in a southwesterly direction, paralleling the Atlantic coast. These mountains are, on an average, from 1500 to 2000 feet above the sealevel. This means that all water from their water sheds must run over falls or rapids dropping a total vertical distance corresponding to this height. In the higher altitudes there are numerous waterfalls with an abrupt drop of many feet, but as lower levels are reached the falls consist mostly of rapids, some grouped so as to present considerable fall in a short distance, and in other places a longer and more gradual slope.

Several well-defined ridges cross the various streams running parallel to the Atlantic slope, on which each river has a decided fall. These ridges extend across two or more states and several streams. These points on the streams present the largest and most economical sites for hydroelectric developments. Near these falls, or between them, are others of a gentler slope which are much more costly to develop.

Each stream has available a certain amount of water power and the problem is to build and operate plants on the same and on different streams, interconnecting them with transmission lines, so that the greatest amount of power can be delivered from all the streams.

For convenience, we will consider the advantages to be gained by parallel operation under the following heads:

More than one plant located on the same stream.
Plants located on different streams.
Effect of low water on a system of plants.
Effect of high water on a system of plants.
Storage.
Break-down capacity.
Auxiliary plants.
Variation of load.
Constructing and operating advantages.

More than One Plant Located on the Same Stream. Rainfall and floods are features that should be carefully considered in connection with hydroelectric plants especially when operated in parallel. To illustrate this point some tabulated data are given regarding rainfall from the year 1900 to 1909 at the stations located at Morganton, N. C., Statesville, N. C., Charlotte, N. C. and Camden, S. C., all forming part of the drainage area of the Catawba river.

It will be seen by referring to this table that in several instances one point may have an excess of rainfall and another have a deficiency, or vice versa.

After the plants are built comes the consideration of their operation during various stages of water. The two stages which interfere with operation are extreme low water and extreme high water. While low water generally extends over the whole country it is very unusual that there are not some places where the streams furnish more water than others, due to variation in rainfall or to climatic conditions. These places may not necessarily be in the same section each year, and the areas of increased or decreased rainfall may shift and vary from year to year.

Low water means a curtailment of power, and it is often found that even with a line of plants located on the same stream the water conditions are different at different plants. There may be

AVERAGE RAINFALL

Year	MORGANTOWN, N. C.				STATESVILLE, N. C.				CHARLOTTE, N. C.				CAMDEN. S. C.			
	Av. precip. for prev. years	Annual precipit.	Excess	Defic.	Av. precip. for prev. years	Annual precipit.	Excess	Defic.	Av. precip. for prev. years	Annual precipit.	Excess	Defic.	Av. precip. for prev. years	Annual precipit.	Excess	Defic.
1900	*11* 47.93	46.68	—	1.25	*6* 53.01	No. Record	—	—	*21* 49.64	46.34	—	3.30	*10* 47.15	51.79	4.64	—
1901	*12* 47.83	63.19	15.36	—	*6* 53.01	62.84	9.83	—	*22* 49.49	62.82	13.33	—	*11* 47.57	58.64	11.07	—
1902	*13* 49.01	44.77	—	4.24	*7* 54.41	48.35	—	6.06	*23* 50.07	45.32	—	4.75	*12* 48.49	45.17	—	3.32
1903	*14* 48.70	52.04	3.34	—	*8* 53.66	53.64	—	0.02	*24* 49.87	39.48	—	10.39	*13* 48.24	55.06	6.82	—
1904	*15* 48.93	42.31	—	6.62	*9* 53.65	36.70	—	16.95	*25* 49.45	41.93	—	7.52	*14* 48.72	37.90	—	10.82
1905	*16* 48.51	57.04	8.53	—	*10* 51.96	49.91	—	2.05	*26* 49.17	42.44	—	6.73	*15* 48.00	42.41	—	5.59
1096	*17* 49.02	57.86	8.84	—	*11* 51.77	50.82	—	0.95	*27* 48 92	47.30	—	1.62	*16* 47.65	51.17	3.52	—
1907	*18* 49.51	47.94	—	1.57	*12* 51.69	39.46	—	12.23	*28* 48.86	39.98	—	8.88	*17* 47.86	45.61	—	2.25
1908	*19* 49.42	66.44	17.02	—	*13* 50.75	Partial Record	—	—	*29* 48.55	54.40	5.85	—	*18* 47.74	51.15*	4.41	—
1909	*20* 50.27	No Record	—	—	—	—	—	—	*30* 48.75	No Record	—	—	*19* 47.97	No Record	—	—

* Mean of 2 observations.

NOTE.—Records of missing months have been interpolated by using corresponding records of adjacent rainfall stations. Italic figures in columns for average precipitation denote the number of previous years.

local rains that benefit one plant one day and do not benefit plants at some distance for two or three days thereafter.

In case of operating under flood conditions the reverse is true, namely; a flood may affect a plant on the upper part of the river and not affect a plant lower down for several days. In the meantime the water has become normal at the upper plant and no longer interferes with its power output or the proper speed of the wheels.

On a system where several plants are located on the same stream, the head operator has many problems which can be solved to the company's advantage by passing water from one reservoir to another, so as to produce the greatest kilowatt-hour output from the combined plants.

Plants Located on Different Streams. It will be readily observed that many of the same conditions and advantages that apply to several plants located on the same stream, apply to plants located on different streams. There are, however, some features in connection with low water and floods which should be considered. The question of low water can be handled much more advantageously when plants are located on different streams as it is rarely the case that areas of abnormal rainfall extend over different valleys and different parts of them to the same extent. The rainfall may vary a great deal even in the same valley, but this variation is always more pronounced in different valleys. Just as the effects of low water are minimized by having plants on different streams, so are the effects of high water. The floods that interfere with the operation of plants are the large ones, and it is a very rare occurrence to have a large flood on two different streams at the same time.

Effect of Low Water on a System of Plants. The low-water flow of any stream or streams in connection with a hydroelectric system operated in parallel, determines the value of the system. In the operation of plants located many miles apart not only can advantage be taken of variation of rainfall in different parts of the various drainage areas, but it is found possible to regulate the flow of water from plant to plant on the streams so as to produce the greatest power output.

In operating such a system of plants on the load in this territory, we are often enabled to lower the ponds or storage capacity towards the end of the week, refilling them on Sundays.

If an operating man has only one plant he dares not take any chances by lowering the water in the pond to too great an extent, the result being that he does not get the amount of power from the plant that he would if it operated in parallel with other plants.

As to just what this increased value of power output is cannot be determined except for fixed systems, but for any system in which there are as many as three plants, well located, it is safe to say that the low-water output can be increased at least 15 per cent.

Effect of High Water on a System of Plants. In the case of low-head plants, high water affects them very materially owing to the fact that the decrease from normal head is a large proportion of total head. On the other hand, the higher head plants are not affected so much. It very rarely occurs that all plants in a system are of the same head; consequently, the system would have an operating advantage in time of high water due to this reason. Also, in considering the flood action on a system of plants on the same stream, we must investigate the velocity of such a flood. There may be heavy rains in one part of the valley causing an excessive local flood that will not affect a plant located thirty miles or more below, and the upper plant can be put back into commission before the flood will affect the plant lower down, and so on.

Storage. It is evidently advantageous to have a chain or system of plants in connection with the storage of water. When the plants are connected together in parallel it matters not what size reservoir each particular plant may have, as all the water can be made available by the operator as if it were in one large reservoir. This, of course, will make it necessary for the operator to draw continuously on plants that have small reservoirs, using the plants with large reservoirs in cases of emergency or heavy peak loads.

Excess or Peak Load Capacity. In every plant it is necessary to have an overload or peak load installation, as no power service has a steady load at all times. In the construction of hydroelectric plants it is always found advisable to install some additional equipment for this purpose. The percentage of this excess capacity is necessarily greater in an isolated plant than it would be where several plants are connected together in parallel. In cases where several plants are operated in parallel the excess capacity can often times be installed in plants nearer the load, or in a more desirable place for operation, than would be possible if each plant had to carry its proportionate amount of reserve capacity.

Breakdown Capacity. It is well known to all operators that interruptions to some plant are liable to occur from time to time, due to breakdown or some defect which may develop. It can readily be seen that with a chain of plants an interruption at one plant would not be serious, as other plants on the system could be called on for overload or excess load during such an interruption. It often happens that some breakdown in one plant could be repaired much quicker if the whole power house could be shut down.

Auxiliary Plants. Due to the extreme variation of high and low water, one of the problems in hydroelectric development is to be able to get as much power as possible from a variable stream. If a plant is based and built on extreme low water, there is from six to twelve months in the year, varying of course with the rainfall, a great amount of surplus power. It becomes very desirable to make installations that will take care of as much of this flowage as it is profitable to sell. These variations are so erratic that they cannot be even approximately determined, and it is therefore necessary to install some auxiliary plants. When plants are operated singly it is generally necessary to place an auxiliary steam plant at the water power plant, and as water powers are generally in some out of the way place, the cost of construction and operation of the auxiliary is high. But where a system of plants is operated in parallel the problem of auxiliary plants is very much simplified. Plants may be located so as to take care of territories at the ends of transmission lines; or they may be in the midst of the largest power districts, thereby reducing the line loss; or they may be placed at a point where low freight rates on fuel prevail.

Variation of Load. The ideal load for any power system is one made up of a great number of different kinds of customers. The greater the territory over which any system operates, necessarily the greater the diversity of manufactures, and the nearer do we approach ideal conditions. The largest part of the load in this particular section consists of cotton mills, and although this is supposed to be a ten-hour constant load there is a variation on our different lines from week to week, due to the market demand for different classes of goods. To cite a particular case; a number of mills in one locality spinning coarse yarn may be shut down in the middle of the week, while the mills in another district, spinning fine yarns, may be running overtime, due to the demand for these particular goods; consequently, a system of plants will have a much better load factor than would be possible with singly operated plants.

Constructing and Operating Advantages. Another great advantage to the construction engineer while building on a stream on which some other plant is operated above him, is the ability to regulate the flow of the river while putting in coffer dams or difficult parts of the foundation. This, of course, would only apply to a plant located below one in operation, but it can be used many times during course of construction.

The advantages of operating a large transmission system are many and easily understood by the practical operating man. The operating manager is able to handle the system from one point to much better advantage than if it had to be operated from different points. He has a better opportunity of training his operating forces, as the men can be promoted from one department to another as they become proficient and familiar with the system.

We next come to the question of cost of attendance for a system of plants. The load in this particular territory is such that it does not require all of the plants to be in operation more than twelve hours a day. This enables the company to so man the stations that twenty-four hour shifts are not necessary in all plants.

ONE TRANSMISSION SYSTEM WHERE POSSIBLE

In the Piedmont section are many small growing towns scattered several miles apart and vying with each other in manufacturing. As there is a large territory to cover its calls for a high tension *distributing* rather than a high tension *transmission* company.

If parallel operation of generating plants is economical, desirable, and capable of better service to customers, why is not one transmission system best to serve a large territory? Let us consider the following problems in regard to the transmission system:

Ability to furnish better service.
Cost of transmission system.
Serving one or more generating companies.
Construction and operation.

Ability to Furnish Better Service. The matter of first consideration to the hydroelectrical engineer of any system, great or small, is reliability of service. If there are advantages in operating generating plants in parallel there must be still greater advantages in supplying customers from one general transmission system. The large transmission system presents many possibilities for belt lines and tie-in lines, which strengthen the service and which would not be possible on a small isolated system. Duplicate lines can be so laid out that while they are not built close together they eventually reach the same point. By this plan they reach and serve separate territories and come together at a fixed point, there furnishing duplicate service. In case of interruption to one line, power can often be furnished from another direction until necessary repairs can be made.

Cost of Transmission System. In the construction of a large distributing system the lines will probably cost more at first than those of the smaller system. As the country develops and the load increases, the relative cost will be reduced, so that the final cost will be less per kilowatt than for several small systems. There will be an increased cost, due to many switching and tie-in stations, but this, I believe, will be offset by being able to work the lines up to their full capacity. The larger systems will only add additional lines as the load increases to warrant their construction, while, on the other hand, it would be almost impossible to lay out the small system so as to use all the copper in the lines to best advantage.

Serving One or More Generating Companies. When a large transmission system is laid out to serve power consumers to the best advantage, it is an easy matter to tap the system and take on additional power from any new generating station.

The operation of a hydroelectric system resolves itself into three parts; generation, transmission and distribution. Any part is susceptible of being segregated so as to determine its pro rata cost or profit. This being the case, it will readily be seen that a large transmission system will furnish to the prospective builder of a generating plant a better market for the sale of his output than he would have if he determined to enter all three fields. It will make no difference to the distributing system whether the generating plants are owned by the same company or by different companies.

Constructing and Operating Advantages. Owing to the fact that most water power sites are in almost inaccessible places, the question of power for use during construction should be considered. If the plant is built with a view to operating in parallel with some other plant it is merely a question of building the transmission lines at first and using power from the completed plants for constructing the new ones. This has been worked out in actual practice and is found very desirable.

CONCLUSION

The advantages enumerated above which are claimed for plants operating in parallel are in the ultimate, economic ones, and this paper does not seem complete without some reference to the general conditions surrounding the water power situation at the present time.

We have already referred to the benefits to be derived from the proper location of the various dams on a stream, but even at this early stage of the hydroelectric art we find it necessary to consider conditions already existing. In many places we find the power of water falls has been partially utilized in a manner which makes complete development of their power almost impossible without destroying existing developments. We also find in many places a little fall above and below sites for development, covering several miles of river front, which is difficult to include. The development is often made to include only the main fall on account of the difficulty of acquiring the riparian rights for the total fall. Again, other obstacles are often encountered, such as highways or railroads which interfere with complete development, and a partial development is made without removing these obstacles which could often be done to the satisfaction of everyone. This is a very poor policy and is equivalent to wasting that much of available power.

Furthermore, almost every undeveloped water power is in some remote place difficult of access. This makes it necessary to provide some means of transportation for machinery and materials during construction. This item of transportation is a large part of the cost of development, especially when the plant is a small one. For this reason, if for no other, each of these developments should be considered very carefully with the idea of developing as large a power as possible, even if it is necessary to spend some time in getting additional water and flowage rights.

And here let me advocate the passage of liberal condemnation laws, so that anyone actually desiring to develop a water power could do so without being blocked by minor or unimportant interests, for up to the present time it has been found that one of the most difficult matters in connection with hydroelectric development is the acquisition of land and riparian rights.

This item represents about 10 per cent of the cost of development. Several of the states have passed condemnation laws, and other states, which have no general law, often give special charters allowing condemnation. While there is a tendency on the part of many people to object to this policy, it should be continued.

It is a well established fact that the growth of the country around a development is very rapid, increasing the taxable values not only by the amount invested in the development but also by the investment in manufacturing interests which follow them.

I know of no business in which as much money has been invested as in hydroelectric developments that has made such a poor return on the investment. Seventy-five per cent of the reports made on proposed hydroelectric developments are jokes. Moreover, the local papers, when a development is proposed or started, are eager to magnify the amount of power, the cost of construction and the value of the investment. The result is that the entire country has been trained to believe in a general condition that does not exist. Promoters have taken advantage of this condition, and many plants have been built or started that have proved failures.

The investigation of a proposed hydroelectric development requires a great deal of work and study by trained and experienced men, as there are more varying features entering into consideration than in any other branch of engineering. Most reports are made hurriedly without proper investigation, hence disappointment follows. The engineers who make these reports are not wholly to blame, for they are seldom allowed the necessary time or facilities to make proper investigation on account of the cost involved.

The standard for determining the cost of power to-day is based upon the cost of power produced from coal. As the supply of coal is consumed the cost of power will necessarily increase and a new standard of cost will be established. Any tendency to block or interefere with the development of water power is necessarily forcing the consumption of coal and hastening the day when the price of power must increase according to the law of supply and demand. I fear that many of our conservation advocates who are endeavoring to prevent the destruction of our natural resources are really hastening it.

We are all aware that our Government, which should publish carefully and accurately prepared reports, is contributing an influence which is not favorable to the early development of our water powers. Some laws have been passed, and still many more proposed, with apparently no other object than to stop further development. The public which has been taught that the investor is getting more than he should, endeavors to block development in every conceivable way. The result of these conditions is that the investor has been sorely disappointed and is ceasing to invest. In the meanwhile, a latent or dormant energy is running to waste, and we are consuming a limited coal supply which should be preserved.

The engineering profession should study these conditions carefully and exert every influence to place this matter before our Government and the public in its true color; thus only can we hope to utilize in the immediate future the vast resources of our streams with the greatest possible economy.

To my mind *true conservation* does not consist in postponing the utilization of power now going to waste, and which can never be regained, but rather in utilizing these resources at present that cannot be kept for use at a future time.

DISCUSSION ON "PARALLEL OPERATION OF HYDROELECTRIC PLANTS." CHARLOTTE, N. C., MARCH 31, 1910.

W. S. Lee: In describing some of the features that enter into the design, construction and operation of our plants here I have endeavored to present them in a general way—in a way which should be considered by every engineer who contemplates a large development consisting of a chain of power plants.

The questions that arise in this kind of work are not always strictly engineering problems. There are commercial and political questions. The problems encountered in this particular section were, principally, a great variation in flow, a scattered market, and a market for power that is used only for a comparatively short portion of the day. I believe that it will not pay to develop an isolated plant in this country, considering the rates at which we have to sell power and the distances over which we have to transmit the power, unless it is a very large one. It is true we have many small powers that can be developed and utilized close by, in cotton mills, many of which have their own plants, but when the transmission field is entered it will not pay to handle these small plants.

While these questions may not be purely engineering problems, they are problems which the engineers of the country must help solve. There is no question that whoever has to operate an isolated plant, with a variable stream, is not going to get power from that plant with the same confidence that he would if he had other plants which he could call upon, or some reserve power. We find that condition in actual experience. With due respect for my own operating department here, I find that it frequently saves the water, fearing that there will not be enough to last through the week, and as a result the water is wasted.

Chas. E. Waddell: I think Mr. Lee has well treated the subject of the economics of parallel operation of plants from the standpoint of the southern engineer, and he has equally well dwelt on the attitude of the public towards these developments. I think he is conservative in estimating the advantages of the investment have been as 5 to 1 wherever a large undertaking of this kind has been made in the South in the increased value of manufacturing sites, manufacturing itself, and of real estate in the vicinity, and I think he might well have added to the paper a corollary on the advantages of such a system to the consumer. Briefly stated these advantages are:

1. With a distribution system such as this, and the use of three transformers connected in delta, a customer has practically a duplicate plant at the cost of one; for, should a line go down or one transformer be destroyed, operation is still possible.

2. The inertia of the large system, once running, is so great that throwing on or off large induction motors does not materially affect frequency or power factor.

3. Uniformity of rates for installations of equal characteristics places all manufacturers on an equal footing, and if competition exists it must be based on factors of cost other than power.

4. The coöperation between a customer and the engineering department of the large hydroelectric companies insures the customer of engineering advice of a much higher order than a small manufacturer would ordinarily have at his disposal.

All of us will heartily agree with Mr. Lee in what he says about educating the public to the great advantages of these systems, and the necessity of passing laws that are equitable and fair and particularly to give the hydroelectric companies greater latitude in the matter of condemnation processes and the right of eminent domain. If I mistake not, it is a law in this state at the present time that power companies have the right of eminent domain for transmission lines. The legislators and the public at large already begin to recognize these interests are public utilities, and should be given powers that are ordinarily delegated to railroads and corporations of that nature. I think it is manifestly fair and right, and I think it is our duty as engineers—because we know both the public's side and the company's side of these questions—to educate the public with which we come in contact to realize the advantages of the universal development of our water resources, their harmonious operation to the advantage of all interests, to recognize the advantage of equality in the rates, and not block development by unjust or antiquated laws that apply to a former age and have no place in the century in which we now live.

Percy H. Thomas: I would like to ask Mr. Lee how the speeds of the various water wheels in the system is maintained, and incidentally, what provision is made for voltage adjustment. And a second question is as to operation—whether all lines of the same voltage are tied together and so protected that any line breaking down will be automatically cut out; or whether the plant and substations are operated in sections, so that if anything happens to one section the lines on this section can be thrown over to another section; or whether separate sections are maintained, the different sections being tied together by instantaneous circuit-breakers? These are three possible ways of operating such a system, and Mr. Lee's experience would be very valuable.

It is interesting to note to what a high voltage this plant is now carried, even though the distances to which power is being transmitted would possibly not demand so great a pressure. I believe it is a very wise arrangement; not only does it give greater efficiency and splendid regulation of voltage, but it provides a large amount of changing current which will tend to neutralize the effect of the inductance of the induction motors, and further will permit a temporary transmission of power through roundabout circuits in case of injury to some main line. Two or three times the normal distance might be traveled, under such circumstances, without causing any particular disturbance of voltage of serious transmission losses.

There is another side to the problem which Mr. Lee has presented, and which he has of course fully considered—how far is it possible to build up a load whose load curve shall follow that of the water power available. It is, of course, desirable to utilize storage to permit the use of every possible kilowatt-hour from the river, but it is also worth while to encourage the sort of load which follows as far as possible the power available. Possibly Mr. Lee would give us a few remarks on the limitations in the control of the load curve—these limitations, of course, are very great.

What is wanted is some way of using overflow power; as for metallurgical or electrochemical work, or some other way. The ideal arrangement would be some process which can be carried on at night, and which does not require a heavy plant investment; giving some product which has a good steady market value and which is easily shipped. For example, if some fertilizer could be manufactured at night with the overflow current, and shipped in carload lots to the country hereabout, it would be a very great advantage to the power system. Apparently, at the present time there is no such use for overflow power which is really practicable and available. It would seem almost certain, however, that in the future there will be found something which will be more satisfactory.

Considering Mr. Lee's discussion of the advantages of multiple power stations, not only do we gain from having a large number of hydroelectric plants in the same system, but we will gain, as the author has brought out, by having them widely distributed not only three consecutive power houses on one river, but having the power stations on opposite sides of the distribution area allowing the source of power for any particular load to be chosen at will.

Mr. Lee has spoken of the advantage in looking ahead in laying out a large power system. There can certainly be no question about the wisdom of that principle. I think it is also true that every big power system, like every other large undertaking, is an evolution, and must have its growth guided by its past experience; and if we start with a central idea which appears best at the time, it is not wise to determine conditions too far ahead, because conditions are likely to change, and it will be better to have the development flexible enough to take advantage of the situation existing at the time of action.

D. B. Rushmore: A feature of Mr. Lee's paper deserving of particular discussion is the use of steam auxiliary plants in connection with large hydroelectric systems where the power stations are developed to a point above the minimum flow of the streams. In a few localities, such as Niagara Falls, steam auxiliary plants are needed only as an insurance against breakdown of transmission lines. Such plants may, however, perform various functions, such as taking the peak loads, of supplying the wattless current of the system, etc. At the present time the development of a hydroelectric system necessarily involves the use of such steam auxiliaries.

A. M. Schoen: The points of advantage to be derived from the parallel operation of hydroelectric plants, as explained by Mr. Lee in his very able paper, are too self-evident to need discussion, but if these advantages accrue from tying together a single group of plants in a fairly circumscribed area it would seem that the extension of the same system over a wide area would accomplish results even more to be desired. One of the principal factors justifying the arrangement recommended by Mr. Lee is the fact that if, with several plants so grouped together, each stream takes its water from a different drainage area, there will be a greater tendency towards flattening out the primary power curve, thus increasing the salable primary power against the corresponding decrease in the secondary, as extreme low water in two well separated basins at the same time is unlikely, and this improbability continues to increase with the number of streams drawn upon and the increased separation of their drainage basins.

Take, for instance, one of the southern counties, the commissioners for which recently requested me to formulate specifications under which four competing hydroelectric power companies should be permitted to run their transmission and distribution systems. Two of the companies were located at adjacent points, on the same river, while the other two were supplied from entirely different streams, taking their rise and supplementary supplies hundreds of miles from each other and from the first river. Any arrangements between these four companies by which they might supplement each others' power in extreme cases would seem to be mutually beneficial, as such an arrangement would result in increasing the salable primary power to a greater or less extent for all four without calling for additional equipment, except in the pole lines, assuming, of course, that all were using the same voltage, periodicity and frequency. This serves to accentuate the particular point I had in mind when rising to discuss Mr. Lee's paper, namely, the need for conforming to some general standard when installing plants of this kind, for in my opinion, the time is coming when there will be some general working arrangement, even if the ownership is different, between plants of this character operated in the same section of the country. Indeed, it is hardly too great a stretch of the imagination to say that the time may come when sections rich in water power, such as the Piedmont section of the southern Appalachians, will be covered by transmission lines fed at intervals from the various power houses, thus creating one large interdependent system furnishing a maximum primary power supply to the country within reach, and under the most advantageous conditions both to operator and consumer; and should this occur, the next step in natural sequence when such relationship between the properties existed would seem to be an arrangement of dams across streams at judiciously selected points between the mountains, resulting in the impounding of these waters by means of artificial lakes and a consequent increase in the water stage of the streams affected with corresponding increase in primary power.

Carl Hering: Regarding the utilization of electric power from hydroelectric plants at such times during the day, night or year when there is plenty of water and a light load, there is probably no better way to utilize that power than for some electrochemical or furnace processes which can be started and stopped at prearranged times, and which require large amounts of power but must get this power very cheaply in order to make the processes commercial.

It seems to me that this has not been given the attention which it deserves. Such power could be delivered very cheaply, yet with great profit, as the cost of it to the producer is extremely small because this cost should be charged with only the difference between the cost of operating with and without this extra load. If power at such low costs were offered at prices agreed upon for reasonably long terms, it would probably find a sale when the offer became generally known.

Even a furnace might be operated during a limited period every day, if enough current could be obtained during the rest of the day to merely keep it hot; and when furnaces are designed and proportioned more carefully to reduce the heat losses, as they undoubtedly will be after it becomes known how to design them properly, these stand-by losses ought to be reasonably small. A case has been reported in which this was profitable even when coal was the fuel, and it would therefore be much more so when the source is an excess of water, and when it becomes possible to design the furnaces more correctly.

H. N. Muller: It might be of interest to the people here to know that power is now being used in the off peak periods in the Pittsburgh district for the manufacture of steel, or rather the refining of steel that has been preheated and somewhat refined in the open hearth furnace, or made from the scrap, at a cost of about one cent per kilowatt-hour for current. This has been carried on for over a year, and while I do not know what the manufacturers' profit has been on this steel, which is used principally for high grade tool steel, they are still completely equipped with crucibles, and I feel they would revert to the former methods if the electric furnace was not more profitable.

W. L. Waters: Mr. Lee's paper deals in a complete, though brief, manner with the fundamental engineering and economic questions connected with hydroelectric power distribution. The only suggestion I wish to make on this subject is that the induction type of generator should be considered more frequently for such installations. The disadvantage of operating a large number of small power stations, is the increased expense due to the attendance required for each station. In large city power stations it has been found more economical and advisable to operate power stations of 100,000 to 200,000 kw. capacity, when the conditions in regard to the magnitude and location of load justifies such a size. In a well distributed water power system such as Mr. Lee has referred to a power station of this capacity is usually impossible as the water power is not located at one point.

The induction generator consists of an induction motor operated above synchronous speed, and the advantage of this type of machine is simplicity of construction and operation. The induction generator does not require any direct current exciting system or complicated switching gear. In addition there are no governor or parallel-operation troubles and the units once put on the line can take care of themselves, the load being regulated by the governor of the prime mover. The objection to induction generators is that they require a wattless magnetizing current which must be supplied by the system. Just as an induction motor takes a wattless magnetizing current from the line and delivers mechanical power, so the induction generator takes wattless magnetizing current from the system while it supplies the watt component of the whole.

Two years ago I presented to the Institute a paper on the induction generator as applied to large power station work. In this paper I dealt mainly with the application of this type of generator to large power stations operating a considerable amount of synchronous apparatus, and the question of such units in connection with large water power systems was only briefly touched on; the reason for this being that there was practically no large overhead transmission system operating with the high voltage at which the Southern Power Company is operating at the present time. The possibility of operating large overhead systems at 100,000 volts changes the situation completely. Mr. Fraser states that the capacity charging current for 140 miles of the Southern Power Company's 100,000 volt line is about 7,000 kilovolt-amperes. These 7,000 kilovolt-amperes will supply the full load wattless magnetizing current for 20,000 to 30,000 kw. of steam-turbine-driven induction generators or about one-half that capacity of waterwheel-driven units. Mr. Lee will tell us the Southern Power Company expects within the next five years to have the 100,000 volt line so extended that the charging current will probably be increased to 20,000 kilovolt-amperes. If this is the case the overhead system would be capable of supplying the full load wattless magnetizing current for from 30,000 to 100,000 kw. of induction generators, the exact capacity depending upon the speed and the voltage at which they are operated.

The commercial history of the induction generator has been comparatively brief. The first application of any size was a

1200-kw. unit installed in the Baltimore Copper and Smelting Rolling Company's plant about six years ago, while recently three larger units have been installed in the Interborough Rapid Transit Company's power station in New York City. The generators in both of these installations supply power to rotary converters which transform the alternating current to direct current. The induction generator appears to have been somewhat neglected in the past because the conditions were not favorable to its adoption. The necessity of a wattless magnetizing exciting current which must be supplied from the system, is a great disadvantage in a number of cases. But with large city power stations operating synchronous apparatus, or an extensive high voltage overhead transmission system, with large capacity charging current, the conditions are much more favorable to this type of generator. In any system such as that of the Southern Power Company the arrangement suggested would be; synchronous units installed in one or two of the large power stations and induction generators in all the smaller stations. The generator units in the smaller stations would run continuously on the circuit without attention, the governor of the prime movers regulating the load, while the voltage on the system would be controlled from the large synchronous power stations. The suitability of the induction generator for any such system would depend to a great extent on the speed at which the units operated. the voltage for which they are wound, and the power-factor of the load on the alternating-current distribution system. And, in any case, the advisability of adopting or not adopting such an arrangement of induction generators in any large complicated system such as that of the Southern Power Company could only be decided after the system has been laid out in detail, and all the economic and engineering features been given due consideration. My object in bringing forward the induction generator at this time is not that it is considered advisable to adopt this type of generator universally in such installations, but that as conditions are gradually changing and becoming more favorable to the adoption of this type of unit, it now deserves more attention than it has received in the past.

Chas. F. Scott: Mr. Lee's paper besides presenting the general conditions confronting the Southern Power Company, shows also a new stage in the development or evolution of electrical transmission.

The high tension transmission system of several years ago consisted of a generator, raising transformer, line, and a lower transformer with some distributing lines. The transmission system consisted of a single transmission line from one generator to one substation. More complicated designs rapidly developed. In one type a number of power plants supplied a single point; possibly Los Angeles may serve as an example which receives incoming power from several directions. Then, again there is another type in which power is generated at one point and is distributed by various transmission lines in different directions, each of these lines supplying stations at various points en route; Niagara Falls is typical of this condition.

In the case of the Southern Power Company we are apt to think that operating at 100,000 volts is its great feature, but a statement of Mr Lee's shows that there is something more notable. He says now that this is not a high-tension transmission system, but a high-tension distribution system. There are many scattered power houses, and many distribution centers.

A number of years ago, when the Niagara plant was being laid out and great interest was concentrated on the generators of mammoth and unique form, one of my colleagues, who was engaged in the development of switching apparatus, made a remark which struck me on account of its originality and novelty. He said that the great difficulty and the big problem in large electrical work would not be in the generators, but in the switching and controlling apparatus.

I have thought of that remark many times since, and I believe it is more true to-day than when it was first spoken. In a plant with high-pressure circuits and many receiving and distributing points, such as has been described this morning, the problem of switching and controlling apparatus constitutes the large electrical problem. So that this plant illustrates, not only the new commercial-political relations, as Mr. Lee has pointed out but also marks a new stage in electrical operation and the types of apparatus which are required.

In brief, the operating conditions, the inter-relation between stations and operators, involving such questions as those Mr. Thomas asked, and such questions as Mr. Waters brought out a moment ago in their discussions—these are the large and important elements upon which the success of the plant will depend.

The relation of electricity to the conservation of energy is one which has received attention at the hands of our President in one of his papers before the Institute, and it seems to me Mr. Lee has brought out some features which are descriptive, in a large and broad way, of the larger service which electricity will have in the conservation of our natural resources. It not only saves the waste of water power and enables it to be utilized, but by entering into a whole region, by making a power system of a whole state, it equalizes the different variables which occur in the operation of each individual system which Mr. Lee has pointed out. Now, by interconnecting many plants into one general electric system covering the whole stage, these individual elements or variations can largely be wiped out, and we can get that general average which means the highest general efficiency, so that we equalize power, and we save power, and furnish a better and cheaper power, as was brought out in the discussion yesterday.

With regard to the relations of the engineer to the general problem, I would almost disagree with Mr. Lee, when he apparently limits the function of the engineer to the purely technical problems. He says in the beginning of his paper that some of the problems are commercial rather than engineering. Taking our natural resources, and applying them most efficiently under the conditions which exist, I think, like most of the things which he has brought up, can properly be placed under broad engineering. I think he is right also in stating that the proper way for engineers to handle the large conservation problem is by attacking the problem in a large way and getting efficient results. And I believe that the general common sense of the American people is such that they do not object to having things done in a large way on a sound engineering basis, but what they do object to is having them done on a false and unjust social and commercial basis. Our commercial and political friends should recognize the same kind of standard that the engineers work to, high efficiency, the greatest good to the greatest number, on a fair and just basis; in fact engineers are setting the standard of principles which should be adopted in commercial and political life, as they must practice them in their professional life.

In talking with one of the older men in this community, who has seen things build up in the South for many years, and in speaking of the new life which has come to the district, and the new methods in cotton mills, he said that pioneer work of this kind requires imagination, initiative, and nerve. He said that is what the Southern Power Company has, and I am sure we all agree with him.

Edw. W. Shedd: Mr. President and gentlemen, I have been exceedingly interested in the paper that has been presented by Mr. Lee, and I desire to offer just one suggestion which I think has not been touched upon in the discussion, but which Mr. Lee brought out in his paper, and that is the great importance of the question of transportation; and I am sure that you will all agree with me that that is a question of transcendant importance, and it is a question which must be met and worked out if the fullest development of our southern water powers is brought to pass, and it is a question which I think works in most uniformly and nicely with the question of hydroelectric development.

For nearly two years I have been working in this territory, purposely selecting the territory in which the Southern Power Company is operating, upon a system of railways which is designed to meet the needs of the territory as regards transportation, and which I think in the near future is bound to be built.

I want also to emphatically endorse the suggestion of Mr. Lee and others who have discussed the paper as to the value and importance of engineers and every one else educating the public, especially perhaps the political public, as to the advisability of giving to these quasi- public corporations sufficient rights, particularly in the way of eminent domain, to enable them to carry out all their important developments which are in progress. It seems too bad that many valuable developments are held back by the narrow mindedness of some one man who thinks he has a big corporation to deal with; he will get fifteen times the value of his land, just because the corporation wants a right-of-way through it. Such procedure holds back development in many cases. It is the duty of every electrical engineer and civil engineer, lawyer and banker, to try to educate the public and to work with the legislators, so that a broad-gauge policy can be followed in these matters.

Speaking directly to the point, it has been suggested that we should develop something that would use the water power when the hydroelectric companies have a surplus of water, and when it is not being used for other kinds of business. It has occurred to me to-day, and it has occurred to me many times before, that one very large use, possibly of this power in the night time could be developed by operating a system of railways, particularly in the section of the country in which the Southern Power Company and other hydroelectric plants are operated, hauling the freight in the night. A large amount of power can be used at night in hauling freight, for I see no reason why the freight business could not be done in the night time when there is a surplus of hydroelectric power available. It is my purpose to use hydroelectric power for the operation of railways in the district of the Southern Power Company, carrying freight at night.

Perhaps this is not the place to bring it forward, but the idea has occurred to me that it might be desirable, if it were constitutional to subsidize such industries as water power developments, railways, etc., in the way, possibly of exempting their bonds from taxation. It might be possible in this way to induce the banks and trust companies in the south, which are pretty well supplied now with money, and find difficulty in lending it, to take some of the bonds, of these enterprises as this would make them more attractive as an investment.

It has occurred to me that this might be done by the partial or complete exemption of taxation on bonds issued by hydroelectric plants, and on railways, exclusively within the state of North Carolina, and held, perhaps, exclusively by investors residing in the State of North Carolina. It looks to me as though something of this kind could be worked out very satisfactorily, and this would make the railways and the hydroelectric plants, as you might say, a board of trade, which would be working for the development of the entire country, and at the same time furnish a more attractive investment for the money on deposit in North Carolina, to be used only in this State, and in other states, if such states do the same thing.

President Stillwell: Mr. Scott has already referred to the first of the points which I noted in listening to Mr. Lee's paper, namely, his apparent contrasting of the ideas of engineering considerations and commercial considerations. Engineering, as I understand it, when applied to the solution of these large industrial problems, means the application of commercial business judgment, reducible to terms of dollars and cents, to those problems; that application being based, however, upon special study of the technical underlying problems which are essential as a foundation for the general solution. I think if we were to use the words "technical" and "commercial," in making a contrast, rather than "engineering" and "commerical," we should place the matter in about the right light, because we do not want the community to get into the habit, which I am sorry to say it has acquired in part, of looking upon engineers as men who are incapable of drawing practical deductions. The engineering which is of the broadest kind, is precisely the kind which Mr. Lee himself, a member of the Institute, is carrying on. He has applied broad business judgment, based on technical knowledge, to the solution of industrial and commercial problems. Immediately, that raises a question of engineering responsibility, and that is a point I want to say a word about.

We have now throughout the country an abnormal number of hydroelectric enterprises in the hands of receivers. In every case that I have had occasion to investigate or have learned about, and I have come in touch with a number of them, the failure has been due to the fact that at the outset the proper kind of commercial-engineering brains were not brought to bear on the problem. I do not know an important case where the thing that caused the enterprise to fail could not or should not have been foreseen. Engineers are too apt to allow themselves to be hurried and pressed by the promoter. In one important case where an estimate had to be revised to an extent which involved the raising of about $2,000,000 in addition to the original amount provided for by the financiers, I am told that the engineer made the excuse that he was allowed only one week to investigate that problem. That excuse is an indictment of the engineer himself. Any man who could undertake to pass on a matter involving large amounts of other people's money, or small amounts, on a matter of such magnitude, in such a short time, ought to resign from the engineering society and get out of the business. He does not belong there.

Mr. Lee made reference to the subject of condemnation of rights for transmission lines, and also of the lines which are essential to the hydroelectric development. Now, there is a point where I believe we can use our influence, not collectively, perhaps, but individually with our congressmen and friends in the legislatures, in a perfectly proper manner, and in a manner that will redound to the benefit of our engineering organization and of engineers as individuals and of the community at large. We have in the country two classes of public utility corporations, aside from those which have to do with the cities, the gas companies and the railways, and now we have to do with these great transmission and distribution systems utilizing water powers. The railways have the right of eminent domain. In general, the power companies have not. Is there any possible reason and logical common sense why they should not have this right? The gross earnings of the railways of the United States are approximately $3,000,000,000, a year. The gross value of our manufactured products is approximately $20,000,000,000 a year. This utilization of power means a general tendency to decrease the cost of the manufactured product. It also means in many cases, and in more cases to come, a reduction in the cost of transportation. Economically considered, therefore, every reason that exists for conferring upon the railways the right to condemn, exists with increased force in the case of the power companies distributing energy for the very many purposes to which the community applies it. Now, this question of natural monopoly must be met, and we must meet it with an effective answer. As citizens many of us are lined up on that side of the question, but we have to face the fact that, at any rate, there is going to be in this country government regulation of rates, especially the rates of public utility corporations. The right of the state has already been upheld in the case of the Consolidated Gas Company in New York, where the decision of the supreme court of the state of New York was appealed to the United States supreme court, and in that case it was definitely decided by the higher tribunal that the state has the right to regulate rates. Now it seems to me that the answer to give to those people who are objecting to a natural monopoly in water power is this—that it is absolutely unnecessary to retard the development of these enterprises at this date, for the reason that just as rapidly as they place themselves in the position where they are imposing upon the community by charging excessive or unfair rates, the state is in the position to intervene and regulate these rates. This practice of conjuring up something that might happen in the dim and distant future in the way of fixing rates is too remote an excuse for justifying any possible retardation in the forward movement of this extremely important conservation, because conservation is, in this case, most emphatically utilization; but we must have our answer, and the answer is not that our rates are moderate—they won't believe it. We can give that answer to those who will believe it, but most of the people will discount such a statement; but our answer should be this—that just as soon as this is a real danger, and not an imaginary one, the state can intervene, as established by the decisions of the supreme court, and fix just and equitable rates.

I think it is the duty and a part of the business of engineers to take a hand in public affairs. I do not see why 20,000 engineers in this country should sit back and let other people, five per cent of whom do not understand the facts necessary to the commercial solution of these problems, pass upon them, while the engineers sit on the fence and watch them do it. The engineers should get into the game early and meet the people who are interested in these things in a social way, and otherwise, and endeavor in every possible way to educate them. That is what they need. We have talked with many of them, including Mr. Ballinger and Mr. Pinchot, and have seen none of them who do not admit that they need ideas in regard to the practical, technical and economic bearing of some of these questions, which some of us are able to give them.

W. S. Lee: Referring to Mr. Thomas' remarks, he asks about the speed of wheels. We have on the system different heads, different size ponds, and consequently the plant with the small ponds must be run a longer number of hours, and in the case of the larger ponds a shorter number of hours, but with a larger peak load. All the waterwheels permit a certain variation of head and maintain the same frequency. We endeavor to reduce these heads as little as possible, it being our practice in extremely low water to put in our steam auxiliaries in the early part rather than in the latter part of the week. While originally we had the idea that we would run the water as long as we could, and at the end of the week put in the steam to help out the week's load, we find by keeping the head up in the earlier part of the week we get more power out of the system.

Mr. Thomas also asked about voltage regulation. In order to meet the conditions with which we were confronted, that is, differences in voltage, we got out a standard set of specifications giving a list of taps which we were to have on all of our high tension transformers. This calls for a higher voltage to be run on the plant during the time of our heavy load hours. When the load goes off the cotton mills at six o'clock in the afternoon, the voltage on the whole system is lowered. This takes care of the drop in voltage in the line, the transformers being tapped with reference to the distance from the power house. The line which it is hardest to control the voltage on is the line that is not loaded.

Mr. Thomas also asked some questions about sectionalizing the system. I will say that that is a question which I have been dodging in a way. We have certain lines that go to stations or distributing points. We term them switching stations. From these switching stations the lines may branch out into a greater number of lines to cover different territory. We then go on to another point and break the line up into several more lines, supplying different points. All of these stations are provided with automatic switches or fuses. We can sectionalize the different parts of the system from time to time, putting one plant either on one side or the other.

Mr. Thomas also is rather disposed to criticise the voltage we are going to, but I do not think I will answer that because he answered that point himself. He stated that perhaps it would be a good thing to use these higher voltages to run around and come back over greater distances, where there might be a reason for doing this. That is what Mr. Burkholder does. It is fifty miles from here to Great Falls, and Mr. Burkholder does not hesitate to take the current to Salisbury and back again, and by the time it reaches Charlotte it has traveled 150 miles.

Mr. Thomas also asked some questions regarding the distribution of load. That is a question we do not know how to answer. You may have an idea that one particular section of this system is going to develop and you will be surprised to find some other develops much faster.

Regarding the remarks he made as to the location of plants on the outskirts of the district, that is not possible, because the bulk of the power is brought up country and there may not be any water power in that particular district.

Mr. Rushmore referred to steam auxiliaries and synchronous condensers. In connection with that, I will say that we are now installing some of this apparatus at Greenville, South Carolina; we are installing a 10,000-kw. steam-turbine, which will operate as a synchronous condenser, and we are arranging to install another similar set at a point we have not yet decided upon, which will have a capacity of 6,000 kw.

A paper presented at the Charlotte meeting of the American Institute of Electrical Engineers, March 31, 1910.

A PRACTICAL METHOD OF PROTECTING INSULATORS FROM LIGHTNING AND POWER ARC EFFECTS

BY L. C. NICHOLSON

The problem of adequately protecting a high-tension transmission line against injury by lightning is an important one. Various solutions have been proposed, but it is generally conceded that complete protection of high-tension porcelain insulators from destruction by lightning effects has not been attained. Grounded overhead conductors, relief gaps on insulators, lightning rods supported on the transmission line structures or on separate structures alongside, and station-type lightning arresters at points particularly exposed, are some of the principal preventive devices employed, any of which serves to ameliorate conditions, but none of which affords ideal protection to the line.

The 60,000-volt transmission lines of the Niagara, Lockport and Ontario Power Company from Niagara Falls to Syracuse and other cities in western New York, were placed in operation in July, 1906, just in the midst of the lightning season, and without any of the usual methods of line lightning protection. Troubles developed which, though not unexpected, proved of serious consequence to the successful transmission of power during lightning storms. There was little opportunity in that season to adopt any corrective measures, either experimentally or otherwise, but in the following years the company has exerted every effort to ameliorate these troubles.

The experience of four years has served to indicate something of the real nature of lightning effects which result in insulator failures, and has led to the development of an inexpensive and efficient means of protection. The object of this paper is to relate the experiences and experiments leading to the protective measures finally adopted, which from one summer's trial appear to be sufficient.

This plant was thoroughly described by Mr. Ralph D. Mershon in a paper presented at the Niagara Falls Convention* June, 1907. For purposes of reference, Fig. 1 shows the extent and description of lines, the connection and approximate capacity of the stations.

Figs. 2, 3, and 4 show types of line structures employed. In all cases insulator pins are of steel and are grounded.

Fig. 5 shows the principal insulator used, and, with the exception of a few smaller ones of the same general design, the only type of insulator employed until 1909. This is known as the "3-part main line" insulator. Its principal dimensions are:

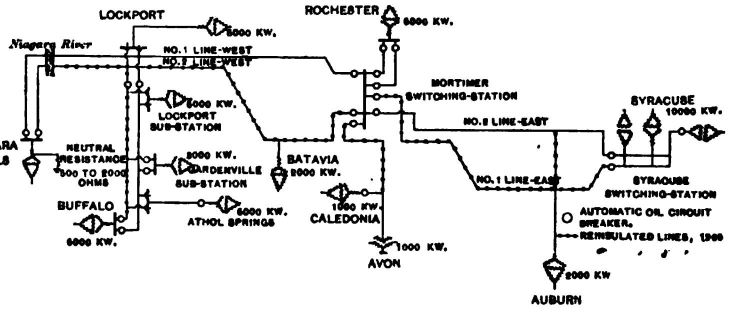


FIG. 1.—Diagram of transmission lines and stations—1909

Diameter of headpiece, 14½ in.; diameter of intermediate shell, 13 in.; diameter of center shell, 11 in.; length of intermediate shell, 12 in.; length of center shell, 17 in.; height over all, 19½ in. The dry flash-over voltage, that is, the voltage which will cause a flash-over when the surface is dry and clean, is 195,000. The wet flash-over voltage at 1/5 in. per minute precipitation at 45 degrees is 120,000.

Electrical tests on these insulators before their erection on the line consisted of 75,000 volts, three minutes on each part before assembling. The complete insulator was not tested after assembling.

During 1906 only one line was in service to various points. By the beginning of the lightning season of 1907 the second (duplicate) line was placed in service, making a total mileage

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* TRANSACTIONS A. I. E. E., Vol. xxvi part ii, p. 1273.

of 400, containing 7000 structures and 23,000 insulators. Except for the addition of a few single branch lines from time to time, the lines have been virtually the same for three years.

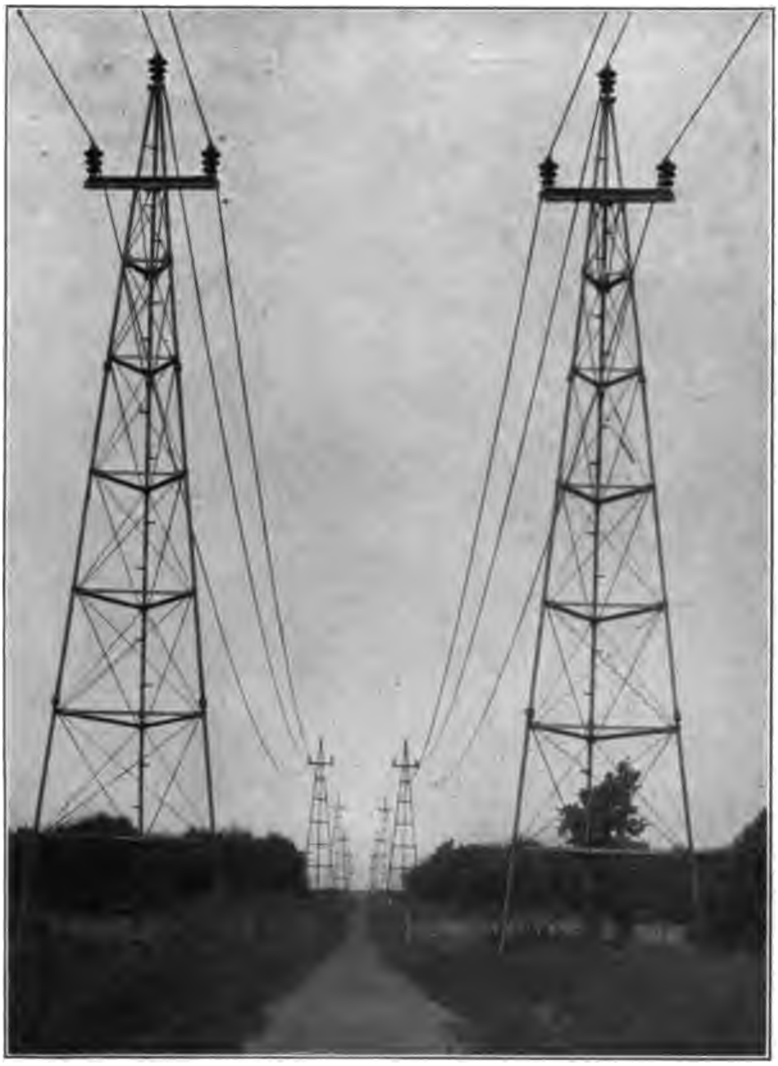


FIG. 2.—55-ft. tripod pipe towers

Switching facilities and general operating conditions, however, have been constantly improved. Since early in 1908 automatic oil circuit-breakers have been used in the duplicate lines at all important stations and paralleling points, making possible automatic sectionalizing of lines and a quick restoration of power in case of an interruption.

Lightning troubles have been entirely confined to the line. No station troubles, chargeable to lightning, have developed.

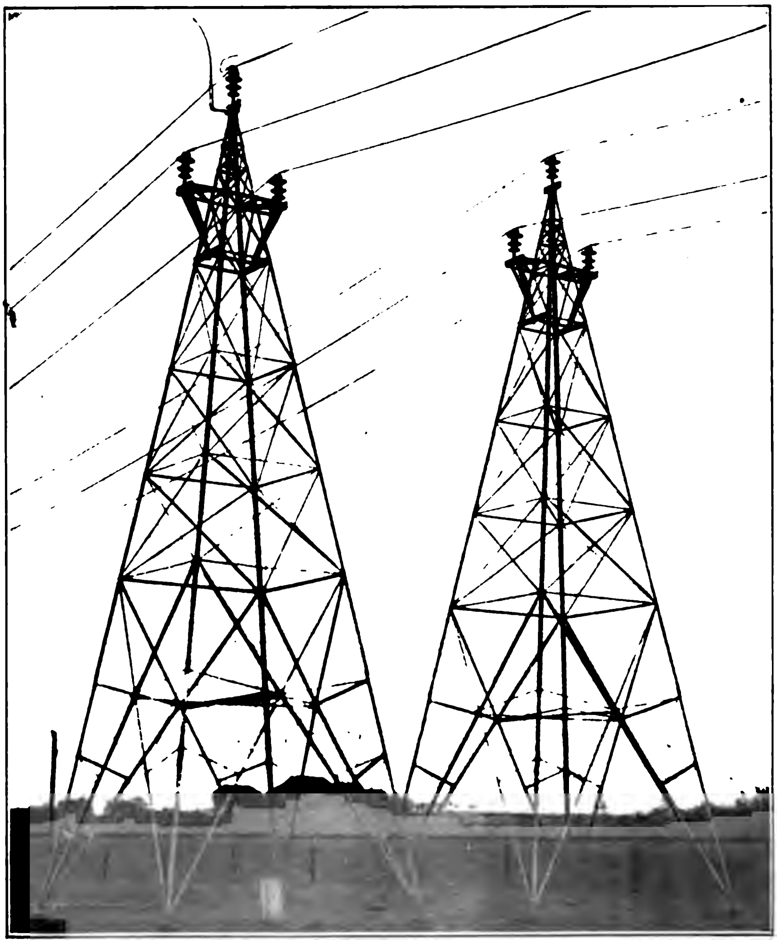


FIG. 3.—55-ft. structural steel towers, showing a relief gap, as used in 1907

Experience clearly shows that lightning in the vicinity of the line induces high potentials between the line conductors and earth. This potential causes one or more insulators in that immediate vicinity to flash over or puncture, or to be shattered in some part or parts, even though no flash-over or puncture occurs, or to be shattered by the power arc following the initial flash-over or puncture. These various causes intermingle their effects so as to obscure the first cause. Thus it has been found that insulators may be shattered completely either by pure lightning stresses, or by the heat of a power arc

FIG. 4.—35-ft. wooden A-frame structure

which follows the initial discharge from conductor to pin over the outside surface. Moreover, an insulator may puncture by lightning, and subsequently be shattered by the heat of the power current passing through the puncture, in which case it is impossible to say whether the puncture preceded the shattering or vice versa. A fairly concise idea of the nature and magnitude of the destructive forces may be gained by a study of the broken insulators in place.

Fig. 6 shows a collection of twenty derelicts, resulting from a single severe storm, and gives a fair representation of how insulators are destroyed by lightning in combination with high-power effects.

The usual caes of line disablement involves a single insulator, which is either punctured from the cable or tie-wire to the top of the pin, or, being sufficiently strong to resist puncture, is broken by the flashover arc. Frequently several neighboring insulators are more or less damaged by what appears to be the effect of sudden mechanical forces which shatter or break the shells very much as a hammer blow would destroy them.

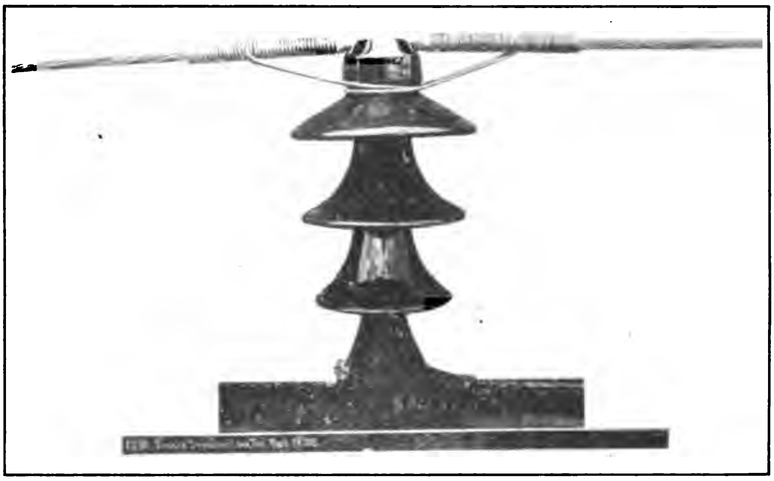


FIG. 5.—3-part main line insulator

Extreme cases infrequently occur when many insulators in a restricted locality are entirely destroyed. Such disturbances usually center at a particular line structure on which all the insulators may be entirely destroyed, and one or more insulators on several adjacent structures in each direction destroyed or injured, the injury decreasing in severity away from the focus. Even in the most severe cases, however, the entire effect is confined to within 2,000 feet of the line. Such accidents are atuttribed to direct strokes on or very near the line. The mechanical forces exerted on insulator parts in such cases appear to be enormous, breaking the porcelain into small bits of irregular and curious shapes, and distributing them over the right-of-way for several hundred feet. Fortunately these extreme cases are of rare occurrence and do not enter largely into the lightning protection problem.

Just where direct stroke effects leave off, and just where induced potential effects begin and end, is, of course, indefinite. It is definitely known that a stroke 500 feet distant may cause a flash-over or puncture. It is thought that disturbances may be felt from bolts 2,000 or 3,000 feet away, this being also determined by the size of the discharge, and perhaps by electrostatic conditions in general.

FIG. 6.—Insulators removed from the line after damage by lightning and power effects

The insulator problem as outlined above presented itself by the end of the lightning season of 1906, although at that time its nature was not appreciated as fully as it became later in the light of the subsequent experience. Thirty-five insulators were disabled by puncturing or shattering, out of a total of 12,000 installed. These breakages occurred on eight different occasions and consequently caused as many extended interruptions to parts of the service. In addition, there were ten momentary interruptions caused by short-circuits or grounds which tripped the controlling circuit-breaker, but did not disable the line.

Analysis of the insulator failures with respect to their location showed a very remarkable result. The number of insulators disabled on the top wire was four times the number disabled on a single side wire, or twice the number disabled on both side wires.

This result formed a basis for corrective measures which were taken previous to the lightning season of 1907. These devices consisted of relief gaps installed on insulators at regular intervals on the top wire of both duplicate lines, and the installation of high resistances in the neutral earth connections of star-connected transformers. Fig. 3 shows the type and construction of the relief gap which was employed.

These gaps were spaced 2200 feet on approximately 240 miles of line and 4400 feet on 100 miles, while on 60 miles no gaps were installed. At the time of selecting these spacings there was very little data for guidance. The only definite information available was that during 1906, before the lines were used, insulators were destroyed within a mile of a point where all three conductors were short-circuited and thoroughly grounded. The 2200- and 4400-foot spacing of the relief gaps on the top wire was adopted in an experimental attitude, the intention being to increase or decrease these distances as future experience dictated. The width of gap first adopted was six inches, corresponding to a discharge voltage of 70,000 volts, depending more or less upon weather conditions. This was also a subject of experiment.

It was intended by proper spacing and setting of the relief gaps, to limit the maximum possible voltage between top conductor and earth to less than the puncture or flash-over value of the insulators, and thus prevent the failure of insulators on the top wire due to the usual lightning effects. It was also expected that when discharging through the relief gaps, the top conductor would act to some extent as an overhead grounded conductor, and in this way afford some protection to the two side wires. An adjustable concrete resistance of 500 to 2000 ohms was connected in the neutral earth connection of the sending transformers, and 5000- to 10,000-ohm resistances at five different sub-stations in the neutral earth connection of star-delta connected receiving transformers. The purpose of installing these resistances was primarily to limit the discharge current to earth from the top wire through the relief gaps to a value which would not disturb operation, and the arc of which would quickly follow up the horns of the gap and discontinue. In the same way it was thought that these resistances would limit the power-current over an insulator containing no gap, in the event of a flash-over, to a value which would not work such havoc to the insulators as had formerly occurred when operating the system with thoroughly grounded neutrals. The 5000- to 10,000-ohm sub-station resistances were, of course, not necessary to attain the end sought. They were installed as a precautionary measure against abnormal potentials which might accompany grounds on the system. Their use was later discontinued, all neutrals except that at the generating station being insulated.

The operating results of the lightning season of 1907 did not fully justify the use of the relief gaps from a theoretical standpoint, and showed them to be rather an objection than an advantage from a practical operating standpoint.

It was early apparent that the gaps perfectly protected the insulators containing them, but that their protective influence was felt very slightly a short distance away on the same conductor, and was not felt at all on the two lower conductors. This was true with gaps set as low as 4½ in.

The following tabulation shows the season's results:

	Insulators disabled on top wire	Insulators disabled on both side wires
At a relief gap	0	6
220 feet from the nearest gap	2	3
550 feet away	15	17
1100 feet away	11	13
2200 feet away	4	1
On a 60-mile section containing no relief gaps	9	5
	—	—
Total	41	45
Grand total		86

Insulators on line—23,000.

Relief gaps on line—750, approximately 25 per cent of which discharged one or more times.

These results demonstrate the extreme localization of lightning effects and the difficulty with which the charges travel along a conductor.

It appears from this table that the net effect of the use of the gaps was to save some insulators on the top wire. The number of line breakdowns was not reduced, while voltage disturbances and momentary interruptions were numerous. For this reason the relief gaps were removed before the lightning season of 1908. The grounded horn was left in place to act as a lightning rod. The concrete neutral resistance at the generating station was retained to prevent short-circuits between any one phase and ground.

A study of the insulator failures of 1907 showed that the majority of them were due to puncture, usually from the tie-wire in the neck to the top of the pin. A few punctured vertically from the cable to the pin. Approximately 25 per cent, and perhaps more, were shattered by power arc following a complete or partial flash-over. Comparatively few, it is believed, were shattered by direct stroke, although about 40 were injured by lightning stresses, but were not incapacitated thereby.

In view of the large proportion of punctures, it was decided to apply high potential to the lines and to weed out the weak insulators. This proved to be a slow and expensive process, so that very little was accomplished before the advent of lightning in 1908. A three-minute test of 100,000 volts to ground was applied to 109 miles of line containing 4000 insulators, and resulted in the puncture of 80.

These tests showed what there was already good reason to suspect, *viz.*: that the insulators were not tested sufficiently before erection, and that many of those on the line could not resist lightning stresses, and some were liable to fail from abnormal voltages incident to operation. As stated above, the insulator parts were tested to 75,000 volts each, but no test was made on the assembled insulator.

The lightning season of 1908 was a particularly severe one, resulting in the destruction of 226 insulators and the injury of 100 more.

The failures may be classified approximately as follows:

1. Punctured:

Top wire	75
Side wires	39
Total	114

2. Shattered by direct stroke:

Top wire	22
Side wires	9
Total	31

3. Shattered by power arc, following flash-over:

Top wire	56
Side wires	25
Total	81

The 100 insulators which were injured were damaged by lightning stresses, or by power arc effects. They were still operative, however, and were replaced at convenience.

The lesson of the year was not new, but it showed more forcefully than had been realized before, that even if all insulators were capable of resisting puncture, they would continue to be shattered by a power arc following a flash-over. It was argued that by the proper testing of all insulators puncture could probably be prevented, but the fact that such a large number had been already destroyed by flash-over gave little reason to suppose that insulator losses and line interruptions could be materially reduced by providing puncture-proof insulators. They must be also fire-proof.

The only practical way of making the insulators puncture-proof was to remove them from the line, test each one to its dry flash-over voltage and return the perfect ones to the line. There was some question as to whether or not such a test would be effective, since an insulator which would flash over under 25-cycle voltage from a testing transformer, might puncture under the sudden attack of a lightning shock. However, the fact remained that insulators, presumably sound and dry, had flashed over in service because of lightning, rather than puncture, and this justified the belief that a 25-cycle dry flash-over test was sufficient. Subsequent experience has verified this conclusion.

A device for rendering insulators fire-proof, or rather proof against injury by power arc in the event of a flash-over, was developed to meet an obvious need. As shown by Fig. 7, this device consists of two metal rings concentric with the insulator, a lower one which is situated near the base being considerably larger in diameter than the insulator parts, and supported by grounded metal risers attached to the pin; and an upper one somewhat larger than the neck of the insulator, just opposite the tie-wire, suspended from the transmission cable, and electrically connected to it. Details of construction are evident from the figures.

These rings serve as electrodes, to which the power arc automatically transfers immediately after its formation between the tie-wire and pin, over the surface of the insulator. When holding between these rings, the arc is removed sufficiently from the insulator to prevent injury to the porcelain by heat.

It was determined experimentally that the intense and concentrated heat at and near the ends of a large power arc is largely responsible for the damage wrought. This is particularly true of the lower terminal which passes up the pin to the heart of the insulator and shatters it. In other words, the insulator is broken from the bottom upward, by the lower end of the arc. The upper terminal, located on the tie-wire, is not so destructive, on account of the tendency of the arc to flare upward and away from the porcelain. If, however, the very crater of the arc comes into actual contact with the porcelain, by reason of being located on the nether side of the tie-wire, or by reason of burning the tie-wire in two, which it may do if it remains at a single point, the headpiece of the insulator will be broken.

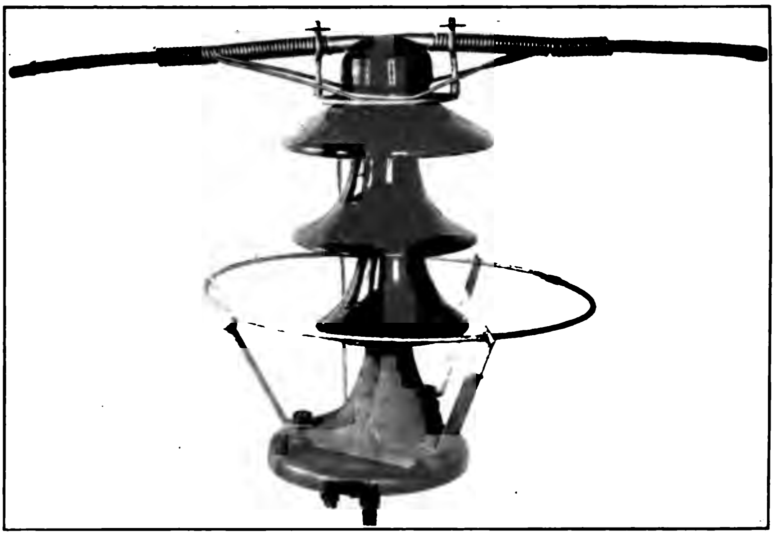


FIG. 7.—Arcing rings, to prevent injury to insulators by power effects

Considerable experimenting with high power arcs showed that the lower portion of the arc was averse to assuming anything like a horizontal position. It very much preferred not to make the bend about the base of the insulator to reach the pin. Thus, it was found that the lower arcing ring would take the arc immediately after its formation to the pin, (which was accomplished by means of a fuse from tie-wire to pin, placed well up under the insulator parts) almost irrespective of the location of the ring with reference to the base of the insulator. On a quiet summer day, with practically no air movement to drive the arc away from the insulator, and naturally cause it to attack the ring, it was found that the arc instantaneously transferred from the pin to the lower ring, even though the ring was 20 in. larger in diameter than the base of the insulator, and as much as 4 in. below the base. The flaring nature and large size of these arcs, together with their tendency to assume an upright position afford the explanation of these results.

In the absence of wind it was apparent that the arc traveled rapidly from place to place around the insulator, and did not remain in any one place long enough to burn the tie-wire seriously. For this reason the headpiece of the insulator did not suffer, except perhaps to lose a little glaze. Under wind conditions, however, the arc hides behind the insulator on the leeward side and remains at or near one place on the tie-wire, sometimes burning it in two, and by coming into actual contact with the porcelain causes a breakage of the headpiece, but only the headpiece. The cure for this condition proved to be the use of a second ring about the head of the insulator, separated at all points from the porcelain. It was located just opposite the tie-wire, and of sufficient thickness fairly to resist serious burning.

Numerous tests were made, using as high as 30,000-kw. generator capacity, which under the short-circuit conditions of the test delivered 1200 amperes at an initial voltage of 60,000. In no instance was an insulator when equipped with both arcing rings damaged to the slightest extent. Fig. 8 is a night photograph of a 30,000-kw. arc. An insulator with arcing rings, in the midst of the fire, does not show. It was perfectly whole and fairly cool after this experience.

A typical case showing the manner in which insulators are destroyed by power arcs is shown in Fig. 13, which depicts an insulator destroyed in service by a power arc following a flash-over by lightning.

The possible damage to the transmission cable by burning in the event of the upper terminal of the arc traveling out along the cable, owing to wind blowing in the direction of the line was fully dealt with experimentally, with and without arcing rings. It was found that a breeze of 3 miles per hour (estimated) parallel to the line was sufficient to drive the arc out on the cable to a distance of 12 feet in four seconds. This was true whether the insulator was equipped with arcing rings or not. The amount of burning by three successive four-second applications of a 1200-ampere arc is shown by Fig. 9. It will be noted that the cable is not damaged materially at any one place, but that the scarring is distributed. This cable, which is 214,000 cir. mils aluminum, still retains 95 per cent of its original strength.

Fig. 8.—Night photograph of a 30,000-kw. 1200-ampere arc on an insulator equipped with arcing rings

As to what direction of wind, with reference to the line, will just cause the arc to go out on the cable, it is concluded from test results and observations on lines in service that with sloping ties such as are used on these lines it is necessary that the wind blow at an angle less than 30 degrees to the direction of the line. This value is not materially influenced by the presence of arcing rings.

Generally speaking, it is true that the transmission cables are not more exposed to burning with arcing rings than without them, and in neither case is the burning at all serious. Fig. 10 shows a section of cable blistered in service by a short-circuit arc from a generating capacity of approximately 60,000 kw.

The arcing tests outlined above showed considerable latitude in the effective location of the lower ring. In addition, potential tests were made to determine the effect of this ring in various positions upon the flash-over voltage of insulators. It is evidently possible to set the ring high up on and close to the insulator, and thereby materially to decrease the effective insulation, since the initial discharge may pass to the ring, either from some point on the insulator or vertically downward from the cable, instead of passing over the entire insulator to the pin. The extent of this influence not only depends upon the location of the ring, but in a fortunate way upon the condition of the insulator surface. Thus the dry flash-over value may be reduced as desired, to protect against voltages which are apt to puncture the insulator, while the normal minimum wet flash-over voltage need not be reduced. The insulator is thus left to develop its full flash-over value when most needed, and when least likely to result in puncture.

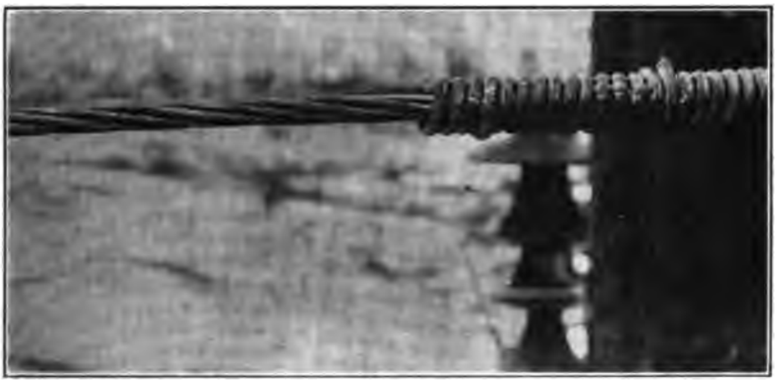


FIG. 9.—214,000 cir. mils aluminum cable burned by three applications of a 1200-ampere arc

These effects appear graphically in Fig. 11. Curve *a* represents the ordinary performance of an insulator on a metal pin under spray, the flash-over voltage decreasing with the increase of water. Curve *b* shows its performance with the arcing ring so proportioned and so placed with reference to the insulator parts as to effect a considerable reduction in the normal dry flash-over voltage, the initial discharge being to the ring instead of to the pin, without reducing the normal minimum wet flash-over voltage. Point x designates neutral conditions at which the initial discharge is as likely to strike to the ring as to the pin; at slower precipitation it strikes to the ring, and at higher rates to the pin. Of course, different insulators and different rings give different curves, but in any case it is possible to determine by experiment the size and setting of a ring necessary to accomplish definite results, within certain limits. Comparatively long insulators lend themselves best to such protection, and other things being equal, they need it most.

An important advantage arising from the use of a ring for this purpose, especially on long insulators of the type under consideration, is that the total reduction of voltage is effective on the lower part of the insulator, and relief is given where most needed. Thus it is well known that in an insulator of the pin type, the shell next the pin is subjected to more than its proportion of the total voltage acting. The potential gradient from the top of the grounded metal pin to the tie-wire in the insulator neck is believed to be such as to impose about 50 per cent of the total applied potential upon the pin-piece or inner shell of the insulator under consideration. At dry flash-over, therefore, the inner shell must resist a puncturing e.m.f. of something near 100,000 volts. This excessive potential on the inner shell may be reduced as much as desired by placing the lower arcing ring in proper proximity to the edge of the second or intermediate shell. A definite spark-gap is thus provided in parallel with the

FIG. 10.—214,000 cir. mils aluminum cable burned in service by a short-circuit arc from six 10,000-kw. generators

lower part of the insulator, insuring the inner shell against puncture and, therefore, in all probability, the entire insulator.

Moreover, when a discharge of short duration occurs from, say the edge of the second shell to the lower ring, it is evident that the resistance of the surface of the insulator above the edge of the second shell is in series with such a discharge and has some deterrent effect upon the passage of the power-current. This is purely an operating advantage. Several cases have been discovered on the lines in service where such action has occurred. It is believed to be infrequent, however, since if an insulator flashes over by lightning, either partially or totally, the power-current is very apt to follow.

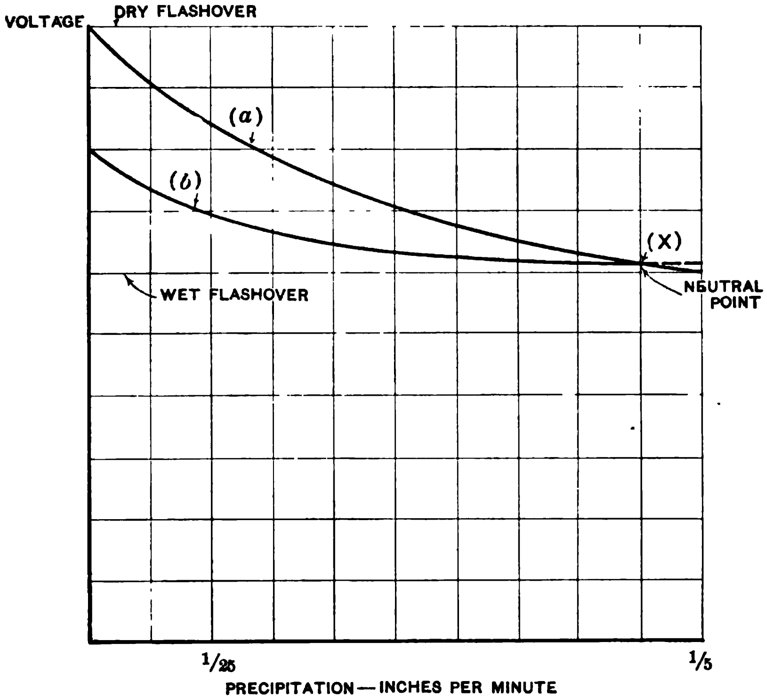


FIG. 11.—Flash-over characteristics of an insulator under spray, with and without arcing rings

(*a*) Without arcing rings

(*b*) With arcing rings adjusted to lower the " dry flash-over " without affecting minimum " wet flash-over "

In addition to these considerations, the earth potential brought up around the insulator undoubtedly has an effect in ameliorating the puncturing tendencies of high potentials, and provides more favorable electrostatic conditions at times of sudden shock. On this account it was thought that the long three-part insulator would suffer very much less than formerly from breakage of parts by lightning strains, and this has been fully substantiated by experience.

Before the summer or lightning season in 1909 a corrective programme as outlined below had been adopted and executed.

All the insulators on one of the duplicate lines and on some of the important branches, 195 miles in all (see Fig. 1) with more than 11,000 insulators, were removed from the line and subjected individually to a three-minute dry flash-over test of 195,000 volts from a 50-kw. 25-cycle testing transformer. Those which stood this test were returned to the line, and were installed on the two lower wires exclusively.

The results of this test are interesting and are shown in the following tabulation:

Total number of insulators tested (recorded)	10480
Total number failed by puncture of one or more parts	4172
Per cent failed	39.5

Individual parts failed as follows:

	Number of insulators failed	Per cent of number failed	Per cent of number tested
Headpiece only	504	12.1	4.8
Intermediate piece only	229	5.5	2.1
Pin piece only	2317	55.5	22.1
Head and intermediate pieces	34	.8	.3
Head and pin pieces	28	.7	.2
Intermediate and pin pieces	830	19.9	7.9
All three parts	230	5.5	2.1

It is seen that 81.6 per cent of all failures involved the pin-piece, and that 55.5 per cent involved the pin-piece only.

It is only fair to say that these dry flash-over tests are very much in excess of any requirements which were anticipated at the time of the manufacture of these insulators. Had they been tested complete before their first installation, it would have been at a voltage certainly not in excess of 150,000, which is at present considered fairly high for a three-part 60,000-volt insulator. Prior to inaugurating flash-over tests on insulators from the line, some 2,000 insulators in stock were tested to 150,000 volts, 3 minutes, resulting in a loss of 7 per cent, which cannot be considered excessive for an insulator of this shape.

On the top wire where most damage by lightning had occurred in the past, and on the lower wires to the extent necessary to accomplish their insulation, a new type of insulator, shown in Fig. 12, was installed. This is a four-part insulator of about the same outside diameter as the old style three-part insulator, but considerably shorter, 6 inches in fact. It flashes over dry at 190,000 volts, and wet at 105,000 volts. The individual parts and the assembled insulators were tested to dry flash-over voltage for 3 minutes. There was a loss of 3 per cent of assembled insulators by this test.

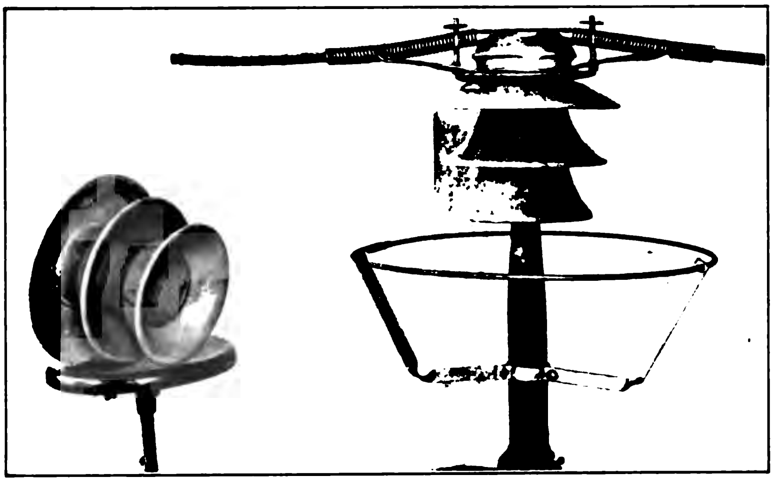


Fig. 12.—New style four-part insulator installed on top wire, 1909 Also shows method of attaching arcing-ring supports to cylindrica pins

An insulator of this design was selected in the light of experience, which clearly indicated that long insulator parts can ill resist the mechanical stress of lightning shocks, and that three thicknesses of porcelain are not sufficient safely to resist puncture in insulators having high flash-over characteristics. Moreover, short shells allow sufficient creepage at high voltage to effect a more nearly uniform distribution of potential upon the several parts, which prevents the puncture of any single shell by a disproportionate division of potential. In short, this four-part insulator was designed to flash over rather than to puncture, and to do this with some margin of safety against puncture.

Lower arcing rings were installed on all insulators in such a manner that relief occurs at a maximum of 160,000 volts, and also in such a manner that wet flash-over values are not reduced. The maximum puncturing potential is thereby limited to approximately 30,000 volts less than the actual voltage which all insulators withstood under test, thus effecting a fair margin of safety against puncture. This result is accomplished by the use of a 26-in. by ⅜-in. iron ring, located approximately 2½ in. above the base of the three-part, and 2 in. below the base of the four-part insulators. It was thought that this relief was desirable for the three-part insulator, since practically the entire 30,000-volt reduction tends to relieve the inner shell, the one most liable to puncture. While not considered necessary for the four-part insulator it is not objectionable, and gives the advantage that the lower arcing ring is in a better location to attract the power arc, since this insulator is, comparatively speaking, a very short one.

Upper arcing rings were not installed until late in the season, after experience had shown them to be necessary.

The second line was not tested or protected in any way.

Since both lines are on the same right-of-way for a considerable distance, and in general pass through the same section of country, being at most a few miles apart, a definite comparison of the operation of the two lines for the lightning season of 1909 shows the value and effectiveness of the reinsulation and arcing ring protection. Also a comparison of these results with those of former years is of interest. It is to be remarked that the line selected for reinsulation is, when on a separate right-of-way, the southerly one, and apparently lies more in the usual path of electric storms than the one which was not reinsulated.

Table I is a comparison of lightning effects on reinsulated and non-reinsulated lines during 1909.

Item 1 shows that one insulator was disabled on the reinsulated lines against 54 disabled on the non-reinsulated lines. Fig. 13 pictures the one insulator lost on the reinsulated line. This is a clear case of breakage by power arc, after flashing over by lightning. It occurred early in the year, before inspection of the work had been made. This failure was due to improper installation of insulator and ring. The 54 insulators disabled on the non-reinsulated lines were destroyed in the same way as were those lost in former years, *viz.*, shattered by lightning, shattered by power arc and punctured.

TABLE I, SHOWING LIGHTNING EFFECTS ON REINSULATED AND NON-REINSULATED LINES, 1909

Reinsulated lines 195 miles, 11,078 insulators.
Non-reinsulated lines 217 miles, 15,121 insulators.
(Reinsulated lines are indicated in Fig. 1.)

Item	Reinsulated lines	Non-reinsulated lines
1. Insulators disabled	1 (*a*)	54
2. Insulators injured (replaced at convenience)	13 (*b*)	36
3. Occasions on which a line was disabled by breakage of one or more insulators	1 (*a*)	15 (*c*)
4. Short circuits or grounds which tripped controlling circuit breakers but did not disable the line	19	12 (*c*)
5. Number of days on which lightning was observed at one or more points on the system	44	44

(*a*) Broken by power arc. Insulator and rings were improperly installed.

(*b*) Nine injured in headpiece by power arc—no neck rings installed. One injured in lower skirts by power arc. Three injured in lower skirts by lightning stresses.

(*c*) Low, on account of practice of removing voltage from 110 miles of non-reinsulated line during lightning, to prevent breakage by power effects, and to obviate attending disturbances.

Item 2 shows that 13 insulators were injured on the reinsulated lines. A careful inspection of these lines was made after lightning storms to determine the exact performance of the arcing rings, and to learn whether or not their location was such as to give the desired results. The results of this inspection are as follows:

Total number of flash-overs found	38
Flashed but not injured	24
Headpiece injured (no upper ring installed)	9
Skirts injured by power arc	1
Skirts injured by lightning	3
Insulators disabled by power arc (improperly installed)	1
Arced to pin before transferring to ring (10, 4-part; 6, 3-part)	16
Arced to ring only 9, 4-part; 12, 3-part)	21
Arced to pin only (4-part insulator destroyed)	1

No insulator was punctured either totally or in any of its parts.

Fig. 14 shows an insulator, protected by a lower arcing ring, which flashed over successfully.

Fig. 15 pictures an insulator, the headpiece of which was broken by a power arc, burning the tie-wire in two. Eight others were affected similarly. No upper arcing rings were installed on any of the insulators which were broken in this manner.

Fig. 16 shows the damage done by lightning stress to a three-part insulator. It had not flashed over. Three were injured in this manner.

Item 3 shows one occasion on the reinsulated line, and 15 on the non-reinsulated line, when the lines were disabled by the failure of one or more insulators. The single failure on the reinsulated line was due to the one insulator appearing in Item 1.

Fig. 13.—Four-part insulator destroyed by power arc. The only insulator disabled on the reinsulated lines 1909

Fig. 14.—Insulator, protected by lower arcing ring, which flashed over successfully

Item 4 shows momentary line interruptions caused by grounds or short-circuits, in which instances the lines were not disabled, but were all right for service at the next application of power, usually within thirty seconds. There were 19 of these interruptions on the reinsulated lines and 12 on the non-reinsulated lines. The fact that there were fewer on the non-reinsulated lines is believed to be due to the operating practice of removing voltage from more than a hundred miles of non-reinsulated line during the known progress of lightning storms in the vicinity of the lines. This was done to obviate damage by power arcs, and to prevent attending disturbances to the system. It is interesting to note that this section of non-reinsulated line was disabled twice while no voltage was on it.

Considering Item 4 in conjunction with the results of line inspection mentioned above, it is evident that the lower arcing ring is not close enough to reduce the degree of insulation of the line under the average conditions of moisture during lightning storms. This is shown by the slight difference in the number of the momentary interruptions on the two lines, and by the fact that on the reinsulated lines in about half the instances the initial discharge was to the insulator pin, and in about half to the arcing ring. At the same time all puncturing of insulators has been eliminated. For these reasons it is believed that the rings have been placed so as to operate as originally intended.

Fig. 15.—Insulator injured in head-piece by power arc. No upper arcing ring was installed

Fig. 16.—Insulator with second shell injured by lightning shock

Item 5 shows the number of days on which lightning was observed at one or more points on the system. This item is interesting in connection with Tables II and III.

Table II is a comparison of lightning effects on the reinsulated lines during 1909, and on the same lines previous to reinsulation during the years 1907 and 1908.

Table III is a comparison of the lightning effects on the non-reinsulated lines of 1909 and on the same lines in 1907 and 1908.

These tables are self explanatory. Attention is called to the extra severity of the lightning season of 1908, and to the fact that the lines which were reinsulated in 1909 had formerly received rougher treatment than had the other lines.

TABLE II, SHOWING LIGHTNING EFFECTS ON REINSULATED LINES DURING 1909, AND ON THE SAME LINES BEFORE REINSULATION DURING 1907 AND 1908

Item	1907	1908	1909
1. Insulators disabled	59 (*a*)	139 (*c*)	1
2. Insulators injured (serviceable)	16	35	13
3. Occasions on which a line was disabled by the breakage of one or more insulators	12	26 (*c*)	1
4. Short-circuits or grounds which tripped controlling circuit-breakers but did not disable the line	32 (*b*)	38 (*c*)	19
5. Number of days on which lightning was observed at one or more points on the system	41	54	44

(*a*) Low, on account of relief gaps.

(*b*) High, on account of relief gaps. This is one-half the total number on the entire system. In addition there were 100 grounds and short-circuits on the system which did not trip circuit-breakers.

(*c*) High, on account of severity of season.

TABLE III, SHOWING LIGHTNING EFFECTS ON THE NON-REINSULATED LINES OF 1909, DURING 1907, 1908 AND 1909

Item	1907	1908	1909
1. Insulators disabled	29	81 (*b*)	54
2. Insulators injured (serviceable)	15	66	36
3. Occasions on which line was disabled by breakage of one or more insulators	9	23 (*b*)	15
4. Short-circuits or grounds which tripped controlling circuit-breakers but did not disable the line	32 (*a*)	42 (*b*)	12 (*c*)
5. Number of days on which lightning was observed at one or more points on the system	41	54	44

(*a*) High, on account of relief gaps. This is one-half total number of entire system. In addition there were 100 grounds or short-circuits on the system which did not trip circuit-breakers.

(*b*) High, on account of severity of season.

(*c*) Low, on account of operating practice of removing voltage from 110 miles of line during lightning storms.

From Table III it appears that lightning effects in 1909 were slightly more than half those in 1908, and somewhat in excess of those in 1907. It is therefore believed that the reinsulated lines have been subjected to a lightning season of average intensity.

Concrete instances may be cited which show definitely that protected insulators have withstood severe lightning. In sections where the lines are 26 ft apart on the same right-of-way, insulators were destroyed on the unprotected line in quantities, and in a manner which indicated extraordinary lightning severity. On the protected line in the same locality insulators flashed over uninjured. On six known occasions all the insulators on a structure discharged, and on six other occasions two insulators per structure were involved. Of the 38 protected insulators which are known to have been affected, 21 were on the lower wires. These results are all indicative of severe lightning effects.

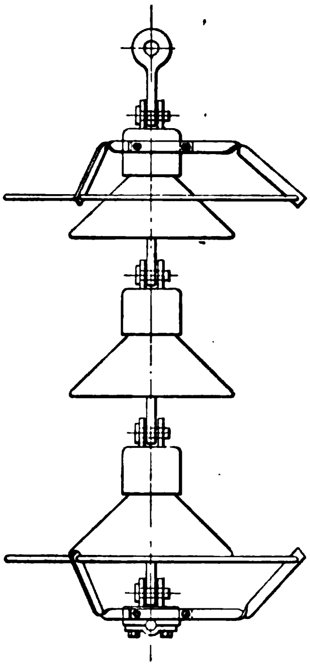


FIG. 17.—Arcing rings applied to a suspension type insulator

This experience with sound insulators protected by arcing rings justifies the feeling that extended interruptions due to line breakdowns by lightning will be very rare in the future, if they do not entirely disappear. Prevention of occasional momentary disturbances, caused by the discharge of one or more conductors to ground from the effects of lightning, is believed to be impossible, since potentials exist at times which are too great to be insulated, and too severely localized to be relieved by lightning arresters at a distance. Duplication or multiplication of circuits controlled by proper automatic sectionalizing apparatus tends to prevent such interruptions from reaching the service.

Virtually no experience has been had with arcing rings on untested insulators. The work of applying them on the remainder of the system, omitting the testing of insulators, is in progress at present. In view of the material protection against puncture which the lower ring affords to the pin-piece of the three-part insulator, which piece, as the testing of 11,000 of these insulators shows, is the one most liable to puncture, and which if saved will probably result in saving the entire insulator, satisfactory results are anticipated.

Before undertaking the rather expensive experiment of reinsulating its lines and equipping them with arcing rings, the company sent representatives to various transmission plants in the United States and Canada to inquire about line troubles in general, and particularly regarding the effectiveness of overhead grounded conductors. The result of this investigation was not altogether favorable to the overhead ground wire. Various opinions were obtained expressing its usefulness and its uselessness. No plant comparable in extent and type of construction with the one under consideration was discovered which did not have to contend with the shattering and puncturing of insulators by lightning, as well as with occasional short-circuits during lightning storms. Considering the heavy expense of properly installing an overhead grounded conductor, and the extra load it would impose on the line structures, together with a large element of uncertainty as to its efficacy, the idea of installing one was abandoned.

While intentionally designed to protect insulators mounted on grounded metal pins it is believed that grounded rings would be beneficial to insulators on wooden pins also.

In view of the extensive use of suspension insulators, some experimental work has been carried on which indicates the necessity for, and effectiveness of, arcing ring protection on this type of insulator. The arrangement shown in Fig. 17 apparently accomplishes the desired results.

DISCUSSION ON "PRACTICAL METHODS OF PROTECTING INSULATORS." CHARLOTTE, MARCH 31, 1910.

President Stillwell: Gentlemen, we have listened to a very interesting paper on a device which I believe is quite new in the art, and original with Mr. Nicholson or his associates; a device that, aside from the results obtained in connection with the plan used in the Niagara Falls construction, will probably be tried in many other instances. At any rate, it appears to me highly suggestive and important in this connection. I believe that if the attention of our designing and operating engineers can be concentrated in respect of overhead transmissions, on the subject of automatic limitation of the destructive effects of a short circuit, results of great value can be accomplished.

I recognize fully the enormous difficulties presented, but they are no greater to-day, apparently, than the analogous difficulties which we faced twelve years ago in connection with underground work, and to-day the underground cable systems are equipped with automatic devices which protect the service so that when a cable fails the only indication of that fact is given by the recording instrument at the power house and the substation. In the case of the Interborough system in New York City, there are, I think, five hundred miles of 3-phase cable in service operating at 11,000 volts. The difficulties that troubled us greatly five years ago are substantially eliminated, and the last time I asked Mr. Scott, who is in charge of the operations of these plants, about his interruptions of service, he said he had forgotten the subject. The records showed they had seven failures of cables during the previous year but not one of them caused an interruption of the service.

In the case of the Southern Power Company, where networks of distribution are being built, it will be possible some day, perhaps even now, to use automatic circuit-breakers in a way which will reduce very materially the commercial interruptions resulting from lightning or other short circuits on the line.

F. P. Catchings: I think in many respects that this paper which Mr. Nicholson has presented this afternoon is one of the most important we have listened to at this meeting. For one reason, particularly, I think so; the problems and difficulties of obtaining the money and financing transmission systems or power plants, and then putting them together, building them after we have obtained the money, you might say are more or less minor difficulties, which we understand and which can be overcome, but the effects of lighting and allied phenomena are rather more obscure, and one of the prime necessities, if not the most important requirement, is to keep these plants in operation —to see that there is a continuity of service. I think the statement in that connection given by Mr. Nicholson sounds the key-note of the whole situation where he says: "No plant comparable in extent and type of construction with the one under consideration was discovered which did not have to contend with the shattering and puncturing of insulators by lightning, as well as with occasional short-circuits during lightning storms." I think that right there, in that paragraph, is a challenge to the electrical engineers of this country, because no matter how much money is invested in the plant and distribution system, unless fairly constant, or nearly constant service can be given, it will not be as successful as it would be otherwise.

The company with which I am connected attacked this problem of insulator puncturing and smashing in a manner similar to that undertaken by Mr. Nicholson, except that we placed the horn gaps on the towers, about 500 feet apart, previously trying the plan of building horn lightning arrester stations every mile or so, and we found, as Mr. Nicholson did, that insulators would puncture on the adjoining tower, within five hundred feet of a five-inch or six-inch gap to earth, so that these discharges and surges were probably of such great frequency that they would not travel 500 ft. of the copper cable, but would discharge through or over an insulator; a horn gap was then placed on every insulator. The line is about fifty miles long, 50,000 volts, Y-connected, and there are some 1,500 of these gaps on the line. They are spaced about five inches, there being approximately 30,000 volts difference of potential between the two horns. We have had the horn gaps on two years or more, and in that time only lost two insulators. One of these was weakened by having been shot with a rifle, so it was not full strength, and the other was punctured through the top. As Mr. Nicholson brought out, it is much more desirable to have momentary fluctuations in voltage or winks of voltage in the line than to have an insulator punctured or smashed and be shut down for several hours. The customers will stand the winks far more readily than they will the shut-down.

There is one question I will ask Mr. Nicholson; is there any drop in voltage caused by the discharge between his arcing-rings?

J. W. Fraser: It seems to me that Mr. Nicholson's solution of this matter is a very good one, and I think you will all agree with me that he has given us something which will be of lasting benefit. He has found a way to protect the insulators, but he has not yet discovered any way of preventing short-circuits.

I was glad to hear our President say that he expects in the next few years to see a distributing system so equipped with automatic circuit-breakers as to be able to cut out lines which were hurt by lightning or in any other manner. I think we need such automatic regulation very much. It has occurred to me several times and has been impressed upon me lately, that the factor of safety in insulators is entirely too small, and I should like very much to hear the opinion of the transmission engineers here in regard to this point. It is customary to use a three-part insulator for 50,000 volts, and a four part insulator for 66,000 volts, and any one who has done any testing on insulators knows that between 50,000 and 60,000 volts, as a rule is all that can be depended upon for one piece of porcelain. It seems reasonable to expect that interruptions could be greatly decreased by increasing the insulation of transmission lines. When we step, say from 50,000 to 100,000 volts, we practically cut the copper to one forth the original area, and we believe that part of this saving could be well invested in insulation. I have been making a rough mental calculation, and I find that doubling the insulation on a 100,000 volt line, increases the entire cost of the whole system about 7.5 per cent. If this extra investment would cut the interruptions in two, the money would certainly be well spent.

E. E. F. Creighton: The protection of insulators is one of the problems that has not received enough attention. It is the most important one in protection at present. The problem of the protection of apparatus against lightning is solved. The information and data given by Mr. Nicholson is of great value.

One thing particularly that needs comment, and needs the assistance of all transmission engineers, is the subject of the spill-over of the power from the insulators, with strokes of lightning, not on the line, but near the line. Mr. Nicholson gave two cases only where the lightning stroke was about a quarter of a mile from the line, that caused flash-overs of the insulators. He gave another case, where the distance, I believe, was seventy feet, on an adjacent telephone line, and that also caused flash-overs. Up to the present time the use of the overhead ground wire is about the only protection advocated for lines of moderate potentials. This particular system has no overhead grounded wire, and it would be a very valuable thing to know whether a stroke as near the line as 70 feet would have caused a spill-over on the insulators if overhead grounded wire had been installed for protection.

It is difficult to get information on this subject, and I would like to suggest one definite method of study—that is by photography. During night storms point a camera in each direction along the lines, at a point as far above the line as possible; change the film after each flash, note whether it causes a flash-over of any of the insulators, and note also by means of station recorders the simultaneous disturbance in the station, especially of the lightning arresters. At the present time there is being put on the market a definite discharge recorder, which will record the exact time when a discharge takes place in a lightning arrester, also tell the phase in which it occurred, and whether it extended to ground or not. It will also give a measure of how long the discharge continued through the lightning arrester and an indication of the current or quantity of electrolyte by the size and nature of holes it bores.

I will ask Mr. Nicholson whether he has any further information of the effect of strokes near the line in causing spill-overs.

If lightning strikes directly on a pole or tower it seems evident that a discharge must take place over an insulator of the power line—even if an overhead grounded wire is used.

J. S. Jenks: My intention is not to discuss this most important paper this afternoon, but rather to give you a few conditions which the West Penn System has overcome and some slight idea of our methods ot determining the cause and rectifying same, giving us reasonable protection and practically the same effect that Mr. Nicholson has obtained in his plant.

In the first place we started with the lightning arrester. We made very exhaustive tests and records. We not only recorded the time of each discharge on record sheet, but also the phase and the territory in which the discharge occurred. We have continued this record up to the present time and expect to continue it indefinitely, to a certain extent, in that we keep a record of every arrester which discharges; a record of every storm which occurs and when it reached each portion of the system. We also have a telephonic report from each station on our system telling of the coming of a storm. This places the operating force in position to be ready to manipulate any switches or make any changes in the operation which we think essential.

Our transmission system consists of a loop of 185 miles of line, divided into seventeen sections and fifteen substations. Each section is protected by relief gaps and disconnecting switches as it enters and leaves the substation. Just inside of the substation wall it is protected with a lightning arrester; then it passes to the automatic switch and to the bus. The buses have disconnecting switches in the center, making it possible to divide the system at any point, operating one-half the system from either direction. This makes a flexible method of cutting out any one section that is in trouble.

We experienced trouble from the flashing over of the insulators, where we were protecting railroad crossings with grounded pins and arms, in line with railroad specifications. The majority of our construction is wooden poles, wooden arms and pins, where we have had no trouble from flashing over. We overcame the flash-over troubles by taking a lead from the top of the insulator to one side, letting the discharge go to the grounded arm a safe distance from the insulator. We found this advisable, rather than letting the discharge strike from the line, on account of the trouble we had with aluminum, due to burns. I notice that Mr. Nicholson's experience with aluminum due to burns has been different from ours. We have had numerous lines down—in fact, three cases of trouble before the current was put on the line, due to burns from lightning.

I have brought with me a few samples, which I think some of you may be interested in, showing results of small burns on aluminum wire. We did not test or change the insulators, we obtained our relief without any such expense; as Mr. Nicholson says, it was expected to get relief, from the second line, by simply putting in a discharge gap. I trust the relief will prove satisfactory and justify the risk. The possibility of increased business on the strength of continuity of service is a matter that has been very serious with us. We are in a gas field where we are competing with natural gas sold as low as four cents per 1,000 cu. ft. for power, and twenty-five cents to any person who wants it in the smallest quantity. We have been able to bring our time efficiency—which is based on the effective kilowatt capacity—from about 80.2 up to 99.996. Those last two nines were very hard to get. We have been able to bring it up to this high standard simply by having the automatic devices kept in perfect order, inspected at regular intervals and tested. When we get a case of direct stroke, or something of the kind, we frequently have the section between two substations dropped out of service; we try closing the line breakers; if we get a short-circuit or ground the line is left off and inspected. We have a great many strokes, spill-overs or surges caused by some stroke in the vicinity, which are simply relieved without any interruption whatever.

A word in regard to the factor of safety on insulators. Our transmission carries 25,000 volts. We have, after some little season of experiments, raised our factor of safety higher than the majority of people. We endeavored to get a factor of safety of five on the insulator we used, never putting on an insulator that has a factor of safety less than four. Sometimes the manufacturer will fail to be able to give us five as a straight run, but we compromise and take anything that is not less than four. That is a standard a little higher than most company's.

As to the possibility of direct stroke in the vicinity of lines, we have a record in our office which shows that we had three poles shattered by lightning and knew nothing of it, did not even have a surge. These poles support two three-phase lines, the lines being arranged with the long arm on top, the wires equilaterally placed, and the apex at the bottom. The poles were shattered between two wires only thirty inches apart. So far as we know, that actually happened without even giving a disturbance of voltage. The way we arrived at that conclusion is that our inspectors, who inspect and make records of everything which they find on the line, the condition of every pole and every little chip out of an insulator, etc., inspected the line one day and reported the line in perfect condition; two days following, a very severe storm in the meantime intervening an inspector reported three poles right together which were shattered where the lines crossed over a telephone line. We considered very seriously the matter of overhead ground wires for guarding our line at one time, when we were having the majority of our trouble, but after some experiments with iron wire and fixtures in the coke region where the detrimental effects of the sulphur fumes on the iron wire are prevalent, it was decided to let the grounded wire and fixtures necessary to support the same alone, and go to an increased factor of safety on our insulator, and have some relief gaps for the line.

C. F. Scott: There are two sides to this paper, one that has been presented by Mr. Nicholson, recounting the history of different ways of doing things and results obtained, and another, looking at it from the standpoint of the kind of problem which was presented some two years ago to the transmission company with which he is connected. The conditions are something like this: The company had its important line in service, the insulators were proved inadequate, the exigencies of speed in construction had necessitated putting up insulators without complete tests, and the best thing under the circumstances was probably to do as it did, although it had to take certain chances. It was found then that some of the insulators on these lines, which extended out hundreds of miles, were breaking down. More than that, it was found that when the insulators themselves were possibly in good condition, the conditions were such there would be a flash-over even on a perfect insulator which might destroy the insulator. One of the first requisites was to determine some method of finding the bad insulator, which might be one mile, or ten miles, or fifty miles out on the line, it being almost impossible to see by inspection if they were punctured or not.

The result was the invention of the very elegant method of locating defective insulators described in a paper by Mr. Nicholson before the Institute some two years ago. Now, Mr. Nicholson has pointed out how very difficult it was to make tests of insulators on the line and to replace the poor ones. Different methods were tried, spark gaps were put up at intervals on the upper wire, which was the one which was damaged most often, and yet this proved inadequate. What was to be done? Most of us would condemn the insulators and say that new insulators should be provided, but it was impracticable to get new insulators at once. Mr. Nicholson took the conditions as they were, and in a way which now seems simple, and obvious after you see it, but not before you see it, he made this simple addition for the protection of the insulators, meeting an emergency, which was a very serious commercial condition. It is not a matter for laboratory tests in which it makes but little difference whether the result comes out one way or the other, but it was a very serious emergency condition on a very important transmission line which must be in continuous operation, where the facilities for making tests were very meager. And under these conditions, leaving the insulators as they were, he has devised a method for the protection of these insulators; and the simpler the method the greater the ability required to discover and apply such a method. The idea of putting some kind of a spark gap or lightning rod all around the bottom of an insulator is rather ridiculous when proposed at first, but it is because he has taken that simple and ridiculous thing, and gone ahead and accomplished a notable result that I think marks one of the greatest strokes of ability in the work which he has done.

Most of the pictures of insulators do not look formidable in size, because we have nothing to compare them with, but on one page in Mr. Nicholson's paper we see a piece of an insulator placed alongside of a barrel, and we see that it is about half the size of the barrel. The size here is about the limit, it seems to me, in physical dimensions and weight which is permissible for the upright pin insulator. As we go to these higher voltages new elements come in which are not found with the little insulators. This matter of flashing over and breaking off petticoats is a thing that has come up in the larger insulators. Again, in the three-part insulator, the distribution of potential within the insulator, which Mr. Nicholson pointed out, becomes a serious matter. The different parts of the insulator, which are cupped one inside the other, do not distribute the voltage uniformly, but the inner part of the insulator, next to the head of pin, probably has to sustain an e.m.f. of twice as much per tenth of an inch, as that toward the outside, and it is a remarkably fortunate thing that the new distribution of potential caused by the placing of the protective rings tends to more nearly equalize the voltage strains throughout the insulator.

As to a minor point, that of the factor of safety, Mr. Frazer thinks that it would be well if we could double the present factor of safety. I wonder if we had insulators which were twice as good as at present whether we would not shift up the 100,000 volts and make it 150,000 volts for the transmission line, and thus tend to retain the present factor of safety. That would be the temptation certainly.

Another question should be asked, and that is how we should measure this factor of safety. Mr. Jenks uses a factor of safety of five; he uses insulators tested at 125,000 volts on a circuit of 25,000 volts. If a 100,000 volt circuit is supplied with 200,000 volt insulator, then there is the same margin of 100,000 volts, although the factor of safety is only two. I think it probable that we may reduce our factor of safety as we go up higher in voltages. Possibly the 100,000-volt margin would be good in one case, and hardly enough in another, but I doubt whether it would be at all expedient to get a factor of safety of four or five by going to 400,000- or 500,000-volt insulators for use on 100,000-volt circuits.

I was interested in what Mr. Creighton said about the recording device for telling what lightning was doing. It certainly does give an excellent insight into the operation of the plant in connection with lightning disturbances to have such records, and it was my pleasure last summer to pass through Montana and spend a day or so at Mr. Gerry's plant, which is the Helena Power Transmission Company, the old Missouri River Power Company. At that plant there is a most excellent record of lightning disturbances recorded putting paper slips in the lightning arrester gaps. They have a number of the multigap arresters, and papers are placed in the gaps next to the line and also in the various shunt circuits and ground circuits. These little telltale papers are taken out from time to time after storms. They give a record showing the results of the discharges in each wire of each line, at each end, and the character of that discharge is indicated by little holes or big ones. The condition is duly recorded on the little slips and the record is transferred to a larger sheet of paper so that one may see the whole record, showing the action on the different lines at each of its ends, and at the different points of each arrester. One can trace down how far the discharge went through the arrester, and where it passed off, and further, he can note the character of the discharge at each place.

I found there that the multi-gap arresters, with shunt resistances, had given such good service that the operating company considered this type as its standard. Electrolytic arresters were being tried but until they had demonstrated their value in service, the multigap arrester which had served efficiently so long were regarded as the standard arrester.

Percy H. Thomas: This is another one of our rare papers, wherein we have a perfectly definite, scientific record of the information obtained from commercial plants that will enable us to draw some conclusions which are almost mathematically definite.

This paper, it seems to me, taken in connection with the paper two or three years ago on the Taylors Falls lightning arrester experiments give us a pretty broad idea of what the transmission engineer has to meet in the protection of lines against lightning.

There are certain definite results and conclusions which we can draw from Mr. Nicholson's paper.

First, when insulators puncture, instead of flashing over, (then perhaps requiring an hour, or even half a day, to get the line into service again), this trouble can be presumably eliminated by the use of the rings proposed by Mr. Nicholson.

Second, where the insulators flash over and are broken by a power arc, the same remedy will apply.

Third, the attack of lightning on the transmission line, as distinguished from the station apparatus, is extremely local. Of this we have abundance of evidence now. One or two poles distance is too far removed from a ground to be at all sure of protecting an insulator.

Fourth, a resistance in the neutral point of the rising transformers may be a great help in maintaining service. I think Mr. Nicholson would probably agree to this statement. Thus grounding of one line is the cause of a much smaller arc than without this resistance, and furthermore the resistance enables the maintenance of voltage on the system, so that reverse-current or overload relays can act while if a dead short-circuit should come on the system, the voltage being entirely removed from the relay, the relay cannot act.

Another point which has not been emphasized, but which is important, is the question of burning that is caused in the transmission line wire by an arc from the pin to the wire. Mr. Nicholson has given illustrated experimental data on this matter, and although I do not suppose it would be safe to draw conclusions from this case for all other cases, yet it gives a definite starting point. Mr. Nicholson fully realizes the fact that although the puncturing of insulators is overcome by the rings momentary interruption of the service is not preventive. Nevertheless the actual operation of the system has been very much benefited by the rings.

It is now very clearly established that insulators can be shattered by lightning alone without current from the generator, and without puncturing the insulator. The petticoats may be shattered without there being a direct puncture to the pin. This is a curious result and this is not the first time it has been brought forward. Presumably a remedy can be found for this condition; it would appear to be a mechanical strengthening, of the petticoats. The exact method will be for the insulator manufacturers to recommend. Ribs on the petticoat might be used, or a heavier petticoat.

Although we have not as yet gotten perfectly continuous service, we can still take a little comfort and not put so much stress on each occurrence of a momentary interruption. There are some classes of service where this is a serious matter, but as power systems go, a wink in the light, or the dropping off of the service for a moment or two, provided it does not occur too often, is not such an overwhelming handicap after all.

I notice Mr. Nicholson has made a study of the reports of various operating companies of the effect of ground wires overhead, and though I do not understand that his report is unfavorable to the ground wire broadly, yet, under the conditions which exist in his plant, he did not think it worth while to try them. I think we still ought to hope that the overhead ground wire will cause a very great decrease in the percentage of interruptions. The critical feature is not so much the mere putting up a ground wire in any convenient location on the pole or tower that may happen to fit a particular structure, but to so install ground wire and to so support and ground and locate it as to give the best opportunity for protecting the line in the light of the conditions to be met as we know them. One condition is the extreme tendency of an induced stroke to side flash when it strikes a ground wire. That means that between towers, on any long span, for instance, a stroke reaching the ground wire, would tend also to spill over on to the transmission wires. Thus, the middle of the span the ground wire should be more widely separated from the conductor than in the towers.

At the latter point where the ground connection is direct to earth, there is not the same necessity for using large spacing. The steel ground wire can usually be strung tighter than the copper wire, and there is often no reason why it should not be drawn above the transmission wire in the middle of the span, the point where the flash-over is most likely to occur.

Two ground wires would be better than one, especially where two transmission lines are on the same set of towers. I think we can safely assume that the attack of lightning is not directly from above; it tends to come from one side or the other and with a single centrally located ground wire may thus first reach the transmission conductor. The use of two ground wires will greatly reduce this tendency.

The cost of the ground wire is a serious item, but under favorable conditions we can erect transmission structures, in which the ground wire shall be an important element of the mechanical stability of the system. In that case, we could perhaps save its cost elsewhere in the system. I will ask Mr. Nicholson if he has any note of any cause of flash-over or puncturing of insulators, other than lightning. There was a time when we used to hear of " internal strains " and other similar troubles in the system, but in recent years we have not heard so much about that sort of trouble.

Mr. Fraser has brought out the fundamental necessity—more margin of safety. We used to have transformers go down frequently. The remedy has been to make better designs and use a larger margin of safety; the troubles with transformers have largely disappeared. If it were possible to do the same thing with high tension insulators, we should certainly be better off.

I feel pretty sure we would have progressed faster in our protection against lightning if that was the only problem we had to think of. The conditions are not at all favorable for the development of protective means. It is very rarely after the original design that in any particular practical case, there is a chance to act intelligently, and carefully and thoughtfully, to lay out a line for protection from lightning. Once in a while there is a company which is large enough to give opportunity for the engineer in charge to make a practical study of the lightning problem, as in the case of Mr. Nicholson's company, and to give an opportunity to try out the result of some method, and if that does not succeed, then to try something else. This is the method of investigation from which we are most likely to get results, as is indeed shown by the present instance.

J. A. Sanford, Jr.: Referring to the statement made by Mr. Scott that he understood that the insulators on Mr. Nicholson's line were rushed in on the line without complete test, using this fact as justification for the loss of insulators by puncture after installation, I think there is one statement in Mr. Nicholson's paper which partially covers this matter and which is better justification for the above loss than the fact above referred to. The statement I refer to is as follows:

"The lesson of the year was not new but showed more forcibly than had been realized before that even if all insulators were capable of resisting puncture, they would continue to be shattered by a power arc following a flash over."

This statement would seem to show that although the manufacturers might have done everything in their power to furnish the best insulators that the art knew at that time, there still would have been a considerable amount of trouble from the breaking of insulators, due to lightning, which loss could only be overcome by the adoption of some protective device as is described in Mr. Nicholson's paper.

Referring to the question of factor of safety, I think that any of the manufacturers who would make a recommendation will recommend an insulator with a reasonable factor of safety, which, hitherto has been a rather flexible quantity, and that the engineer need not have any fear in allowing manufacturers to state what insulator is suitable for a given case, provided full information is furnished with the inquiry stating actual operating voltage, style of construction, and climatic conditions.

With reference to the size of insulator, Mr. Scott brought up the point that some of them were perhaps half the size of a barrel. The largest pin type insulator I know of was furnished to the Edison Company of Los Angeles, being 18 in. in diameter, about 14½ in. high, and this insulator weighed net 43 lb. The largest suspension type units used up to the present time have been made up of two pieces of porcelain, the largest being 14½ in. in diameter and the distance between the point of suspension and the lower petticoat of the insulator being about 10 in.

E. B. Merriam: There are a few points which I wish to mention based on observation of the destructive effects of high-power electric arcs on insulators. A power arc provides a path of low resistance, which on a large system permits a tremendous amount of current to flow, at the same time preventing an abnormal rise in the line voltage, the circuit being opened by protective apparatus. The resistance of these arcs is quite low and might be compared to an equivalent length of No. 0000 copper wire stretched around the insulator. It is the low resistance of this arc which holds the line voltage down until such a time as the circuit can be opened by the line oil circuit-breakers. The size of the arc is not always a measure of its destructiveness as the reflection of the vapors may give the appearance of an arc of great magnitude. A small arc will sometimes cause more trouble than a large one if it is allowed to hold for any appreciable length of time. The time element, therefore, figures quite largely in the amount of damage and burning to the insulator.

The pin insulator, having a petticoat around the insulator pin, is particularly susceptible to the ill effects of heavy power arcs, hence the necessity of protective rings. These petticoats may be broken off one after another on account of the arc "pocketing" and hanging close to the porcelain. The suspension type of insulator, owing to its peculiar construction, has an inherent protection as the arc has a tendency to flare away and extinguish itself. Tests on the suspension type of insulator indicate that protective rings are not necessary. In making tests of this nature it is highly essential that they be made out of doors under operating conditions, as the wind causes the arc to "wander," and the pressure and condition of the atmosphere also have marked effects on the arc, making a laboratory test misleading.

Harris J. Ryan: By practice and investigation that are record breaking for extent of facilities employed and the experience encountered, Mr. Nichclson has advanced greatly our understanding of the related causes that bring about injury and failure of high-tension transmission line insulators. To limit the damaging effects of these causes, he devised and applied to the insulators rings that accomplish their purpose in two fundamental ways:

1. The power arcs that follow a "spill-over" are held free of the insulators.
2. The stray static field set up by the arcing ring is made to crowd the field set up by the skirts of the insulator. For the upright insulator this is so managed that the capacity of the shell next to the pin is considerably diminished. The charge entering such shell from the top of the pin is lessened and the electric stress or pressure gradient there applied is correspondingly lowered. The net result is a more uniform distribution of potential gradient among the several shells along the route of maximum electric strain.

The paper brings up again the principle that pressures are developed on transmission lines at times, that are too high to be withstood by any practical system of insulation and that their effects are localized to such a degree that they cannot be cared for by arresters distributed to a reasonable extent. This and the principle that governs the use of arcing rings have been realized by the author of this paper in a new design of an upright insulator in which enough well-disposed porcelain is used to set the puncture pressure safely above the arc-over pressure. It has been shown that this insulator in combination with arcing rings, has made an important advance in transmission practice.

Mr. Nicholson made tests to determine the destructive effects of power arcs upon transmission lines with and without the use of arcing rings. He found that the arcing rings exercised no material influence in this matter, *i.e.*, they neither increased nor decreased the liability to such damage. In the early part of the paper the author tells us that, "The gaps perfectly protected the insulators containing them". Did they also protect the aluminum cables at corresponding points from damage by power arcs? When a light wind is running, approximately parallel to the line, and a heavy power arc is thereby drawn away from the arcing ring and over the aluminum transmission cable, could not the damage to such cable be prevented by the use of a suitable aluminum guard covering the cable a few feet on either side of the insulator? If required, the power arc at the remote end of such cable guard could be stopped by a barrier of the same metal in the form of a solid disk or an extension piece deflected at right angles to the cable; for the upright insulator, such barrier-piece should be directed downward; for the suspension-type insulator it should be directed upward. Does Mr. Nicholson's experience lead him to consider that guards of this character for protecting aluminum cable are worth what they cost to apply and to maintain? Does his experience lead him to conclude that the transmission cable mounted from suspension-type insulators equipped with arcing rings would or would not be comparatively free from damage by power arcs because of its under-hung position?

Applied to the suspension-type insulator, the arcing rings, by crowding the stray static field about the lower unit, will distribute more evenly the total electric strain among the different units; this should result ultimately in a real advance in the practice that employs this type of insulator.

Irving E. Brooke: The proper protection of high tension transmission lines from injury by lightning or other electrostatic stresses is one of the most important as well as the most difficult problems encountered in the design and construction of transmission lines. The author states that the test on the insulators in question consisted of subjecting each part of the insulator to 75,000 volts for three minutes, but further states that the complete insulator was not tested after assembling. The writer does not understand why the complete insulator was not tested after assembling. In tests of this nature it is not an extreme case when 10 per cent of the tested insulators will break down when subjected to approximately twice the line voltage for which they are intended.

The fact that so many of the insulators fail and puncture is probably due to the design of the insulator, as the potential gradient is such as to subject the top piece or the pin piece of the insulator to a stress greatly in excess of that for which they were designed. This matter of potential gradient for insulators is one that should be thoroughly investigated.

If insulators are made in more than one piece, and although each piece may stand up under the specified test when the several parts of the insulator are cemented together, the distribution of the electrical stress is not the same as if the insulator was one homogeneous mass. When the insulator is made in one piece it is probable that a uniform potential gradient will be secured. As Portland cement is much inferior to porcelain, at the point of contact of the two materials we may have a very abrupt change in the potential gradient or perhaps a re-distribution of the electrical stresses. It has been demonstrated that one piece insulators seldom fail by puncture from operating voltage, but multi-part insulators fail by puncturing one section at a time, which is undoubtedly due to unequal potential distribution.

The subsequent design of the shorter insulator shows a much better type as regards mechanical strength and also an insulator that will withstand approximately the same voltage test.

It is interesting to note that the lightning troubles have been confined entirely to lines themselves and that no trouble has been experienced in stations or substations that could be charged directly to this source. This may be due in a large measure at least to the fact that the steel tower construction with proper station protection provides an easier and more direct path for the relief of high potential charges induced by lightning than that through the station or substation apparatus. The fact that a number of insulators have been broken by a direct stroke may be on account of the so-called lightning-rod effect of the steel tower construction. An insulator could be designed which would flash over before it punctured, but it is hard to foresee which would give better results unless some protection as described by the author were provided to protect the insulator from the power arc after a flash over occurred. The result showing the number of insulators broken on the top wire should be a good guide in the placing of a ground wire on a transmission line.

The question of putting resistances in the neutral connection of the substation transformers is one that is open to argument on account of the possibility of increasing the potential on the line by limiting the current flow to ground.

It has been shown in many instances that a lightning discharge apparently will not always follow the path of lowest resistance. In some instances it has been known to jump several feet at the turn of the wire rather than follow the same wire only a few feet farther, but in a line at an angle to a direct path, to the ground. This may to a certain extent explain the reason why the station and substation apparatus experienced no trouble from lightning discharge. It should also be a good argument for the provision of a ground wire on the transmission line.

In placing the rings around the insulator the author has shortened the air gap, or distance to ground, and while the ground potential is still carried well up inside the insulator it is hard to make the power arc hold from the pin to the conductor.

The log of operation shows some very interesting results. The fact that the circuit breakers were tripped out so many times on the re-insulated line is probably due to the fact that the placing of the arc rings lessened the line insulation and that it brought the ground potential up nearer the conductor.

James Lyman: The author has shown great ingenuity in successfully overcoming the serious effects of lightning discharges over unprotected transmission lines. The method applied will undoubtedly prove of great value to similar situations where the arrangement of insulators on the pole or tower structure does not permit of an overhead grounded cable located well above the transmission conductors.

The value of such a grounded cable in absorbing the high tension charges from clouds and discharges from clouds to ground has been clearly demonstrated by actual experience on many transmission lines. The effectiveness depends, of course, on its being well grounded at frequent intervals, say at every pole or tower structure, and it should be carried well above the line it is to protect. The potential of the earth is thus brought to the level of the grounded cable, and the transmission line is, therefore, removed from the zone of lightning discharges.

If the overhead cable is badly grounded, as, for example, to dry earth or rock, it, of course, offers less protection. In general it is possible to obtain good grounds at small expense. Where good grounds cannot be obtained, as occasionally happens in crossing mountain ranges and rocky country, the author's protecting rings can well be used in addition to the overhead grounded cable.

I believe the overhead cable, grounded as well as conditions will permit, will always offer a very material protection.

Mr. J. B. Foote, engineer for the Grand Rapids-Muskegon Power Company, adopted an original method of protecting the fifty miles of 110,000-volt transmission line, from Croton Dam to Grand Rapids, without an overhead grounded cable, which apparently is entirely effective, for during the year of 1909, not one case of trouble from lightning occurred, although on an older 60,000-volt wooden transmission line a number of interruptions from lightning occurred.

Steel towers are used with an angle iron extension six or eight feet above the upper transmission line acting as a lightning rod. To obtain a good ground the angle iron base extends two feet below the concrete foundation, or a total of six or seven feet into the ground at each corner. The pole line passes through an open farming country where the soil is deep and moist. The line is thus protected by a lightning arrester at each tower or at intervals of from 400 to 500 ft. The suspension type of insulator lends itself well to this construction and wherever steel towers and suspension insulators are used this arrangement might successfully be adopted.

Max H. Collbohm: The method described in Mr. Nicholson's paper is a means to save the insulators from destruction by electrical forces. It does not offer any direct protection to the transmission wires or the station itself. The usefulness of this method is apparent by the fact that if lightning surges are set up either directly or induced in the power wires with a potential high enough to cause arcing over the insulators then a shut-down of the line may result (particularly in a grounded star connected system) without destruction of insulators, thus permitting service to be resumed immediately afterwards, while if this method was not employed the insulators may be destroyed, resulting in a continued interruption of service until the damaged insulators are located and replaced.

The arrangement of the protection rings at about the elevation of the lower petticoat, with a corresponding reduction of sparking distance between conductor and ground, would seem to make it permissible to materially reduce the length of the pin as used at the present thereby increasing its strength.

There is one point in Mr. Nicholson's paper to which I would like to take exception, *viz.*, the statement that it has been found useless to install guard wires over the transmission lines for lightning protection. Although it is true that guard wires do not afford complete protection to the line, they give however at least a reasonable degree of protection if properly installed, *i.e.*, high above the power wires and grounded at every tower. They should furthermore consist of durable non-magnetic material (at least on the outer rim of the conductor) such as found in copper-clad steel wire, and should be at least as strong mechanically as the power wires themselves.

The writer believes that the past failures of guard wires to protect the line are in a great measure due to infrequent grounding and the use of improper material, such as steel. The writer has made some preliminary experiments with high frequency currents which have proved the superiority of copper, or copper-clad steel, over iron as material for grounded guard wires.

G. Semenza: Mr. Nicholson's paper is interesting from two points of view; the statistical one, on one side, as it describes a number of very severe troubles, and studies them in a coordinate way; and the technical one, on the other side, as it proposes a new protecting device which must be considered with the closest interest. Such a device appears to be theoretically effective, and the figures deduced by experience seem to show that it is so in fact.

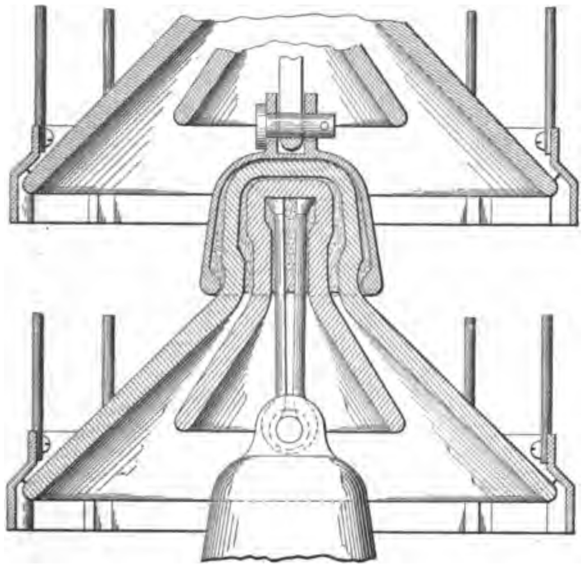
A closer consideration of the figures given, however, discloses some objections which make it desirable to obtain more complete data. First of all, the number of insulators punctured on the old line, both in operation and in the testing room, is considerably in excess of anything heretofore known. The thickness of the porcelain that is punctured in such an insulator ought to stand the testing voltage quite easily, so that, to the writer, the large number of failures would be attributed to imperfect baking of the porcelain.

As to the comparison between the old and the re-insulated line, it is to be noted that while the old line has been left as it was, on the new line 39 per cent of the insulators on the two lower wires, and all of those on the top one, have been replaced with a new and more modern type of insulator. For this reason it is not possible to determine how much of the improvement is due to the re-insulation of the new line.

In a general way it is not apparent how the rings can prevent the puncturing of the insulators. The effect of the rings may be to cause a flash-over to occur more easily than a puncture: such a result may be met by a better proportioning of the parts of the insulators. The protection of the petticoats in case of flash-over must be, on other hand, very effective, as the rings tend to draw the arc out of reach of the porcelain.

I would ask if, in consideration of the slight effects caused by arcs on the cables, it would not be easy to simplify the device by using a single bent wire projecting from the pin and turning upwards to the cable?

J. D. E. Duncan: The paper presented by Mr. Nicholson shows how closely different persons coincide in some cases in the expedients they adopt for the same purpose. The writer has previously developed quite similar arcing rings in connection with high tension insulators devised for use on the Stanislaus installation. One form of these arcing rings shown on a suspension type of insulator is indicated in the diagram shown herewith.



These arcing rings prevent excessive electrical pressure being exerted on any of the insulator elements; where, for example, a portion of the shells or elements has become temporarily ineffective through dust or moisture or where excessive pressure is exerted as in the case of lightning. By surrounding the entire insulator with an arcing ring any arc formed along the surface of the insulator inevitably moves out to the ring through heat and wind action and then the ring itself carries the discharge, the arc then being so far removed from the insulator as not to be dangerous to the porcelain. The rings are arranged so as to have an air space and air circulation around the outer edge of the petticoats so that any heat developed in the rings themselves will not be harmful and as the writer worked up this protective device the rings were mounted on various parts of the insulator structure, such as the petticoats, heads, and other parts.

In theory, the ring is practically a metallic conductor cage arranged around the insulator element and sufficiently removed from it to prevent any contact between the arc formed and the insulator itself, and the arcing distance from the arcing ring to its coöperating arcing points is so arranged as to make this relief path operative before dangerous or puncture voltage is approached. These arcing rings proved entirely effective when tested under conditions approaching those of commercial operation, and arcs generated by a transfor merhaving several hundred kilowatts capacity were disposed of without injury to the insulator in any case.

It may be of interest to briefly refer to the fact that these arcing rings and insulators were devised in connection with the high tension Stanislaus transmission line, which was designed, and the insulators developed, before lines at 100,000 volts were considered practical and before any lines had been put in commercial operation at more than the nominal 60,000 volts potential. A suspension type of insulator was finally adopted as being by far the most suitable for these conditions and because it was especially adapted for such increase of voltage as might from time to time prove necessary. This form of suspension insulator having a plurality of nested domes and attached petticoats has proved highly reliable under commercial conditions, as is evidenced by the operation of this Stanislaus transmission line for over ten months without interruption.

L. C. Nicholson: Replying to Mr. Catching's question concerning voltage disturbances accompanying discharges to the rings, there is practically none when one phase discharges. This is on account of a high resistance neutral which limits the current flow to about 30 amperes. Voltage disturbances accompanying simultaneous discharges on two or more phases are very great; in fact, under such short-circuit conditions there is practically no voltage anywhere.

Mr. Creighton asks for concrete cases of lightning stroke at various distances from the lines, and the corresponding effects upon the line. I regret that we have no very considerable data on this point. I have ventured to make a statement which indicates how we feel about it—less than 500 feet away is very dangerous, more than 3000 feet away fairly safe. Various observations made from time to time seem to indicate these general limits. Causes other than lightning which may produce flashovers are few. Opening a long section of unloaded line by means of open-air disconnecting switches sometimes sets up surges which cause flash-overs. The accidental grounding of one phase as by a tree branch or other object, lightning arrester discharge, etc., may cause flash-overs to occur on another phase at another point on the line, due to the sudden re-arrangement of the electrostatic conditions of the system. Surges produced in this manner frequently reach very high values.

I agree with Mr. Thomas that insulators may be shattered completely by pure lightning effects, unaccompanied by puncture or power. I think he is also correct in that the attack of lightning is frequently from the side instead of from above. I have a case in mind where two east and west parallel lines twenty six feet apart, insulated in the same manner suffered very unequally from lightning, the south line sustaining practically the entire damage, the north line being nearly immune. In this case the storms approached from the southwest.

As to the length of time necessary to injure an insulator by a large arc, a perceptible time is required, though very slight, perhaps about one quarter second, with a 10,000-kw. arc.

Mr. Ryan suggests the use of a metal disk on the cable to prevent the arc travelling out beyond the unprotected portion of the cable. We have experimented with this and other equivalent arrangements, but have not found anything that will deter the arc. In fact any obstacle on the cable appears to be objectionable since it furnishes a shielded zone in the lee of which the arc may rest and accomplish considerable burning.

Protection by a sleeve or serving of small wire would be entirely effective provided such protection extended far enough along the cable. However, such protection would necessarily extend, say, 50 feet each way from the insulator, since frequently arcs travel this distance along the wire. Two cases are on record where the arc extended from the lower ring to a point on the cable 250 feet from the insulator. If the passage of the arc along the cable is unobstructed, the burning is not serious. Twelve cases occurred in the season of 1909 in which the cables were blistered for from 5 to 50 feet. No cable was burned seriously enough to warrant repairing. Our conclusion is that the cable should be bare, so as to allow the arc to travel readily along it, which action forestalls serious burning at any one point.

In the case of suspension insulators, protected by rings, burning of the cable cannot occur since it is impossible for the arc to come in contact with it.

Something has been said about automatically sectionalizing parallel lines in case of a ground on short-circuit on one of them. We have found it entirely feasible to cut out a grounded line automatically by the use of a specially constructed relay. However, short-circuit, low-voltage conditions are very hard to treat, and while some progress has been made with automatic devices they are at present considered far from satisfactory.

As to the efficiency of an overhead ground wire in protecting against lightning, several gentlemen seem to construe my remarks on this subject as being entirely unfavorable to the use of a ground wire. Such was not intended, and our reasons for not installing such protection are as stated, *viz.*, the heavy expense incident to properly installing it on structures such as ours, already built, together with the extra load such wire or wires placed well up above the line would impose; and, as a result of an extensive canvass we concluded that the benefits to be derived from such protection were far from ideal and did not warrant the expense. We were looking for something better and less expensive than the overhead ground wire. It may be that it takes overhead ground wires, arcing rings, suspension insulators, and more, to eliminate all lightning trouble.

Mr. Brooke concludes from the log that the reason the reinsulated line tripped out so many times is due to the fact that the placing of the arcing rings lessened the line insulation and brought ground potential up nearer the conductor. We interpret the operating results differently. For example, considering the 38 cases of flashover found upon inspecting the reinsulated line, tabulated on page 261, 17 were complete flashovers to the pin, and consequently the entire insulation of the line was developed. Moreover there were two-thirds as many trip-outs on the old line as on the reinsulated line, and in addition there were 15 instances of disablement on the old line. Assuming approximately the same amount of lightning on the two lines, the reinsulated line shows 20 trip-outs against 27 on the old line. I call attention here to an observation omitted in the paper, *viz*, in only three cases of the thirty-eight inspected was the initial discharge vertically downward from the cable to the ring. In thirty-five cases the discharge emanated from the tie wire in the neck of the insulator, either to the pin or to the ring. Our conclusion is that under average conditions of moisture on the insulator surface during storms the rings are not close enough to reduce the degree of line insulation. It is entirely feasible to lower the ring so as to develop the full dry flashover value of the insulator, in which location the ring is equally effective in taking the power arc off the pin.

Mr. Semenza's opinion that insulators should be designed so as to flash-over before they are punctured is entirely concurred in. This is what we have attempted to get in the new style four-part insulator. On the other hand, given any insulator, it is possible by a ring to reduce its dry flashover value to a point comparable to its puncture strength, and at the same time keep the wet flashover value normal. There is, moreover, no great objection from an operating standpoint to doing this. This is what we have done with the old type insulator.

As to replacing the ring by a gap from the cable to a single bent wire, leading upward from the base of the pin, this would be equally as effective as a ring, but for only one condition of wind direction. An insulator flashes over on its wettest side, which is the windward side, in a lightning and rain storm. Were the proposed gap set at a value less than wet flashover so as to attract all flashovers (wet and dry) two objections arise; first, the degree of line insulation is reduced and, second, under certain wind directions the arc would attack the pin and destroy the insulator. A continuous metal ring enables the arc to shift readily around the insulator and to accommodate itself to all wind directions, and always to the leeward of the insulator. A horizontal gap at the top of the insulator, if set below wet flashover value, will prevent injury to insulators by power arcs, but such gaps are more difficult to construct and if set close enough to prevent insulator " spill-overs " are a menace to operation. Our experience with gaps of this nature indicates that it is impossible to adjust and to keep in adjustment a large number of them.

I wish here to add some data which shows the effect of the lower ring to reduce the puncturing tendency of the three-part insulators. We recently had occasion to test 800 of these insulators, first with the ring in place and then with the ring removed, the voltage in each case being sufficient to cause flashovers, *viz.*, 160,000 with the ring and 195,000 without the ring.

Failures with ring	3 per cent
Failures without ring	22 per cent

Of the 3 per cent failures with ring, only 1.25 per cent was due to failure of the pin-piece, whereas of the 22 per cent failures without the ring, 17 per cent was due to the failure of the pin piece.

Mr. Duncan proposes the use of metallic rings supported on the insulator parts. I understand from his remarks that this device was developed experimentally, with small amounts of power. Several years ago an arrangement such as this was proposed for our insulators, but subsequent tests showed it to be entirely without effect when large amounts of power, say, 10,000 kw. and over, are put into the arc. Since the damage to the insulator is caused by the lower terminal of the arc running up the pin, the only cure is to take the arc off the pin automatically and immediately after its formation. So long as this is not accomplished, the insulator will be destroyed. Experiments show that the attenuated portion of a large power arc approximately eight inches and more away from its termini is not destructive to porcelain even though in continuous actual contact therewith. For this reason little good is accomplished by " short-circuiting " the arc as it passes the edge of the insulator skirts, while allowing its terminal to remain on the pin of an upright insulator or the metallic links of a suspension insulator. Furthermore a very slight breeze causes the body of the arc to flare clear of the insulator skirts, even with conducting bands about them, which action prevents the metal bands from performing any function. There is no reason why the arrangement mentioned will not limit the puncture stresses to any desired amount.

The operating results given in the paper would hardly be complete without referring to our Waterloo of 1910, when two insulators on the reinsulated line were exploded by what appears to have been a direct stroke of lightning. A number of other insulators on adjacent structures flashed over, but were uninjured. This incident shows that there is a degree of lightning which is fatal to protected insulators, but from past experience we know that such occurrences are very rare.

During another storm of 1910, the telephone line 100 feet from the power line was struck and several poles splintered. Flash-overs occurred at that point on the power line, but no insulators were damaged. This result indicates that the line is practically proof against breakage by anything less than a direct stroke.

The general bearing of this situation it seems to me is this—we have transmission lines which will operate practically without extended interruption, but with a number of momentary interruptions during the season, momentary short circuits, I should say, which are sufficient to throw out of step the present type of synchronous receiving apparatus on the system. I believe the results point to the necessity for the design and the use of synchronous apparatus, which will suffer heavier disturbances of voltage than the present type can withstand.

A paper presented at the meeting of the American Society of Mechanical Engineers New York, April 12, 1910, the American Institute of Electrical Engineers co-operating

MOTOR APPLICATION TO MACHINE TOOLS

BY CHARLES FAIR

The subject of motor application to machine tools is rather a difficult one to treat satisfactorily in an abstract way. However, in this paper I shall try to point out the fundamental principles underlying motor applications to machine tools and trust that these will aid, not only in the selection of the proper motor and control, but in their application to machine tools as well. Observing these principles will have a marked effect upon production and will reduce maintenance to a minimum.

Since much has been written on the advantages of motor-driven tools, it will suffice here to mention briefly only a few; such as sanitation, unobstructed light, absence of belts and belt troubles, head room for cranes, hoists, etc., elasticity of arrangement, ease of adding new tools and of moving and rearranging tools, close speed regulation, greater power and overload capacity, maximum output of tools, power transmission, facility for running only such tools as are required for overtime work, and finally, under modern structural conditions, avoidance of the well-understood difficulties of line shaft installations in cement buildings. These points are admirably illustrated in the following photographs.

Figs. 1 and 1a are views showing the interior of a machine shop of a large manufacturing company. As this is one of the largest buildings ever built to be used exclusively as a machine shop, it would probably not be amiss to give here a brief description of the building and the machines.

The building is 295 ft. wide and 800 ft. long. The total floor space of the building, including galleries is 490,000 sq. ft. or 11.2 acres. It contains 997 machine tools operated by 1047

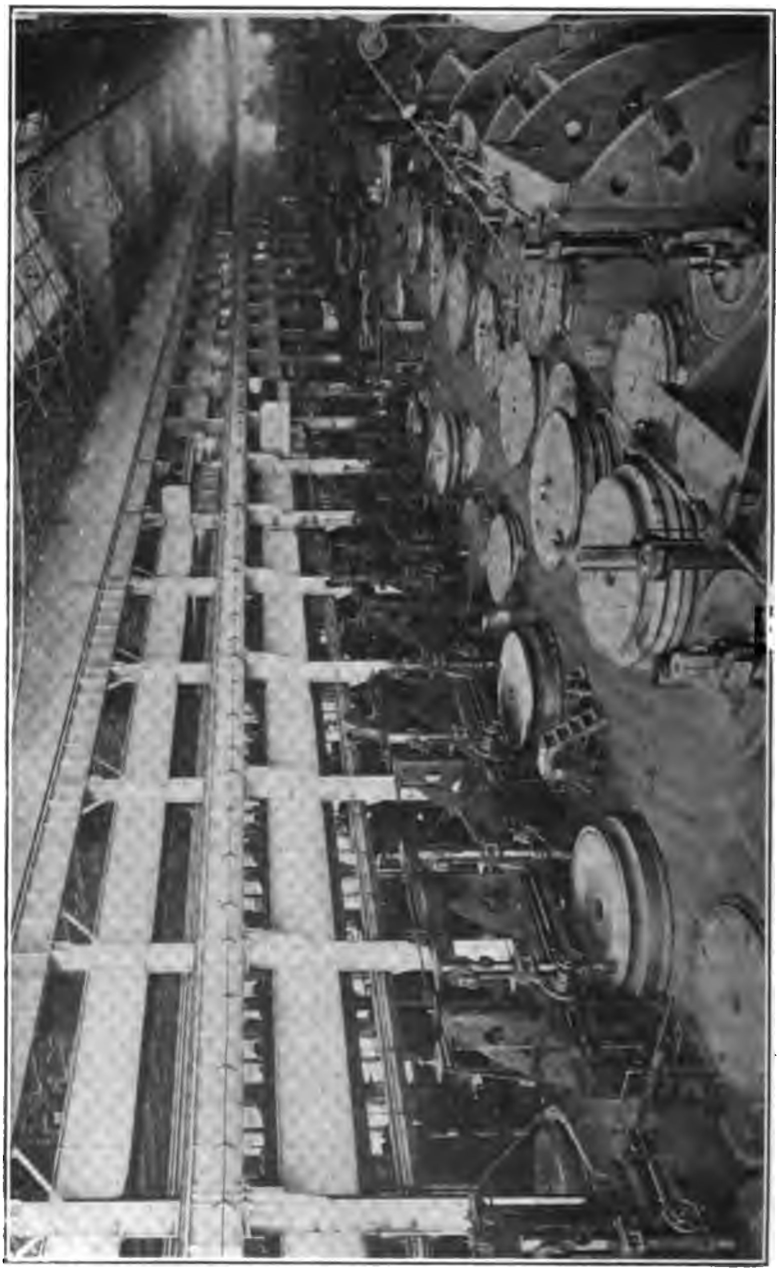


Fig. 1

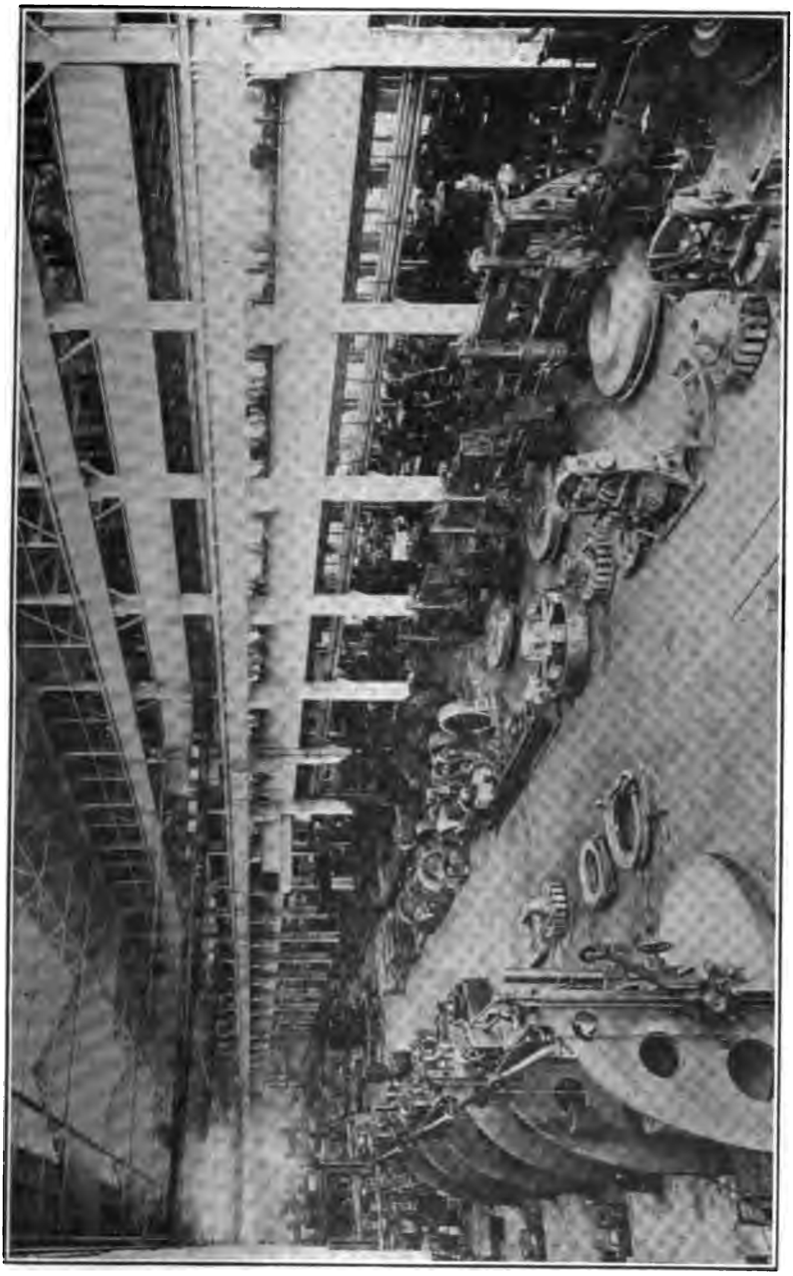


FIG. 1a

motors, 941 of the tools being driven by independent motors, and a number of them requiring two or more motors. There are 56 of the smaller tools, all of which are located in the second gallery, which are arranged in groups varying from six to twelve tools per group. The machines range in size from a 40-ft. boring mill down, there being 51 boring mills 6 ft. and over, and 36 portable tools used on the iron floors. This large number of tools requires for handling work, 35 cranes ranging from 5 to 50 tons and 8 electric hoists, as well as 8 freight elevators and 2 gantry cranes.

Fig. 2 is a very good illustration of the overhead clearance due to the use of individual motors and shows a number of 8-ft. boring mills. Each of these mills is driven by a 20-h.p. adjustable-speed motor, the cross-rail being raised and lowered by a 3-h.p. motor. The controllers for operating both motors are shown fastened to a bracket which in turn is bolted to the machine. These machines are placed under a gallery, as shown in the illustration, as also are the boring mills shown in Fig. 3. The latter are placed directly behind those shown in the previous illustration, thus making a very compact arrangement of tools and at the same time allowing plenty of room for handling work. Except in the case of the first mill on the left, the controllers for operating this group of boring mills are arranged as shown on the first mill on the right.

Fig. 4 is a view of another building looking down the center aisle of the second floor. This shop is a modern reenforced concrete building in which no line shafting whatever is used, even though the majority of the tools are old ones changed over to individual motor drive. Although many of these tools require short belts, this is a very different matter from belting from lineshaft to countershaft and from countershaft to tool.

Fig. 5 shows a group of lathes driven by individual motors. If this group of lathes were belt-driven and arranged as compactly as shown, with two belts from line to countershaft, the ceiling would be literally a mass of belts.

Fig. 6 shows a punch press department. All the punches and shears in this building are individually driven by alternating-current motors, although such tools are also frequently driven by direct-current motors.

Up to comparatively few years ago in the majority of the shops where motors were used, they were simply belted to the lineshaft or countershaft of the tool. Adjustable-speed motors were not so commonly used then as now, nor were they made in the great variety of sizes and speeds now obtainable. Today, especially in the case of new tools with their requirements of higher power and closer speed regulation, due to the use of high-speed steel, it becomes not only more convenient, but in many cases almost a necessity, to apply the motor directly to the tool.

FIG. 2

FIG. 3

When the work of actually equipping a factory with motor drives is undertaken, it will be necessary to study the conditions of operation, which vary greatly with the product manufactured,

Fig. 4

Fig. 5

and while in some cases these conditions are comparatively simple in others they are more complex. The arrangement of tools will to a large extent depend upon the nature of the work, and as to whether alternating or direct current is available; it will also depend upon whether the convenience of operation and handling of material are of sufficient importance to call for a considerable number of individual drives, or as to whether it is to be generally a group-driven shop.

In driving tools with individual motors it will be remembered that the motor not only supplies the power and speeds best adapted to the tool, but that the speed of the motor alone in many cases covers the entire speed range of the tool, and that the motor can be applied directly to the tool, making a compact unit.

Fig. 6

When equipping tools with individual drives, the controlling apparatus as well as the motor should be attached directly to the tool when possible. This arrangement allows moving the tool by simply disconnecting the leads and connecting them in the new position. In the case of portable tools this, of course, is an absolute necessity.

A graphic recording wattmeter in circuit with a tool not only tells the actual power consumed by the machine, but also shows whether the tool is operating at its maximum rate, by registering the time of unproductive cycles or the length of time the tool is idle; and by analysis, the cause of the lost time may be discovered and result in a change of conditions with a corresponding increase in production. Poor lineshaft alignments have been detected by watching the integrating wattmeter. Many shops are paying dearly for lack of attention to alignment of shafts, etc.

Difficulties concerning the choice of the type of motors for tools have been considerably exaggerated. The following table will, in a general way, aid in the choice of motors. The great variety and the sizes of tools of the same name make it necessary in a general list, such as this to double-check a number of tools.

MOTORS FOR MACHINE TOOLS

Tool	Direct current			Alternating current		
	Shunt	Comp.	Series	×	♯	✱
Bolt cutter	†			×		
Bolt and rivet header		20% 40%		×	♯	
Bulldozers		20% 40%		×	♯	
Boring machines	†			×		
Boring mills	†			×		
Raising and lowering cross rails on boring mills and planers		60%	†		♯	
Boring bars	†			×		
Bending machines		20% 40%		×	♯	
Bending rolls		40% 80%	†			✱
Corrugating rolls		20% 40%		×	♯	
Centering machines	†			×		
Chucking machines	†			×		
Boring, milling and drilling machines	†			×		
Drill, radial	†			×		
Drill press	†			×		
Grinder—tool, etc	†			×		
Grinder—castings		20%		×		
Gear cutters	†	20%		×		
Hammers—drop		20% 30%			♯	
Keyseater—milling—broach	†			×		
Keyseater—reciprocating	†	20%		×		
Lathes	†			×		✱✚
Lathe carriages			†		♯	
Milling machines	†			×		

MOTORS FOR MACHINE TOOLS—(Continued)

Tool	Direct current			Alternating current		
	Shunt	Comp.	Series	×	ƒ	✱
Heavy slab milling	†	20%		×		
Pipe cutters	†			×		
Punch presses		20% 40%		×	ƒ	
Planers		20%		×	ƒ	
Planers—rotary	†	20%		×		
Saw—small circular	†			×		
Saw—cold bar and I beam	†	20%		×		
Saw—hot		20%		×		
Screw machine	†			×		
Shapers	†	20%		×		
Shears		20% 40%		×	ƒ	
Slotters	†	20%		×		
Swaging		20%		×	ƒ	
Tappers	†			×		
Tumbling barrels or mills		20%		×		

× Squirrel cage rotor.
ƒ Squirrel cage rotor-high starting torque.
✱ Slip ring induction motor with external rotor resistance.
† Might be used for tire lathes as it allows slowing down when cutting hard spots.

It must be kept in mind, however, that various circumstances, such as size or roughness of work, flywheel capacity, etc., may call for radical departures in choice of motors, this list being compiled to meet average conditions. Shunt motors, for instance, are used in the following cases; when the work is of a fairly steady nature; when considerable range of adjustment of speed is required, as on lathes and boring mills; and on group and lineshaft drives, etc.

Compound-wound motors are used where there are sudden calls for excessive power of short duration, as on planers, punch presses, etc.

Series motors should be used where speed regulation is not essential and where excessive starting torque and slow starting speeds are required; as, for instance, in moving carriages of large lathes, in raising and lowering the cross rails of planers and boring mills, and for operating cranes.

When in doubt as to the choice of compound or series motors of small horse power, the choice might be determined by the simplicity of control in favor of the series motor. Series motors, however, should never be used when the motor can run without load, as the speed would accelerate beyond the point of safety.

The alternating current motor of the squirrel cage rotor type corresponds to the constant-speed, shunt, direct-current motor, but with a high-resistance rotor it approaches more closely the characteristics of a compound direct-current motor. It is understood that the variable-speed machines, checked in this list under the alternating-current squirrel cage rotor column, have the necessary mechanical speed changes.

The slip-ring induction motor with external rotor resistance would be used for variable speed, but this must not be construed to mean that it corresponds to a direct-current, adjustable-speed motor, as it has the characteristics of a direct-current shunt motor with armature control.

The self-contained, rotor resistance type would be used for lineshaft drives, and for groups when of sufficient size.

Multi-speed, alternating-current motors are those giving a number of definite speeds, usually 600 and 1200 or 600, 900, 1200 and 1800 rev. per min., and are made for both constant horse power and constant torque. These motors would be used where alternating current only was available, or direct current limited; and the speed range of the motor, together with one or two change gears, would give the required speeds.

One of the most important features in the selection of motors and one that is persistently overlooked, is the strict adherence to the use of standard motors, and by standard motors is meant standard armature shafts as well. The importance of maintaining standard armature shafts will be readily recognized by the factory management when it is pointed out that by such an arrangement spare armatures are reduced to a minimum, and that in an emergency it is possible, where these are not carried, to replace an armature or even a whole motor, from an idle tool, or from a tool of relatively less importance at the time. Also, of course, stock motors can be supplied promptly by the manufacturer and shipments materially improved if special shaft extensions are not called for. That special features in a motor are sometimes desirable, is not to be denied; it may so happen that the advantages from some special feature in the motor may more than offset the disadvantages above referred to, but in cases where these features are thought necessary they should be carefully considered before final decision.

The sketches in Fig. 7 show a number of arrangements used in order to maintain standard motor shafts. In addition to these, many forms of flange and split couplings are used. The method which is selected for connecting standard shafts will depend upon the conditions surrounding the drive under consideration. Tools which only a few years ago were equipped with special motors are today driven by standard motors, and as a result are easily and quickly repaired. In the early days of the motor drive many special features were thought necessary in the motor to make it adaptable to the tool; special frames, shafts and speeds were required by the tool builder, and little thought was given to the interchangeability of parts. It is therefore easy to recognize in these early equipments responsibility for the existing idea that special features in the motor are still necessary for tool equipments. Many of these features are now recognized as unnecessary, and today the tool builder in many instances builds his tools ready for attaching standard motors.

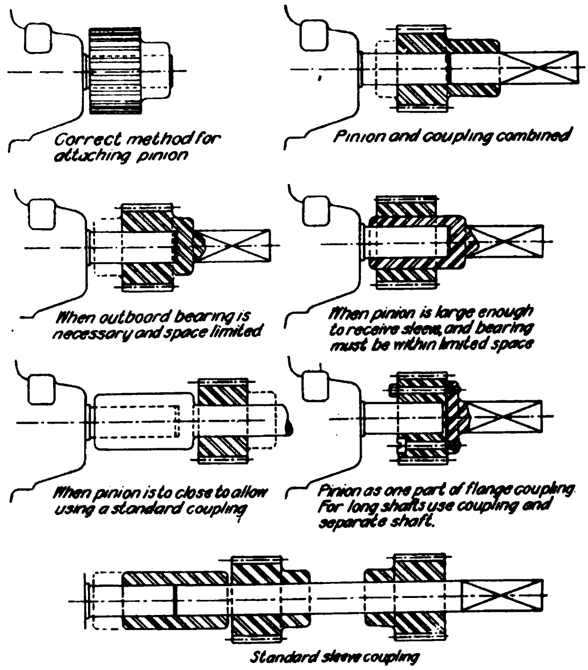


FIG. 7.—Some methods used to maintain standard motor shafts for the interchanging of armatures

At the present time, so far as tools are concerned, we think of the motor largely as a means of driving the tool and not of the possibilities of the motor becoming the main element of the tool construction. Here again, high-speed steels, together with the improvements made in the motor, will produce many new designs in tools with corresponding higher efficiencies.

The old prejudice existing against the electric motor, which was mostly a mistrust due to a lack of familiarity with its operation, is rapidly dying out, and today motors are found driving machines in shops of every description.

Equally important with the choice of motors is that of control. In selecting the control it is necessary to consider the nature of the work, its accessibility to the operator, the method of attaching it to the tool and in some cases its relative position to other tools; for instance, an open type starting rheostat should not be exposed to danger of short-circuit from flying chips. In the majority of cases, a shunt motor of ¾ h.p. and less would be started by a switch. Exceptions to this would be motors on tools that must be gotten under way slowly, and grinders driven by direct-current motors for reasons of safety. With adjustable-speed motors, care should be taken to throw the switch on full field. Series motors up to 8 h.p. or even larger can be started by switch. Exceptions to this would be cranes and tools requiring a certain amount of armature speed regulation. Larger motors, for tools where starting service is infrequent or not severe, and for lineshafts and for group drives, would be satisfactorily operated with a dial type controller, which is cheaper than the drum controller, provided, however, that the controller is placed in a protected position.

When making the installation, accessibility to the controller in case of accident should be kept in mind, even though of little importance so far as starting up is concerned. The starting apparatus should be placed where the motor or some of the moving parts can be seen by the operator. On individual motor-driven tools, where the motor is started and stopped many times a day or where the starting conditions are of a severe nature, or where tools are edged along, drum type controllers with extra heavy starting resistance should be used. For adjustable-speed motors, using the drum type control, the field control should be through fingers making contact on segments of the controller drum and not by sliding contacts on a dial, as with the latter, trouble will develop sooner or later. Motors above 40 or 50 h.p., under these severe conditions, are best operated by a master controller which operates contactors for cutting out steps of starting resistance, and if adjustable-speed, the field control should be taken care of, as stated above, by fingers making contact on segments of the drum. This class of starting apparatus will stand any quantity of abuse and, by the addition of a simple current limit relay device, becomes practically a fool-proof protection for the motor. There are cases where it might be advantageous to use master controllers and contactors even with smaller motors.

Alternating-current squirrel cage rotor type motors, two-phase and three-phase, up to 5 or 8 h.p., generally speaking, can be thrown on the line, depending largely upon power conditions. Above 5 or 8 h.p. they should be operated by compensators. The self-contained rotor-resistance type would be started by a sliding resistance in the rotor, and the slip-ring type by a controller with external resistance.

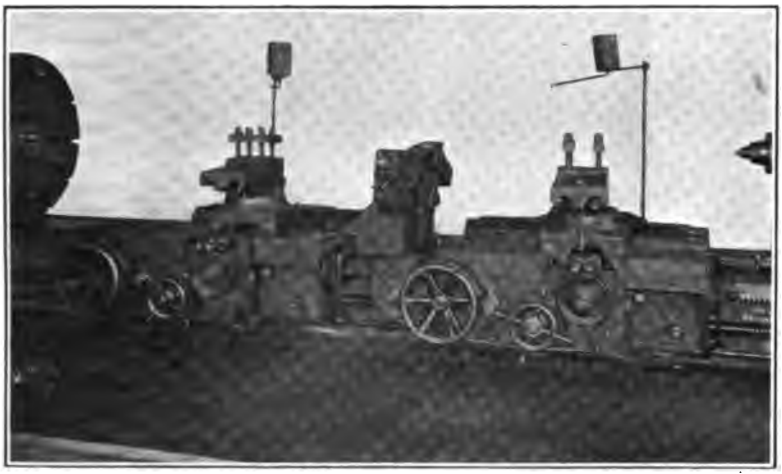


FIG. 8

Upon the convenient arrangement of the control depends, to a considerable degree, the output of the tool, and the importance of the arrangement from the standpoint of the operator cannot be ignored, since the output of a tool will be materially increased when an operator can start and stop the tool and obtain at all times maximum cutting speeds by simply turning a handle. The controller must be placed in a safe position and should be accessible for repairs, which very often means that some arrangement is necessary to bring the operating handle within easy access of the operator. A familiar illustration of the convenience of control is the arrangement so commonly seen on lathes, whereby the operating handle travels with the tool carriage and allows the operator at all times a complete control of his tool. The motor and control for moving lathe carriages is perhaps not quite so familiar; such an arrangement is shown in Fig. 8, which shows a 60-in. lathe, the main drive being a 35-h.p. 635/1270-rev. per min. motor and the carriages being operated by a 3½-h.p. series motors, while Fig. 9 shows the method of fastening and protecting the trolley for operating the motors on the lathe carriages. The latter illustration shows a 42-in. lathe, and was selected because in addition to the regular method of fastening the trolley it shows the change necessary in the supporting brackets if taper attachment be used. Strange as it may seem, this most important feature, the convenience of control, which bears directly on production, is ignored in the majority of the tools where the control is of the greatest importance. This convenient arrangement of control is shown in the following illustrations

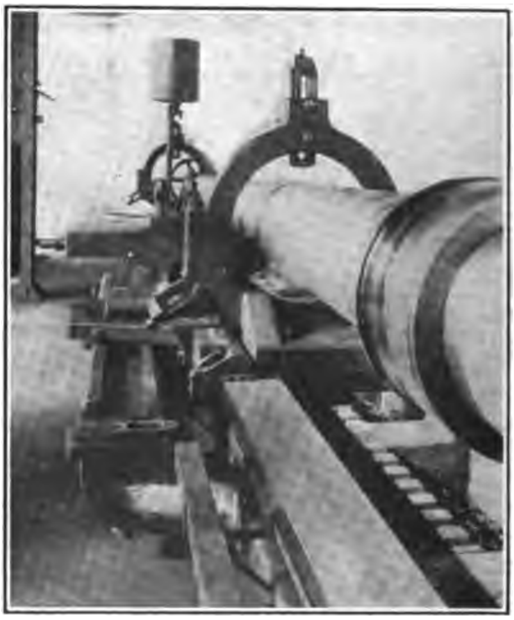


Fig. 9

Fig. 10 shows an 8-ft. boring mill, driven by a 20-h.p., 600/1200-rev. per min. adjustable-speed motor. The cross-rail is raised and lowered by a 3-h.p. motor. It was a very easy matter in this case to place the controllers in the most accessible position for the operator by fastening them to a bracket which in turn is bolted to the machine. Boring mills on which it is not convenient to have the controller placed as shown in Fig. 10, might be arranged as in Fig. 3, previously shown, which calls for an extension of the controller shaft, a coupling, a bearing bracket and an operating wheel; or again as in Fig. 11, which shows the arrangement of control on a 16–25-ft. boring mill, which is operated much as the one shown above but with the addition of a universal joint. This mill is driven by a 50-h.p., 500/1000-rev. per min. adjustable-speed motor, and two 15-h.p. constant-speed auxiliary motors.

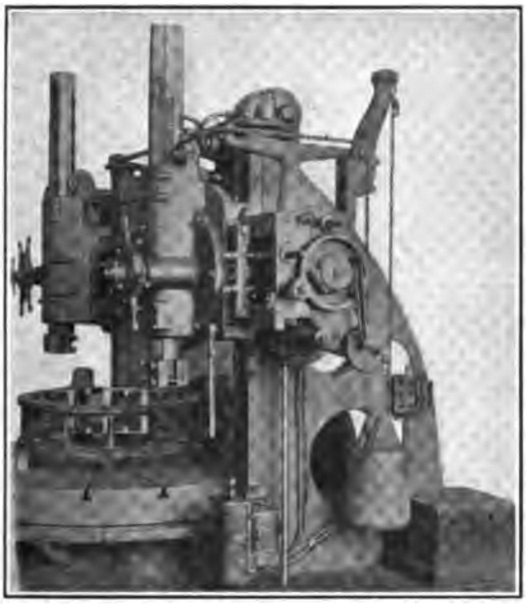


FIG. 10

In the case of the vertical milling machine shown in Fig. 12, it was desirable to provide two positions for the control—one that at all times could be operated from the floor line, and one traveling with the cutters, which at times might be ten feet or

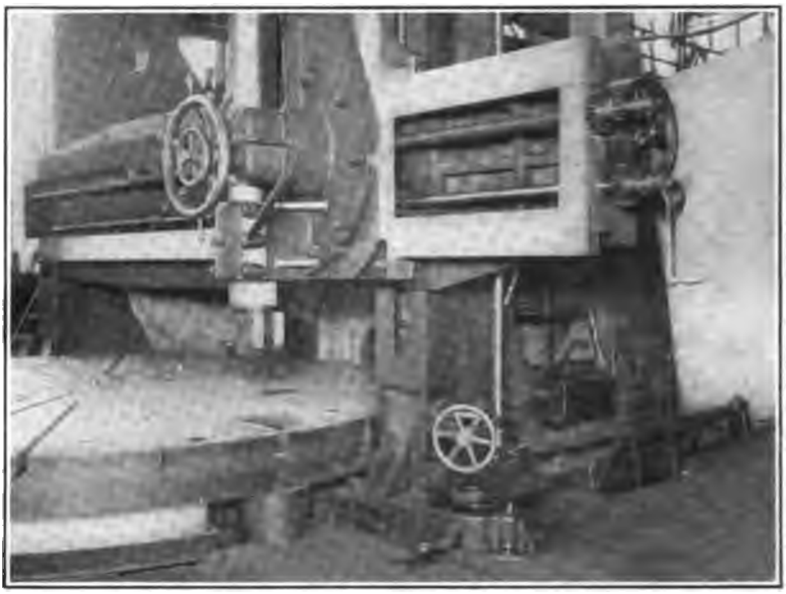


FIG. 11

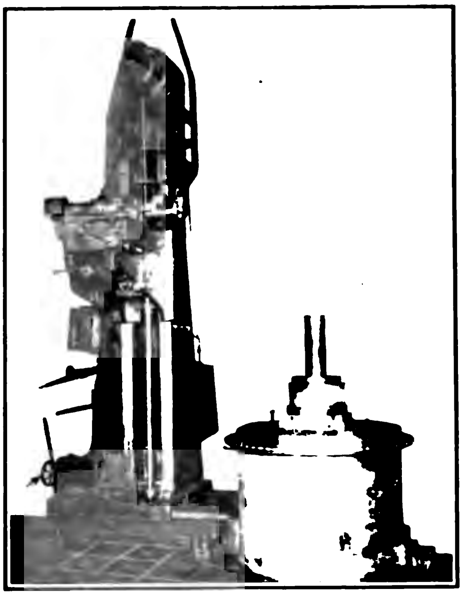


FIG. 12

more from the floor. On account of the limited space for the controller it was necessary, in order to bring the operating wheel in the proper position for the operator, to use spur gears, universal joint, and bevel gears.

Fig. 13 shows a vertical milling machine, driven by a 7½ h.p., constant-speed motor, and shows clearly the operating wheel together with the safety latch which drops in place when the controller is brought to the off position.

On slotters it is often necessary to put the controller on the left side of the tool with the operating handle on the right, as shown in the case of a 12-in. slotter, Fig. 14, driven by a 5-h.p., 500/1500-rev. per min., adjustable-speed motor.

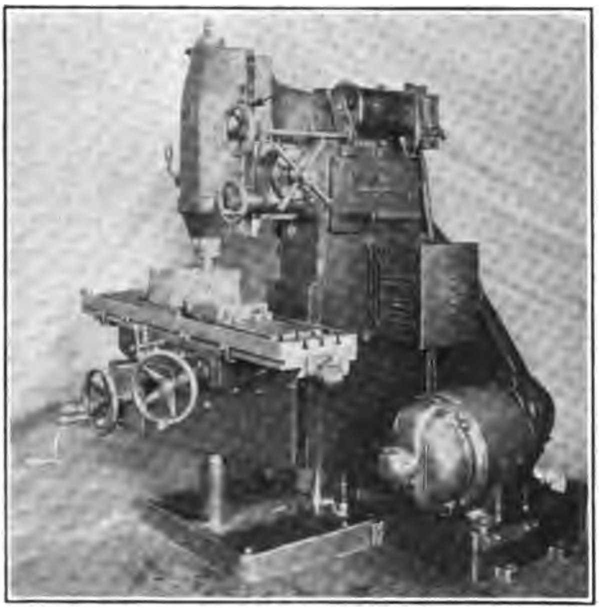


Fig. 13

Fig. 15 is a 60-in. slotter, driven by a 20-h.p., 890/1330-rev. per min., adjustable-speed motor through pneumatic clutches, and for moving the table a 3-h.p. motor is used. Two controlling stations were necessary on this machine, the work at times being so large that it was not practicable to operate the front wheel, yet for the majority of the work it was the most satisfactory position. The safety latch for the off position is clearly shown on the operating wheel. The controller is seen on the rear of the machine.

In the case of the milling machine driven by a 5-h.p., 500/1500-rev. per min., adjustable-speed motor, shown in Fig. 16, it was at times, on account of the nature of the work, essential that the operating handle be placed in the position shown.

Fig. 17 shows the motor and controller travelling with the head of an 84-in. rotary planer, driven by a 15-h.p., constant-speed motor, the current being received through sliding contact which is on the rear of the machine and is completely enclosed. The controller is placed under the platform, while the controller handle is brought out at the top of the pedestal as shown.

FIG. 14

The horse power required for driving tools calls for the exercise of considerable judgment, especially in the case of alternating current motors where power factor enters into consideration. Exhaustive tests have been made to determine the amount of power required to drive tools, but it is to be regretted that many of these tests are lacking in essential features that would make them valuable. Conclusions drawn from incomplete data are apt to be misleading; as in the case of tests made with motors which are considerably underloaded or overloaded, and where efficiencies are not taken into consideration; or where the material used and duration of test are not stated; or where there has been failure to state whether the test was a practical one or merely a breakdown test. The conclusions drawn from breakdown tests are often deceptive and should not be used for determining power to drive tools; also it does not follow that a tool which stands up longer than another under breakdown conditions, will do the same under practical conditions. The majority of the formulas now in existence for computing horse power required for tools are generally misleading and useless, and no general formula that would be of practical value has been developed, as the power required varies with the metal worked, the cutting speed and many other conditions.

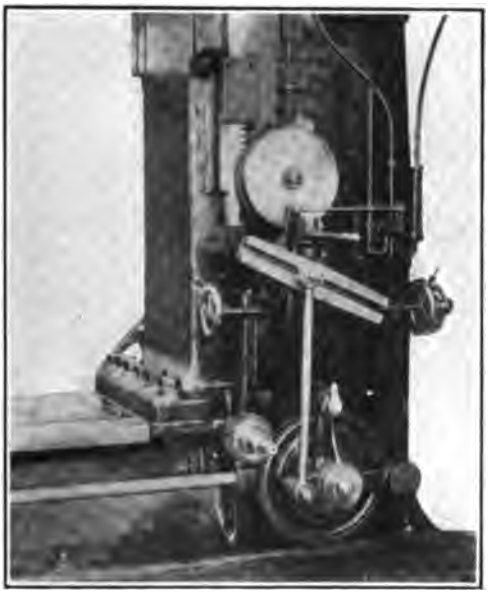


FIG. 15

The construction of the tool is seldom taken into consideration when estimating horse power, yet some of the worm-driven tools are notoriously inefficient. Other tools are so constructed that the greatest part of the power delivered to the tool is consumed in friction losses and not in useful work; again, the tool may be constructed upon approved lines but may not be stiff enough to stand the strains to which it is subjected, thereby causing considerable loss of power, all of which, as well as the difference in power due simply to the shape of a cutting tool, has been repeatedly proved by tests. In one instance, it required 72 per cent more power to drive a plain spiral milling cutter than the same cutter nicked.

The advent of the high-speed steel and the high-power tools, together with the increased speed of old tools, makes much of the data bearing on horse power collected up to a comparatively short time ago, of somewhat doubtful value. From the above, and from the fact that the duty required of a tool in one shop may be more severe than that in another, it will be seen that it cannot be accurately stated that a definite size of motor is required for a given tool. In the majority of cases, however, the horse power for small tools has been pretty well fixed. With the larger tools the variation in horse power required is much more pronounced, and at the same time, is more important on account of the size of the motors involved. This variation in horse power is often as much as 4 to 1 and sometimes even 6 to 1.

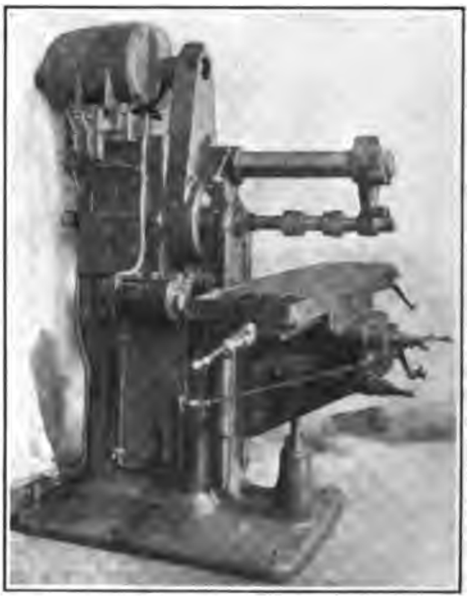


FIG. 16

Considerable difference of opinion has developed as to the advantages of individual versus group drives, and while it is generally agreed that it is advantageous to have the larger tools individually driven, the agreement by no means extends to the smaller ones. Under certain conditions there is no question as to the advantages of the individual drive for small tools, as, for instance, where small tools are necessarily placed among larger ones, or to allow convenient placing of tools in the assembling departments. The cases where it would be advantageous to have small individually-driven tools are numerous.

Little trouble is experienced in obtaining new tools already arranged for attaching motors, since many of the tool manufacturers are alive to the superiority of the motor drive and have for years built tools especially adapted for motor drives. Unfortunately, others have seen fit merely to arrange them for attaching motors, while still others leave the purchaser to attach the motor as best he can, consequently the best results are not always obtained.

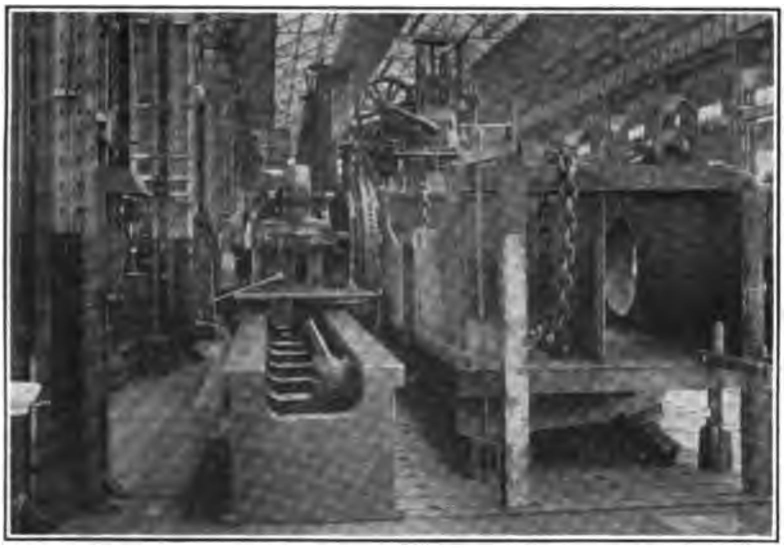


FIG. 17

When the driving of old tools by individual motors is under consideration, it is important to take into account the nature of the work, the speed range, the number of similar tools to be equipped and the condition of the tool. It sometimes happens that when a tool in itself would not call for an individual drive, certain circumstances might make such a drive advisable.

As an illustration, when the majority of tools in a shop have become individually driven, there might still remain a number of scattered tools, which, unless they were driven by individual motors, would necessitate the running of a long line of shafting; or, in the event of moving into new quarters—a cement building perhaps—it is decided not to use line shafting. It is understood, of course, that when old tools are scrapped the motors can be transferred to other tools.

Some interesting methods for attaching motors to old tools are shown in the following illustrations.

FIG. 18

Fig. 18 shows the headstock of what was originally a belted type, 24-in. lathe changed to a motor drive. This equipment makes a very durable and satisfactory drive, and calls for a standard 5-h.p., 500/1500-rev. per min., adjustable-speed motor. The shaft carrying the sliding pinions and handwheel is made large enough to receive the motor shaft, thus avoiding the use of a special armature shaft. The illustration shows clearly the motor, motor base, yoke, gears, bearing bracket and the quill which replaced the old cone. Room was left between the sliding pinion and gears in order that the pinions might be turned freely when sliding from one gear to the other.

The 30-in. lathe, shown in Fig. 19, is driven by a 5-h.p. motor, and like the lathe shown in Fig. 18, is a most satisfactory drive.

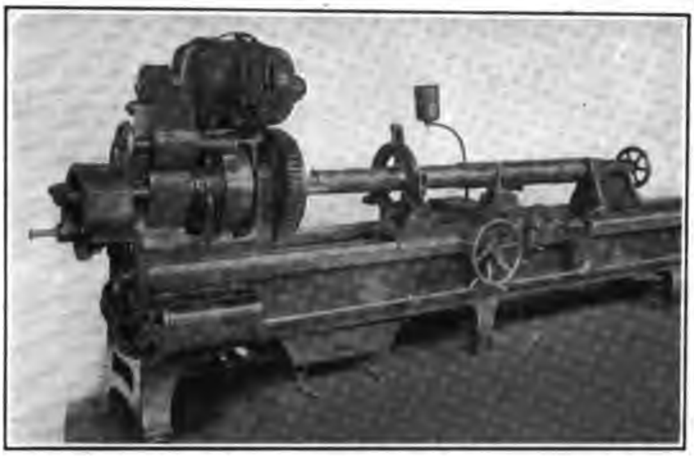


Fig. 19

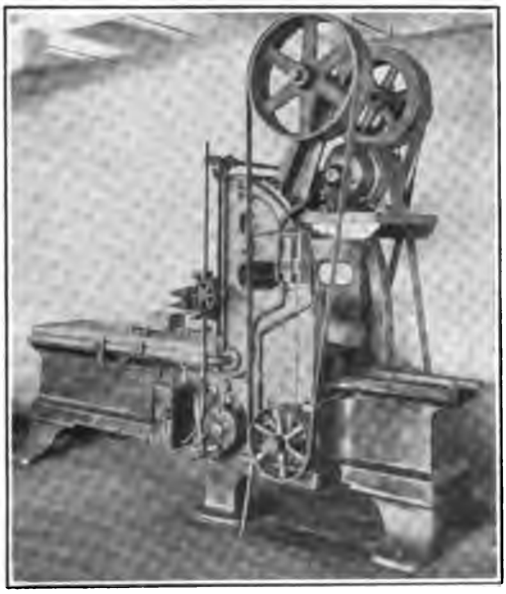


Fig. 20

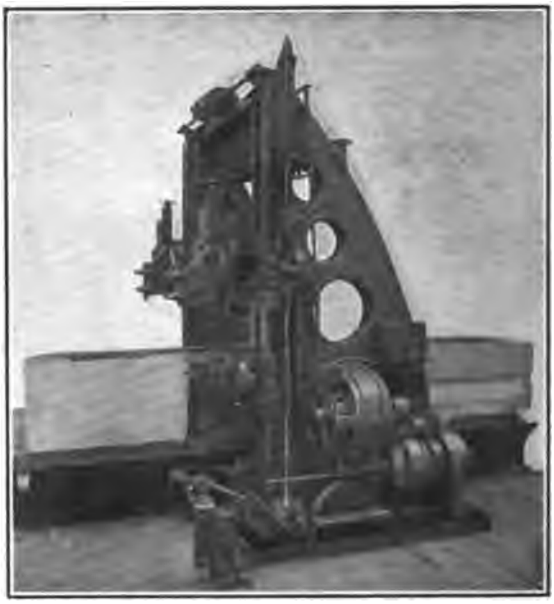


Fig. 21

Fig. 22

It differs from the former principally in the use of a positive clutch instead of sliding pinions. These lathes, as well as the majority of lathes which are motor-driven, are operated by a handle fastened to the right side of the lathe carriage to give the operator at all times complete control over his tool.

Fig. 20 shows a 24-in. planer. This is an inexpensive way of driving planers up to 42-in. or thereabouts, and has proved highly satisfactory. It is a decided advantage to have the controller conveniently located even on planers.

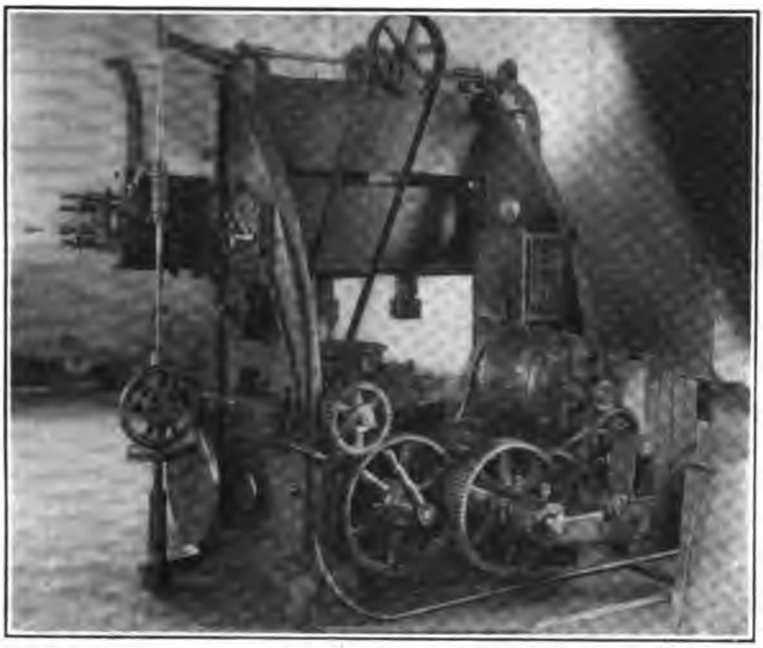


FIG. 23

Fig. 21 shows an old 120-in. planer driven through pneumatic clutches. In this case there was not room for the controllers on the machine so they were placed in the most convenient position for the operator, as shown. The small controller at the rear of the large one is for operating the motor which raises and lowers the cross-rail of the planer.

Fig. 22 shows clearly the small motor for raising and lowering the cross-rail on a 72-in. planer. The main drive, which is through pneumatic clutches, is also clearly shown.

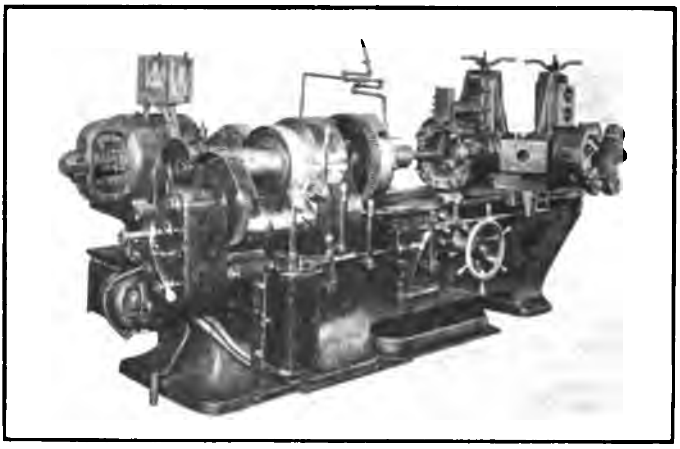


Fig. 24

Fig. 25

Fig. 23 shows a 60-in. boring mill changed to motor drive, the cone having been replaced by gears and motor as shown.

Fig. 24 shows a turret lathe driven by a 7½-h.p., 500/1500-rev. per min., adjustable-speed motor, and a ¾-h.p., constant-speed motor.

Fig. 25 is a 36-in. chucking machine driven by a 5-h.p., 500/1500-rev. per min., adjustable-speed motor, and shows a very simple method of attaching the motor; in fact, the brackets for supporting the motor were originally made for an entirely different machine.

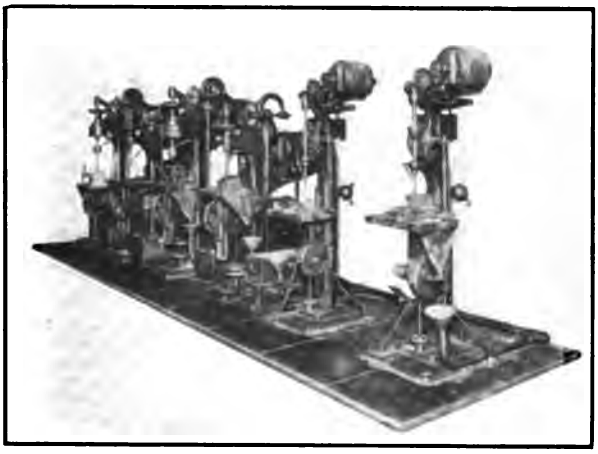


Fig. 26

Fig. 26 is a group of drills driven by adjustable-speed motors. It would be hard for one who had seen the original group to recognize this group of drills as the one originally driven by ropes, counterweights, etc.

The application of motors to tools, whether old or new, is not a difficult matter, and from the foregoing illustrations and the explanatory comments we trust that the advantages claimed for such applications have been made fairly evident.

A paper presented at the 245th meeting of the American Institute of Electrical Engineers, New York, April 15, 1910.

EDUCATION FOR LEADERSHIP IN ELECTRICAL ENGINEERING

BY SAMUEL SHELDON

Introduction. There seems to be a prevalent opinion that engineers in general, and electrical engineers in particular, do not occupy as important positions among the leaders in this country as engineering enterprises occupy in affairs in general. An attempt is made in this paper to determine how far this opinion is warranted, to give the characteristics of electrical engineering leaders, to consider the educational advantages which they have enjoyed, to formulate those essential characteristics of leaders which can be imparted to the individual by educational processes, and to discuss some of the problems met by educators in carrying on these processes.

The Importance of Electrical Engineering. This can be determined best from a statistical study. The following data concerning individuals and money values have their origin in various United States Census reports. Although they refer to different periods during the last decade, they are sufficiently related to warrant their use in this connection. The importance of an item is expressed by the percentage ratio which its occurrence bears to all occurrences in the same class.

The opportunities for achieving great distinction seem limited to professional service, the enumeration in the table including artists, architects, authors, scientists, clergymen, dentists, engineers, journalists, lawyers, federal, state and municipal officials, army and navy officers, physicians and teachers. However, of those having non-professional occupations there are 73,384 bankers and 792,887 merchants, a few of whom have achieved distinction in their occupations.

TABLE I. OCCUPATIONS OF PERSONS IN THE UNITED STATES. 1900

Occupations	Persons	Importance
All occupations	29,285,922	100.0
Professional service	1,264,737	4.3–100.0
Electricians	50,782	4.0
Civil engineers	20,153	1.6
Mechanical and electrical engineers	14,440	1.1
Mining engineers	2,908	0.2
Engineers and electricians	88,283	7.0
Engineers	37,501	3.0
Telegraph and telephone lineman	14,765	0.05
Telegraph and telephone operators	75,080	0.26
Machinists	283,432	0.97
Engineers and firemen (not locomotive)	224,546	0.76

TABLE II. DISTRIBUTION OF CAPITAL IN THE UNITED STATES

Distribution	Amount in dollars	Importance
Total wealth of the United States	$120,000,000,000	100.0
Electric railways (1907)	3,774,772,096	3.1
Central stations (1907)	996,613,622	0.8
Electric manufactures (1905)	174,066,026	0.1
Telephone and telegraph (1907)	1,034,909,579	0.9

The amounts set opposite to electric railways and to telephone and telegraph represent the total par value of outstanding stock and bonds and include permanent and other investments. In the case of central stations the amount represents the total cost of plants.

Assuming that one-half the group of mechanical and electrical engineers belongs to the latter class, the number of electricians and electrical engineers in the United States constitutes 4.6 per cent of those giving professional service, and 4.9 per cent of the total wealth of the country is invested in electrical industries.

The Importance of Electrical Engineers. In order to estimate the importance of engineers in the control and direction of the affairs of the country use has been made of the book "Who's Who in America," which has been employed frequently in connection with statistical studies of educational and sociological problems. It contains the biographies of several thousand persons whose achievements are widely known in some worthy line of effort. It arbitrarily includes the names of Cabinet members, Congressmen, Governors, United States and State Appellate Judges, general officers of the Army and Navy, Bishops, College and University heads, and heads of the leading national societies devoted to educational and scientific aims. In the preface of the 1906–7 edition there is a statement as to the comprehensiveness of the book, namely, that it

> " has reached a stage of such completeness in selection that very few contemporary Americans of the very highest rank of prominence will be missed from its array of notables."

All the names of Members of the American Institute of Electrical Engineers and 815 of the 4312 names of Associates, as appearing in the catalogue of members under date of August 1, 1907, have been compared with the list of names appearing in the 1906–7 edition of the above book. A similar comparison has been made with 1017 of the 2084 Members of the American Society of Civil Engineers, employing a list of members issued under date of February 1907. The number of engineers as well as the number of non-civil engineers whose names are to be found in the geographical index of the 1908–9 edition of " Who's Who in America " has also been determined. The resulting estimates of these investigations are embodied in Table III.

TABLE III. NAMES IN " WHO'S WHO "

Source of names	Number	Importance
" Who's Who " 1906–7	16,216	100.0
Members of A. I. E. E. (546)	98	0.8
Associates of A. I. E. E. (4312)	32	
Members of A. S. C. E. (2084)	259	1.6
" Who's Who," Geog. Index 1908–9	18,418	100.0
Civil Engineers in index	191	1.0
Non civil engineers in Index	367	2.0
Engineers in Index	558	3.0

Of all the names appearing in the Index, 3 per cent are of engineers—the identical percentage represented by engineers as compared with all those giving professional service in the United States, as shown in Table I.

Again of all the names appearing in the 1906–7 edition of " Who's Who " 1.6 per cent appear also in the list of members of the American Society of Civil Engineers for 1907—the identical percentage represented by civil engineers among those of professional occupation. It is probable that this list includes nearly all those holding a place in " Who's Who " because of prominence in civil engineering. The number of names, 259, is larger than that of those appearing with the special qualification " civil" in the Index, namely, 191, but there are doubtless prominent civil engineers whose names appear in the Index as " engineers " without any qualification.

It is also probable that the number of names from the Institute membership, appearing in " Who's Who," 130, includes nearly all those inserted therein because of prominence in electrical engineering. The number of non-civil engineers, 367, whose names appear in the Index, among whom are included electrical, mechanical, and mining engineers, as well as a few civil engineers, serves as a check upon this estimate. If, therefore, the electrical engineering profession be considered as embracing those who are designated as " electricians " by the United States Census enumerators, the importance of its leaders among the country's leaders, 0.8 per cent, is materially less than the importance of the profession, 4.6 per cent, and of the

TABLE IV. DEGREES HELD BY NOTABLE MEMBERS

Degrees	Number	
Without Degree		19
Bachelor's Degree		39
B. A.	16	
B.S.	16	
B.Ph.	4	
B.M.E.	1	
LL.B.	2	
Engineering Degree		45
M.E.	24	
E.E.	10	
C.E.	4	
Annapolis	6	
West Point	1	
Master's Degree		21
M.A.	13	
M.S.	6	
M.Ph.	1	
M.M.E.	1	
Doctor's Degree		35
Ph.D.	22	
Sc. D.	7	
LL.D.	4	
M.D.	2	

related capital invested, 4.9 per cent. If, on the contrary "electricians" be not included, and they cannot properly be included in the professional class, the importance of its leaders is slightly greater than the importance of the profession, but materially less than the importance of related capital. If "electricians" be considered as the educational product of trades schools, as distinguished from technical schools and colleges, the electrical engineer must still be considered, for the immediate purpose, to be not as important as his affairs.

The results thus far obtained lead to the conclusions that engineers are as notable as they are numerous and that electrical engineers are very much over-capitalized. It is possible that this may bear the interpretation that electrical engineers are overworked and that, therefore, the electrical engineering profession offers unusual opportunities for young men.

The Characteristics of Notable Electrical Engineers. The number of academic degrees and their designations, held by the 98 notable Members of the Institute, are given in Table IV.

The distribution of those degrees among the 98 Members is given in Table V.

TABLE V. DISTRIBUTION OF DEGREES

Number of Degrees	Holding Members
0	19
1	42
2	21
3	10
4	4
5	2

Of the Members without degrees 11 had the advantages of college instruction but did not graduate and 14 of the holders of one degree pursued post graduate studies without receiving a second degree. The percentage of Members holding college degrees is 80.6 and of those who have had college instruction is 90.0. The corresponding percentages for those whose names appear in "Who's Who" are 56 and 70, respectively. These Members, therefore, appear to have enjoyed unusually extended educational advantages. Especially noticeable, in the preceding tables, is the large number of bachelors', masters' and doctors' degrees, and the relatively small number of engineering degrees. This is significant as to educational influences but has undoubtedly resulted from necessity and not from intention, as will be concluded from a consideration of Table VI, which gives the age distribution of 94 notable electrical and 122 civil engineers. It should be remembered, however, that some institutions bestow a Bachelor's degree after completion of courses nearly identical with those offered by many other institutions as leading to engineering degrees.

TABLE VI. AGES OF NOTABLE ENGINEERS

Ages	Electrical	Civil
30– 34	3	0
35– 39	17	7
40– 44	22	20
45– 49	31	12
50– 54	5	13
55– 59	8	18
60– 64	5	16
65– 69	1	14
70– 74	2	11
75– 79	0	5
80– 84	0	2
85– 89	0	3
90– 94	0	0
95–100	0	1

The average age of the electrical engineers is 46.2 years, of the civil engineers, 57.5 years, and of all those whose ages are given in " Who's Who," 53.3 years. The electrical engineers are therefore too young as yet to be properly judged as to their achievements. Inasmuch as the greatest number of students are graduated from college at the age of 22.5 years, the average of the notable engineers who are the subjects of this study were graduated from college in 1883. As stated by Professor Norris, the beginnings of formal electrical engineering study in educational institutions in this country were made about 1880. This explains the smallness of the number holding the degree of electrical engineer; namely, 10 out of 140. If a subsequent and comparative study be made along the lines herein pursued in 1913, or better in 1918, the values of special educational methods may be better estimated.

Before undertaking to determine the educational attainments of the subjects of this study there must be a recognition of the fact of original nature and of its great importance in determining life's progress. Thorndike says:

> "It is wasteful to attempt to create and folly to pretend to create capacities and interests which are assured or denied to an individual before he is born. The environment acts for the most part not as a creative force, but as a stimulating and selective force."

It must be postulated that persons with a record of extensive achievements are constituted of the proper clay and that notable electrical engineers have inherited the original traits essential to greatness.

Estimates of the acquired traits of these engineers have been obtained from five of their contemporaries who are considered to have good judgment, and who know many of them personally and all of them by reputation. Each of them has selected and graded ten names of those who appeal to his judgment as of greatest achievement in the electrical engineering profession. Each has also given a rough estimate as to the extent of attainment of five fundamental acquired traits an exceptional amount being marked 1 a noticeable deficiency being marked 3, and all other conditions being marked 2. The five traits were mental training, distributed and comprehensive knowledge, facility of expression, discipline of the will, and aesthetic taste. The results of these estimates concerning the twelve of highest rank are embodied in Table VII. The estimate-marks, corresponding to each trait and each person, are arranged in order one above the other, so that the mark of any judge is always in the same row relative to the top row. One judge, after selecting his ten most important individuals, seemed unable to grade them without first analyzing their traits, although he was unaware of the fact that he was to be requested subsequently to make such an analysis. This person is generally recognized as having superior judgment, and this incident is illuminating as indicating the mental processes leading up to his making of a decision. His estimates are to be found in the fifth row from the top in the table.

In the first column the individuals are represented by the letters of the alphabet. In the second column are shown the perspective or bulk estimates of the relative ranks of the individuals as given by the first four of the five judges. A numerical average of these estimates is also appended. The arrangement of individuals is not in accordance with these averages, for weight is given to the extent to which an individual appears in the lists of all the judges and to the extent of his acquirements. Thus A, B, C, and D appear in all five lists; E and G in four;

TABLE VII. ESTIMATES OF ACQUIRED TRAITS

Individual	Bulk estimate of rank		Training of the mind		Comprehensiveness of knowledge		Facility of expression		Discipline of the will		Aesthetic taste	
A	2 3 1 1	1.75	1 1 1 1 1	1.0	2 1 2 2 1	1.6	1 1 1 2 1	1.2	1 1 2 2 2	1.6	3 1 2 2 2	2.0
B	1 2 2 2	1.75	1 2 1 1 1	1.2	1 2 2 2 1	1.6	1 2 1 1 3	1.6	1 2 3 2 2	2.0	2 3 3 3 2	2.6
C	4 1 4 3	3.0	1 1 1 1 1	1.0	1 1 1 1 1	1.0	1 1 1 1 1	1.0	1 1 1 1 1	1.0	1 1 1 1 1	1.0
D	8 ⎧4 ⎩5 7	6.0	1 2 1 1 1	1.2	1 1 1 2 1	1.2	1 1 1 1 1	1.0	1 1 1 3 1	1.4	3 3 3 3 3	3.0
E	5 5 — 4	4.66	1 3 — 1 1	1.5	1 2 — 3 1	1.75	2 2 — 1 2	1.75	3 2 — 3 3	2.75	3 2 — 3 2	2.5
F	— — 3 5	4.0	— — 1 1 1	1.0	— — 1 1 1	1.0	— — 1 1 1	1.0	— — 1 1 1	1.0	— — 1 2 1	1.3
G	— 6 7 10	7.66	— 1 1 1 1	1.0	— 1 1 2 1	1.25	— 1 1 2 1	1.25	— 1 1 1 1	1.0	— 1 1 1 1	1.0
H	— 7 — 6	6.5	— 1 - 1 1	-1.0	— 1 — 3 1	1.67	— 1 — 3 1	1.67	— 1 — 1 1	1.0	— 1 — 1 1	1.0
I	3 — — —	3.0	1 — — — —	1.0	1 — — — —	1.0	1 — — — —	1.0	1 — — — —	1.0	1 — — — —	1.0
J	6 10 — —	8.0	1 2 — — —	1.5	3 2 — — —	2.5	3 2 — — —	2.5	3 2 — — —	2.5	3 2 — — —	2.5
K	— 9 8 —	8.5	— 1 1 — —	1.0	— 1 1 — —	1.0	— 1 1 — —	1.0	— 1 1 — —	1.0	— 2 1 — —	1.5
L	9 — — 8	8.5	1 — — 1 —	1.0	2 — — 2 —	2.0	2 — — 3 —	2.5	3 — — 2 —	2.5	3 — — 2 —	2.5
Group average.........				1.12		1.46		1.46		1.56		1.83

F, H and K in three; J, K and L in two, and I in but one, as will appear upon inspection of the remaining columns.

Individuals C and F hold unique positions. Of these C has a perfect score as to acquired traits, but in bulk estimate he is ranked first by one judge, second by another, and fourth by two others. A nearly perfect score is held by F, but he appears on but three of the five original lists. These apparent inconsistencies are perhaps to be explained by the facts that C has had too good taste to pursue glory or wealth while F is young and may yet have his opportunity.

The average of the estimates of the acquired traits of this group of twelve picked men shows three things: first, these men have broadly developed their faculties and have acquired to a large extent the five fundamental traits; second, they are especially characterized by their well trained minds; and third, if it be considered desirable to modify existing educational methods so as to improve upon the character of the leaders, as exemplified by the individuals of Table VII, attention should be directed toward those educational processes which result in comprehensiveness of knowledge, facility of expression, discipline of the will, and a development of an aesthetic taste.

The Acquired Traits of Leaders. Trained minds are so predominant in the Institute that a treatment of the nature of mental training and the points of differentiation between trained and untrained minds is considered unnecessary.

The extent of knowledge is nearly infinite and few have any realization of how great it is. As an illustration, in the Dewey decimal system of cataloguing books—the system in use in most of the large libraries—to each book is assigned a number which classifies it both as to its contents and as to its location upon the shelves. The first integer of its number places it in one of the following ten classes:

0. General Works.
1. Philosophy.
2. Religion.
3. Sociology.
4. Philology.
5. Natural Sciences.
6. Useful Arts.
7. Fine Arts.
8. Literature.
9. History.

Each of these classes represents a large field of human interest which can be estimated as to its extent by the number of printed books which exist as records of achievements in it. It cannot be stated truthfully that any one class is more extensive than another. Uniform distribution of books does not exist in individual libraries, but large libraries differ materially in their distributions. For instance, Brooklyn public libraries are especially strong in Sociology and Literature, but are not weak in any class.

Each of the ten classes is subdivided into ten sub-classes, which again in turn are each subdivided into ten sub-sub-classes and so on so far as may be necessary. The book receives in its number a succession of integers which successively locate it in the subdivisions of the system. In this system electrical engineering bears the number 621.3, being a subdivision under mechanical engineering, which latter is itself a subdivision under engineering, which last is a subdivision of the main class, Useful Arts. An electrical engineering book may also bear the number 537.8, as comprehending an application of electricity, which is a part of physics—one of the natural sciences. Therefore electrical engineering knowledge, as thus measured by the location of the books which record it, has an importance, with reference to the whole domain of knowledge, of two parts in 10,000 or two one-hundredths of one per cent. Of course this is not a true indication, and it would be sensational to claim that palingenesis, hermeneutics and manichaeism are fully as important as electrical engineering. But it serves to call attention to the fact that electrical engineering is a very highly specialized field for human endeavor and those who labor in it should not permit themselves to be confined to its limits.

That it is desirable for college students to gain at least a superficial knowledge of all fields of human achievement is being recognized by many educators. Harvard University has recently adopted the following rule which will go into effect with the class which is to enter next fall:

> " II. For purposes of distribution all the courses open to undergraduates shall be divided among the following four general groups. Every student shall distribute at least six of his courses among the three general groups in which his chief work does not lie, and he shall take in each group not less than one course, and not less than three in any two groups. He shall not count for purposes of distribution more than two courses which are also listed in the group in which his main work lies. The groups and branches are:

1. Language, Literature, Fine Arts, Music.
   (a) Ancient Languages and Literatures.
   (b) Modern Languages and Literatures.
   (c) Fine Arts, Music.
2. Natural Sciences.
   (a) Physics, Chemistry, Astronomy, Engineering,
   (b) Biology, Physiology, Geology, Mining.
3. History, Political and Social Sciences.
   (a) History.
   (b) Politics, Economics, Sociology, Education, Anthropology.
4. Philosophy and Mathematics.
   (a) Philosophy.
   (b) Mathematics."

Leaders as a type have at least a superficial knowledge of the subject matter of all these groups and a full knowledge of that pertaining to at least one group. Formal education of engineers always comprehends some material of the second and fourth groups but is frequently deficient as to the first and third groups. Under such circumstances the graduate attains a knowledge of things and his thinking self, whereas he is left ignorant concerning the methods of thought and of action of man and men. Such ignorance is fatal to leadership, for the very word implies a man to lead and men to follow.

Facility of expression, spoken, written, or wrought, is essential as a vehicle for the conveyance intact of the definite concept of the brain of the man to the minds of other men. Other things being equal, the engineer who can speak effectively, as well as write, is the engineer who will exert the widest influence. Skill in the oral presentation of a plan, in the defence of a position, in the advocacy of a reform, or even in the making of a graceful and apposite response to a toast, has largely contributed to many a man's success. It is especially desirable for those who hope to occupy positions of executive responsibility.

To say that a disciplined will is essential to leadership is to utter a commonplace. In these times of intense life, when fatigue prevails, when haste kills perfection and thought robs sleep, it is indeed a luxury to remain a leader. Will's control of desire must be absolute.

That elusive trait, aesthetic taste, is essential for admission to the aristocracy of culture. It must ever remain indefinite and will not submit to standardization. While some of its elements may be present at birth others may undoubtedly be acquired, with a resultant modification of the complex.

Doctor Johnson distinguished between natural and achieved taste. He said that if he had no duties and no reference to futurity, of all things he would like to drive briskly in a post-chaise with a pretty woman at his side. This was his natural taste. At the same time he said to Boswell:

> "Do not, Sir, accustom yourself to trust to *impressions*. By trusting to impressions a man may gradually come to yield to them, and at length be subject to them, so as not to be a free agent, or what is the same thing in effect, to suppose that he is not a free agent."

That is, our natural likings and dislikings are no safe guides; they must be controlled by education.

It seems evident that a man cannot become a leader of men if he be proscribed from intercourse with those who are wisest and most influential.

The Educating of Engineering Leaders. If it be assumed that engineering students, to become leaders, must acquire by education the fundamental traits which have been discussed, present methods pursued in their education could be improved upon.

Consider, first, existing institutions which have the usual requirements for admission and which bestow an engineering degree after four years of work. Their courses and methods could be so modified as to better the chances for leadership of all their students. The modifications should be three-fold and as follows: (1) a new system of selection of entering students should be adopted, (2) new subjects and methods should be introduced, and (3) time must be found for new subjects. The details of these modifications lie without the scope of this paper, and the wisdom of attempting them is questionable, for existing institutions, which are supported by the state, should be inclusive rather than exclusive, and those which depend upon distributed philanthropy must ever present the plea of extended usefulness.

A more discriminative system of selection at entrance would undoubtedly decrease the number of students and increase their average age. Of course a better resulting quality of product would be expected after four years. The great advantage to be obtained, however, by this discrimination, is the elimination of students of harmful influence, whose characters or circumstances militate against earnestness in endeavor and discipline of desire.

One subject of tremendous educational importance is recommended for consideration, namely, an extended study of literature as an art by the appreciative method. Art orders experience by the imagination, employs particularizations presenting truth, concretely, and appeals to the emotions, to the will, and to the taste as well as to the intellect. Literature is preeminent over the other arts—for its range of suggestion is the widest, it offers the most complete and definite intellectual content, and it represents life most fully. Its study develops the imagination and as Woodberry says:

> " So far as we realize the world at all beyond the limit of our private experience of it, we do so by the power of the imagination acting on the lines of reason: * * *. The scientist lights his way with it; the statesman forecasts reform by it, building in thought the state which he afterward realizes in fact; the entire future lives to us—and it is the most important part of life—only by its incantation."

It is significant that, of the 35 volumes which constitute the five-foot-shelf library of Dr. Eliot and which are considered by him to contain the elements of a liberal education, 22 have been classed by an expert cataloguer as " literature ".

The education of leaders and of all engineers does not cease until their retirement and the problem in hand relates to what may be termed their formal education. The general type of engineering leader has enjoyed more formal education than would be represented by the ordinary four-year course. A modification of this course so as to make it an equivalent would probably result in a corresponding rise in the average age of graduation. Those who recognize the long time required make different recommendations as to how it should be occupied, as an arts course followed by an engineering course, an engineering course followed by an advanced arts course, or a simultaneous pursuit of an arts and an engineering course. The last has some points in its favor, for maturity is an important factor in the successful pursuit of some arts as well as of some engineering subjects. But all these plans are faulty, in so far as they contemplate the inclusion of arts courses as they are at present taught in the ordinary college. There is a total lack of adjustment between the colleges and American life, as evidenced by a series of papers on this subject presented by prominent educators at the last Baltimore meeting of the American Association for the Advancement of Science. Especially evident is the lack of coördination between the arts courses and the engineering profession. Until the demands of law, of medicine and of trade are met by adequately modified curricula and methods of teaching a marked improvement cannot be expected in a plan of engineering education which includes this instruction.

But is it not folly to attempt to educate all when the presence of the many who are sure to fail impedes at every step the progress of those who are destined to succeed? Institutional rivalry and individual ambition may say nay, that it is the way of democracy. But, if West Point, with its 500 cadets, can so adequately supply the leaders for 80,000 armed men, could not an engineering school of similar proportions supply the leaders of engineers? With the assurance of continued opportunities for promotion, would not choice residues follow each process of elimination? What might not a professor accomplish with such material? With practical skill, acquired in the post graduate laboratory of organized experience, what difficulty could be encountered in the construction of a Panama Canal? Is not the performance of such a task of greater value to civilization than that relic of barbarism—a victory at arms? The entire feasibility of such an institution makes one long to see it building. If Federal support be lacking, why not that of those whose wealth increases each day as the sweat pours from the face of the engineer?

DISCUSSION ON " EDUCATION FOR LEADERSHIP IN ELECTRICAL ENGINEERING ", NEW YORK, APRIL 15, 1910.

Charles S. Howe: I shall not attempt to discuss all of the interesting questions which have been raised by Professor Sheldon, but only one or two points which have struck me most forcibly. Professor Sheldon says that the electrical engineers who have attained an eminence in their profession do not seem to have engineering degrees, at least very few of them have the degree of E.E. Now, we have found in discussing the reports which have come from the various engineering colleges, that very many of the engineering colleges do not give the degree of E.E. One or two of the oldest and most noted of the technical schools in the country do not grant the degree of Engineer at all, and I think that this may account in part, at least, for the fact that so few of these eminent engineers have the degree of E.E.

In discussing the question of leadership and the preparation for leadership, I am led to say a word or two in regard to the education which we are trying to give in the technical schools, which I believe is along the proper lines, whether for the training of the ordinary engineer or for the training of the engineer for leadership. Among other things, we are trying in the first place, to give the students a certain amount of knowledge. I sometimes think that perhaps we lay too much stress upon that. In the past that has been our principal object, but nevertheless, we must give the student a certain amount of knowledge— a great number of facts, and of course, he forgets most of this before he graduates. But far more important than the giving of facts by teaching a few definite things, is the ability in the student to know where to find the things he wants at any time of his career. That is, the ability to search. If he has been properly taught to search he will have received something far more beneficial to him than the few facts which he has been able to digest and carry away with him.

I believe that in our technical schools we have not paid enough attention to this branch of education, that we ought to teach our students to use dictionaries, and encyclopedias, and books of reference, libraries in general, the catalogs of the great manufacturing establishments, the magazines, the special reports of societies, etc., until, when a student is confronted with any problem, he will practically know just where to go to find the proper information upon that subject.

The other thing which we should try to teach him is to think, to reason for himself. That is the hardest task which we have. I believe, however, that it would be possible to lay out a systematic course of instruction in teaching students to think for themselves.

Most men are not leaders, as Professor Sheldon has said, they are men who follow, they follow the men before them, and this process of thinking is, as a rule, at the present time learned by men themselves, without very much instruction on the subject. If we can only develop methods by which students will understand the laws of learning to think, to think along engineering lines, we shall greatly increase the number of leaders, and I believe the leaders themselves will be still greater leaders.

Professor Sheldon has emphasized the importance of broad knowledge, of facility of expression, etc., and I believe that he has rightly done so. The technical institutions are fast coming to the point where they believe that the instruction in engineering colleges should be broader than it has been in the past. Perhaps it might well be asked why we do not now insist that every student coming to a technical school shall first be a college graduate. The reason, of course, has been that the technical schools have utterly been unable to graduate men enough to fill the places open for them. If all the technical schools required a college degree for admission, we would not be able to graduate more than one-quarter as many students in technical schools as we now do, and there would be a smaller proportion of men ready to take the positions which are open to the technical graduate. That is the reason why, in the past, we have not insisted upon the broader training.

I fully agree with Professor Sheldon also that men should be taught facility of expression. The subject of English composition and rhetoric especially has been greatly neglected in most of our technical schools, until within a very few years. Now we are beginning to devote more time to this subject, because we are finding out that the technical graduates we have been sending out without any ability to write, without any facility of expression, do not succeed as well as the men who can express their thoughts well upon paper and present engineering subjects to Boards of Directors or to organizations like this.

Professor Sheldon also made some suggestions in regard to improvements which might be made in the technical schools. He speaks of new methods of admission. I do not know whether it is possible to find any way of admission by which we shall be able to find a set of men of greater ability, more energy, who will take higher rank in their studies, and who will make better engineers after they get out into the world. I doubt if we can do it by any system of entrance examinations. We can do it, however, by weeding out the students while they are in the college. Of course, the technical school does that now to a considerable extent. I think, possibly, the process at times might be carried further.

Dr. Sheldon has said that new subjects should be introduced. I heartily agree with him. There are many things we ought to teach in the technical schools which we do not teach now. It is also suggested that new methods should be employed, and again I think he is entirely right. Whether it is going to be possible to teach new subjects and use new methods in a four years' course, I am very much in doubt. I rather think that the technical schools are coming to the conclusion that in the future we must have a five years' course instead of a four years' course. Whether we shall be able to train any more men for leadership, I do not know. Leadership depends upon many qualities. Now, we can only take the product which comes to us, and try to improve it. We cannot make native ability, and some of the qualifications for leadership are the natural qualifications of the man. These we may improve, but we cannot create them.

Another thing which is necessary for leadership is the ability to get along with and to handle men. That is something that it is exceedingly difficult for us to teach in the technical school. It is the man who can work with other men, get along with them, and handle them, who generally achieves the greatest success.

Abraham Flexner: It seems to me that in this country we have been rather apt to concentrate our educational processes on instrumental proficiency, on the making of men who could do particular things efficiently and well—good surgeons, good doctors, good lawyers, in the narrow and professional sense in which those terms are used.

The problem which Mr. Sheldon raises, namely as to how cultural and vocational standpoints can be combined in any one educational discipline, is fundamently a logical before it is an educational problem.

We are dealing here with two apparently exclusive concepts, culture and vocation. We ordinarily apply the term " Culture " to experience in so far as it is expansive, sympathetic, enlarging, releasing; we distinguish from culture " vocation ", as practical, immediate, concentrative, limiting. To the engineer, culture would seem to be art, history, economics; but to the artist, the activities and implications of engineering would have to represent the enlarging, releasing, that is cultural aspects of experience.

The attempt to conceive the cultural and the practical as different in kind would, however, break down of its own weight; for obviously, any one object or interest can be either the one or the other by turns.

If, now, one particular content may, according to point of view, serve in both capacities, being simultaneously culture to one man and vocation to another, it is obvious that the distinction is not really fixed and fundamental. The actual relation, instead of being one of permanent opposition or contradistinction, is, I think, rather to be likened to the relation between a map and any town or state upon it. On a map of the United States the state of Ohio is, the moment one's attention is concentrated upon it, seen as against all the rest of the map. None the less the state is all the time part of the map, from which it is at the moment, and from a particular point of view, abstracted. We can, I think, conceive the logical relation between culture and vocation in some such form.

Within this inclusive mass, certain typical forms are differentiated for practical purposes; and any one of them, as seen isolated from, and against the background of, all the others, becomes an occupation, a vocation, emphasis upon which proceeds from practical necessity. Any single aspect, when emphasized, concentrated, separated out, from the mass, becomes then the vocation of the man who is thus engaged. Everything else, representing experience that is beyond him, that he must reach out for and go out of himself to get, is, as we say, culture.

The apparent change in the stuff itself is thus the inevitable consequence of the changed angle from which it is regarded. The vocational view is near and detailed because the eye is fixed, the hand ready to act; the cultural view is vaguer, less responsible, more wayward, because it tends to leave the immediate in order to follow out suggestions and clues. It is indeed a rare individual that takes easily by turns both attitudes towards a single object—as, for example, Metchnikoff can and Goethe could do.

If then, the distinction between culture and vocation is thus shifting, conventional, a matter of convenience, a temporary point of view, it is clear that there is a certain untruthfulness and inadequacy involved whenever the effort is made to isolate vocation from the cultural plexus, to treat it wholly within itself. Provisionally such isolation is, of course, warranted in so far as it serves a purpose. But relations are falsified if the lines are held tight. The inadequacy of a specific and narrow treatment of engineering education, such as Mr. Sheldon has pointed out, is due, I think, to this unnatural separation of the practical ingredients of engineering as a vocation from the social background and interrelations which really constitute the opportunity and content of engineering as a profession.

It is no more possible to realize in its fulness the meaning of engineering or of medicine (when they are taken alone) than it is possible permanently to treat the state of Ohio as an entity. Within any one geographical division there are indeed certain relations to be established and certain facts to be learned. But our knowledge of it is dead unless these threads are followed out beyond state lines into the rest of the map.

If, then, this logical relationship that I have pointed out is sound, it follows that vocational or professional training must have a background, the whole background of our social life, just as the activities and interests of engineering must themselves be part of the background for men whose vocations lie in other parts of the field.

The word cultural cannot then be restricted to any particular set of interests and activities. It is nothing but an historic accident that the untechnical treatment of literary and artistic subjects has come to be specifically known as culture.

The details of an educational scheme which shall seek to put into effect the relationship that has been pointed out can hardly be discussed in the few moments at my disposal. We have learned well enough how to educate for the vocational life; but not as yet how to achieve the vocational with due deference to the cultural, as the Germans have done; we have yet to solve that problem. The medical schools are just now experimenting with what they call the combined course—the effort, that is, to combine the cultural and the vocational treatment of certain fundamental medical sciences.

The technical training of the engineer, like the technical training of the doctor, is focused on details; it does not lift its eye to follow out into the tangle of life the lines of suggestion that would enrich and diversify and enlarge. It stops at the state line, to recur to the metaphor of the map. And all the time this unnatural isolation defeats itself—for the engineer, like the physician, is one of the builders of the future. The narrowly technical education makes him just instrumentally proficient; only if his training extends out into the cultural tangle, will he get a voice in determining the line that social evolution shall take, only then will he be a creator of the future and not merely a tool of the present.

I wonder if it may not turn out—I speak very hesitatingly here—that the engineering school will have to define its purpose anew, revising its procedure in conformity therewith. Four years do not suffice to produce a highly specialized engineer with cultural outlook besides; to train a boy in both instrumental and cultural mastery of the art. Perhaps the lines of the technical school may have to be laid down more broadly, on the assumption that a subsequent apprenticeship may shape the young graduate to his definite practical use. Time and interest might thus be gained within or prior to the engineering course for the cultural as well as the technical treatment of the content of its curriculum.

Doubtless such a treatment sounds very leisurely just when we are finding time too short. I believe that economical use of the years available for schooling will make possible interesting and perhaps successful experiments in this direction. At any rate let us not be afraid to experiment. Outside the elementary school we are not as yet, unfortunately, given to educational experimentation. I cannot believe that there is really anything to be feared in conceding to secondary school or college teachers a much freer field of experimentation than they have as yet been allowed. As a matter of fact, the great problem in education as in society, is not how to prevent, but how to secure innovation.

In this new modern world, which the engineer has done so much to reconstitute, we creatures of habit, continue in a futile and feeble way to do the things that have been doing for centuries past. It will take a good deal of philosophic and logical dynamite to blow the thing to pieces and clear the way for a fresh, adequate, and modern construction.

J. W. Lieb, Jr.: We are living in a practical age, a period of intense industrial activity and large accomplishments—ours is the age of coöperation and efficiency. It is not enough that a given task be accomplished, or a vast public work completed, the world asks also, has it been done efficiently, with a reasonable economy of time and money, and with a proper adaptation of the means to the end.

While this close scrutiny is given to the relation between expenditure of effort and result achieved, between input and output, between cause and effect in the material accomplishments of our times, a scrutiny not less searching and thorough is being directed to our educational methods and their highest product—the college graduate.

One of the important questions occupying the public mind at present, and upon which the searchlight of inquiry is being directed, is this:

Is the college graduate of to-day, the finished product of our universities, our colleges, and our technical schools, occupying a position in professional activities, in the industrial world, and as a citizen, which justifies the expenditure of time, money, and educational effort sacrificed in his preparation?

Is the college graduate successfully fulfilling a distinct mission in our social system not only in furthering industrial developments, not only as a leader in thought and an exponent of culture in its highest sense, but also as an effective force making for righteousness in the community, and is he making his service and sympathies felt in the uplift and progress of humanity?

Is his success in life—measured also by purely commercial standards—such as to demonstrate without question that the time and expense necessary to produce him, is a wise investment?

I think Professor Sheldon has afforded several clues to the consideration of some of these questions. He has referred in his paper to the specialization in the field of electrical engineering. This hardly needs emphasis, as we know that in our institution, the American Institute of Electrical Engineers, we are beginning already to sub-specialize within the domain of electrical engineering, and we find that this subject of itself is becoming already too broad for one man to become expert in all of its ramifications. This has also taken place in the past history of the broader field of engineering, and now the technical schools in mechanical engineering find it most difficult to fairly cover the field with the tremendous expansion which electrical engineering has brought about, and they are face to face with the proposition of subdividing their courses into the several constituent fields.

Dr. Sheldon has referred to the importance of facility of expression, both oral and written. This is a subject which appeals to me very strongly, because as a matter of experience, I have found that it is one direction in which the product of our technical schools is most apt to be deficient. The product of the technical school has had strongly instilled into him the power of analysis, the method of approach, the weighing up of the pros and cons of a problem, but it is my opinion that he has not been sufficiently well grounded in the power of expressing and of presenting his conclusions. This is a most important element, a most important faculty, which the successful engineer should possess if he wishes to present his findings and have them adopted; the power to clearly and strongly present his views, to be able to defend them with good judgment and force, so as to impress the people who are to place their money upon his judgment. In this particular direction it appears to me that our technical schools might well devote a larger share of attention.

It has seemed the purpose of the discussion to take up the suggestions which Dr. Sheldon has made as to the modifications in the present methods of technical instruction. As one grows older, one feels the lack of the broader culture to which repeated reference has been made, which it has not been possible for the technical schools to give. This is a serious proposition, as we are already face to face with the evident necessity of expanding the course from four to five years. This expansion is of pressing importance, from the standpoint, one might say, of vocational requirements, and where, usually, the time for a wider acquaintance with the humanities is not afforded. This is a serious question which the engineer is facing. It is almost impossible for the engineer to make up for lost time after graduation. The necessity of following the tremendously rapid developments in all of the fields of engineering makes self-culture a matter of extreme difficulty; and therefore, the most that the purely technical school can hope to accomplish is to instill into the minds of the students a love for purely cultural studies, for literature, and art, in all their various manifestations, in the expectation that they may be followed during more mature opportunities that come in after professional life.

We all know that the responsibilities resting upon the engineer are ever increasing. Many subjects, such as old-age pensions, systems of compensation for labor, prison labor, child labor, and subjects of this character, are left in the hands of lawyers or professional politicians. Now, this should not be the case. The professional engineer who has come in contact with these subjects in their various manifestations should take a more active part in developing the public mind and directing the activities of the state and the nation in the direction of meeting these living questions. In order to do this it is necessary for the engineer to have something more than a merely vocational training, it is necessary for him to have a wide basis of culture, wide human sympathies, and a wide knowledge in many fields; and it is to be hoped that our technical schools will rise to the opportunity of conferring upon their students a more thorough recognition of the value, even to the vocational man, of a broad basis of culture and entertainment.

A. E. Kennelly: Some of the statistics presented by Dr. Sheldon, while they seem strange at first sight, may perhaps be explained without great difficulty, as he has himself suggested. For example, the fact that there are comparatively few electrical engineers with the degree of M.A. is a fault that time will rectify; because there has not been opportunity in the past to obtain many electrical engineers among the men who have received that degree. Again, the fact that we have no notable electrical engineers over seventy-four years of age, ought not to be interpreted on the understanding that the good die young, because the profession is still too juvenile.

In regard to the vexed question as to what subjects are cultural and what subjects are vocational, I would venture the proposition that all subjects are either vocational or cultural merely according to the way in which they are taken and given, and that there is no other criterion. In fact, I would go so far as to say that in a certain sense all subjects are equally worthy and equally grand. There is no subject which, of and in itself is more worthy or more deserving of study than any other subject, if treated in a broad sense. It is only when considered with reference to some particular vocation, or some particular duty that certain studies become of preeminent importance. The selection of specific technical subjects of study is of absolute necessity, in order to economize time; because the training years are limited, and we cannot indefinitely stay in school.

In regard to the requirements or qualifications for leadership, I think we must all agree with Dr. Sheldon in the general propositions that he offers, but I think there is one item that deserves some emphasis; namely that the qualifications which are competent to train men to lead are also qualifications that train men to follow; that men, before leading, must be able to follow, and that the requirements of the man who shall follow are discipline, and faithfulness, and earnestness in whatever he undertakes.

It seems to me that the qualities for training in following, depend largely upon the cultivation of ideals. Ideals cannot be created any more than learning can be created, but ideals can be fostered.

I believe that the elevation of ideals is of the greatest importance, so that anything we do, whether we sweep a floor or put up a station, may be done with the best of our ability, and with whole soul. By that criterion alone is our work to be judged.

William McClellan: I think it would be interesting if Dr. Sheldon, in connection with Table 7, would arrange to weight the various qualities, instead of considering them all of equal value, so that when we come to the general average, we should have some way of discovering whether the judge would claim 1.83 or 1.12 as a direct comparison. In other words, would he consider " training the mind ", " comprehensiveness of knowledge ", " facility of expression ", " discipline of the will ", and " aesthetic taste " as all of more or less equal value.

We all look at questions of this sort from different points of view, and as I think of the men whom I should consider leaders in electrical engineering, I find that their leadership is not on account of their wide knowledge of electrical engineering but is due to their having the same qualities that make certain lawyers, clergymen, or medical men leaders. That is to say, it is these characteristics or attributes of the man, himself, which give him leadership and that these characteristics or attributes are general.

Now, it may be stated quite positively that a large accumulation of detail information does not make a man a success. Success comes from reasoning along original lines,and such reasoning is possible only if the man has a thorough understanding of fundamental underlying principles.

History has shown that a physicist or a chemist with a thorough understanding of the composition or properties of matter has been able to do engineering work of the highest order when called upon, although his training in details of engineering has been very scanty.

The possession of this general fundamental information by a man on leaving college is all the more important when it is remembered that, for the most part, he is hunting for a job and is willing to take it in any branch of engineering, whether in the particular one for which he prepared or not.

I believe that there is sufficient evidence now of a change in our educational courses to show an effort to produce men trained as engineers rather than as certain kinds of engineers. . Unity is being introduced gradually; and, perhaps, some day, we shall have a broad profession of engineering, like, at present the professions of law and medicine.

Personally, I should be very glad to see the colleges of the country give up all consideration, in the undergraduate courses, of special engineering degrees; and give to all their students the same course, graduating them with the degree of Bachelor of Science.

In the arrangement of our college courses, we could learn a great deal from a consideration of what is done in medicine and in law where the undergraduates take practically the same studies barring, perhaps, a few electives in the senior year, and specialize when they get out into practical work.

President Stillwell: I want to call attention to two things that have been emphasized particularly. In the first place, I do not agree with Mr. Lieb entirely with regard to what he said about the difficulties of self-culture after graduation. I believe that the man who stops his education upon graduation, and exclusively specializes, makes a great mistake. There are any amount of opportunities for a man to continue his education in a manner that is broadening and effective. The other suggestion is this; that education in almost any line that teaches logic and a sense of proportion is engineering education. In constructive engineering the most valuable faculty, in my judgment, is that which may be designated as the sense of proportion, what the painters would call perspective.

In one large engineering undertaking some years ago I had occasion to have the number of contracts determined which entered into the equipment; which had nothing to do with civil engineering, nothing to do with the digging of holes in the ground, but simply with equipment, mechanical and electrical. These contracts were not divided, they represented links in a chain. There were one hundred and seventy of them. Now, I think it is not often realized that there are so many factors entering into a large modern engineering construction in the electrical and mechanical field. No mathematician can possibly produce an equation representing the values of the factors entering into that aggregated plant. The mental characteristic, which is comparatively rare, and which after all is the most valuable, is something which may come partly from education, but I believe it is largely innate, that is, proportion and judgment, to determine relative values, and to aggregate the factors which enter into one of these complex matters in a manner that will produce an operative, well balanced and economical result.

Wm. J. Berry: The discussion of this paper has been very interesting, and all the speakers seem to be in substantial agreement with the writer. It is surely most significant that men who have attained eminence in the practice of their profession have joined with educators in pleading for a broader training for the engineer. It seems to me, however, that we are in grave danger of losing sight of an important factor in the problem of engineering education—the student himself. There is a certain limit beyond which not even the best student can work efficiently, and in planning our curricula, care must be taken not to exceed the average limit of the students who remain after all the elimination tests, to which reference has been made, have been applied. Some of the " haste which kills perfection," of which Professor Sheldon speaks, has, undoubtedly found its way into our technical schools through a desire to do more than can be accomplished with thoroughness in the allotted time.

The college of the humanities, aiming to give cultural training, applies to the subjects studied the extensive and appreciative method; the technical school, the purpose of which is vocational instruçtion, employs the intensive and critical method, yet the latter institution usually requires a greater number of courses than does the former. Harvard College demands for the bachelor's degree a minimum of seventeen and one-half courses (or the equivalent in half courses) of which not more than six may be taken in any one year. recently there came to my notice the case of a student in an engineering school of established reputation, one of the best two men in his class, who, at the end of the first semester of his senior year had to his credit the equivalent of sixty-one half courses, representing a total about double that of a college senior, and an annual average of seventeen half courses as compared with the latter's maximum of twelve. The college man spends from fifteen to twenty hours a week in attendance on lectures, the technical student devotes from thirty to forty to required work in the lecture hall and in the laboratory.

We are all agreed that the ideal training for the engineering leader must consist partly of vocational and partly of cultural subjects in the sense in which those terms were defined by Dr. Flexner, but even with the five years course suggested by Professor Sheldon, not many new subjects can be added to the existing curricula, unless it be possible at the same time, to eliminate some of those already present, or better methods of instruction can be found than any now employed.

A. S. Langsdorf: It seems to be the general opinion of contributors to discussions on engineering education that the average product of the traditional four-year course is, if not actually mediocre, at least so little beyond that stage as to be damned with faint praise. Most criticisms of the usual curriculum are so vague in their constructive tendencies as to be valueless, while many offer remedies impracticable because of the limited time available. But to whatever extent the strictures are justified by the facts, it cannot be questioned that Dr. Sheldon has gone to the root of things by pointing out the necessity of adopting a new system of selecting entering students; for that, to my mind, is the crux of the whole problem. It may well be doubted whether refinements of the course of study are of any value to a student who lacks some generations of cerebral development, no matter whether that lack be due to heredity or to early environment.

Any one who has had to do with the administration of technical schools knows very well that the hardest work falls upon those whose duty it is to eradicate from the freshmen mind the " kindergarten idea " of education. Our preparatory schools are so strenuously engaged in maintaining the pupils' interest that there has been a distinct loss in the disciplinary features that make for real efficiency; the interest of the student is an important element, but it is not the paramount issue.

The institution which aims to develop leaders as its principal output, and not as a by-product, must deliberately put aside the temptation to brag about the size of its student body, and must recognize the fact that there is such a thing as an aristocracy of intellect. While any man is the better for a schooling, it is given to few to be educated. It has been said that the American standard in higher education is a rather high average and a corresponding low maximum; what is wanted is an educational " load curve " with more "peaks ", or at any rate, higher ones.

Signs are not wanting that technical schools are alive to the demands being made upon them; witness the developments of recent years in the way of lifting engineering education to a really professional basis by the introduction of more or less complete graduate courses. It is a practical certainty that engineering education is going through the same evolutionary process that has characterized the development of medical education, and for identical reasons.

Samuel Sheldon: In reference to the discussion of Mr. Howe, with regard to my recommendation that a new system of selection of entering students should be adopted, I think it is well recognized that nearly one-third of entering freshmen should never have come to the technical school. What they lack is not that which the school or any one else can give them, but is natural ability. Examinations, conducted along standard methods and lines, cannot determine much else than the candidates' acquired abilities. There should be, it seems to me, for proper justice to those who are expecting to become educated, an examination that will determine whether or not the proper natural traits are present.

A paper presented at the San Francisco meeting of the American Institute of Electrical Engineers, May 5, 1910.

EMERGENCY GENERATING STATIONS FOR SERVICE IN CONNECTION WITH HYDROELECTRIC TRANSMISSION PLANTS UNDER PACIFIC COAST CONDITIONS

BY A. M. HUNT

No matter what care and skill are exercised in designing and constructing a hydroelectric plant, with accompanying high-tension transmission lines, absolute continuity of service is a thing which cannot be assured. This is more particularly true of our western plants as compared with those of the eastern section of the country, and is especially true in California. Practically all of our important hydroelectric plants are located on streams which find their way down the western slope of the Sierra Nevada range of mountains through deep canyons. The sides of the canyons are usually very steep, and furnish very poor foothold for ditch construction. The cost of driving tunnels is usually prohibitive, and in the majority of cases, box flumes, built of lumber, are used to carry the water.

Our winter season is one of rains and heavy precipitation, and it is not infrequent that flumes go out, due to water-soaked foundations, slight leaks undermining footings, breaks caused by falling rocks, or other causes. This means an interruption of power service. Interruptions may and do come from line troubles due to many causes.

Interruptions of service were more than occasional in the earlier days of transmission work on the coast, and even to-day with the better construction and design, and greater care and watchfulness in operation, they occur often enough to be matters for serious consideration.

The best means for avoiding the serious results from interruptions of service, is to reduce the period of time during which power is off the line. Any interruption of service is serious, but if a prospective power purchaser could be assured that his interruptions would be a minimum, and that when they did occur, they would be of very short duration, he would not be so apt to refuse to purchase power from the hydroelectric company on the score that the supply was not dependable. Such shortening of duration of interruption can best be accomplished by having at the receiving and distributing point an emergency generating station, maintained at all times in such a state of preparedness that it can be started and put on the line in the shortest possible time.

Under the conditions existing in California, it may become necessary to operate such a stand-by plant continuously for considerable periods, due to seasons of low water, and it is, therefore desirable that its economy should be good. In fact, I believe I may safely state that no stand-by plant has been installed on the coast which has not become an important operating factor of the system with which it is connected.

I propose to discuss the type of stations for this service, making comparison between a station having generators driven by gas engines, and one in which steam-driven turbo-generators are used. I shall try to establish the thesis *that the turbine station can be so designed as to be built at much less cost than the gas-engine station; that it can be kept in a state of preparedness where it can be put into service on the line as promptly as the gas engine station; that its stand-by charges will be less than for the gas-engine station; and that its economy, when called on for continuous operation, will be at least as good as that of the gas engine station.*

Premises Assumed. The station shall have a capacity for continuous operation of 25,000 kw. at 85 per cent power factor.

Crude petroleum will be the fuel used both for generating steam and for gas making.

The station to be located at a point where spur-track facilities are available, and where ample water supply can be had.

In making comparison of economies with station in continuous operation, it is assumed that the load factor will be 50 per cent.

GENERAL OUTLINE OF GAS ENGINE STATION

The station will contain 12 units, each having a continuous load capacity of 2085 kw. at 85 per cent power-factor. The size of unit is small for a station having such a large capacity, but it is extremely doubtful if any of the engine builders will agree to build and guarantee larger engines, especially for use with gas made from oil. The experience with the large gas engines in the Martin station of the Pacific Gas and Electric Company indicates that the safe limit was passed there.

The following quotations from recent letters received from one of the large gas-engine builders is also confirmatory:

> From reports made by various members of our engineering department, who have noted the large continental engines in operation, we gather that while some very large cylinders are still operating in the single-acting type, the European, and particularly the German companies, who have built larger than 42 inch or 44 inch diameter, using cast iron as the material, have been compelled to replace practically all of their cylinders, leads us to believe that they should not be attempted at all in cast iron, and if steel is used with cast-iron bush, the cost per brake h.p. will be much larger than a smaller sized unit, without any gain in efficiency or lessening of operating expense.
>
> If economy is the controlling factor, it would seem to us that a size such as our 37½ in. x 48 in. (3100 brake h.p.), which can be made safely, with cast-iron cylinders would be a better proposition than a larger engine with longer stroke and larger diameter of cylinders which it would be necessary, or desirable, at least, to make of cast steel. We can readily understand how large power houses want turbine units of very large capacity of 10,000 kw. or more, as the economy of the turbine unit increases perceptibly as the sizes grow larger, and these very large units can show economies which are difficult to reach with the smaller sizes, but with the gas engines, if there is any difference at all, the reverse is the more likely to be true, as cylinders of moderate size can be effectively cooled and used with water of ordinary temperatures, while with the very large cylinders, in order to keep certain spots from getting hot enough to ignite the gas, other parts of the cylinders have to be kept unnecessarily cold. The desirability of good parallel operation also tends to cause a choice of smaller cylinder diameters, as with very large engines the slow speed and great number of poles cause the generator builder's requirements for operation to be very close indeed, and the weight of the flywheels becomes prohibitive, both from the point of first cost and from the ability of the bearings to stand the load without heating.

The gas required per 24 hours will be 7,500,000 cubic feet, based on 650 B.t.u. per cubic foot, 50 per cent load factor, and assuming that by reason of the relatively small size of units, the engines will always be operated at approximately full load.

The gas-generating plant will consist of three oil gas sets, each capable of producing 2,500,000 feet of gas per day, with necessary condensers, scrubbers, and purifiers, and a holder capacity of 2,250,000 cu. ft. to equalize the daily load. It is assumed that the units will have twin tandem engines, and the over-all size of foundation for one unit will be 70 ft. by 30 ft. Allowing for passages, the size of electric generating station will be 76 ft. by 400 ft. if engines are placed in one continuous line, or 152 ft. by 200 ft. if placed in two parallel lines. The station will have the usual compressed-air starting equipment.

GENERAL OUTLINE OF TURBO-GENERATOR STATION

This station will be assumed to contain two turbine units, each having a continuous capacity of 12,500 kw. at 85 per cent power-factor. Each unit will have its condensing equipment, and the boiler plant will contain water-tube boilers in units of the largest size available. The boiler settings to be built so as to lose as little heat as possible by radiation from exposed surfaces. All boilers to have tight fitting dampers, which may all be opened from a central point. The oil and steam supply for burners to be controlled from the same central point, and so arranged that burners may be operated from such point. It is also figured that igniters will be fitted in the furnaces which can be operated from the central point, so that fires can be started under all boilers simultaneously.

The boiler capacity in the station is assumed to be such, that maximum load can be carried by forcing boilers 33⅓ per cent beyond builder's rating. This is easily done with oil fuel. Neither economizers nor superheaters will be used.

In connection with the plant will be installed heat storage, consisting of vertical steel cylinders containing water under a temperature due to 200 lb. steam pressure, thoroughly protected with heat-insulating material. The water and steam spaces of these cylinders will be connected with the boilers through automatic stop valves which will open whenever the pressure in the boilers is greater than in the heat storage cylinders. In the heat storage cylinders will be installed internal electric heaters having capacity sufficient to maintain the temperature of the water in them, or, in other words, to supply the heat losses from radiation and convection. The capacity of these heat-storage cylinders to be such, that by reduction of the gauge pressure from 200 to 25 pounds, sufficient steam will be formed to operate the plant at full capacity for thirty minutes. All steam connections to be as short and direct as possible, and all precautions used to keep radiation and condensation losses at a minimum.

On the above assumptions, the following calculations are based:

Rated Horse Power of Boilers Required. The turbines will require at 12,500 kw. load with 175 lb. steam pressure, 28 in.

vacuum, and without superheat, 16.69 lb. of steam per kw-hr. To handle auxiliaries of the plant and the oil burners will require 10 per cent of that required for the main units, or the total maximum amount of steam per hour required will be 459,000 lb. This can be furnished by 11,475 rated h.p. of boilers, working at 33⅓ per cent overload. It is assumed that this boiler power will be installed in 16 units of 720 rated h.p. each.

The amount of heat storage required in connection with each of the above boiler units is calculated as follows:

When the pressure on water under a temperature due to 200 lb. steam pressure is reduced to 25 lb. about 13 per cent of the water will pass into steam at gradually reducing pressure. The assumption was made that the heat storage shall be capable of furnishing steam for the plant for 30 minutes at full load, or 229,500 lb. This is increased by 33⅓ per cent to allow for reduced economy of the turbines with the falling pressure, which calls for 229,500 plus 76,500, or 306,000 lb. As 13 per cent of the water in the storage cylinders passes into steam, they must contain 306,000 divided by 0.13, or 2,353,847 lb. Each of the 16 boiler units will, therefore, need 147,116 lb. of hot water in storage. Assuming the water to weigh 60 lb. per cubic foot at temperature due to 200 lb., the volume of the containers will be about 2800 cu. ft. This volume will be provided by one cylinder, 12 ft. in diameter by 26 ft. in length, allowing steam space over the water. Each of these cylinders will weigh approximately 120,000 lb., and will cost delivered and in place not to exceed 6½ cents per lb., or $7,800. Each storage cylinder will supply 1563 kw. of station capacity, or the cost of storage per kilowatt capacity of plant will be about $5.00. These figures are given to show that the cost is not prohibitive.

COMPARISONS

Comparison of First Costs. The cost of the gas-making station, as above outlined, is assumed as being $1,000,000, complete with buildings and storage. The figure is based on data procured within the past two years, and if in error, is possibly too low.

The cost of the electric generating station complete, including gas engines, generators, piping, switchboards, wiring, foundations and buildings will be approximately $2,250,000, based on recent quotations.

At these figures, the cost per kilowatt capacity of station for combined gas and electric plant will be $130 per kw.

The cost of the steam-turbine plant complete, including turbo-generators, boilers, heat-storage cylinders, piping, condensers, switchboard, wiring, foundations and building will not exceed $1,500,000, based on recent quotations. The cost per kilowatt capacity of station is, therefore, $60.

The steam-turbine station cost is approximately 46 per cent of that of the gas-engine station.

Comparison as to Rapidity of Getting into Operation on the Line. It has been demonstrated in the Martin Gas-engine station, previously referred to, that one of the large engines can be brought up to speed, its generator synchronized, and connected to the line in 30 seconds. In order that this may be done, however, the operator must be at his station when the signal is given. In the station assumed, 12 engine operators would be required, each at his post, all equally trained to accomplish this, and probably an equal number of switchboard operators. Even then, difficulties in synchronizing such a number of machines simultaneously would probably take a longer time. The expense of keeping such a large operating force as this calls for, is too great to be feasible, and I assume that each operator will handle two engines, and that he will get the two generators on the line in two minutes. I should consider it exceptional work if the entire station could be in operation on the line in two minutes.

In the case of the steam-turbine plant, the following sequence of operations would be followed: The turbo-generators would be operating on the line as synchronous motors to assist in regulating power factor, and with vacuum maintained on the steam ends, with the air pump operating. Steam would be in the main line up to the throttle valves, also on oil-burner line. If current on the line fails, the rotors of the units will continue to revolve for many minutes. Immediately on notice, the operator will begin opening his throttle valves, and energizing his fields from a storage battery, and could easily synchronize the two machines and get on the line within less than two minutes. The air pump, if operated during the period of starting from the storage battery, would require no attention, and if a jet condenser is used, the only requirement in connection with circulating water is that the injection valve shall be opened.

Concurrently with the above, the boiler-room operator will release and open all boiler dampers at one operation, and from the same central point put steam and oil on all burners, and by the use of electric igniters start fires under all boilers simultaneously. The steam pressure in the heat-storage cylinders will gradually fall until at the end of 30 minutes it will have reached 25 lb. By the expiration of that time, the boilers can be brought to steaming condition under a pressure of 25 lb. or more, and will pick up the load.

I consider that I have reasonably established the fact that the steam-turbine station can be put on the line as promptly as the gas-engine station.

Comparison as to Stand-by Charges. I shall consider this on the basis of the annual stand-by charge per kilowatt of capacity of plant.

Assuming that the fixed charges of interest, depreciation and taxes will amount to 10 per cent. which favors the gas-engine plant, the annual charge against the gas-engine plant will be $13 per kw. and $6 against the steam-turbine plant.

I will assume that the gas-engine station proper can be taken care of by two crews of six men each at the engines, and two at the switchboard, which is certainly more than fair to it. These men will get not less than $100 per month, or an annual pay roll for station of $19,200.

The gas-making plant will also require two crews, each assumed to require six men which number is an absolute minimum. Their average wages will be not less than $100 per month or an annual pay roll of $14,400. The combined pay rolls will be $33,600, or an annual charge ot $1.34 per kilowatt of capacity.

To keep the gas-generating plant in condition such that it can begin making gas with a reasonable degree of promptness. the generators must be kept fairly hot, which will require expenditure of fuel. I have no data of my own as to the fuel necessary for this purpose. Mr. E. C. Jones, chief engineer of the Pacific Gas and Electric Co., informs me that with an expenditure of 150 gal. of oil per day, it is possible to keep a 2,500,000 cubic-foot oil-gas set, at a temperature such that it can be brought to condition for commencing to make gas in 20 minutes. Three such sets will, therefore, take 450 gal. per day. The annual stand-by fuel charge, oil being figured at $1.00 per barrel, will amount to $3,911, or 16 cents per kilowatt of capacity.

It is assumed that the steam-turbine station will require two crews, each composed of the following; two turbine operators, one switchboard man and two firemen. The average monthly wage is taken at $100 per month, which would make the annual pay roll $12,000. or 48 cents per kilowatt of capacity. The heat-storage cylinders will be covered with extra thick heat insulating covering, around which will be built an enclosing shell of brickwork. It is assumed that the heat losses per square foot of shell, per fahr. degree difference of temperature per hour, will not exceed 0.1 B.t.u. The total surface of all heat storage proposed is 37,728 sq. ft. With a temperature of external air of 70 degrees fahr., the heat loss per hour will be 689,790 B.t.u. The main steam piping that will be under steam will have a surface area of not to exceed 3,500 sq. ft. The loss from this surface is taken as 0.2 B.t.u. per degree difference of temperature per hour, or a total loss on account of such surface of 221,900 B.t.u. The combined loss of 911,690 B.t.u. is equivalent to 359 h.p-hr., or 270 kw-hr.

In other words, it will only be necessary to use a little over 1 per cent of the capacity of the plant to keep the heat storage and main steam pipes up to temperature, as the electric heaters will transform the energy at practically 100 per cent efficiency. I think I may safely state that any of our hydroelectric plants have for at least 22 hr. per day energy going to waste in an amount much greater than 1.1 per cent of the peak load, and that under such circumstances the waste energy should not be considered a charge against the plant. The radiation losses, as above taken, would in two hours reduce the temperature of the water in storage less than one degree fahr., so if no waste energy were available for two hours daily, the effect so far as the value of the heat storage is concerned would be negligible. The original heating of the water, and restoration of temperature of the water in the storage cylinders after a run would be accomplished by the use of steam from the main boilers.

It is assumed that steam will be kept on one 300 h.p. boiler, to operate pumps, to supply steam to burner lines and as an emergency precaution. An allowance of 450 gal per day will maintain pressure on this boiler, and permit the use of 1000 lb. of steam per hour, and at $1.00 per barrel will amount to a yearly charge of $3911, or 16 cents per kilowatt of capacity.

The stand-by charges per kilowatt capacity of the two plants will be as follows:

	Gas engines	Turbines
Fixed charges	$13.00	$6.00
Pay rolls	1.34	0.48
Fuel used	0.16	0.16
Total stand-by charges	**$14.50**	**$6.64**

The stand-by charges for the turbine plant are less than 46 per cent of those for the gas-engine plant.

It would be entirely legitimate to make a small charge against the gas-making plant for maintaining steam on one of its boilers, but this has been neglected in the above.

If the entire loss of heat from storage cylinders and piping were made good from the auxiliary boiler, the annual fuel charge for this service would not exceed $2,000.

I believe the above discussion proves my statement that the stand-by losses of the turbine station will be less than for the gas-engine station.

Comparison as to Costs of Continuous Operation. If I have been correctly informed, the manufacturers of the large gas engines at the Martin station, previously referred to, guaranteed them to deliver a brake horse power-hour on 18 cu. ft. of oil gas. No data as to the results acutally obtained have ever been given out, but from such information as I have been able to get, I do not believe that the results are any better than those indicated above.

From a paper read before the Detroit meeting of the American Gas Institute by Mr. E. C. Jones, chief engineer of the Pacific Gas and Electric Co., in October, 1909, I take the following data:

There will be required 8½ gal. of crude oil to produce 1000 cu. ft. of gas, and from the process of manufacture there will be a by-product of 20 lb. of dry lampblack per 1000 ft. of gas made, which should be credited to the gas-making process. A portion of the lampblack will be required for generating steam used in the manufacturing process. It is impossible by any method of treatment so far found economically practicable, to reduce the moisture content much below 25 per cent and it is generally fired when containing at least this much moisture. I assume that at least five of the 20 lb. will be used for generating steam, leaving 15 lb. to be credited.

There is no way in which this lampblack can be used in the plant outlined herein for gas-making, although water gas apparatus could be installed to utilize it Mr. Jones in the article previously cited, states that using the lampblack in water gas apparatus, 40 lb. wet lamp-black (30 lb. dry) will make 1000 cu. ft., using 6.8 gal. of oil for enriching. As 8½ gal. of oil are used for 1000 cu. ft. of gas under the straight oil gas process, each 30 lb. of lampblack saves 1.53 gal. of oil, or for the 15 lb. excess produced in making 1000 ft. of oil gas, 0.77 gal. In order to give the gas-making process every credit it can be entitled to, I deduct this 0.77 gal. from the 8⅓ gal., leaving 7.56 gal. net, chargeable to each 1000 cubic feet of gas made.

If the generator efficiency is 95 per cent, and 18 cu. ft. of gas are used per brake horse power, the amount used per kilowatt hour will be 25.24 cu. ft. The number of kilowatt hours per barrel of oil, from the data above, is 220.1.

To arrive at the kilowatt hours at the switchboard per barrel of oil in the steam-turbine plant, the following assumptions are made: That the average load-factor on the turbines will be 75 per cent when in operation; that the auxiliaries of the plant will require 10 per cent of the steam taken by the main units; that the evaporation of water will be at the rate of 12 lb. per lb. of oil.

The turbine assumed, is one where the steam consumption at three-fourths load will be no greater than at full load, or 16.69 lb. per kilowatt hour. Adding 10 per cent for auxiliaries gives 18.36 lb. of steam required per kilowatt-hour, or at the evaporation assumed, 1.53 lb. of oil. The oil weighs 336 lb. per bbl., and the number of kilowatt hours per bbl. of oil will be 219.6 as against 220.1 for the gas engine. Attendance and fixed charges have been previously shown to be less in the case of the steam plant, so I consider that I have established the remaining statement as to economy made in the earlier part of this paper.

I have endeavored in the argument made to use data and assumptions that in all cases favor the gas-engine station, and feel that on this score I have opened the door to criticism by proponents of steam plants for this class of service.

In closing, I cannot refrain from calling attention to the desirability of fuller information relative to the gas engine station at Martin, which I have previously cited. Judging from current reports it does not seem to have been an entire success. It is said that it is still in the contractor's hands, five years after installation, and that the purchasing company has abandoned it so far as use is concerned. Nothing has ever been published regarding its difficulties and troubles nor as to its economic results, and I hope that in the discussion of this paper those who know the facts will give the engineering profession the benefit of them.

DISCUSSION ON "EMERGENCY GENERATING STATIONS FOR SERVICE IN CONNECTION WITH HYDROELECTRIC TRANSMISSION PLANTS UNDER PACIFIC COAST CONDITIONS." SAN FRANCISCO, CAL., MAY 5, 1910.

President Stillwell: Accepting the reasoning of this paper, it would seem unquestionable that in this case the installation of large gas engine units instead of steam turbine units, was a blunder. The paper can be criticized fairly, I think, in respect to some details of the assumptions upon which its estimates are based. For example, I think that if the auxiliary plant is intended not only to be operated for a short time, in the case of an interruption in the transmission service, and also to be used in conjunction with the transmission of power in case of low water, the unit chosen is too large. The modification, however, that would result from changing the size of the turbines would not affect very materially the annual stand-by charges of the two plants.

L. Jorgensen: Nearly all water power companies of importance have found it necessary to keep auxiliary power plants in their greatest load centers, especially if these are large cities. The units in these plants are mostly steam driven, and, in order to be in readiness for service, part of the boilers are kept under steam at all times.

The expense connected with keeping the boilers under steam is considered to be of less importance than the additional assurance against long interruptions of service. Mr. Hunt has brought out a new device which promises to do away with the necessity of keeping the boilers under fire. This idea seems very simple and possible of application. Where real estate is high, there may be some objections to the extra space required for the heat storage cylinders, as these cannot be installed anywhere, but will have to be located near the boilers, in order not to complicate the steam piping too much.

The space, however, occupied by a plant of this kind will always be less than that required for a gas engine station. Where space water power is available during the greatest part of the 24 hours, electric heaters seem to be very appropriate for compensating for the radiating losses, otherwise it would seem to be more efficient to use super-heated steam (or saturated steam) from the 300 h.p. boiler kept under steam continuously.

Mr. Hunt is very conservative when he allows 33⅓ per cent for reduced economy in the turbine. It is true that with steam at 25 lb. gauge, expanding to 28 in. vacuum, about 33 per cent less energy is given off, than with steam expanding from 175 lb. gauge to 28 in. vacuum. Therefore, the actual loss would be the average loss, or 16.5 per cent. The turbine should lose but very little in mechanical efficiency if a few tricks are used.

Suppose the steam turbine is a five-stage impulse turbine designed for best economy at 150 lb. gauge pressure at the throttle.

This turbine will still have a high efficiency when working with steam of 175 lb. and 125 lb. pressure. At about 75 lb. pressure the first stage cannot be used any longer and must be by-passed. At this pressure the steam has twice the volume, and, therefore, only about one-half the weight per unit volume as at 175 lb. The energy of the flowing steam is $\frac{m}{2}v^2$ and as the mass at 75 lb. is only half that at 175 lb., the nozzles in the first stage are not big enough to let a sufficient quantity of steam through to pull full load and cannot be made big enough if the velocities of steam are to be right. The velocity v must be kept practically constant, in order not to lose in mechanical efficiency, as all the different blade angles are only correct for one value of v. Cutting out the first stage means a loss of about one-fifth in efficiency, but this loss has already been allowed in the 33 per cent. As further expansion takes place and the throttle pressure approaches 25 lb. it becomes more difficult to keep the velocities in the remaining stages at their correct value. It will perhaps be necessary to work the pumps somewhat harder to increase the vacuum ¼ in. or so, not so much for the extra power derived thereform, as this would probably be used by the pumps, but in order to keep the velocity of the steam through the different stages at its proper value. In this way the turbine will not lose perceptibly in efficiency through the whole performance.

K. G. Dunn: I think there should be a further explanation made regarding the title of the paper. This should state that it is under Pacific coast conditions, and it should also state under our present knowledge of gas manufacture.

It is unquestionably true that the thermal efficiency of the gas engine is much higher than the thermal efficiency of any prime mover, therefore, it seems rather paradoxical to state that the efficiency of the steam plant is higher than that of the gas plant.

When we start with fuel, oil, and contemplate that 8½ gallons of oil are required for 1000 ft. of gas, we have a gas generator efficiency of approximately 50 per cent, while a boiler efficiency of 75 per cent with fuel oil is easily maintained, and in that fact lies the increased efficiency of a steam plant over the gas engine plant. I think the estimates are conservative for the gas engine plant. With high hydrogen gas, it is impossible to obtain the economies stated in the paper.

There is another point which comes under the head of hot water storage, that we suggested for a plant something like five years ago, which was to put in electrical heaters in connection with each boiler, these heaters to be placed in circulating pipe, the action being similar to that of a house boiler. One of these heaters and circulating pipe would be connected to each individual boiler, and they could be left in service without interfering with the installation of the plant at all. There is a plant on the coast to-day that is making up designs and working this proposition, out, and unquestionably it will make a good proposition.

A few years ago, the transmission companies felt that auxiliary plants were not necessary, but in Los Angeles, San Francisco, Portland, Seattle, Spokane and all of the other large centers and congested districts on the Pacific Coast, each one of the operating companies has adopted the plan of installing a certain percentage of steam auxiliary plants to the total hydroelectric output, and unquestionably we will see developments along the lines as suggested in this paper very soon.

C. L. Cory: Mr. Hunt, in his consistent and careful manner, has with discrimination chosen the subject of the paper, namely, " Emergency Generating Stations for Service in Connection with Hydroelectric Transmission Plants under Pacific Coast Conditions." While what I may say in discussion has no direct application to the principal points in the paper, yet I trust it will have a general application to the subject.

Notwithstanding the definiteness with which the subject has been treated by Mr. Hunt, a man who has given much attention to the generation of power and the use of the gas engine, but who is more familiar with the power situation under eastern conditions than on the Pacific Coast, after reading Mr. Hunt's paper expressed some surprise that the conclusions of Mr. Hunt did not indicate that the gas engine has an important position in the large power generating station.

I have been fortunate in having discussed the application of the gas engine for the generation of electric power with the author of the paper and I wish to draw attention to some of the points showing the difference between the emergency station on the Pacific Coast and the general use of the gas engine as largely used in many eastern industrial plants.

A specific illustration given careful consideration within the past year will illustrate the difference between the conditions discussed by Mr. Hunt and those evidently assumed by the individual mentioned, who from his experience evidently has a great belief in the gas engine. The situation under consideration required the provision of a power plant having a total capacity of approximately 10,000 kw. for the operation of a large copper mine. It had been shown by careful investigation that the body of ore to be worked would keep the mine and mill continuously in operation for a period of not less than twenty years. At the power plant site California fuel oil costs $1.65 per barrel, this price being fixed by a 65-cent cost in the field plus freight. On the other hand, New Mexico coal could be obtained at a total cost of approximately $5 per ton, this figure being obtained by adding to the cost of the coal at the mine the freight to the power house site. The question to be decided was what kind of a plant to install, hydroelectric with transmission line, gas engine or steam driven units.

Ultimately without question there will be a hydroelectric plant installed to work in conjunction with the reserve plant at the mine, but what was under consideration at this time was the choice of type of reserve plant to install.

Upon careful investigation it was found that there were a great many places where gas plants are in successful operation, but none on the Pacific Coast using gas made from our California crude oil. Producer gas has not up to the present been made for large units from California oil. By producer gas I mean gas having a thermal value of from 150 to 200 B.t.u. per 100 cu. ft. If I understand the situation the gas used at the Martin station is the ordinary illuminating gas, having a heat value of from 600 to 650 B.t.u. per thousand feet. The quality of gas used in your gas engines will very materially affect the operation of the engines and the service derived therefrom.

In connection with the reserve station, in this particular instance of the 10,000-kw. plant for the copper mine, the distance of transmission would be approximately 60 miles, and as a result of three separate investigations the complete cost of such a hydroelectric plant would be $250 per kilowatt of station capacity, which would correspond to about $300 per kilowatt which could be delivered. The load factor on the plant will be between 90 and 95 per cent, and under such circumstances it would seem that the water power plant must be given very serious consideration. However, the reliability and continuity of operation in this instance were of such great consequence, as has been well indicated by Mr. Hunt, that the reserve steam station is now being built, and will be in operation before the hydroelectric plant can be completed.

In addition to the points that I desired to bring out regarding the distinction between conditions as set forth in the paper and existing on the Pacific Coast, and those conditions which are quite different where blast furnace gases or producer gas is used in many plants in the East, I have one question to ask in direct reference to the paper regarding the capacity of the steam turbines to continuously carry full load when the steam pressure drops to the comparatively low figure mentioned in the paper, or to question the capacity of the turbines and generators under such low steam pressure conditions to carry the full normal load.

L. L. Johnston: In selecting oil as the fuel to be used in several types of power plants of which comparisons are made, the steam turbo is immediately placed at considerable advantage over a gas engine plant in so far as costs of construction and operation are concerned. The abundance of low priced oil on the Pacific Coast, the high efficiency and capacity of steam boilers when oil fired and the very low first cost of an oil fired steam plant has compelled the adoption of oil as fuel and steam as the type of equipment for a plant in preference to all others.

The writer noted recently a large steam turbo-emergency plant near the city of Seattle within a few miles of coal mines and where coal is cheap. Yet this plant was fired with oil shipped from California.

It has been shown by estimate and experience that the gas engine can make the best showing only where fuels are comparatively expensive or where a low grade of coal or lignite must be used for fuel which gives poor results when fired under steam boilers but good results in gas producers. An oil gas producer has not yet been developed of sufficiently low cost and high efficiency to permit its adoption in connection with gas engines for general power purposes.

Considering the above, in discussing Mr. Hunt's paper, the most that can be shown in favor of the gas engine is that it can, under some conditions, do considerably better than set forth.

Regarding the size limit of gas engines having been reached in the largest units now in operation, it will be recalled that the same was said twenty years ago of 15 h.p. gas engines.

To-day there are several hundred thousand horse power capacity of large gas engines in the east. Most of these are in steel mills and in units of 3500 to 4500 h.p. capacity each. One of these units at Bessemer, Pa., has been operating continuously night and day for the past six months with a total loss of only three hours during that time.

Several experienced builders are now developing gas engine generator units of 5000 kw. capacity.

Some years ago when the Martin station was planned steam turbos of 12,500 kw. capacity there were not yet in commercial use. Also, the larger sizes which could have been selected were at that time going through a stage of development and giving more or less trouble, and the best ones required some minutes in which to be warmed, brought up to speed and put into service without damage to themselves. The gas engine had already demonstrated its ability to be put into service in a short time after standing cold.

Considering that the company owning the Martin station was already in the gas manufacturing business, that its gas equipment could be used in connection with gas engines, and with the other above facts in view, it seems logical therefore, that it should have selected gas engines to be used in its electric stand-by plant.

It has been remarked that the principal difficulty with the gas engines at the Martin station is caused by the high hydrogen content of the gas supplied, which has resulted in cracked cylinders.

However, gas engines are operating successfully at a plant in Lebanon, Pa., on coke over gas which contains a greater percentage of hydrogen than the oil gas at the Martin station.

Experience has shown that some designs of gas engines will operate successfully on a gas containing a comparatively large percentage of hydrogen while others will not. Also that some designs of gas engine cylinders will crack from various causes while others will not.

The fact that the gas engines at the Martin station have been in a state of overhaul so much of the time since their installation looks bad. However, inasmuch as the design of engines is different from the successful ones now operating in this country, the trouble must be laid to a design which has not yet been perfected. Had the engines been of the same design as those in the eastern steel mills, the results might have been quite different, the plant a welcome place to visitors and its merits discussed by engineers throughout the country.

Taking up the several comparisons in the order given by Mr. Hunt.

1. *Comparison of First Costs.* The first cost of the steam plant is favored in that it consists of only two large sized units. Should one of these become disabled only 50 per cent of the plant would remain for service. While in the gas plant about 92 per cent would remain should one unit become disabled.

It appears that the steam plant should have an additional turbo-unit to make it more comparable with the gas plant. On this basis the steam plant would cost approximately $72 per kw. of capacity on a 25,000-kw. rating.

Regarding the cost of the gas making station $1,000,000 appears rather high tension though the writer has no costs at hand to show otherwise. However, it must be remembered that the gas generating station of the Martin plant forms a part of the company's domestic gas manufacturing equipment and contains much apparatus, that would not be required in a strictly power gas plant. The gas generators there have a rated capacity of 3,500,000 cu. ft. of gas per day each and can be pushed to 4,000,000, or, each unit can supply gas for more than 9,000 B.h.p. capacity of engines. This large capacity of gas generator units should contribute toward a low first cost of the plant. These gas generators are simple in construction and consist principally of steel shells 16 ft. in diameter, lined with fire brick and filled with brick checker work.

Considering the fact that at the Martin station the gas plant forms a part of the company's domestic gas equipment and that several large gas holders and relay gas generators are necessary in any event, it will be seen that the first costs and operating charges against the gas engine plant can be materially reduced below those given.

Estimates have been prepared which show that large gas engine electric stations comprising engine generator units of the largest size used in the eastern steel mills, together with coal gas producers, can be constructed complete for $100 per kw. A similar plant but with oil gas producers, especially if constructed in connection with a domestic gas manufacturing plant should not cost more than $100 per kw.

Considering the above, the first cost of an oil fired steam plant would be approximately 72 per cent of that of an oil fired gas engine plant.

2. *Comparison as to Rapidity of Getting into Operation on the Line.* In this comparison it appears that the possibilities of the gas engine have been neglected.

Special consideration is given to the general design and appliances for the steam plant to facilitate its economical construction, operation and quick starting, namely; the plant is designed with only two large sized units; a storage battery supplies the exciter current. Heat storage tanks supply steam instantly, and an arrangement is devised by which all the boilers may be started simultaneously from a central point.

In order for the gas plant to maintain its record of starting in 30 seconds, it is pointed out that twelve engineers would be necessary, also an equal number of men at the switchboard.

There are several movements necessary to start a gas engine, all of which could be operated from a central point by a device similar to that described by Mr. Hunt, to be used in connection with his steam boiler plant, and all of the engines could be started and brought up to speed at the same time.

Regarding the problem of synchronizing a number of gas engine generator units, it is possible by having the exciting current flowing in several generators, to start them all and bring them up to speed in step. With this method of paralleling, combined with starting all units from a central point, it would be possible to start the entire plant as one unit and put it into service within 30 seconds and with a minimum of engine and switching labor.

3. *Comparison as to Standby Charges.* Based upon the foregoing figures it will be seen that the costs of a gas engine electric plant when operated in connection with a domestic gas manufacturing plant can be reduced considerably below Mr. Hunt's estimates.

4. *Comparison as to Costs of Continuous Operation.* Several years ago Mr. H. G. Stott, before a meeting of this Society in New York, called attention (TRANSACTIONS A.I.E.E. 1906), to the high economies possible to be obtained with a combined plant consisting of part steam and part gas equipment, so arranged that the waste heat from the gas part could be utilized toward generating steam for the steam part. The advantages in first cost and fuel economy of such a plant are so marked that it appears that any estimates for plants in which gas engines are considered, should cover this type of plant rather than a straight gas engine plant. The highest efficiencies attained in steam practice are accomplished largely by returning for use all possible waste B.t.us. with the assistance of economizers, feed water heaters, condensers, etc. Similar refinements in gas engine plants have not yet come into general use. However, they are being developed along the lines now followed in steam practice.

The oil gas generators at the Martin station are not as efficient thermally as they might be if designed especially for power purposes. Much heat is now wasted to the atmosphere in the process of heating the brick checker work and in cooling the gas which might be utilized in generating steam for auxiliary power uses.

The writer has prepared estimates showing comparative costs of a steam turbo plant and a combined steam and gas plant both using oil fuel. In the case of the combined plant it is assumed that the waste heat which can practicably be recovered from the gas engines and gas generators is delivered to the steam part of the plant in feed water. Also, that the lamp black resulting from gas making is burned under the boilers of the steam plant, together with the necessary fuel oil.

The assumptions are that each plant will contain 25,000 kw. capacity of equipment; the combined plant consisting of 15,000 kw. capacity of steam and 10,000 kw. of gas equipment. The combined plant is arranged so that the gas part runs continuously at nearly full load while the steam part handles the variable load and peaks. Also spare units would be included in the steam equipment.

The first cost of the steam equipment is taken at $65 per kw. and the gas at $115 per kw. on this basis the excess cost of the combined plant over the straight steam is $500,000.

The annual costs show that the combined plant can make a saving in the fuel item of $117,152 over that of the steam plant. However, on account of the higher fixed charges of the combined plant, the total annual net saving over the steam, amounts to only $55,153. This saving by the combined plant will pay 11.1 per cent interest on its excess cost.

This saving is perhaps not sufficient to warrant the construction of a combined plant under the conditions assumed. However, should a combined plant be constructed in connection with a gas manufacturing plant under conditions similar to those at Martin station, the first cost of the gas engine plant could be somewhat less than shown above. Also the labor charges against the gas engine plant would be somewhat less. Estimates for a combined plant on this basis, and assumptions similar to those above, taking the cost of the gas equipment at $105 per kw. and the steam at $65, show that the combined plant can be constructed for an excess cost of $400,000 and that its annual saving will amount to $73,000. This saving will pay 18 per cent on the excess cost. This should be sufficient to warrant the construction of such a plant and considering that this is based upon oil at $1.00 per bbl., which price may advance, there should be ample margin for safety in such a conclusion. Further economies could be obtained by returning to the power plant the waste heat from the gas manufacturing part of the plant.

The combined plant as estimated will give 266 kw-hr. per bbl. of oil.

While there are some conditions where steam turbo plants are obviously better suited, it would seem that all considerations of large fuel power plants should include a close investigation of the possibilities of the gas engine.

A. H. Babcock: It seems to me that in this gas engine discussion, as in many others of an engineering nature, we engineers are prone to look at the economies in a physical sense and not enough toward the economies in the financial sense. The court of last resort in regard to such things is the balance sheet.

Mr. Hunt, in his paper, has mentioned 650 B.t.u. gas as used in the engines in the hypothetical station he has constructed. It seems to me that his figures need a little revision in this particular, and that it will be safer to work with gas not quite so rich. When gas as rich as 600 or 700 heat units is ignited in an engine cylinder there is a real explosion, whereas producer gas of 130 or 150 heat units ignited in a cylinder gives a result more nearly in the nature of a push; the one is like dynamite, the other is like old fashioned black powder. We have heard a great deal about the high hydrogen content of the gas used in the Martin station engines as the origin of much of their trouble. It seems to me that the very rich quality of the gas has more to do with the difficulty than the hydrogen.

Mr. Johnson has been investigating gas engine projects on the West Coast for the last year, and is, therefore, especially qualified to have an opinion on them, particularly with reference to the economic side. He has found in many cases that while there are very cheap fuels available, and a high physical economy of the plant can be shown, the high first cost of the machinery and apparatus produces fixed charges so high that the physical economies of the processes are entirely wiped out, as far as the balance sheet is concerned. It seems to me that we are much in the same position with relation to our water plants, especially where there is more water in the securities than in the hydraulic systems, and it is my opinion that it is possible to construct a steam plant, oil fired, almost anywhere on San Francisco bay and compete successfully with the highly capitalized long distance transmission line power. I am aware that on many balance sheets the matter of fixed charges is not taken into account as it should be, and that reports made by engineers to financial men are misleading frequently in this respect. It is immaterial whether we ignore these fixed charges entirely, or whether we transfer them to the next generation, the fact is that they must be paid some time, and therefore it is misleading not to take them into account in our financial statements.

K. G. Dunn: I would like to call attention to one fact that should be taken into consideration when comparing gas engine plants with steam plants. In a gas engine plant, there is no possible overload capacity whatever. In the ordinary steam plant, each unit is capable of a continuous overload capacity of not less than 25 per cent, and it has a peak load capacity of 50 per cent overload. When you take the peak load capacity into consideration, it is unquestionably true that a steam plant can be installed for one-half the cost per kilowatt.

W. A. Doble: There is one point, Mr. President, I think should be brought out, and that is, that a gas engine or a reserve capacity plant of 24,000 kw. is extraordinarily large, and there are not so many transmission companies that would be justified in putting up a plant of that magnitude. It has occurred to me that the plant should be very much smaller than that, and though Mr. Hunt treats the matter very fairly, I do not think the paper shows clearly that under conditions of one-third or one-half that capacity, that these conditions would be favorable or as favorable.

There is another point with reference to putting in plants of this kind as against water transmission. It is interesting to know in this connection that the Pacific Oil and Power Company of Los Angeles which own its own oil wells, transmits power 129 miles and sells oil. It also uses some in its stations, and is now increasing the number of stations, because it is going into long distance transmission. If we consider a composite plant of steam and gas engines, and then a turbo-unit, I am afraid we would have to make a triple power plant, and then where would we be?

F. G. Baum: My criticism of Mr. Hunt's paper is, not in the conclusions, but in the method presented, which starts out like a debate or argument, presenting in the beginning the statement which it is intended to *maintain* rather than by presenting both sides of the question and then drawing the conclusions at the end. An engineer should be a judge and not an advocate and he should avoid being put in the position where he *must advocate* one side and not discuss and weigh both sides of a question with an open mind.

In both the gas electric and the steam electric plant we burn oil at one point and produce kilowatt-hours at another. But in the gas engine plant there are two inherent weaknesses in the process of developing power.

1. The process of making gas is intermittent.
2. The process of destroying the gas or changing it from gas to mechanical energy is intermittent.

In these two fundamental defects lie the inefficiency of the gas engine process of power development. As a general proposition, intermittent processes are inefficient because they waste more or less time, and because the time is wasted the machine must be larger, and because it is larger, it wastes more time, etc. Hence the cost of the machine increases and the waste time and its by-products become more and more a loss.

To make things efficient we make them "hum," that is, produce a constant *high speed* condition at each instant of time. That is what we do in the electric motor, the tangential or turbine water wheel, the centrifugal pump, the steam turbine, etc. Of all the power units the tangential water wheel driven generator is the simplest.

In the steam turbine process of developing power we have practically a constant condition at each point of the machine for each instant of time, and hence the mechanical conditions for efficiency are good. We also have conditions right for producing units of large capacity, which again is a very decided advantage over the gas engine unit. For constant power in large units (except under conditions where the gas engine burns waste gases) the steam turbine is far preferable to the gas engine and because we can make it " hum "—that is, get the advantage of high speed and constant power, it has certain inherent advantages over the reciprocating steam engine.

The disadvantage of the steam-electric unit for emergency purposes is the delay in getting up steam. Whether the scheme for steam storage outlined by Mr. Hunt is practical or not I do not know, but as he has proved his case on the assumption that it is practical, I presume he has had experience with the scheme. It is an easy matter to prove theoretically the gas engine highly efficient, but in the practice the results may be different; hence theoretical proofs must be backed up by practical results before they can be accepted as final."

President Stillwell: So far as this particular gas engine plant is concerned, Mr. Johnson's contribution to the discussion furnishes a clear and perhaps an adequate explanation. Not infrequently what apparently is a serious engineering blunder results from circumstances purely local and transitory, which properly exonerate the engineer from responsibility.

A. M. Hunt: It was not my intention in writing the paper to indicate in full detail and outline the design of a plant. The estimates have been made simply as a basis for comparison. As a matter of fact, each individual case would have to be considered upon its own merits, and worked out accordingly. I should, in all probability, in designing a station of this character, arrange it in such a way that the water in the boilers would be in circulation in connection with the heat storage, and my reason for not doing that in the paper was this: I had no data on which I could calculate or even approximate the radiation losses from the surface exposed in the boiler, so I cut that out as the easiest way of avoiding the point. Mr. Stillwell as well as several others, have referred to the fact that the steam turbine station is equipped with but two large units, which is not just in making the comparison. This, in a measure is true, but it is partially offset by the fact that in a gas making station, the gas generators are assumed as only three, so if one of them is out of use, one-third of the plant would be unavailable. It may be argued that the gas generator is a machine that does not work all the time. From time to time the gas generator must be shut down and allowed to cool off, the brick work re-set, and so forth; so that, as a matter of fact, in such a station, it might be considered that four gas generating units should be employed.

Mr. Jorgensen, in his remarks, speaks as if the heat storage

proposition were a new element. It is not. I recall that back in the '90s, if not earlier, this question of heat storage was discussed in connection with generating stations in England by Mr. Halpine. He worked it out at some considerable length, but what application was ever made of it, I do not know. Mr. Stillwell, says that it was actually employed. In that instance, as my recollection serves me, it was intended to equalize the daily fluctuation of the load on the boiler plant and avoid the necessity of the installation of larger boiler capacity, and possibly getting also higher efficiency.

I am surprised that no one has taken exception to the fact of using the electric heater in the heat storage, although, I believe, some one did mention the fact, that he would prefer to maintain the temperature of the water by using steam from the auxiliary boiler. As a matter of fact, I admit that the electric heater is perhaps what might be called " finicky ", still it could be made of such elemental simplicity, that I believe its use would be justified, at least, in certain cases.

Mr. Jorgensen criticized the increased steam consumption of the turbine under reducing pressure, as being stated by me as too high. I do not recall the details of my calculation on this, and, in fact, I will say frankly, that it was a matter of guess as I first put it down, but subsequently I ran across one of the turbine designers and requested him to calculate it for me and he came back and said, " You are a very good guesser, I worked it out as about 32 per cent," so I let it stand.

Mr. Dunn has made some remark with reference to the efficiency of the gas making process as compared to the efficiency of the use of fuel in the boilers. It is quite true, in reference to the present method used in making gas from oil, and the present method is the only one at this time commercially operative. It is true that a number of people are working on the problem of making producer gas from oil, having a lower heat value, and a higher efficiency, and I know of at least two such processes that are in tentative commercial shape. I should not be surprised to see either of them developed in the near future to a point where they can be given serious consideration, and in such case, the gas engine side of the controversy would be at greater advantage.

Professor Cory, in his remarks, raises the query as to the possibility of the turbine keeping up and carrying the load at the reduced pressure. It is entirely possible, but would, of course, necessitate the turbine being especially designed for the end in view.

Mr. Johnson rather infers that I am not entirely fair to the gas engine in taking oil as the fuel for my basis of operation, and yet under conditions as they exist here on the Pacific Coast, oil is, of necessity, the economical fuel.

Mr. Babcock left the inference that he may have something up his sleeve in the way of near-at-hand supply of fuel.

believe I know myself of certain " pseudo " coal mines in the near vicinity, but I should be afraid to offer any consumer the coal from them.

Mr. Johnson also attempts to smooth down the criticism with reference to the installation of gas engines as the Martin station. It is to be regretted that he must be the one to stand up for the station, but when he states that the gas engines were adopted because they were installed in connection with the gas plant, with which they were manufacturing gas for domestic and other purposes, here, I think he is wrong. I do not think Mr. Johnson was on this coast at the time that plant was installed. That plant was installed, if my information is correct, because it was a necessity at that time, under the conditions of a contract made for the supplying by the Pacific Gas & Electric Company, or its predecessors in interest, that a plant should be installed which would be capable of being started within a given interval of time, and put current on the line, as a guarantee that continuity of service would be afforded. It was not installed to make gas for domestic or other purposes. It was installed solely and purely for power purposes. It is true that if it were installed in connection with a gas manufacturing plant for domestic service, the unit of cost would perhaps be somewhat reduced; but this was not the case in the instance I have in mind. You cannot build a plant and use it both for power service and for domestic service. If the plant is devoted to power service, it must be held for that, and not at any time used on domestic service, except in case of ultimate emergency.

Mr. Babcock takes some exception to my having made the comparison on the basis of gas having such high heat value. I do not know how he would make a gas of lower heat value out of crude petroleum by any present operative process. As I have stated, there are processes in line of development to-day that may lead to that outcome.

Mr. Doble's criticism as to the size of the plant selected for the purpose of comparison is entirely just. There are few plants in existence on the coast that I know of where a 25,000-kw. emergency plant would be justified, but at the same time I do not think the legitimacy of the argument, or the result, would be very much different, even though the size of the plant were quite materially reduced.

Cary T. Hutchinson (by letter): Mr. Hunt justly says of water-power plants, " *absolute* continuity of service is a thing which cannot be secured." This might also be said with equal truth with regard to steam plants or any other kind of machinery. His opinion evidently is that a stand-by steam plant is necessary in order to secure *satisfactory* continuity of service, and that this plant is required principally to guard against failures of machinery, including transmission lines, and not primarily to make up the deficiency in the water supply.

Mr. Hunt proposes a plan which does not by any means secure

" absolute " continuity of service; in fact, it does not provide for as great continuity of service as can be provided by a steam plant. He seeks to lessen the cost of the stand-by service and to this end proposes hot water storage under pressure, arrangements by which the labor is minimized and certain other devices all tending to this, but all on the other hand diminishing somewhat the degree of insurance secured. A steam plant for the most effective stand-by service should have pressure in all the boilers, up to the throttle, auxiliaries in operation and fields of generator excited—indeed, one might even say that the generators themselves should be turning over. The plant also should be practically fully manned, and should have the same capacity as the load for which it is a reserve. If this degree of insurance against interruptions is required, I think it can easily be shown that the most economical way to obtain it is not to build the hydroelectric plant.

The investment cost of such a hydroelectric plant including substation, but not including distribution lines, will certainly be $200 per kilowatt of delivered power and probably greater, say, $250. The total annual cost per kilowatt of plant capacity will be at least $22 and probably more, including interest, depreciation, maintenance and operating expenses. A reserve steam plant of equal capacity, of large units, (and this is the only kind of plant that I am considering) can be installed complete for not more than $75 per kilowatt. The total stand-by charges against this plant, including all fixed charges, maintenance, labor and such fuel as is necessary to keep it in instant readiness for operation, based on a number of detailed estimates made by persons familiar with the conditions of the Pacific Coast, will be approximately as follows, per kilowatt of capacity:

1. Fixed charges	$10.00
2. Labor	2.50
3. Fuel and Supplies	2.50
Total	$15.00

But whatever this amount may be, it is a charge which will remain unchanged if the same plant is used for service instead of used as a stand-by plant. With oil as fuel, the cost of generating energy over and above the stand-by charges already referred to will not exceed 4.5 mils per kilowatt-hour. For an additional expenditure of $22 the steam plant can be operated on a load factor of 4880 hours, that is, approximately 56 per cent, for the same total annual cost. There will furthermore be a saving in the investment cost of $200 per kilowatt; that is, the same gross and net earnings can be obtained for $75 per kilowatt instead of $275 per kilowatt, in other words, the investment for the same gross earnings is reduced to less than 30 per cent.

I think it is safe to say that no competent engineer could possibly advise the construction of a steam plant as a stand-by station under these conditions, which apply pretty closely to the Pacific Coast.

If such a high degree of insurance against interruptions is not required, the next question that arises is the best way to obtain what might be called " satisfactory " insurance of commercial operation. This could be accomplished in several ways, one being to install a steam plant of lesser capacity than the total, say, 50 per cent; but in this case, of course, there would remain considerable interruptions to service. It is doubtful whether the additional cost involved in a steam plant of 50 per cent capacity for stand-by service only, is justified, and it would seem that the better way is to build a hydroelectric plant without steam reserve of any kind, but in the most permanent way possible, eliminating flumes as far as possible, constructing tunnels wherever feasible, and using reserve generating sets and duplicate transmission lines, preferably on entirely independent rights of way. The records of the Stanislaus transmission would seem to indicate that when properly constructed and maintained such a transmission line on the Pacific Coast is very nearly free from interruptions. If two such lines were built on independent rights of way, the service in as far as this part of the plant is concerned, would certainly be satisfactory.

It is fairly certain, however, that no water-way composed largely of flume can be built that will not give continuous trouble; tunnelling should be resorted to wherever possible. This is dictated not only by reliability of service but also by economical considerations, in many cases, inasmuch as the total annual charges against the flume line, including maintenance and depreciation will frequently exceed those of a tunnel to take its place, as the following example, which is fairly typical, indicates.

A flume line having a capacity of 200 second-feet, probably would cost under average conditions $30,000 per mile. The annual cost of this line for interest, depreciation and maintenance would be not less than $6000 and might be as high as $7,500 per mile. A tunnel of this capacity, concrete lined, could be built for approximately $100,000 per mile; its maintenance and interest would be, say, $6000. The tunnel is, therefore, as cheap, mile for mile, as the flume, but in many cases one mile of tunnel will replace several miles of flume, and the advantage of the tunnel is much greater.

It would seem to me that the best engineering solution of this problem is then to build the hydroelectric plant in the most substantial manner possible, to construct reservoirs of the maximum possible capacity, in order that the water power may be utilized at a load factor of 100 per cent or as near this as it is feasible to bring it, and then to supplement the delivery of the water power plant by a steam plant at the point of consumption which acts as a stand-by plant to the extent of its capacity and also as a peak load plant under daily service conditions. It seems folly to build a steam plant for stand-by service pure and simple when by comparatively small addition to the annual cost this plant can be used to bring in a large amount of additional business.

The following comparison between the cost of a system of reservoirs to utilize the drainage area to the fullest extent and of a steam plant to make up the deficiencies in the water supply is fairly representative of the Pacific Coast conditions:

Precipitation	60	in.
Runoff, 55 per cent = 2.44 sec. ft. =	33	"
Assume development for 2.2 sec. ft. =	30	"
Runoff for six low water months, 0.45 sec. ft	3	"
Runoff for six flood months	30	"
Use for power during six flood months	15	"
Storage during six flood months	15	"
Needed for power during six low water months	12	"
Remainder lost in evaporation and seepage	3	"
Storage 15 in. equal 35,000,000 cu. ft. per sq. mi		
Drainage area	250	sq. mi.
Total reservoir capacity	8,750	million cu. ft.
Cost of reservoirs, at $200 per million	$1,750,000	
Total annual charges, at 6 per cent	$105,000	
Head	1,200	ft.
Average flow, 250 × 2.2 sec. ft. =	550	sec. ft.
Average delivered power at sub-station	33,000	kw.
Load factor	50	per cent
Capacity of sub-station	66,000	kw.
Low month discharge, 250 × 0.45	112	sec. ft.
Low month, discharge, of average	20	per cent
Steam plant capacity (say 75 per cent)	50,000	kw.
Cost of steam plant	$3,750,000	
Annual cost of stand-by service	$750,000	

That is to say, if it were possible to construct reservoirs of sufficient capacity, the entire runoff from this drainage area could be utilized at an investment cost of $1,750,000, and an annual cost of $105,000, as against an investment of $3,750,000 for the equivalent steam plant, and an annual cost of $750,000, a saving of $2,000,000 in investment and of $645,000 in annual charges.

P. H. Thomas. In his heat storage steam relay arrangement Mr. Hunt has given an ingenious and in one sense a feasible plan for maintaining an uninterrupted supply of power on a distribution system. This general subject of relays in power systems is receiving a good deal of attention at the present time and, as seems to be usual under similar circumstances, engineers are inclined to take an extreme view, some one way and some the other. It is the opinion of the writer, however, that the wisdom of the installation of a steam relay plant is not one to be settled off hand without a careful study of the conditions of any particular case. There are cases of course where such relay is imperative but there are also many cases where it would not be warranted.

The absolute necessity of a local relay arises with some sorts of load, as mine pumps, hoists and some work in connection with furnaces of various sorts, but these are exceptional forms of load, and furthermore are usually service for which a relatively high price for power is obtained. With other systems however, the dominating consideration is different, namely, is that of economy, on account of competing power. In these cases, usually, an occasional interruption, while perhaps excessively annoying, is not a source of very great actual expense either to the company or to the consumer. Of course frequent interruptions have a serious harmful effect on the sales of power. At the present time the standard of our best transmission plants, after the initial starting and trying out periods is good. It must not be forgotten also, that no form of alternative power is entirely free from interruption so that relative excellence is all that is required. It is obvious that the extra investment required by the relay may be very considerable.

It will frequently be found that the real necessity for a steam relay exists only for some few customers so that a relatively small relay will suffice. Such a condition is not so serious. Again the same reliability may be sometimes attained by some alternative method. The high class engineer's most necessary quality, his sense of proportion, should here come into requisition. I do not here wish to be understood as decrying steam relays broadly but merely to call attention to some to their disadvantages and limitations.

What can actually be expected of a steam relay in the matter of preventing all interruption of service? Take the case where the relay is within a few hundred feet of the consumer who is to be protected. If the relay generator is not on the line there will be a certain brief interruption in case of a sudden failure of the main supply, long enough to get the generator on the line and the boilers steaming at their proper rate. If the generator is floating on the line there will still occur the equivalent of a partial shut down for the boilers which have been banked cannot be momentarily forced to give full steam capacity, without some such storage devise as is proposed by Mr. Hunt. Again if the trouble is one that causes a short circuit or a ground it may open the steam generator breakers or otherwise momentarily prevent its taking up the load. Even in the case of successful automatic circuit breakers there will usually be drop enough in voltage from a good short to throw out any synchronous apparatus on the consumers circuits.

Taking the case where the system is one of distribution at high potential as well as transmission, as is the case in most hydroelectric systems, there will be only one consumer who will get the full protection of such a relay since the others must be fed through some portion of the high tension line and trouble on this portion will cut off the relay.

It is thus clear that only in a few cases will it be possible, by means of a relay entirely to prevent *momentary* interruptions of a consumer's supply and in these actual success would be secured only by the best of upkeep and concentration of effort on this one result.

When, however the elimination of interruptions of the service of some considerable duration is considered, the case assumes a very different aspect. A steam turbine and banked or even cold boilers can be gotten into service and onto the line in less than perhaps an hour, and sometimes much sooner, if planned and operated for this purpose. That is as protection against interruptions caused by serious accidents that more or less permanently disable some part of the supply system and that consequently require time for repair, the banked boiler steam relay will serve admirably, except of course for cases where the injury interrupts the communication between the relay and the consumer. For momentary interruptions on the other hand such as flash-overs on line insulators where no permanent injury is done, the service can be re-established on the original circuits more quickly than a new set of operators can get it started on a new set of circuits.

On the side of the advantages of the steam relay there is much to be said. A system provided with a steam relay is usually much more flexible in operation as well as having the direct advantage of possibility of using the ***relay power on regular load.*** In fact the most satisfactory basis for the installation of a steam relay is the rendering possible thereby of the sale of increased total power. The well known curve of flow of many streams showing a sharp minimum for a relatively short period of the year, far below the average, limits the maximum sale of power, while with a steam plant supplementing the low water, a much larger sale is possible, supplied nearly all the year around by the hydraulic apparatus. In this well known case the great limitation of the steam relay, its extra cost, is partially obviated, for the output of extra generating capacity in the hydraulic apparatus, which takes the steam load most of the year will not usually add anywhere nearly proportionally to the capital cost. This is the natural use of the steam relay. But in such a case it has in one sense ceased to be strictly a relay, but is rather a supplementary source of power. It will have the strict relay function, however, at times of plentiful hydraulic power.

While every case must depend on its particular circumstances, it is clear that for reasons of capital costs a ***steam*** relay, at least where no supplementary power is produced, should be installed only where very strong reasons exist therefore. Suppose, for example, that the relay plant installation costs per kw. one half as much as the hydraulic development. This means that 50 per cent will be added to the fixed charges of the hydraulic system, which constitute the chief expense charges of such a system. But more, the expense of banked fires, trying out the steam apparatus periodically as well as the maintenance of at least the skeleton of a steam organization, will add very greatly to the small operating expenses of the hydraulic plant. When it is remembered that the added reliability of service will add little or nothing to the price to be obtained for power, the hand:-

cap in the dividend paying possibilities of the plant due to the steam relay are evident. It should be remembered, that exception is to be made in the case of steam relays which supplement a minimum hydraulic power and hence justify their added capital charge by increased sale of power and in the case of mining plants and other plants where a very difficult transmission exists and exceptionally high prices can be obtained for power and practically absolutely uninterrupted services is essential.

This discussion so far is not intended to minimize the importance of reliable service, but is preparatory to raising the question whether some other better way cannot be found to serve the same purpose.

In the first place in important work it is necessary to use only structures and apparatus that are substantial and reliable. No amount of relay will compensate for inferior construction. In the second place alternative lines and apparatus all through a system must be provided, for the purposes of inspection and repairs if for nothing else. Any unit must be spared when necessary. To reduce this additional cost of the spare capacity thus required, the units should be several in number so that the duplication of one unit will not be a large percentage of the total. This applies both to transmission lines and generating stations. Thus the real essential is to have several generating stations of the most available sort rather than one hydraulic and a steam station.

With at least two hydraulic generating stations and duplicate transmission lines following different routes most of the essential *relay* advantages of the steam relay are obtained and the duplicate or spare apparatus forms a part of the regularly effective elements of the system. As long as it is not practicable at most points of the system to absolutely eliminate *momentary* shut downs, even with a steam relay, it is the opinion of the author that in general, with the exceptions already noted, the first effort should be directed toward securing the necessary reliability through good construction and a number of hydraulic stations and duplicate lines following separate routes, if possible, rather than to suffer the duplication of capital in a steam station, to be *used purely as an emergency relay.*

Additional exceptions may be made where a single consumer is given a special relay of relatively small power or where personalities of some sort enter or a steam station is already in existence and can be obtained at small cost.

Mention should be made of the extreme importance of strict discipline and careful organization and planning in advance the procedure to be followed in case of trouble, as well as intelligent superintendence, in actually realizing reliable service.

It should also be remembered that exceptional freshets, land slides, earthquakes, tc., are rather "acts of God" than preventable accidents and are beyond the responsibility of the generating plant and it is not perhaps necessary or wise to permanently raise the power rates on account of the reserve apparatus capital charges necessary to forstal such catastrophies, especially as they may occur in many and unforseen ways and to guard against all will be prohibitive or impossible. When the maximum load comes but a few hours in the year as frequently happens it is clear that at other times there is plenty of relay apparatus, thus substantially providing against accidents.

In the study of reliability of service, it will be well to put more thought and emphasis on the automatic relay apparatus for separating good from bad circuits and limiting the short circuit damage, for by these great benefit can be done the service at little expense.

To summarize, the purpose of the above discussion is to bring out the point that the real function of a steam relay is to supplement the supply of power so that more kw. can be sold; and that emergency alternative service will best come from the use of several power houses of the most available sort and transmission lines following different routes and by providing spare units for each essential element.

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THE DEVELOPED HIGH TENSION NET-WORK OF A GENERAL POWER SYSTEM

BY PAUL M. DOWNING

The greatest incentive to the development and construction of hydroelectric transmission systems has been high fuel costs. This is particularly true in California, where, until the discovery of oil a few years ago, practically every industry using steam as a motive power had to depend on coal imported from Australia or British Columbia.

Owing, however, to the natural advantages due to the topography of the country, the possibilities of utilizing the waters for hydroelectric development were early recognized, and probably more has been done along pioneer lines in this state than anywhere else.

In the preparation of a paper on this subject, therefore, I have confined myself entirely to conditions as they have developed and as they exist in California at the present time, and to the experiences in connection with the different transmission systems, which together form probably the greatest mileage of high-tension net-work to be found anywhere in the world.

On account of the rapidly growing demand for power, it was not possible to wait for results, which, under ordinary conditions could have been obtained from actual operation, but, under the circumstances, things have been done which very conclusively confirm a statement made by Mr. Charles F. Scott in his paper on Electrical Power Transmission, read before the International Electric Congress held in St. Louis in 1904, wherein he states that problems of transmission are not problems that can be solved in the laboratory alone, but the apparatus must meet the precise conditions of operation and be judged by experience.

The first polyphase high-voltage transmission system in the world was the one from Mill Creek to Redlands, a distance of 16 miles. The original installation consisted of three 250-kw. three-phase generators delivering 2400 volts at their terminals, and seven 100-kw. transformers stepping up from 2400 volts to 11,000 volts at which potential power was transmitted to Redlands. The unqualified success of this undertaking almost from its very inception, gave a great impetus to the industry, and within a very few years other installations were made, each with its particular type of apparatus and character of construction.

The Colgate power house of the Pacific Gas & Electric Co. was really the nucleus of the present 60,000-volt net-work, in that it was the first to install apparatus to operate at that voltage, and it was, at the time, the largest and most important hydro-electric station in this part of the state. The history of this plant is unique, in that the generators were installed, in operation, and overloaded, before the construction work on the building was completed.

The system of the Pacific Gas & Electric Co. as it stands today represents the consolidation of a number of smaller companies, each with a system peculiar to itself, and none of them designed with a view of ever tying in with any other system. As a result, almost every type of apparatus from the comparatively small, low voltage, rotating-armature generators, to the larger, more modern, rotating-field, high-speed machines, is represented.

This Company controls and operates eleven different hydro-electric generating stations, having an aggregate capacity of 68,130 kw., distributed as follows:

Power house	Capacity in kilowatts	Generator voltage
De Sabla	13,000	2300
Centerville	6,400	2300
Colgate	14,200	2300
Yuba	660	2300
Alta	2,000	500
Auburn	500	500
Newcastle	800	500
Folsom	3,750	800
Electra	20,000	2300
Deer Creek	5,500	2300
Nevada	1,320	5500

Ten of these have a common frequency of 60 cycles and run in parallel on a 60,000-volt net-work which is also supplied with additional power from four independent companies.

The Great Western Power Co. delivers 60,000 volts by stepping down from its main line voltage of 100,000; the Sierra and San Francisco Power Co., the Northern California Power Co., and the Snow Mountain Power Co., deliver current at 60,000 volts direct.

At times, the load carried by these four companies amounts to an aggregate of 41,500 kw. In addition to the foregoing, we have the following reserve steam and gas engine plants which operate in parallel with the transmission lines when occasion requires; *viz.*, Oakland steam turbine station, San Jose steam station, and Martin gas engine station.

The total reserve capacity at these three stations amounts to 21,500 kw. In Martin station are located two 4,000-kw. frequency changers (from 60 to 25 cycles) which are operated from the transmission line. The 25-cycle side is run in parallel with the 25-cycle gas engine-driven units, and also with the 25-cycle steam-driven station of the United Railroads.

The entire mileage of lines represented by the different systems which are tied together, exclusive of those of 11,000 volts and under, amounts to 1,920 miles.

The voltages of the different lines making up the net work are as follows:

150 miles of 100,000-volt line.
1,390 miles of 60,000-volt line.
380 miles of 20,000-volt line.

It will be noted that lines of 11,000 volts and under are not included in the above for the reason that these lower voltage lines are considered as distributing lines and not as transmission lines.

The paralleling of stations in this manner, regardless of the length of line between them, or the loads carried, has not developed any difficulties, but on the contrary, it has been found that it could be done much more readily than where the generators are paralleled in the same station; nor is it customary to do this paralleling at generating stations alone, or on the low voltage side of sub-stations. As a matter of fact, it is done almost entirely on the 60,000-volt side, using transformers of relatively small capacity connected from line to ground for synchronizing purposes.

The governing and the division of load between the different stations furnishing power to a system of this kind is not as great a problem as it would at first appear. Each station, excepting one, takes its alloted portion of load and makes no attempt whatever to govern, unless the frequency varies beyond certain predetermined limits, the speed control being left entirely to a single station. All important power houses are equipped with governors, which, except in the case of the governing station, are set so that they will be sluggish in their action, and will not operate except on wide variations of speed. Those in the governing station should obviously be adjusted to regulate as closely as possible. The governing is not limited to any one particular station, but it can be done at any station having sufficient capacity to handle the fluctuations of load.

In order to operate, as we do, with a large number of stations running together, we found it necessary to have a chief operator, or what we have seen fit to call a "load dispatcher," who, so far as the details of operation are concerned, is in absolute charge of the entire system. Water cannot be taken out of a ditch or flume, a power house superintendent or foreman cannot shut down a generator or change the load carried on the station, and a line crew cannot work on a line, without first having the approval of the load dispatcher's office. He is at all times in direct telephone communication with every part of the system, and in the event of trouble which might interrupt service, has absolute control of all matters in connection with the re-establishing of service. In his office there is a board showing diagramatically every generating station, transmission line and sub-station on the system,together with dummy switches representing every air and oil switch, and the exact position of these switches, that is, whether open or closed. In addition to the record as shown by the board, a very complete log is kept of every detail in connection with troubles of any kind, loads carried by the different stations, and any other matters pertaining to operation.

Telephone circuits are run on all transmission lines, but these are not depended upon for anything more than local use, such as for linemen reporting on and off the line, etc. They do not give satisfactory service when used over long distances, and they become inoperative when there is trouble on the line and when they are most needed.

For communicating between important stations we have circuits leased from the telephone company, which run on its regular toll line leads, and being over entirely different routes are not affected to any extent by transmission troubles.

METHOD OF OPERATION

As stated above, the different stations are, for the greater part of the time, operated in parallel. There are two distinct advantages in operating in this manner:

1. The regulation of voltage is much more readily accomplished.
2. The capacities of the different stations can be utilized to their fullest extent.

On the other hand, there is a distinct disadvantage, as trouble on any part of the system will, to a certain extent, affect the entire system.

The inductive drop on the long lines forming a net-work of this kind is obviously high, especially where the induction motor load is heavy, and the power factor correspondingly low. The synchronous motor load represents a very small percentage of the entire load, and there is little opportunity to over-excite the fields and use them as boosters. The wattless current, therefore, becomes quite a problem, and has to be taken care of either by distributing it among the different power houses, or by taking it entirely on a single station, which can be handled very readily by proper adjustment of generator fields.

From an operating standpoint, and in order to better guarantee continuity of service to the more important districts, a reserve steam plant is very essential, and in this respect the modern steam turbine serves the purpose admirably. By reason of the fact that it operates equally well at all loads it can be connected in parallel with the transmission line, and under normal conditions will carry a good portion of the wattless current. At the same time it acts as a stand-by, and in case of line trouble it can pick up the load on very short notice.

Troubles on the long lines forming net-works such as this do not always seriously affect the entire system, but show only as momentary drops in voltage. The station generators are connected directly to the line, without circuit-breaking devices of any kind, and power is never cut off the lines unless it is impossible to keep it on. Immediately on the slightest indication of line trouble, the system is separated, leaving different sections or districts supplied from different sources. If the trouble is far enough removed from the generating station it will not be very severe on account of the inductive and ohmic drop of the intervening lines, and generally the operators will have time to separate the sections without more than a temporary drop in voltage. If, however, the trouble is near a power house, that particular station will be thrown out of synchronism with the system, and even the machines in that station may be thrown out of synchronism with each other.

CONNECTION

The greater number of the lines feeding into the system are supplied from transformers delta connected on the low-tension side and star connected on the high-tension side, with the neutral grounded.

This arrangement has proved very satisfactory, and while it might be said that there is a disadvantage in using such a connection on account of the grounding of one wire throwing a short-circuit on the system, yet there is a question as to whether or not this is a real disadvantage.

If all lines could be run through sparsely settled districts, or where there would be little liability of damage to persons or property were a wire to come down, there would, doubtless, be some advantage in operating with a delta connection, but where lines are run along public highways and through more or less thickly settled districts, it seems almost necessary that there should be some very positive indication to show when a wire goes down.

Some objection has at different times been raised by the telegraph and telephone companies to a grounded neutral system, on account of the inductive influences due to current through the ground, at times when the load is unbalanced. Experience, however, has shown that this is not the real cause of the trouble, but that the troubles these companies have are the result of what might be called static unbalance, or high-frequency disturbances due to arcing grounds, or other causes which occur to a greater extent in an ungrounded system than in one where the neutral is grounded, and therefore at zero potential. This statement is borne out by experiments that have been made on telephone circuits paralleling or carried upon the same poles as the transmission wires, where loads aggregating as high as 3,000 kw. have been transferred from three to two transformers of a bank, or vice versa, with practically no effect on the telephone service other than slight change in the tone of the line.

Our usual practice is, where one of three transformers in a bank at the generating end is out of service, to carry load up to the capacity of the other two, or should occasion demand, to over-load the two, making them carry the normal load of the three. It is not necessary to limit the unbalancing of power delivered to the line in this manner, and we would have no more hesitation in cutting out one of a bank of three 1500-kw. transformers than in cutting out one from a bank of three 100-kw. transformers. This same condition obtains in the case of step-down transformers. When the load to be supplied is small, and where the expense of installing three, or even two transformers to give a three-phase distribution would not be justified it is customary to install a single transformer, connecting it from the line wire to ground. Installations of this kind ordinarily give no trouble whatever, but work as satisfactorily as though a bank of three were installed. Careful attention must always be given to the ground connection. These are made by connecting to the water mains, and also to ground plates buried to a depth depending on the character of the soil.

Occasionally it has been found where only a single transformer is used, that a severe static stress occurs on the low-tension side, which is severe enough to puncture the insulation of the lower voltage transformers supplied from the main transformer. These instances, however, have been comparatively few, and while it is something which might be expected from a connection of this kind, it very seldom occurs, and it has never been serious enough to make it necessary to abandon the practice.

The connection on the low-tension side of the step-down transformers is either delta or Y, depending entirely on the particular voltage condition to be met. Where the Y connection is used, the neutral is grounded in the same manner as on the high-tension side, and to the same ground wire.

So far as the actual operation of the system is concerned, there is no preference as to the connection on the low side, but for economic reasons the greater number of low-tension distributing systems are supplied from the Y-connected transformer. We have never yet had any troubles which we could trace back and find to be the result of the manner in which transformers were connected.

TRANSFORMERS

The capacities of transformers used, range from 100 to 1500 kw. Most of them, except some of the smaller sizes, are shell type, oil-insulated, and water-cooled. The most satisfactory case for oil-cooled transformers is one of boiler iron mounted on a cast iron base and having a cast iron top.

A great deal of discussion has been heard concerning the merits of the different insulating materials used in transformers for high voltage work, the kind of oil to be used, and the methods of cooling the oil. During the past few years the tendency of the transformer manufacturers has been toward the use of a press board or horn fibre for the insulating barriers between the coils, this material being used to replace the micanite used in the earlier transformers. This gives a transformer of lower first cost but one correspondingly less staunch and reliable.

The micanite insulation has two distinct advantages; first, it will not absorb moisture as readily as the pressboard or horn fibre; and second, being non-inflammable, it will localize trouble, and a burn-out in one coil, unless it be exceptionally bad, will not damage adjacent coils. Until a few years ago all of the transformers on the system had micanite insulation. They would be received from the factory, and without attempting to dry them out, they would be filled with oil and put into service. The oil was generally shipped in iron drums containing from 50 to 100 gallons, and when received, it would be put into the transformer without treatment of any kind, and even without being tested to see that it had the proper dielectric strength. The pressboard has superseded the micanite, and the methods of handling transformers have entirely changed. We now find it necessary to dry them out thoroughly even after they have been standing without oil for not more than ten days or two weeks. The oil also is being handled much more carefully than formerly, and separate samples taken from the different tanks in which it is shipped, must be tested. If the dielectric strength is found to fall below a certain standard, it is safe to assume that the low insulating qualities are due to moisture, which can be readily removed by heating to a temperature slightly above 212 degrees fahr.

The pressboard or horn fibre will not only absorb moisture from the atmosphere, but it will, when in direct contact with water, absorb sufficient of it to allow the layers of fibre making up the sheet, to separate, thus rendering it worthless. This objection to its use might on first thought seem hardly worth considering, but in practice it is an important one. In handling transformers out of doors during stormy weather, or in the event of a damaged water coil allowing water to get into the winding, the pressboard would be damaged to such an extent that the transformer would have to be torn down and the barriers replaced.

As to the relative fire risks of air- and oil-cooled transformers, I think that it is now generally conceded that the oil type with a properly designed case is the safer of the two.

The greatest danger from an oil-insulated transformer is from fire external to the transformer itself, which might damage the case and allow the oil to escape.

In a number of instances there have occurred fires which have heated the boiler iron cases to such an extent that the oil has been badly carbonized and the paint on the inside of the case burned entirely off without damage being done to the winding. After removing the damaged oil and cleaning the winding, the transformers have been refilled with new oil and immediately put back into service without trouble. In one particular instance which I have in mind, a fire occurred in a wooden switch gallery almost directly over a bank of 700-kw., transformers which at the time were not in service. Before water could be turned on the fire the transformers had become very hot, and when water was finally turned on, the cast iron tops had become so hot that the water coming in contact with them, damaged them beyond repair. The windings of the transformers were uninjured, and after being dried out were put back into service and are operating to-day.

From the view point of the man who has to operate the transformer, particularly in connection with long high-voltage lines, I am inclined to question the advisability of attempting to sacrifice the reliability of the transformer in order to cut down the first cost. In the absence of any approved device or apparatus that can be relied upon to take care of high-voltage line disturbances, the transformer must bear this burden to a very great extent, and the breaking down of a transformer with the resulting interruption to service, will, in a very short time more than offset any saving in first cost. For this same reason the three-phase transformer is at a disadvantage, as trouble on one phase would entirely interrupt service, unless a spare were installed.

For cooling the oil we employ the usual method of circulating water through copper coils immersed in oil. Different metals have been used in these coils, but on account of there being less liability of copper being acted upon by acids in the cooling water, and also because of the fact that it will not corrode, it has been found most satisfactory. In localities where there is any great amount of mineral in the water, a cooling coil will in time become filled to such an extent that it will not carry a sufficient amount of water to cool the transformer. This deposit closely resembles boiler scale, and in some instances it can be removed by taking the coil out of the case and hammering it on the outside to loosen the scale, after which it can be blown out by either steam or compressed air. In cases where it cannot be removed in this way, we have used dilute muriatic acid as a last resort, but as this acts upon the metal of the coil, as well as upon the scale, it cannot be considered entirely satisfactory.

Periodic pressure tests are made on all cooling coils without removing them from the transformers, and very often without taking voltage off the transformer. This we do by disconnecting both ends of the coil and allowing the water in the lower turns to either drain off; or, if both ends of the coil come up over the case, a small rubber hose is inserted on the riser side of the coil and the water syphoned out. To know that the coil is thoroughly dry, and that in the event of its breaking down under pressure, no water will get into the transformer winding, a light blast of air is passed through the coil, which, with the heat from the oil on the outside of the coil, will in a very short time remove any moisture which might remain. One end of the coil is then plugged and air pressure applied by means of an ordinary automobile tire pump. A small pressure gauge connected to the coil shows the pressure on the coil, and also whether or not there are any leaks which would allow the pressure to drop. Generally where there is no back pressure on the coils, 15 to 25 pounds will be as high a test as is necessary.

SWITCHES

Outside of the lightning arrester or line discharger for taking care of high voltages, high-tension switches were probably slower to develop than any other piece of apparatus used in connection with long transmission lines. It is only during the past few years that there have been any high-tension switches on the market, but there are now a number of different designs, all of which have proved generally satisfactory.

The system of the Pacific Gas & Electric Co., was one of the first to use oil switches for voltages in excess of 40,000. As early as 1900 we built and put into operation, switches which were of practically the same type that we are now using. While the switch was in the experimental stages, the frame work supporting the tanks were of wood, and the tanks themselves were the ordinary fibre or paper mache tubs such as are used for laundry purposes. Switches of this kind served their purpose well, and are even now in use after years of service, but where they are called upon to break heavy loads, such as come on at times of short circuit, they are apt to throw the oil out of the container when operated.

To overcome this trouble, we designed a four-break switch, along practically the same lines, but with a considerably greater depth of oil over the contacts. Four-break switches similar to the one shown in Figs. 1 and 2, have been in service in some of our largest power houses for several years, and they have never failed to open the line under all conditions of short circuit.

The particular features which recommend this switch are:

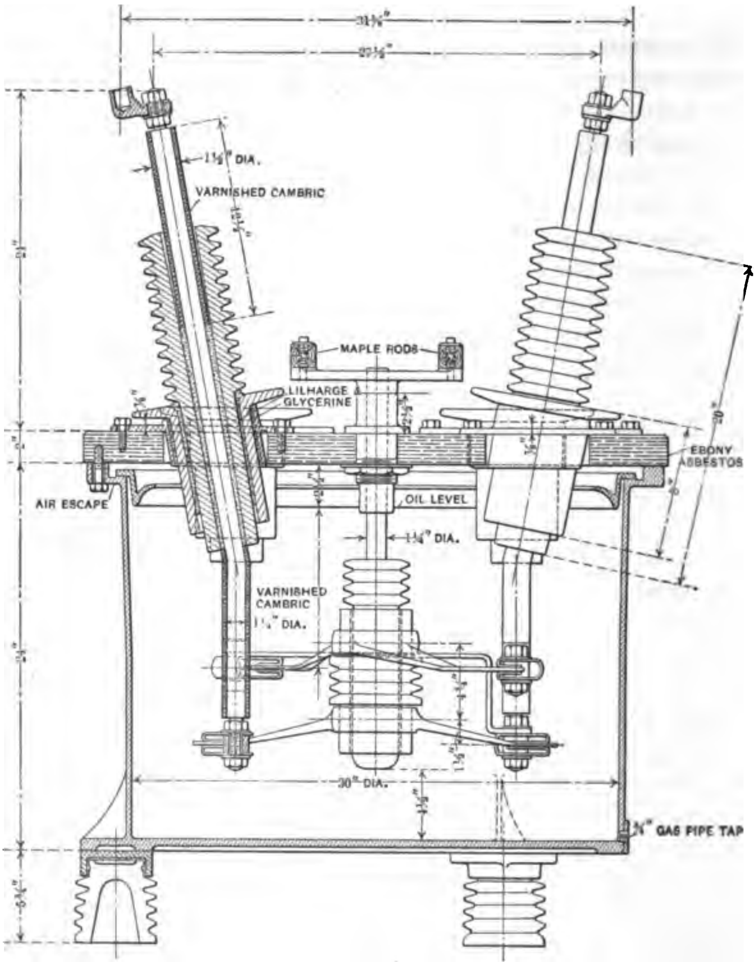
1. The absence of any insulating material that might become saturated with oil and catch fire either from leakage or from an arc.
2. The insulation of the switch from the ground, thereby affording the greatest protection against break-downs due to surges or other high-voltage disturbances when the switch is open.
3. A constant depth of oil over the contacts at all positions of the blades.
4. The comparatively small amount of space taken up by the switch.

We have never attempted to operate any of these high-tension switches either automatically or by any electric or pneumatic means, preferring rather to keep to the more positive hand-lever control. This control has generally proven quite satisfactory, but we have just installed some reverse current relays to be used in connection with the automatic operation of switches on lines which are tied together at both ends. We have yet to learn to just what extent these can be successfully employed, on account of the inherent weakness of alternating-current reverse-current relays, whose operation is dependent on both current and voltage, and the fact that in cases of severe trouble the voltage may drop so low that the relay will be inoperative.

Lightning Arresters

Except in the higher mountain districts the Pacific coast is comparatively free from lightning, and we make no attempt whatever to protect against lightning disturbances.

On most of the early installations, lightning arrester apparatus, such as was on the market at the time, was installed at different points along the line. Practically every type of multi-gap arrester was tried, all of which proved to be a menace rather than a protection on account of their arcing over whenever there was a heavy line disturbance. The result has been that long since they have been abandoned, and we now use only the horn-gap type arresters with the air-gap set so that they will arc



SECTION ON A-B

FIG. 1—Elevation of high-tension switch

across on voltages approximately 25 per cent above normal. The particular design of arrester used, consists of two gaps in series with the ground side, connected directly to earth without resistance.

These are used more on account of their being voltage limiting devices than on account of their being a protection against high voltages. Discharges over these arresters always cause a drop in voltage, and very often a momentary interruption to service until the arc breaks. We do not install them at every station, but only at the power houses and more important stations where heavy switching is done. The electrolytic arrester now on the market has been installed on some of the lines in this state but as they have been in service only a short time, little can as yet be said concerning their efficiency or effectiveness.

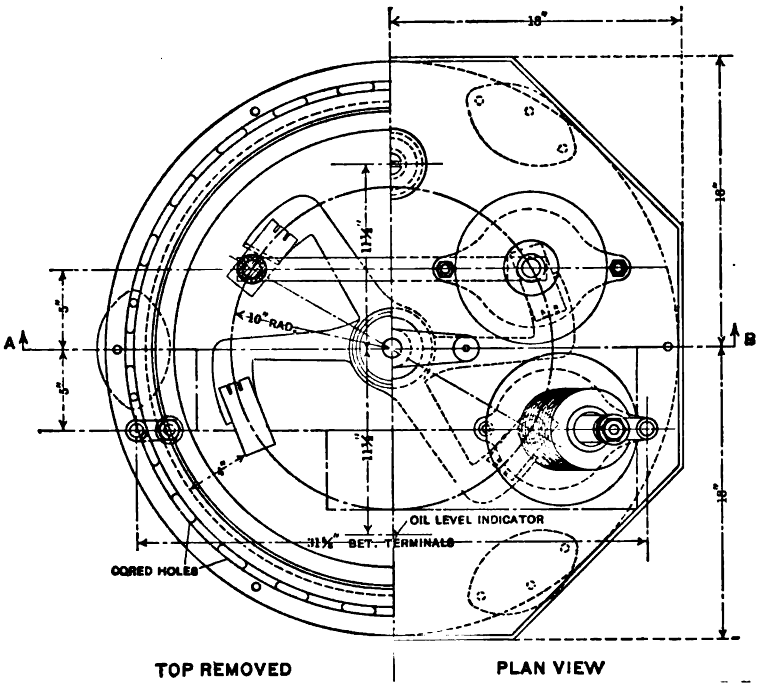


Fig. 2—Plan of high-tension switch

Insulators

The question of line insulation for the high voltages now being used on transmission lines, is the most serious problem engineers have to face, and while it is true that both the design and quality of the insulators manufactured to-day are far superior to those of a few years ago, it is also true that the limiting voltage of a transmission system is governed by the insulators.

The climatic conditions of the greater part of the Pacific coast are peculiar in that there are two seasons, one wet and one dry; and it may seem strange to say that the insulator trouble during the dry season, or just when the first rains start in, is as much as or more than there is during the winter storms. The trouble is due to leakage over the surface of the insulator on account of the dirt and the salt which is deposited by the ocean fogs. As soon as the heavy rains come, this accumulation of dirt, etc., is washed off, and the number of insulator troubles is materially reduced. The number of insulators that actually puncture are very few, the greatest trouble being due to leakage. As a striking illustration of troubles of this kind, I might state that insulators operating successfully at 60,000 volts in the mountain districts outside of the fog belt, and where there is little or no dust, give a great deal of trouble on 11,000-volt lines in the bay district where they are exposed to more severe conditions of dust, fog, and smoke.

Troubles of this kind generally affect insulators on grounded and ungrounded structures differently. If they are supported on poles where the leakage path to ground is a high resistance one, the top of the pole will be burned off, and generally the insulator is not damaged. But where metallic structures or grounded pins are used, thus giving a low-resistance leakage path to ground, the insulator is more often damaged by the arc, which very often is great enough to burn off the line wire.

Troubles of this kind naturally bring up the question of what design of insulator will best meet the conditions, and whether or not the theory that as much of the insulator as possible should be kept dry is a correct one. This theory has been carried out in the vertical or pin type insulator with the result that in the three- and four-part insulators a good portion of the inner petticoat is protected from the rain and cannot be washed by the elements. It therefore becomes necessary to shut down the line and wipe them by hand. This cleaning is especially necessary in the fog district near the bay and along the coast, where it has to be done about twice each year. The suspension insulator has a decided advantage in this respect, in that a much greater part of the surface of the insulator is exposed to the rain and dirt, and is washed off during stormy weather. However, with the higher voltages at which this type of insulator is designed to be operated, there is every reason to think that similar troubles will be experienced, and doubtless the same homely means will sooner or later be resorted to in order to overcome it.

DISCUSSION ON " THE DEVELOPED HIGH TENSION NET WORK OF A GENERAL POWER SYSTEM ", SAN FRANCISCO, CAL., MAY 5, 1910.

Markham Cheever: One of the most serious problems that to-day confronts the engineer of an extensive transmission system is the automatic disconnection of disabled lines and apparatus. As the author points out, the fullest utilization of station capacities and the best general regulation of voltage can only be obtained by operating the whole system in parallel. However, the occurrence of anything abnormal at any one point causes a disturbance over the whole system.

Most of the large transmission systems have been a matter of gradual growth, the extensions being made to meet particular requirements, rather than to conform to a comprehensive scheme. It is thus that complicated net-works have arisen, making extremely difficult the satisfactory application of automatic switches. The general experience with automatic switches installed to cut out only the disabled section of transmission line has been unsatisfactory, but it is gratifying to note that relays have been designed to meet the conditions found in one large eastern transmission system and appear to be operating with success. The effort toward maintaining continuous service involves a thorough consideration of the arrangement of trunk lines and feeders, as well as the development of relays that will perform their function properly.

A Member: There is one point on which I would like to ask for information from the eastern engineers and that is the extent to which automatic disconnection devices are used on high tension lines or connecting on to sub-lines or sections of the main line in cases of trouble. I would like to know the class of device that is used for that purpose, and whether it is operated simply by means of relays, operating trips and compressed springs, or whether a small storage battery is used for operating solenoid controlled switches.

President Stillwell: The first instance that I know of, in which the problem of cutting out automatically at both ends a short-circuited feeder was seriously attempted, was in connection with the underground cable system of the Interborough Rapid Transit Company in New York. In that system the Manhattan Power House and the 59th St. Power House are tied together by eight triple cables No. 4/0 B. & S. gauge, and as each station contains nine alternators capable of developing 7500 kilowatts each, and about three times normal current on short circuit, the conditions imposed by short circuit in the cable system are extremely severe. During the development of plans for the Manhattan, the fact that without some such device a cable failure at practically any point might tie up the entire overhead transportation system of New York was realized and discussed, and some of our leading engineers took the position that the possibilities of trouble were such that the use of a high-potential system of distribution from power house to substations was not justified. It was suggested as an alternative that the power be supplied from a number of independent direct current systems.

The automatic circuit breakers first tried were not satisfactory. They were of the type in which one element is connected across the line through a transformer. They generally failed to work for the reason that a heavy short circuit dropped the voltage to a point where they became inoperative.

In the case of the Manhattan substations each is supplied through at least three cables and in most cases five are used. This permits the use of an actuating device for the circuit breakers which depends not upon potential, but upon difference of current flowing in the short circuited feeder and in the other feeders which supply the substations.

Devices of this kind have proved very satisfactory, and now a short circuit in a feeder cable very rarely, if ever, causes trouble in power house or substation. The automatic circuit breakers operate effectively to disconnect the feeder at both power house and substation.

When I became connected with the Niagara Falls Power Co. in 1907, I found in operation a service to Buffalo, supplied through transformers, which increased the dynamo potential from 2200 to 11,000 volts. There were metallic devices at the 2200 volt terminals of the transformers, and also at their 11000 volt terminals. In Buffalo the step-down transformers were similarly equipped, and a short circuit in Buffalo usually blew all four sets of fuses.

The first step that we took in the direction of remedying this was to devise the time-limit circuit breaker, which is now extensively used in power house work. Andrews at Hastings, England, prior to this time, had devised and used the reverse-current circuit breakers, but we did not attempt the use of these at Buffalo.

I see no reason to doubt that it is possible to equip such high-potential networks as you have here in California with automatic overload and reverse current circuit breakers, which will be effective in reducing largely the interruptions of service due to short circuits on the line. In the Carolinas, the Southern Power Co. now has some eight hundred miles of interconnected overhead circuits and have experienced considerable trouble from lightning. The engineers of the company are beginning, as Mr. Downing is here, to make experimental trials looking to improvement by means of automatic circuit breakers. It is good economy to spend even very considerable amounts of money to avoid interruptions of service. They hurt the business and limit materially the rapidity with which the transmission of electric power is being developed in competition with power locally generated.

I should like to ask Mr. Downing a question which relates to the matter of frequency. Some ten or twelve years ago Professor Perrine, then consulting engineer to the company which installed, as I understand, the first plant of the many which now constitute the system of the Pacific Gas & Electric Co., called upon me at Niagara and invited suggestions regarding frequency. I advised him to adopt 25 cycles as being better adapted than 60 cycles to transmission over great distances, pointing out that such systems always grow far beyond the original scope contemplated, and that with the increase in length of circuit, difficulties due to impedance drop would become very weighty. Those installing the plant to which I refer ultimately decided to use 60 cycles, and I should like to ask Mr. Downing, whether, from his present experience, which has covered so wide a range, he would choose 60 cycles if he were to take this matter up *de novo*, or whether he would use a lower frequency. I should also like to ask him about interruptions of service. Any information Mr. Downing may see fit to give relative to these subjects, I am sure would be highly interesting and useful.

L. R. Jorgensen: With eleven different hydroelectric stations to feed into a common network, the continuity of service depends more upon the character of the network than it does upon the character of the power stations. Generally the hydraulic conduit is the weakest link in power generation and transmission, but not so in this case where we have many plants delivering power into the same system. In case of electrical trouble on the system the affected portion is cut out so as not to disturb other portions of the network. If this selection of the affected portion can be done automatically, it is the quickest and easiest way. The larger the system of transmission lines, the more difficult it is to lay out a system of automatic overload switching that will work satisfactorily. In any system, however, it can only be of advantage to have the incoming feeders to substations provided with inverse time-limit overload relays. These relays will work exactly as intended, if the whole substation load can be taken from one feeder at the time, or, if not, the different feeders should feed separate bus bars or separate sections of bus bars. In case, however, the different feeders and bus bars must be paralleled in the substation, the inverse time-limit overload relay would not work at all times as intended, and the reverse-current relay should be substituted. But, if the installation can be made to suit the former relay, it is the best, as the reverse-current relay has not reached the end of its development. The inverse time-limit relay, however, is entirely reliable. Whether the outgoing feeders from the generating station, feeding a complicated network, should be provided with automatic overload relays is a question that perhaps must be answered in each case by trial to find out if the automatic feature does more good than harm.

E. F. Scattergood: There are three or more points which I would like to speak of in a suggestive way. Mr. Downing spoke of the pin type insulator. It has been demonstrated to the satisfaction of engineers in Southern California, at least two or three of them to my knowledge, that on 16,000-volt circuits, affected by fog, the seven-inch two-part mushroom type insulator gives much better satisfaction; that is, the insulator that is spread out flat gives much better satisfaction than the two-part insulator of the same character but with a top section drooping umbrella-shaped. That seems to be demonstrated without question and would simply follow out Mr. Downing's idea of a more open insulator.

The second point is in regard to oil switches. To my mind it is demonstrated quite clearly, that high-tension oil switches should contain a considerable amount of oil; that is, a large cross section of oil on a level with the point of break and a considerable depth above, as indicated by the paper, and that the break should be horizontal; under these conditions the moving terminal is traveling in fresh cool oil if there is any heat at all generated, and at the same time in case there is a partial breakdown on the part of the switch, that is, the formation of gas in the oil at the break, the gas tends to lift, but as there is a large cross section on a level with the break there will be quantities of fresh cool oil banked around on all sides, ready to flow in. So that we have both terminals at all times flooded with fresh cool oil.

The third point is in regard to the telephone system mentioned in the paper. I think you are all acquainted with the two opposite ideas expressed by engineers on the amount of insulation that should be placed on a telephone line in conjunction with high-tension lines. I have heard it stated that one should not use larger than pony glass insulators, in order that there may be leakage of charges which would affect the telephone line. I have heard it stated by well-known engineers that such has been demonstrated. On the other hand it is stated by engineers that there should be strong insulation of telephone lines to avoid their being charged from the high tension lines, especially if on the same poles; and that on a wooden pole line, for example, if the high tension crossarms are put on with lag screws in the center of the pole, and the telephone arm is put on in the same way, using pony glass for insulation, the telephone line will be noisy on account of the lack of insulation.

I want to speak of an instance from which engineers present may draw their own conclusions, because it is not absolutely definite. In connection with the Los Angeles aqueduct we have a telephone line of 250 miles in length, built on separate poles. Notwithstanding the fact that it parallels 33,000-volt power lines, built for Aqueduct construction, along 200 miles of its length. It was built on separate poles and run underground, through well grounded iron pipe, wherever crossing high-tension lines in order to insure perfect safety in its use by all classes of men engaged in the aqueduct construction. Standard D.P.D.G. glass insulators were used and the indoor wiring at telephone stations was carefully installed on porcelain knobs. My idea was that the line should be well insulated, and when it was completed it was what might be termed absolutely quiet, though paralleled by one 170-mile and one 30-mile 33,000-volt line with grounded neutral and a third power line similarly grounded, of between 50,000 and 60,000 volts, for about 20 miles. An additional point is that one and one-half years after its installation, apparently due to deterioration of the insulation, the line gave considerable trouble from noise.

The fourth point I want to put more in the form of a question. The author of the paper, Mr. Downing, speaks of having no trouble in paralleling these different stations, which were built without expectation of their being paralleled. I understand that he means that there is practically no trouble in operation. I would like to ask if he has made any readings or tests to ascertain how much power is being lost in the connecting lines, due to the current necessary for keeping the stations in parallel, aside from the current which would exist there, due to the load. I know of one instance which has since been corrected, but which existed for a while in Southern California, in which a 1500-kw. unit at a considerable distance, tended to hunt a little and sometimes more, and in several instances, when it was carrying as much as 900-kw., it was pulled off the line without the other stations experiencing increase in load. I might say that the hunting in those instances was not sufficient to disturb the system for good operation and good service, yet was bad enough to lose the whole output of that generator up to 900 kw., in a distance of some 40 miles.

W. F. Wells: The conditions in the east are somewhat different from those of the west, and yet you may be interested with a few of the various details. The company with which the speaker is connected operates two generating stations, having a total capacity of 48,000 kw. The current is generated at 6600 volts, 25 cycles, and the transmission lines are all underground. These voltages may seem low even when it is considered that the entire distribution system is underground. These two stations are operated in multiple and all of the substations, about twenty, are connected to the one 6000-volt network. The general method of handling the current is similar to that described in the paper, and which has been used for the past eight or ten years. In order to prevent accidents a very strict code of rules has been prepared and each employe operating in a generating plant or substation, receives one of these rule books, for which he has to sign a slip stating that he has received and read the same. There had been some cases where an employe claimed that he did not know a certain rule was in force, and the court decision in case of accident was adverse to the company. For that reason, both the company with which I am connected, and others in Chicago and New York, have issued these rule books, which are very simple, and which give the general rules pertaining to operation, so that each employe knows how far he may go in any matter. Reliability is the most important thing as shown by one instance. The company has a contract with the City of New York, in which there is a penalty of $500 per minute for interruptions of service, in case current is desired. The transformers used are all of the air-cooled type, no water or oil cooled ones being used. In regard to the switches for these voltages, we have had the same trouble you have experienced on your high tension switches. The present type manufactured by the two large companies operate satisfactorily up to a capacity of say, 40,000 to 50,000 kw., but where the station capacity goes beyond that, and in the case of a short-circuit near to a station, the results are liable to be disastrous.

Reverse-current relays in the cable system are always operative as there is a storage battery in practically each and every one of the substations, thereby insuring a sufficient supply of low-tension current at all times. It is stated in the paper that the horn type arresters are set for a voltage of 25 per cent above the normal. It has been found on our system that voltage surges frequently approximate 100 per cent beyond normal. That probably is due to the greater capacity of the eastern underground cable as compared with the western aerial lines.

John Harisberger: I would like to ask Mr. Downing what experience he has had in opening the switches on the transmission line. The present practice is to cement pins in to the insulator. It would be a splendid idea to use an iron pin in the insulator. I have found that very satisfactory.

P. M. Downing: There is a question in regard to cementing the iron pin to the insulator. In the Puget Sound district, we have practically abandoned that practice by using a threaded iron pin for 60,000 volt service, and have found it very satisfactory.

A. M. Hunt: There is one minor incident in operating transformers that has come to my attention which I thought I would mention. It might be of value to some of you in operating work.

At a substation of the Pacific Gas & Electric Company located at a prominent manufacturing extablishment, there were located three 100-kw., 60,000-volt transformers. It was found that one of the water cooling coils was leaking slightly. It was a very serious matter to shut down the plant. After thinking the matter over, I rigged up a syphon so that the coil could be kept under minus pressure, and it was operated that way for twenty-four hours in order to keep the plant going. Of course, in such a case the leakage would be from the oil side to the water side, and if serious would reduce the oil level, but in this case the leakage was not sufficient to be serious.

A. O. Austin: The extremely variable conditions effecting line insulation on this system have been pointed out by Mr. Downing, and it is in regard to insulators for these conditions that I would like to say a few words.

It was in connection with insulators for these lines that the writer started experimental work which resulted in the development of the high efficiency disk suspension insulators, which have been installed on the largest lines during the past year. Most of the insulators on this system, in addition to having a large percentage of the surface protected, have large variations in diameter throughout the leakage path, and in addition, have the surfaces of highest resistance, limited by small striking distances. This, with a high electrostatic stress on the small shells is the cause of the great depreciation in insulation as the insulator becomes coated with dirt.

The present insulators on this system were the best that could be had at the time they were installed; manufacturing conditions, however, have improved rapidly within the last few years, and it is now possible to make high efficiency insulators which do not depreciate to the same extent when coated. With high efficiency insulators, I believe it possible to insulate these lines so that it will not be necessary to clean the insulators. The high efficiency designs are small for the rating, and are so designed that the surfaces are cleaned by the wind and rain to a much greater extent than the low efficiency insulators.

With the high efficiency designs, it is also possible to provide the line with a much larger factor of safety, the suspension insulators permitting of practically any factor of safety as regards line insulation. The suspension insulators in use on the Pacific Coast are of low efficiency type, having some of the faults of the present pin type insulators, and it is to be hoped that high efficiency insulators will be installed under the same conditions, so that comparisons may be made when insulators have assumed a permanent working condition.

C. F. Adams: There are one or two points which I would like to bring up, one is the subject of the oil switch, and Mr. Wells has just described the ordinary results from the over loading of the switch under service conditions. I presume he refers to what is ordinarily known as type H switch. The chief trouble that occurs is that which seems to be due to the compression of gases in the cylinder, which is too small to contain those gases, resulting in an explosion. The particular switch which is illustrated in the paper, is built upon the theory that the necessary thing in an oil switch is a sufficient depth of oil over the arc that results from opening the switch, and also sufficient area for venting the switch. The entire rim around the top of the tank is vented by a series of holes giving a resulting cross section of several square inches through which any gases may escape. In actual practice this theory has worked out far better than the idea of allowing the gases to compress and thus extinguish the arc by pressure of oil.

There is another feature in Mr. Downing's address on which I had hoped to hear from the manufacturers. There are two types of construction of high-tension transformers. The original high-tension transformers were constructed on the theory that the potential between the high- and low-voltage windings was a possible source of danger; in other words that a break down in the high-tension windings might be communicated to the low-tension windings resulting in a break down of the distributing system, and for this reason the barriers between windings were made more or less fire proof in their nature—micanite being used a great deal.

That theory has been abandoned, though many cases have been found in which local short circuits in high-tension coils have not extended beyond the limit of the coil, and have not burned through the barriers. In later construction the press board insulator has been used entirely, overlooking this feature of transformer construction, and the barrier simply serves the purpose of directing the flow of oil between the various coils.

Another feature of insulation which he discusses is the water absorbing possibilities of the material. For many years the manufacturers went upon the theory that the oil which would enter the partitions would be sufficient to exclude the possible admission of moisture. This theory has not been borne out by practice, and in fact, it is practically common knowledge that press board thoroughly saturated with oil has a continuous affinity for water that may be in the oil; from my own observation I have found that partitions immersed in oil, after a period of some months, would be found to have this peculiar quality: at the upper end of the partition the insulation might withstand 65 or 70,000 volts, while at the bottom of the partition, the thickness being identically the same, the same partition would break down at from 25 to 30,000 volts, and this insulation feature was practically dependent upon the depth of the immersion in the oil, or the height from the top down.

P. M. Downing: In reply to the several inquiries that have been made, I will endeavor to answer them as well as I can.

The first is by the chairman as to whether or not, if we had it to do over again, we would select the same frequency. I endeavored to bring out in the paper that one of the hardest problems that an engineer had to contend with in the operation of a long distance transmission line was the holding up of the voltage on the end of the line due to the inductive drop. It can be overcome to a very great extent by the use of a lower frequency, and after the experience which we have had, it seems to me that I would seriously consider a lower frequency before adopting the 60 cycle.

As I stated in the paper, practically all of these plants were built with the idea of operating as independent plants, and not with the idea of ever being tied into a net work such as we are operating to-day. It is for that reason that we fixed upon

60 cycles, and there is no question in my mind but that the lower frequency would be better.

The second point brought up by the Chairman is as to what part or portion of the load can be taken up by turbines operating in parallel with the system; referring now to the particular system which we have been discussing, we do not attempt to take up the entire load. The steam plants are located at the more important distributing centers, where the service is of most importance, and we only attempt to pick up that important service, and do not try to handle the entire load.

President Stillwell: Is that picked up automatically, or do you have an interruption of a minute or so until you get started?

P. M. Downing: Ordinarily it is picked up automatically, that is, without interruption to the service other than a drop in the voltage.

In reply to Mr. Scattergood's inquiry, as to whether or not there was any appreciable amount of power taken to keep the different stations in parallel—that is rather a hard question to reply to, for the reason that it can only be determined by getting all of the load off the line and seeing what was being required. This, of course, is out of the question, and for that reason I do not know. We do know, however, that there is no great amount of wattless current circulating between the different power houses—practically no current whatever through the neutral of the high-tension transformers, such as was discussed this morning in Mr. Rhodes' paper.

Mr. Harisberger brought up the question of the necessity or desirability of insulating the metal tank of the oil switch from the ground.

This practice is the result of experience dating back a number of years to a time when the art of manufacturing satisfactory insulators was in what might be called its infancy.

The porcelain manufacturers were unable to furnish an insulator that could be relied on to stand the break-down strains to ground even on comparatively short lines carrying light loads.

We are to-day able to get a much better grade of porcelain, and in such shape that it is much better adapted to our requirements, but notwithstanding this fact, the duty imposed upon the switch is much greater than formerly, and the necessity of taking every possible precaution in the way of insulating correspondingly increased.

Insulating the tank from the ground gives an additional factor of safety by cutting down the voltage strains on the bushing insulators entering the switch. Nor have we yet heard any good reason why they should be grounded.

It is claimed by some engineers that grounding the switch tanks is desirable on account of safety to persons coming in contact with it. To a certain extent this is true, but I think the instances where men are required or permitted to work around high voltage switches with power on, are so few that it is unwise to sacrifice the efficiency of the switch in order to provide the additional safety, desirable only under what might be considered extreme emergencies.

The particular air switch referred to by Mr. Harrisberger is a horizontal break, pole type switch, consisting of contact jaws mounted on line insulators with a connecting blade rotating in a horizontal plane. The three moving blades are connected together and controlled by a single rotating shaft operated from the ground.

It was designed to be used as a disconnecting switch on small transformer installations, or on branch lines where there is little or no current to be broken. It was never intended that it should handle currents of any magnitude.

A paper presented at the 248th meeting of the American Institute of Electrical Engineers San Francisco, Cal., May 6, 1910.

HYDROELECTRIC POWER AS APPLIED TO IRRIGATION

BY JOHN COFFEE HAYS

INTRODUCTION

Among the many uses to which hydroelectric power is being applied, that of electrically pumped water for irrigation is being advocated at present in a great many instances; and while the mere pumping of the water is so simple as to be hardly worthy of discussion, it may be of interest to point out some of the operating conditions encountered in a project formed chiefly for this purpose.

A hydroelectric system to supply power for pumping water for irrigation will usually be required to build up its own market in the territory served, and it is manifestly necessary at the outset to carefully study the territory. Usually some pioneer work by progressive farmers will show what the land is capable of producing, but the greater part of the territory will consist of barren country planted to grain, or used for grazing purposes, with here and there a town. This land is in large holdings, and the first thing to be determined is the amount of sub-division which may be expected, and whether the proper men are in the field to bring this sub-division about. The character of the land, is of course, of primary importance and the percentage of good land should be carefully determined. Irrigated land should have a slight slope for distributing the water and must be reasonably smooth. Hard pan near the surface must be guarded against, as it generally denotes a rather poor quality of soil. The adaptability of the soil for different products and the climate should be considered, yet data on these two points are hard to get and are usually unreliable. Tests and analysis of the soil would seem to be the natural way of determining its adaptability to the different products, but the agriculturist pays very little attention to these analyses, and has apparently a good reason for this, as they are often unreliable.

In the San Joaquin and Sacramento valleys it has been demonstrated that almost any kind of products may be raised on the good lands. Only a small portion of this land has been planted to citrus fruits, but small groves may be found along the entire length of the valley, and it would therefore seem as though it were all adapted to this class of products if water is applied. The best conditions seem to exist, however, where the mountains rise abruptly from the valley, and the level flat land extends up to the foothills, for, where a long stretch or rolling country lies between the plains and the hills, hard pan and bedrocks are generally very much in evidence.

Due to the fact that the oranges in the San Joaquin valley ripen and are marketed a full month earlier than those in the southern part of the state, they bring exceedingly good prices, and the growth of this industry is very rapid. The present citrus districts, as in fact is most of the land in the citrus belt, are above the existing irrigation canals, which in most instances divert all of the water available from the rivers, and are therefore entirely dependent on ground waters for irrigation; and, as the profits from this crop warrant a large expenditure, it is naturally the best market for power for pumping purposes. Aside from citrus fruits, all kinds of high-class products, such as deciduous fruits, berries, vegetables, nuts, vines, and alfalfa are to some extent also irrigated by pumped ground water.

The amount of water required for the irrigation of different products varies to such an extent in the different communities that it is impossible to get any figures which would be at all accurate. The character of the soil is accountable for the difference to a large extent, but the cost of water and the personal equation are accountable to a very much larger extent. There is usually a marked tendency to the over-use of water. The duty of irrigation water in California is believed to average about 2 ft. in depth in addition to the average rainfall.

In the Imperial valley, in 1906, 120,000 acres were irrigated and a total average depth of 2.04 ft. was used, the main crop being grain. In San Diego county on land planted to citrus fruits an average depth of 1.5 ft. was used from 1889 to 1899. Subsequent dry years, it is stated, lead the growers to believe that too much water had been used. Around Los Angeles it is estimated that an average depth of 2.4 ft. is used.

In the Modesto and Tyrlock districts as much as 8 ft. to 10 ft. in depth was used at the start, but in 1908 the depth varied from 1.2 ft. to 3.6 ft. In the Fresno district very little water is applied to the surface of the land at present, the land being sub-irrigated by seepage from the canals.

COMPARISON OF GRAVITY AND GROUND WATERS

Where gravity waters are available this method of irrigation is usually much cheaper than by ground waters, and will consequently be used in preference. However, the difference in price is not as great as is popularly supposed, and the cost of irrigation in the case of high-class products is really one of the small items in the total expense, and therefore the use of ground waters may show advantages which will easily offset the difference in actual cost. Ground water irrigation has the following advantages all of which are of considerable importance:

First, the duty of water is higher, due to the fact that it is more economically used on account of the cost of pumping, and the water that is not evaporated and absorbed by the products again sinks into the ground to replenish the underground supply and be used over again.

The second advantage is the drainage function, as the overuse of surface water has, in many cases, ruined excellent land by causing the raising of alkali to the surface, and thousands of acres of the finest lands in the large irrigation districts have been waterlogged and ruined by the excessive use of gravity waters.

The third advantage of ground water irrigation is the freedom from weed seeds which are often carried by ditches and canals, and which, if they do not actually ruin the property, greatly increase the cost of cultivation.

The fourth advantage which the pumped water has is its convenience, and the absolute independence of the farmer using it. The matter of taking turns at the water, and having to use it when you do not want to, and not being able to use it when you do want to, or trouble with the man further up the ditch taking all the water in the dry season and flooding you out in the wet season is entirely done away with where ground waters are used.

The writer has found it impossible to obtain any reliable information regarding the cost of gravity water irrigation except from the large irrigation districts, and even this is incomplete.

The large irrigation districts in Central California are not fully developed, and to take care of the lands which are not yet irrigated, but which are paying their portion of the irrigation tax, reservoirs must be built. The drainage of these lands may be counted upon to cost as much or more than the irrigation. In the case of the small ditches practically no record of costs is ever kept. The cost of litigation is another large item which may be charged to practically every ditch and canal system. Taking all these things into consideration, it will be seen that, even where actual cost is concerned, the pumped water may compare very favorably with surface water in cost, and in fact, there are instances where it is actually cheaper.

The only argument aside from the less expense that the writer has heard advanced in favor of the surface water irrigation is the fact that the surface water may be a better quality, it being nearly always soft and pure, while the ground waters are sometimes hard, and in some cases alkaline and injurious to the products. There are, of course, cases where these conditions exist when the use of ground water is out of the question.

Where intensive farming is practiced and the ground waters are entirely depended upon, some concern has been felt as to the sufficiency of the underground supply, and undoubtedly many localities could be found where more water would be withdrawn from the underground basins than is restored by natural process. The Lindsay district is entirely planted to citrus fruits and other high-class products requiring a large amount of water. Every drop of water used for irrigation, domestic and stock purposes is pumped from the ground, and the water level averages a depth of 60 ft. to 70 ft. when pumping. It would seem that the Lindsay section should show a diminution of the ground water supply, if it is to be a serious problem, as it is probably the most disadvantageously situated district in the county in this respect, yet the water after twelve years of heavy pumping is standing as high in the wells as ever. It is also to be noted that the wells are not what might be considered deep, their average being about 150 ft. to 200 ft., and, as the cost of pumping is insignificant when compared either to the profits or to the expense of the grove, it is apparent that much deeper wells may be indulged in if the waters show signs of decreasing, and within certain limits, the deeper the well the more water.

The San Joaquin and Sacramento Valleys are also favorable storage basins for ground waters, as the only outlet is the San

Francisco bay through the narrow straits of. Corquinez. The elevation of the Lindsay district two hundred and fifty miles away is about 300 ft., and the ground waters must, therefore, of necessity travel very slowly and be in large quantities.

DEVELOPMENT OF SYSTEM

In determining the policies and the scope of a proposed hydroelectric system for the supply of power for pumped irrigation, it is necessary to determine at the outset the exact territory to be served and the general policies to be followed as regards charges, contracts, extensions, etc., or, in other words, a definite goal must be set, the power company must do everything possible to assist development, and any inhabitant in any section of the territory must be supplied with power whenever it is required. Therefore, the power system simply grows up with the country, and while this growth is taking place (it of necessity must take many years), it must be considered that the power system is in course of construction during the entire period. This is the main feature in which the power project depending entirely upon an irrigation market differs from the project supplying ordinary commercial business in an already well settled community, and this is a difference which is seldom fully understood and the time element not fully provided for.

The initial installation will usually cover various towns and communities, and, if the territory is partially developed, the development will probably be close to the towns. The business available may, therefore, be fairly well concentrated at the start, and consequently profitable as far as it goes, but naturally only a small amount of the ultimate power required will be marketed. The extensions to the system will be made from these towns, and the fact that development of the community always starts near the town and grows outward is a most favorable condition of affairs for a power company. The price of land is always greatest near the towns, and decreases in proportion to the distance from any center, yet the land near the town is the first developed. These towns are built along the railroad, and being the shipping points, the reduced cost of hauling to the railroad to a certain extent offsets the additional cost of the land.

THE HYDROELECTRIC SYSTEM

The character of construction of a system depends entirely on the class of market, and for irrigation a slight discontinuance of service is not serious, therefore a light construction is permissible. The generating stations at the outset should be of a fairly permanent character, but the distributing system may and actually should be of a light and in many cases even bordering on a temporary character, as it is necessary to economize in every way at the outset to warrant the low rate which it is necessary to charge in order that the market may be developed; for it is necessary at the outset to establish a rate which will continue in effect when the system is fully developed. Even the expense of the generating stations may be reduced to a considerable extent at first, and as the system increases and the market becomes concentrated, improvements of a more permanent nature may be added.

Notwithstanding this, the writer has heard engineers of standing make the broad statement that there was no excuse for the use of a wooden flume and that a tunnel was the only proper thing; also that certain plants were altogether too flimsy and temporary in their design, and that the wooden pole line was entirely obsolete. When these statements are made, the writer cannot but think that the assertions are prompted by a lack of regard for the first principle of engineering, namely, economy. Every one who has had any experience with the wooden flume knows the many interruptions of service caused by it, yet, if constant service is not absolutely necessary, what possible type of construction can compare with the flume. It is short lived, but several can be built for the cost of a tunnel, and during the early life of a transmission system every dollar counts. If the system warrants a tunnel, it may be constructed durng the life of the flume to take its place. Of course, if the systems depends entirely upon one power plant, the replacement of the flume is both difficult and expensive, but few existing systems of any importance rely entirely on one plant, and there is usually sufficient capacity available during certain periods of the year to allow for the shutdown of one station. Also an auxiliary steam plant is often cheaper than a tunnel and much more useful.

Wooden pole lines are also perfectly reliable in our California climate and are a very worthy substitute for the steel tower lines in respect to business development, and there is nothing to prevent the construction of the tower line when the wooden pole has outlived its usefulness; no interruption of service is necessary, as the right of way should be wide enough to accommodate both lines.

Among the different parts of the system where considerable expense may be saved is the switching gear, which may be extremely simple at the outset and still ample. A small galvanized iron building on a wood frame is a thoroughly satisfactory building for the pioneer substation, which can be replaced by a permanent and fireproof structure when the business warrants. By the construction of light, inexpensive tie lines one substation may be arranged to temporarily supply the territory of another, and by the construction of a ring system many miles of expensive transmission line may be replaced by a much lighter class of construction, which will answer all purposes for many years.

In the greater part of California the conditions are ideal for long pole spacing. High winds seldom occur and sleet is unheard of, but it is not uncommon to see a line consisting of three wires ranging in size from No. 2 to No. 8 supported by poles spaced from 120 ft. to 150 ft. apart. However, on new lines, the fallacy of this mode of construction is apparently being realized, and much of the new work looks different. In one case the writer has seen a pole spacing of over 500 ft. in use on light lines, 40-ft. poles being used, which made a very nice appearing and businesslike line. Due to the less number of poles used, better poles, cross-arms and insulators may be indulged in. Other details may be treated in a similar manner.

DESCRIPTION OF TYPICAL SYSTEM

The writer has been connected for several years with probably the only hydroelectric power project that depends almost entirely on pumped irrigation for a market, approximately 70 per cent of the power generated being used for this purpose, the balance of the power being used for the ordinary commercial purposes in towns and settlements within the territory served, and for the operation of one interurban railway. The entire territory, however, is supported by the agricultural and horticultural products, and, therefore, the system is believed to be almost as nearly an exclusive power pumping system as can be imagined. The actual conditions obtaining on this system should apply closely to conditions which may be expected in other similar projects.

Territory. The territory of the company referred to comprises approximately 1,050 square miles in Tulare and Kern counties, California, being a strip of country about 50 miles long north and south, and 22 miles wide. The only available gravity waters for irrigation are the waters of the Kaweah and Tule Rivers, all of which have been long ago appropriated.

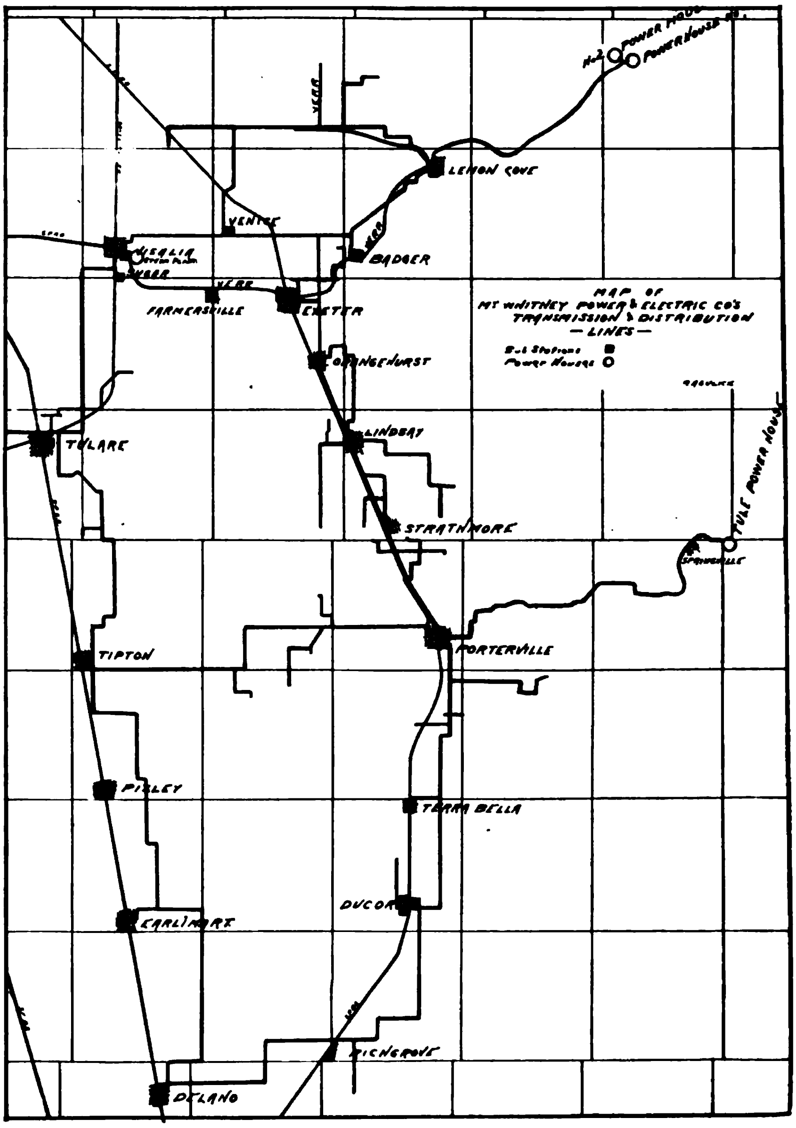


FIG. 1

This gravity water irrigates about 90,000 acres of land and the balance of the territory, or approximately 560,000 acres, must depend entirely on the ground waters for irrigation before they can be made to produce other than grain or pasturage. The average annual rainfall for the territory is about 10 inches, and the soil and climate are admirably adapted for the production of all kinds of high-class products. The territory may be for convenience divided into two sections, the citrus belt comprising approximately 200,000 acres of land, and what may be termed the valley portion. In estimating the power requirements it is considered that approximately half of the land in the citrus belt will be planted to products requiring approximately half as much water as the citrus fruits.

FORMS OF CONTRACTS AND CHARGES

The bulk of the power is sold under three forms of contract, all being for a period of five years or longer. The contract under which the greatest amount of power is marketed, and which is used by the orange grower, is called the "continuous" rate and provides for the supply of current at the flat rate of $50 per h.p. per year, as measured at the peak load at any time during the season.

The second contract, called the "spring and meter" rate applies to other classes of products, such as deciduous fruits, alfalfa, etc., and provides for the supply of power at a flat rate of $25 per h.p. for the period from February 1 to July 31, when the meter is cut in and all current used during the remaining six months is charged for at the rate of 3c. per kw-hr. The minimum payment during the meter period is $1 per h.p. installed, per month, thereby bringing the minimum charge to approximately $31 per h.p. per year, the flat rate charge being based on the maximum demand. In nearly all cases where this contract is used the annual consumption is not in excess of the minimum. as the total amount of current the consumer is entitled to under the minimum may be used at any time during the meter period. The cost of pumping under this form of contract varies directly with the rainfall, but the minimum will be sufficient for the average season. This contract is used to a considerable extent on land which is irrigated by gravity waters, which are not sufficient in the dry seasons, and is in this way used as an auxiliary or an insurance. This contract may also be applied to the orange growers, and the power required would range from $40 to $65 per horse-power per year, depending on the season. Most consumers, however, prefer the regular flat rate contract, and the "spring and meter" rate is seldom used in this district except in the case of a young grove, where less water is required.

The exclusive use of this form of contract for irrigation would, however, be of advantage to a power company where steam power is used as an auxiliary during the dry season, as the operating ratio would be more uniform under these conditions.

The third long term contract applies to power for miscellaneous commercial purposes not pertaining to irrigation and consists of a meter rate with a graded base rate according to the season of the year. For motors having a capacity of less than 20 h.p. an addition is made to the base rate according to the size of the motor, to motors from 20 to 50 h.p. the base rate applies, and for motors from 50 to 100 h.p. a subtraction is made from the base rate. The minimum payment is $1 per h.p. per month for the rated capacity of the motor. This method of charge, while somewhat complicated, works out very satisfactorily in practice, as will be observed from the fact that practically all other kinds of power have been displaced in the territory. The reason for adopting such a rate will be apparent by a study of the load curve and the curve of stream flow. Naturally most consumers can not regulate their demands for power in such a way as to use the greatest amount during the time of the low rate and economize during the time of the high rate, but the general effect is good and a marked tendency toward the desired results is being obtained.

Aside from the above contracts, lighting rates and a monthly power rate are in force, but include no special features.

Under the pumping contracts, it is to be noted that the same rate is made on any size motor, which is most important, as the sub-division of the land into small tracts is necessary for the success of any community, and the small grower should receive all the encouragement possible.

The above contracts all include the following provisions, which are somewhat out of the ordinary:

1. All contracts are acknowledged before a notary public and recorded.

2. All contracts are an absolute lien on the property of the consumer, the property being accurately described in the contract.

3. The consumer grants the company a right of way over any part of the property described.

The use of the current is limited to the land described in the contract.

5. All delinquent accounts bear interest at the rate of 1 per cent per month, compounded monthly.

6. The minimum charge under the flat rate contracts is for 75 per cent of the rated capacity of the motor.

The advantages of the above provisions are as follows:

No. 1 is explained by those following.

No. 2 protects the company against all bad debts and takes the place of the often-used meter deposit. In connection with No. 5 it allows the company to carry the account of some hard pressed consumer longer than might be otherwise done, as the security, is amply sufficient. There are also many cases where the consumer prefers to pay the interest charge, if he can allow his account to run until the returns from his crops are received.

The third clause is one over which considerable trouble was experienced at first, but is nevertheless the most important one to the company, for, in a country where roads are few and far between, it is continually necessary to cross over private property, and the right of way over the property of one consumer allows for the construction of lines to serve his neighbor. The objections raised to this clause were that the company would have a right to run lines all over the consumer's property and might run right through his front yard or over his house, if it wished, but these objections gradually died out, for the company in all cases takes the path of least resistance, the consumer being consulted where it is necessary to run over his land, and the lines are constructed in accordance with his wishes, even though this is not always the shortest way across. It is also the aim to run all transmission lines on section lines, for it is considered that there should be a county road around each section and that eventually there will be. The company has a franchise over all county roads and naturally uses them wherever possible. The land owners have, therefore, been shown that the right of way privilege has not been abused, and that in all cases where their land has been crossed it has been for the benefit of their neighbors.

Nos. 4 and 5 are self explanatory.

No. 6 is incorporated to encourage the use of the proper size motor for the service required. An electric motor operated at full load feels dangerously hot to the layman, and it is apparently the natural tendency of the farmer to purchase a larger size motor than is needed. The determination of the proper size motor is a simple matter, and a partially loaded induction motor has a power factor that does not do a transmission system any good, so the 75 per cent of the rated capacity minimum payment is rigidly enforced.

By the installation of a double throw switch, the flat rate consumer is allowed the use of current for lighting purposes when not using the motor, ten 16-c.p. lamps being allowed for each horse power contracted for; but, of course, this lighting is confined to the residence of the consumer. The grower generally provides a motor of one or two h.p. capacity for pumping water for domestic use, the pump operating in the day time and the lights at night. Lighting is the only use of current allowed under these conditions, although small household appliances, such as a fan motor, flat iron, vacuum cleaner, etc., may be used. Electric heating and cooking, however, are not allowed, the regular meter rate being used for this purpose.

LOAD CHARACTERISTICS AND POWER REQUIRED FOR PUMPING

The load curve, Fig. 3, together with the connected load, Fig. 2, will show better than any individual examples the amount of power which is required for a large territory with varying water levels ranging from a few feet to 90 ft., and with lifts above the surface at the wells varying from two or three feet to several hundred feet, there being approximately 18,000 acres of land under pumped irrigation at present.

It is estimated that one horse power used in the ordinary way during the respective irrigation seasons will irrigate an average of five acres of citrus fruits and 10 acres of other products in the citrus belt, and 16 acres of deciduous fruits, alfalfa, etc., in the valley section.

The following table was compiled from observation at typical pumping plants on the system. In the table the letters at the head of the columns signify as follows:

A. No. of acres of oranges.
B. Average age of orange grove.
C. No. of acres of vines.
D. No. of acres of alfalfa.
E. Horse power capacity of motor.
F. Horse power tested.
G. Depth of water during pumping season.
H. Height water is raised above surface of ground at well.
I. Total head.
J. Acres per installed horse power.
K. Estimated depth of water available over land if operated continuously during pumping period based on 50 per cent plant efficiency.

Plant	A	B	C	D	E	F	G	H	I	J	K
1	30	3	—	—	5	5	86	4	90	6	2.9
2	40	3	—	—	5	3.0	66	4	70	8	1.8
3	54	15	—	—	12	12.1	50	5	55	4.5	6.3
4	50	3	—	—	7.5	5.2	45	5	50	6.7	4.2
5	16	13	—	—	5	4.7	87	3	90	3.2	5.1
6	20	13	—	—	5	4.5	65	5	70	4.0	5.7
7	22	12	—	—	5	4.7	65	5	70	4.4	5.1
8	10	10	—	—	2	2.4	66	4	70	5.0	4.5
9	48	11	—	—	10	9.1	70	5	75	4.8	4.4
10	40	5	—	—	5	4.6	—	—	80	8.0	2.3
11	33	3	—	—	15	12.9	30	100	130	2.2	6.2
12	16	7.5	—	—	10	10	20	100	120	1.6	8.2
13	110	2	—	—	27.5	27.6	40	5	45	4.0	8.8
14	70	3	—	—	15	15	80	—	80	4.6	4.2
15	35	6	—	—	10	7.8	40	—	40	3.5	8.8
16	135	5	100	—	85	69	20	80	100	2.7	4.6
17	66	3	—	—	10	9.7	40	—	40	6.6	5.8
18	111	2	—	—	15	15.8	27	5	32	7.4	7.1
19	140	7	—	—	50	50	60	90	150	2.8	3.6
20	145	7	—	—	50	32.8	60	87	147	2.9	2.4
21	—	—	30	—	15	12.8	28	2	30	2.0	18.8
22	120	10	80	—	47.5	40.1	50	—	50	4.2	6.3
23	—	—	74	—	15	16.2	35	5	40	5	7.2
24	—	—	—	240	10	7.0	0	8	8	24	3.9
25	—	—	—	160	5	5.6	0	16	16	32	3.5
26	—	—	—	260	15	19.2	16	5	21	17.2	5.5

The above table might be extended and averaged to show the horse power and water required for the supply of various products and for the requirements of orange groves of different ages, but there are so many variable elements entering into each case that any such figures, even if based on an average of every plant on the system, would be, in the writer's opinion, practically worthless. In the case of the high lift plants water is usually taken from the main pipe at different levels, but, as the current is charged for at the maximum demand rate and as the pumps are designed for the highest head, only the high head is taken into consideration.

Fig. 2 shows the increase of connected load on the system from 1903 to 1909, inclusive, for power and lights. This curve does not show the railroad load, which is 600 kw. and was connected in February, 1908, and operates at a load factor of approximately 30 per cent throughout the year. Of the total connected power load at the end of 1909, there was 3,776.75 h.p. used for the pumping of water, leaving 573.25 h.p. for commerical power purposes. This applies to all motors over ½ h.p., sizes under this being included in lighting.

Fig. 3 shows the average monthly load curve at the generating stations for 1901 to 1909, inclusive. The shaded portion of this curve represents the load on the auxiliary steam plant, made necessary in 1908 by the disabling of one generator in No. 1 power house and an extremely low water period of the rivers; and in 1909 the steam plant floated on the line until the Tule river plant was completed late in the season, the other power stations being fully loaded.

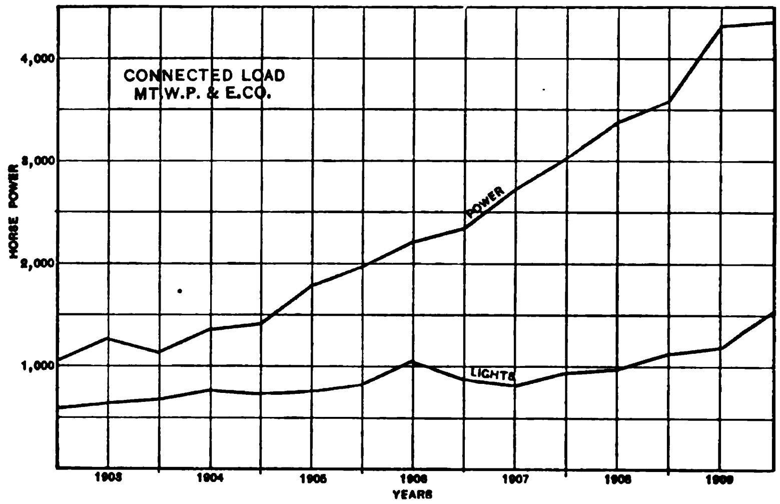


Fig. 2

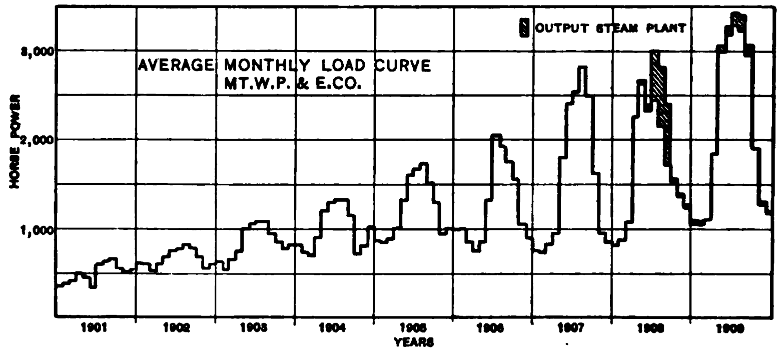


Fig. 3

Fig. 4 shows the load curve for the maximum demand during the years 1907, 1908 and 1909. It will be noted that the maximum demand at the power stations is very much less than the connected load, regardless of transmission losses, although the pumping load is considered extremely steady during the irrigation period, the pumping plants operating 24 hours per day at as near the full capacity of the motor as possible. The lighting load has no appreciable effect on the generating stations during the time of maximum demand as it is balanced by a certain amount of power used only during the daylight hours.

Fig. 5 shows the load factor of the system, and this also clearly points out an important condition to be considered in an enterprise of this character, as it is comparatively low. This curve shows that a large amount of power is available for market during the winter and spring months, and with such market obtainable, the capacity of the generating stations could be greatly increased, as the flow of the rivers is greatest at this time.

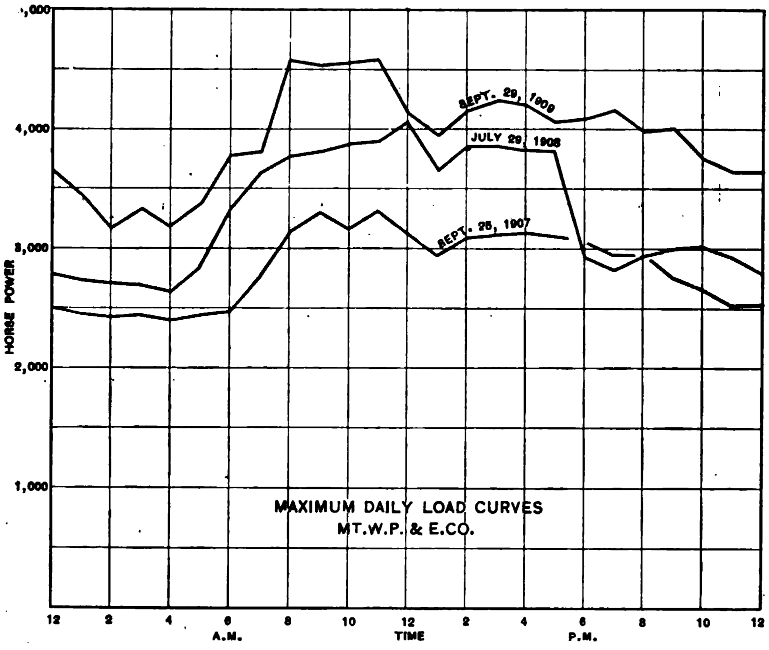


FIG. 4

Fig. 6 shows the characteristic flow of the streams during a very dry season, and is a combined curve of the Tule and Kaweah rivers. All of the rivers flowing into the San Joaquin valley have the same general characteristics, and a comparison of the load curve and this curve of stream flow shows the time of heavy load during the period of low water, and the generating plant must, therefore, be designed for the minimum flow of the stream unless suitable storage reservoirs are available. These reservoir sites are available on some of the streams feeding the valley, but in the case in point are scarce and expensive to develop, and the plants are designed for the minimum flow.

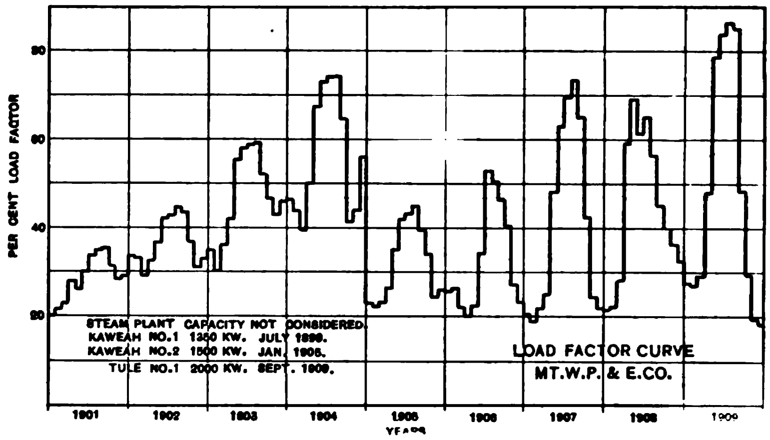


FIG. 5

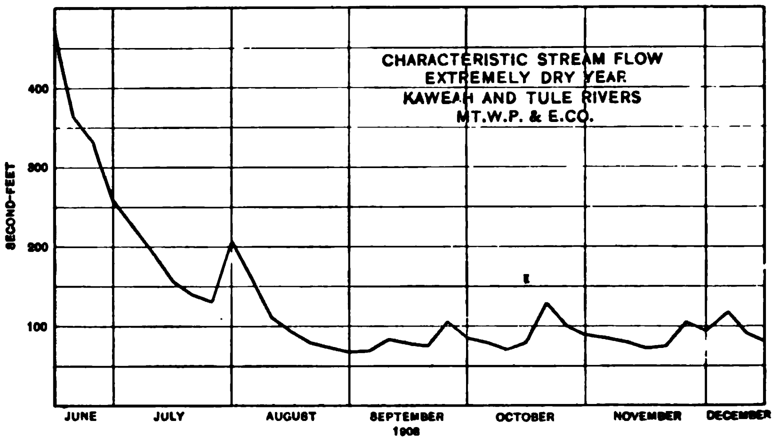


FIG. 6

In connection with the load factor curve, it is to be noted that when the load factor reaches approximately 50 per cent it is necessary to construct an additional plant.

GENERATING STATIONS

The generating stations consist at the present time of three hydroelectric power plants having an aggregate capacity of 4,850 kw. and one turbo-generator steam auxiliary plant having a capacity of 1,000 kw. Two of the water-power plants are on the Kaweah river and one on the Tule river, the steam auxiliary being in Visalia, the principal town on the system. The fourth water power plant, which will have a capacity of 3,000 kw. will also be on the Kaweah river.

Power house No. 1 was the first constructed, and diverts the waters of the east fork of the Kaweah river through six miles of redwood flume. The plant was constructed in 1899, and the flume is to-day perfectly sound and will last at least 10 years longer before it will require replacement. The static head obtained is 1,310 ft. and the generators are driven by overhung wheels on the generator shaft. The equipment consists of three units of 450 kw. each, two belt-driven exciters, and four 500-kw. transformers, one being a spare transformer. The transformers are oil-insulated and were designed to be self-cooled, but additional cooling is obtained by pumping the oil through coils on which water is sprayed. The transformers are located in individual compartments entirely separate from the power house, as are also the lightning arresters and high-tension switches.

Regulation is manual, controlling stands being situated in front of the switchboard, two of which operate deflectors which regulate the amount of water applied to the wheels by deflecting the stream, and one of which regulates the water supply to the third machine by a needle nozzle. At the penstock a regulating reservoir in the form of a large flume has been constructed, having a capacity of 25,000 cu. ft. The main function of this reservoir is to smooth out the daily variation of stream flow, as, due to the method of regulation at the power house, no great economy of water can be practiced, although the needle nozzle allows the regulation of water to some extent. Since the other plants have been constructed, however, no regulation is done at No. 1, which simply takes a certain load and holds it.

Plant No. 2 was constructed during 1904 and put into operation in January, 1905. The water for this plant is diverted from the main Kaweah river, and is conducted to the penstock through 15 flumes aggregating 0.87 mile, and 3.1 miles of ditch. The flumes are all redwood and the ditch is concrete lined, the ditch construction being used where the slopes will permit, the flumes being constructed on the rough broken ground and to cross ravines. A concrete lined penstock reservoir is excavated in the side of the hill having a capacity of 75,000 cu. ft. The static head is 360 ft. and the power house equipment consists of three units of 500 kw. capacity, each direct connected to high-head turbines regulated by Lombard governors. Two turbine-driven exciters are installed, which are hand regulated. Seven 350-kw. step-up transformers are installed in compartments outside of the power house, one being in reserve. The transformers are cooled in the same manner as those at No. 1 by circulating the oil.

The No. 3 Kaweah plant, on which construction is just started, will divert water from the main Kaweah river, which after passing through a conduit 10 miles long, will discharge just above the intake of No. 2, thereby using the water twice. The static head of this plant will be 1,960 ft.

The transformers at Nos. 1 and 2 are arranged on trucks so that they may be easily run into the power house under the crane for repairs, etc., if necessary. In No. 1 individual tracks are run from each transformer, and in No. 2 a transfer truck is run on the track in front of the transformer compartments, so a transformer may be pushed out on to the transfer truck and taken to a short piece of track entering the power house. The switching gear in both stations is arranged so that the spare transformer may be immediately cut in in place of any other transformer.

The buildings at both Nos. 1 and 2 are constructed of corrugated iron on wood frame; foundations, floors and transformer compartments being constructed of concrete. The corrugated iron structure is, for all practical purposes, ample, as the climatic conditions are most favorable, and a protection from rain is about the only requirement necessary. These buildings are, however, cold in winter and hot in summer, and would not be considered strictly permanent or fireproof.

The third, or Tule river plant, was constructed in 1908 and 1909, and started operation in September, 1909. The water is diverted just above the junction of two forks of the river, there being two diverting dams and headworks from which short flumes lead to a point at approximately the junction of the river, and join. The water is conducted to the penstock through

4.5 miles of pine flume, 2.06 miles of concrete lined ditch and 880 ft. of inverted siphon pipe, the siphon working under a 5-ft. head and having its lowest point 120 ft. below the conduit grade. This siphon was used to cross a long gulch.

The ditch is lined with concrete and excavated well into the mountain, very little reliance being placed on the filled bank, the water level being only 6 in. above the natural level of the downhill slope. The ditch is 4½ ft. wide and 3 ft. deep, the sides sloping 1 to 1. It is lined with concrete 2½ in. thick, over which ½ in. of cement plaster is applied. A small amount of alum was mixed with both the concrete and the plaster, which renders the lining practically water tight. Due to the steep slope of the mountain side and the size and depth of the ditch, the sloping of the upper bank to a slope of 1 to 1 required considerable excavation. However, the finished product is a most permanent piece of construction. The flume is of the standard bent and stringer construction, the bents being placed 16 ft. apart, and a strip of burlap saturated with an asphaltum compound is placed under the battens for waterproofing.

At the penstock a regulating reservoir is excavated in the side of the mountain. A small portion of the upper end is 5 ft. deeper than the balance of the reservoir and is used as a sand-trap. The reservoir is 12 ft. deep, 350 ft. long and of an irregular shape, varying from 12 to 125 ft. in width, following the contour of the hill. The side slope is ½ to 1, and it is lined with 8 in. of concrete and ½ in. of plaster. A concrete wall at the end separates it from the penstock.

The reservoir has a capacity of 175,000 cu. ft., which will operate the plant 1¾ hours at normal load. Therefore, in the case of a break in the flume, sufficient time will be available to start the steam auxiliary plant without interruption of service. The reservoir also has sufficient capacity to regulate the daily fluctuation of stream flow during the low water period, so that the highest use may be made of the water. The static head is 1,135 ft., and the whole plant is designed with a view of ultimately doubling the present capacity.

The power house equipment consists of two 1,000-kw. units with overhung wheels, Lombard governors directly actuating needle nozzles, an auxiliary nozzle being provided which automatically opens in the event of the main needle nozzle closing too quickly and ramming the pressure pipe. These auxiliary nozzles, when opened, close at a predetermined speed regulated by the dashpot principle. This arrangement allows the most economical use of the water. Two exciters, each of sufficient capacity for both generators are installed, one being driven by a water wheel and one by an induction motor. Seven 400-kw. water-cooled transformers are placed in the transformer room on one side of the power house, one transformer being held in reserve. Lightning arresters and high-tension switches are in a separate building.

The power house building and arrangement differ from the other plants in several respects. The power house is constructed of ferroinclave on a steel frame, the ferroinclave being plastered on each side with 1½ in. of cement plaster, therefore making a reinforced concrete roof and sides 3 in. thick. A partition of the same thickness divides the generating room from the transformer room and a similar partition divides the transformer room into two compartments, fireproof doors completing the separation. The switch house is constructed of the same material, and both buildings have metal window casings and wired glass windows, no wood being used in the construction. The above may seem inconsistent after the statement that the other power house structures were practically sufficient, and this would be the case, were it not for the fact that the transformers which present a certain fire hazard are placed in the power house building. Also the company has passed the pioneer period, and can, consequently, afford a little more permanent construction.

The switching gear and wiring has been greatly simplified by connecting the transformers in two banks, the spare one not being connected. The transformer "railway system" is also dispensed with simple rollers being provided instead. In the event of an accident to one transformer its bank may be disconnected, the leads removed from the affected transformer, water pipes disconnected and the transformer skidded to one side. The spare transformer can then be skidded into place and connected up and the entire job performed in about one hour, certainly a short enough time for a system of this character.

In connection with all of the power stations, the question of the operator's comfort has been given proper attention. From a practical business point of view, this is a paying investment, as a much better class of men can be procured. Comfortable cottages are provided, the surrounding grounds are cultivated and a small ice plant is a part of the standard equipment. A few fruit trees and a garden will not only greatly improve the looks of the property, but will also greatly reduce the boarding house expense.

TRANSMISSION SYSTEM

As shown in Fig. 1 the transmission system is in the form of a figure 8 or a double ring. In this way current is available at both sides of any sub-station, thereby giving all of the advantages of duplicate lines. The main transmission line from power houses Nos. 1 and 2 feed in at the northeast corner of the system and the line from the Tule river plant feeds in at the center of the system. The steam auxiliary is in the northern ring and can consequently feed both ways. The old transmission lines have wires spaced 36 in., the sawed redwood poles being spaced 120 ft. apart. The new transmission lines in the valley consist of a double circuit, the 34,000-volt lines being placed on one side of the pole and a 6,600-volt distributing line on the other side. The circuits form equilateral triangles, the apex of which point downward; the wires are spaced 36 in. apart on each circuit. The main line from the Tule river plant consists of one circuit, the poles being of cedar 35 and 40 ft. in height and spaced 300 ft. apart. On all new lines a pole spacing of from 300 to 420 ft. is used, with 35- and 40-ft. poles, depending on the character of the country.

The current is distributed from 12 substations situated in the various towns and settlements, and the transmission and distribution systems are laid out to provide for additional substations as the load increases. The substation construction varies, all but one having started in the same way, namely, as a cheap wood or galvanized iron building with the most simple switching apparatus, and, as the substation grows in importance, substantial brick buildings are constructed with more or less elaborate switching gear, storerooms and offices.

The power is distributed at 6,600 volts and 2,200 volts, two-phase, the first distributing being at 2,200 volts; 6,600 volts eventually proved more satisfactory on the power circuits. The city lighting systems distribute at 2,200 volts, two-phase, with the exception of two new systems, where three-phase has been adopted. There are 246 miles of 6,600-volt line, 53 miles of 2,200-volt line, and 28 miles of lighting circuits of 2,200 volts and about the same length of low-voltage line with a connected load of 1,190 kw. of lighting transformers. The consumer supplies the secondary transformers for power supply and the power is measured on the primary side of these transformers.

EFFECT OF POWER PUMPING ON LAND VALUES

While some exception may be taken to the statement that the development in this section is due almost entirely to the application of electric power for pumping purposes, it is, at the same time, believed to be the case, and this seems to be proved by the land values where pumped irrigation has been established.

Unimproved lands lying south of Porterville sold in 1890 for from $5 to $7.50 per acre, in 1900 for $10 to $15 per acre, and in 1909 for $60 per acre and higher. Lands north and east of Lindsay, which sold in 1895 to 1900 at from $35 to $40 per acre, now sell at $150 per acre. The assessed values of two sections, one three miles north-east and the other one mile west of the town of Lindsay, show that in the first instance the assessed value was $14 per acre in 1890, $36 in 1899 and $91 in 1909, and in the second instance $19 in 1890, $36 in 1899 and $117 in 1909. The above figures represent about the average conditions, there being many cases of increase where the figures have been greatly exceeded.

INVESTMENT VALUE OF A POWER IRRIGATION PROJECT

The application of a hydroelectric system exclusively for the furnishing of power for pumped irrigation from an investment point of view is not of the get-rich-quick variety. The investor who wishes to receive immediate results on his money should not enter into any such scheme, unless the power company owns the lands to be put under irrigation, when the project develops into a real estate transaction, the power part being insignificant. Where the project is confined wholly to a power proposition, it should be gone into only by the most conservative investors or developers and pioneers who are content to bide their time and be satisfied for many years without dividends, but with the increased value of their investment. The power company must indirectly meet the opposition of other irrigation districts, and the large government projects, as well as the opposition of gasoline engines and other power, and the charges for service must be as low as possible.

The territory served is sparsely populated at the start, and usually no irrigation is indulged in except by some few scattering pioneers, who may be using gas or steam engines and windmills, and the marketing of power, therefore, depends entirely on the rate at which the territory served is put under high-class cultivation; and this is a slow process. To support a project of any magnitude requires an immense territory, and in the early years of development it is not unusual to construct a line five or ten miles long to supply a motor of as many horsepower; for any part of the territory must be supplied regardless of its location with reference to existing lines, and everything must be done to encourage the development of the entire territory taken as a unit, and, for the first few years, even though the territory is settled rapidly, it can not be hoped to make the power project pay.

The power company after a few years should show a profit above interest charges and operating expenses, but for every dollar earned several more must be expended on extensions, and, while it is true that, after the system commences to show earnings a great many extensions may be taken care of by bonds, these always require a certain amount of money to be provided by the company. If the development is rapid the stockholders are often required to subscribe additional money aside from the earnings, and must in many cases content themselves solely with the increased value of the property. The increased value of the property may be large and the investment, as far as security is concerned, be of the finest, as it usually is; but in this day of progress and quick returns on investments it is rather difficult to find many investors who are content to wait a generation before receiving any actual cash returns on their money, no matter what the company's books may show as to earnings or as to increased value of property.

When the system is fully developed and loaded the dividends may be large, and the reliability and permanence of the market will often place the stock almost on a bond basis, and in this way a carefully planned and developed hydroelectric system for the supply of power for pumped irrigation may be considered a splendid investment, but never in the light of a speculation. It must be clearly outlined at the inception of the enterprise just what is to be accomplished, for it is a long job and one which requires a great deal of looking into the future.

The final results must be arranged for years before they are obtained and everything shaped to this end. A desire to hasten the marketing of the power may set some precedent which would be most difficult to overcome, and the failure to provide for emergencies may undo the work of years and completely demoralize a system. An overloaded system is to be particularly guarded against, as too much valuable produce depends entirely on the service, and any damage to the producer may completely stop development and stifle the entire community. The power company, therefore, has a very large moral responsibility to face, which is not to be lightly considered.

DISCUSSION ON "HYDROELECTRIC POWER AS APPLIED TO IRRIGATION", SAN FRANCISCO, CAL., MAY 6, 1910.

President Stillwell: The possibilities opened up by the application of electric power to pumping water for irrigation in California, are obviously very great. A recent publication by the United States Geological Survey estimates the available water powers of California at 7,000,000 twenty-four hour horse power. Assuming twelve tons of coal per horse power per annum in 24 hour service, that power would require for its production by steam, 84,000,000 tons of coal, which happens to be approximately equal to the anthracite output of the coal mines of Pennsylvania. So vast an output of power, if utilized in manufacturing, would supply a very much larger power market than even California can hope to develop in many years. It is peculiarly interesting that many of these powers exist within practicable reach of land requiring water for irrigation.

A paper which was read at the recent Irrigation Congress at Albuquerque by Mons. Tavernier, Chief Engineer, Department of Public Works, Republic of France, deals with this subject and its conclusions are particularly interesting when considered in the light of similar experience by Mr. Hays and his company. Mons. Tavernier reaches the conclusion that even considered from the standpoint of power economy, it is frequently not more expensive to use water power to operate dynamos, which in turn operate motors lifting water by pumps to the land which requires irrigation, than to distribute water by ditches. According to his figures, the efficiency of the two processes in many cases is practically identical.

E. W. Paul: I would like to ask Mr. Hays in regard to his table given in his paper. I don't quite understand it. He has a plan here of eight and ten acre groves, ten years old, and to irrigate that requires a two h.p. motor. The experience of farmers in the south, with which I am familiar, is that they do not want to irrigate one row of trees at a time, but they want to flood the whole orchard at once. This requires considerable water. I do not think that a two h.p. motor would do that. I would like to ascertain whether they do irrigate the entire ten acres, or do they sit up all night changing the water from one row of trees to the next. I would also like to know if the company with which he is connected requires the motor to be taken off the line on the peak load, and if it does, how they overcome his objection to that feature.

J. C. Hays: The two h.p. motor is correct. Some of them have small reservoirs which will hold the water, and they run that motor continuously 24 hours, and they do irrigate probably ten or twelve rows a day from this little reservoir made of dirt, in some cases, they irrigate a very few rows at a time as they go across their orchard, and they figure that this flat rate will keep them all the time. This dry bog country has to dry out before they can cultivate it. As to taking the motor off on the peak load—as irrigation is the only peak load we have, they work all the time.

F. V. Henshaw: Mr. Hays describes an electric power system which was apparently built entirely on a fore knowledge of there being sufficient underground waters to enable the plant to get its business by pumping for irrigation, and presumably before going into this project, the extent of those waters was very carefully determined. I think it would be interesting to learn from Mr. Hays the extent to which the underground waters of the San Joaquin Valley have been examined, and whether today it is known that there is a sufficient supply there, in all probability, to irrigate all of the land that cannot be covered by surface waters by gravity distribution. Another point occurs to me, regarding the cost of construction; Mr. Hays says: " If constant service is not absolutely necessary, what possible type of construction can compare with the flume?" I take it that the flumes are built very light, and the point is as to how long an interruption the farmer can stand under extreme conditions. We will say an orange grove, which is at a point where it needs the most water—how long can it be without water without serious damage.

J. C. Hays: I do not know the extent of the underground waters in our state. I have read several papers and reports on the subject but believe that the only way we can tell is to pump.

F. V. Henshaw: I thought you had been doing that.

J. C. Hays: Well, we have in some places. But you can hardly call that conclusive. We have been pumping in one district for ten years, and apparently the supply of water is not diminished. So t naturally looks like there is something there. The water shed of the valley is large enough to take care of the underground waters, and the formation of the deltas in these rivers is of such character on the east side that the water percolates very slowly. On the west side, I understand, there is a different condition where the water flows out very fast; consequently, we are liable to find variation in the wells, but there is a very little variation in the wells on the east side.

F. V. Henshaw: Did you find any wells that had a flowing head?

J. C. Hays: Yes, in what I call the valley portion. But artesian wells are not considered very good for irrigation. I personally do not know much about that subject, but I do know that there is sulphur, or something deleterious in the water, and I know of one peach orchard that was killed by it. As to the subject of the flume—I don't know just how long an orange orchard could go without water. They claim in that country that if they do not irrigate for about two weeks in a very hot season, the trees commence to show it. Most of the growers claim that they can look at the trees and tell when they need water.

An interruption on the flume or the line, for instance, would not amount to over 24 or 36 hours, possibly 48 hours, and an interruption of that length would do no damage. Of course, during certain portions of the year, landslides cause some damage, but I do not remember of any landslides occurring during the irrigation season. They always occur in the winter time, and never during the irrigation season.

H. Homberger: The Mount Whitney Power Co.'s system is of particular interest to the hydraulic engineer, being a power system where 80 per cent of the power is generated hydraulically and 70 per cent of the power used for pumping. How entirely different the conditions are from those of the average commercial plant with a mixed load, has been most ably and clearly explained. There were a few points mentioned which I should like to be further enlightened upon.

First, the question of high price permanent construction as compared with low price temporary construction. It was stated that engineers of prominence have broadly condemned the wooden flume and the wooden pole line as compared with the tunnel and steel towers or reinforced concrete poles. Such a stand can only be explained by entire disregard of special conditions; there is no greater danger in engineering than unwarranted generalizing of principles of construction and wrongly applying what is good in one case to some other case where it might not fit in at all. Personally I am not in favor of wood as construction material and would rather see an inorganic material used. To be sure, 20 years is a remarkably long life for a flume, and I think not to stand alone with the statement that half that is nearer the average. Similar are the conditions with a wooden pole line. It seems to me, however that generally too much stress is laid on the difference in first cost and the fact not taken in consideration, that considerable expense is connected with the necessary continuous patrolling and maintenance of such structures, which if capitalized, would go a long ways towards providing for the higher first cost of a more permanent type of construction, which, as stated, will ultimately have to be resorted to anyhow.

A second point: Balancing reservoirs were mentioned at the head of the pipe lines; while the reservoir of the latest plant, the Tule River Plant, has sufficient capacity to operate the plant 1¾ hours under full load, at the Keweah No. 1 station it holds out only 25 minutes and at Keweah No. 2 even less than 19 minutes, which is certainly of little value in case of trouble in the gravity conduit system. The main function of the latter two reservoirs is stated to be, to smooth out the diurnal fluctuations in the steam flow, but even a reduction of 2 per cent in same would empty the reservoir, if the plant is to be kept under full load for 24 hours, which is practically the case during the pumping season, as shown in the daily load curves Fig. 4. Maybe I did not understand this correctly and I should be thankful to have it explained.

Third: With an average load factor of 50 per cent the fixed charges on a hydroelectric plant must be quite high, and with the stated low rates for power it would be interesting to know, whether a large capacity steam plant to be operated during the irrigating season would not make a better financial showing than an additional hydroelectric plant with ten miles of conduit. This might be advantageously located in the Coalinga oil field region, only about 10 miles distant from Visalia, as it might prove more economical to ship current by wire than oil by rail or pipe line.

L. Jorgensen: In general the hydraulic conduit is the weakest link in power transmission for the reason that, from a financial standpoint, it cannot be installed in duplicate. Therefore, on systems with only one or two power plants it is most important to have this link well built. Tunnels are not the only safe conduit, but concrete pipes completely buried are in most cases just as safe, cost only half and require less grade, due to their better hydraulic shape. It is true that a flume costs only about half as much to build as a concrete conduit costs to install, but, if the depreciation, maintenance and interest on the investment are taken into consideration, their cost will be the same. Then the question of whether to use a wooden flume or a concrete conduit is simply a matter of whether the greater amount of money required to cover the first cost of the concrete conduit will balance against the additional safety connected with the use of a buried conduit. How tunnel compares in cost with either wooden flume or concrete conduit will depend upon how much of a short cut it makes. The first cost per linear foot may be four times that of a flume of the same carrying capacity, but a flume or concrete pipe line must follow the contour of the hillside, whereas a tunnel cuts through the hills.

Where the country is flat and otherwise adapted for ditch construction, ditches will be the cheapest, as maintenance cost is lower than for flumes, and depreciation is practically zero. Wooden stave pipes will accomplish the same as concrete pipes and have a lower first cost. If buried they are protected against rolling boulders, frost, etc., but their life is very short and repairs are difficult to make. Taking it all in all the concrete conduit does not seem to be as extensively used as all its good properties should warrant.

E. W. Paul: I would ask Mr. Hays if, on some of these circuits running to pumping plants, he has made any provision on the customers' premises to take care of the motor in case the current goes off the line, that is, as to voltage switches, and also how he even gets farmers to sign the contract described, with the conditions mentioned in his paper?

Ralph W. Pope: I am familiar with the territory where this plant is situated that has been developed for the raising of oranges. I was there twenty years ago when most of it was devoted to the production of wheat. At the time this plant started or a little earlier, the soil had deteriorated owing to continuous wheat cropping. I understand from the author that the soil was exhausted only about four or five inches down, so that orange culture is now pursued with great success. Referring to Mr. Henshaw's inquiries in regard to the pumping, I understand that pumps were formerly operated by windmills or gasolene engines, and that wells had already been dug, so that the question was not whether water cou'd be got there, or not; because it had already been obtained.

There are certain tracts however where the water cannot be reached by digging or boring. The only value pertaining to such land is the possibility of selling it to eastern tenderfeet, which is another source of revenue not mentioned by the author.

In regard to the light construction of this plant, it must be remembered that at the time it was started, while having the water power, something like 7000 h.p., I believe that the question of a market was rather problematical, and ordinarily that is one of the most important questions to be considered in developing a water power plant. It was for this reason that the cheap construction was used in this particular instance. Those of you who are familiar with railroad construction throughout the country, know that in early days the construction was frequently of a very cheap character in comparison with what it is to-day. Railroads at that time were an experiment, but as the importance of proper construction developed, and rebuilding was undertaken it was found advisable to strive for permanency. This paper indicates that it is a long, slow process to develop an enterprise of this kind, but when it is permanently established it becomes an attractive investment, if you can find a territory where these conditions prevail. In Utah, I think they need something of this kind, as they have used up about all the water power that is available in that state.

Markham Cheever: Answering Mr. Pope's inquiry regarding the conditions in Utah, underground waters occur in large quantities in the fertile valleys of Utah Lake and the Jordan River, and artesian wells are numerous. However, this water is not used for irrigation to any great extent.

Utah Lake is one of the largest bodies of fresh water in the West and forms a natural reservoir from which the canals of the Jordan River Valley are supplied. As the lake level lowers during the summer, the outflow is maintained by means of large centrifugal pumps. Several projects involving the pumping of water to land lying at a considerable elevation above the lake are contemplated and one is now in operation. While hydroelectric power is used or proposed for all these pumping propositions, the load is not as satisfactory to the power producer as that of the project described in the paper, on account of the much shorter irrigation season in Utah.

F. V. Henshaw: I would like to add one word, that this matter of underground water is a very essential thing to anybody contemplating going into an enterprise of this kind. I can say positively that in some parts of Colorado, the subject has been very thoroughly investigated and the water is not there. I would like to tell you where, but am afraid it would hurt the feelings of some " eastern capitalists."

A. J. Bowie Jr.: This load curve is different from any others I have seen in that there is no peak in the evening. This is of interest in matters of irrigation, since the value of the power which can be supplied, of course depends on the nature of the load curve and how the power is used. When the peak comes in the evening the power company can afford to supply power very much cheaper to the farmers who will shut down at that time. The load for irrigation differs from other types in that it is possible that suitable arrangements may be made to cut it off for a few hours a day without suffering serious inconvenience. This is particularly true where small reservoirs are used, reference to which has already been made, and the value of these reservoirs I consider of very great importance in the problem of irrigation. These reservoirs should hold about a day's supply for the farmer, who by that means is enabled to employ his water at such hours as are most advantageous. If his pumping station is small, he may use his entire supply in a few hours, instead of having to devote the entire day to the use of water. These reservoirs constructed of earth, are used in a great many parts of the country, and sometimes they are lined when the earth is unsuitable for holding of water. One form lining consists of coal tar, lime, and sand, spread on half an inch in thickness. I have also seen this lining applied where the reservoirs without it would not be able to hold water.

These reservoirs cut down very materially the size of a plant which it is required to install, as well as the corresponding additional investment and they avoid all night irrigation. The economic consideration of irrigation requires a suitable proportioning of the various items of expense which make up the cost of pumping, which may be segregated as (1) the cost of fuel or power, (2) the attendance and (3) the fixed charges, as well as the cost of applying the irrigation water to the land. The sum of these charges should be reduced to a minimum. In irrigating plants the depreciation is generally high. I think, allowing for all fixed charges, 20 per cent, would often be a low figure to cover interest and depreciation repairs and renewals. It is not unusual in countries where fuel and labor are cheap to find the fixed expenses exceeding the other two expenses. A small reservoir would avoid this and be a considerable saving in this way.

In Southern Texas the average depth of irrigation water used annually was 2.7 feet for all crops, while for alfalfa it was 5.7 feet. The efficiency of most of the pumping plants in that country was exceedingly low. That would apply to any country where plants of a similar type were employed. The cost of pumping an acre foot of water one foot high was four cents, and as the power to raise an acre foot of water one foot high is equal to about one water kw. hour, this would amount to about 4 cents per water kw. hr. This is an average of course.

It may be of interest to you to know that we have quite a little irrigation in the Eastern states for truck gardens. The depth of water employed there depends on the source of supply and the cost of obtaining it, and varies from four to eight inches per year. Many farmers are using city water irrigating to an annual depth of about four inches. This costs for water about $25 per acre per year, where as when pumped water is used, about twice the depth is used at the same cost per acre per year. The average increase in crop values per acre due to irrigation, and allowing for wet and dry years, is about $200 per year over and above all expenses. In other words this is the average net profit of the farmer from irrigating. Of course that is large, but the crops raised per acre are of great value, in some cases going as high as $1500 per acre per annum, so that it does not take very long even in a wet year to make a substantial gain.

W. A. Doble: I think Mr. Hays' excellent paper has been somewhat misunderstood with reference to the cost of this Mt. Whitney plant. We must bear in mind that that was one of the very earliest plants to be built, and was considered at that time the most thorough and best construction that could be done. It was considered that that was the best that could be done at that time. The cash was raised in advance and everything was paid for in cash, and it was put in practically at the lowest rate per horse power of any plant that could be built. The type of construction was not adopted as temporary, but simply because it was the best we knew about at that date. We may deal in generalities on the question of the hydraulic conduit. We cannot say that the flume or tunnel is cheaper or better. The Mt. Whitney No. 1 flume is 30,000 feet long, and a tunnel would have to be 20,000 feet long. The flume is not of large size, and therefore it can be put through at a comparatively small cost, and as the cost for the cross-section of the flume increases, the cost of its construction increases very rapidly. As a tunnel becomes larger its cost decreases very largely. We cannot generalize on those things; each case must be figured out for itself, so that I think a wrong impression is gained. The conditions that surround the Mt. Whitney plant are favorable for the long life of a flume or pole line. The average life of a flume in California is about ten years, and then its cost of maintenance becomes so very great that it is a serious tax. Then, again, we must consider the character of the country we are going through. If it is a country where the slopes are gradual, then it is all right for flume construction. It is purely a case as to whether we shall adopt a flume, or a ditch, or a tunnel, and that depends upon the country, upon its size, and also as to whether a combination of the two shall be used, using a flume where it is more difficult, and then using an open ditch where it is more favorable. In southern California we have wooden flumes that are now being replaced with reinforced concrete flumes. I will close by saying that I think some of the members have gained a wrong impression of the Mt. Whitney Company. It was started in 1898, and that is ancient history now.

F. G. Baum: Mr. Hays gives some interesting data relative to the method of making power contracts for irrigation service, which should be of use to other companies in similar service. His remarks on the character of the contracts to meet the needs, and also his remarks on the character of the construction to give the service, illustrate the principle that " local conditions " must be taken into account whenever one goes into new problems or attempts to criticize the work of others.

To say that timber face dams, wooden flumes, simply equipped power houses, wooden poles and simple substations are always wrong, and that concrete dams, elaborately equipped power houses, steel towers and elaborate substations are right, only emphasizes the fact that the man making such statements does not take into consideration all the facts. Very often we do not build more permanently for the very simple reason that the money is not available. One builds a house generally to suit his needs and his pocketbook, and a man is not a fool for building a frame house instead of a brick house. We have ferry boats to go over the water before we have tunnels to go under. We crawl before we walk.

As I stated in a paper " Some Power Transmission Economics " at the annual meeting of 1907: " In designing power transmission systems, it is always well to bear in mind that the ultimate development of the art and of the country has not yet been reached.

" In the early days of railroading, the roads and equipment were not of the present trunk-line standard. Light rails, engines and cars, and unfenced right-of-way, and unballasted roadway sufficed. To construct, at that time, up to the present standard would have meant bankruptcy. Even now the manager or engineer, who would build his branch lines of the same standard as his trunk lines, would invite a receiver to take charge of the road.

" The same conditions hold true for power plants and transmission lines. The wise manager or engineer builds to meet existing conditions, looking into the future as far as he can. He cannot afford to build duplicate plants and lines for every case, nor build all his lines on private rights-of-way with steel towers and other refinements and safeguards. He cannot afford to build a duplicate transmission line, at an additional interest cost of $5,000 per year, when the probability of an interruption, which will cause a loss of revenue of $500 per year to a consumer, is extremely remote.

" It may not be as difficult to determine the proper power station and line to build when unlimited capital and ideal power conditions exist as when there is restricted capital, limited revenue, and low-priced power at the consumer's station. Although in the latter case the amount of money to be expended may be much less than in the former, even more thought is demanded of the engineer; for in the former case, having ample resources, he builds as best he can, while in the latter he must be a judge of conditions and see far ahead, in order that the work which he builds may earn money and at the same time be capable of extension on some plan to meet the growing needs of the country and business.

" On the hydraulic construction and also on the power house and substation installation and construction, the engineer is required to devise something that will pay the largest net income in a given number of years. Sometimes he is called upon to make installations on the assumption that the plant is to be abandoned in a few years. Of course, the engineer will be criticized if he puts in a plant to meet present or apparent future needs and, due to some change in the industry or development of the country, the plant must be remodeled later. But it is the business of the engineer to solve his problems as he sees them."

Much more might be said along the same line to illustrate that construction which may be right for the New York Central R.R., or in the city of New York, may not be right for the Tonapah & Tidewater, or the town of Tonapah.

Engineers must fight the tendency to " build monuments " to themselves. Many of these " monuments " mark the death of a corporation."

Mr. Hays: As to the stream flow and the different reservoirs at power house No. 1, no provision was made for a regulating reservoir when the plant was first constructed, but afterwards, as the load was built up, we found that we had a slight peak; that was back about five years ago, before these curves showed, and we built a little reservoir there with the idea of carrying over the peak load, and as small as that was, it served its purpose very well. On the No. 2 plant, I don't know why that reservoir was put there, it was probably just put there for good measure, and probably because it was a good place for one.

On the Tule River plant we took the matter up carefully as to what size reservoir we should build. We compared the daily load curves with the daily curves of discharge of the river during low water periods and while the stream flow varied to quite an extent during the day it happens to coincide with the load curve. For instance at the height of the peak in the morning the stream flow was greatest and fell off in the evening with the load, consequently very little if any reservoir capacity was required. The reservoir was therefore built to take care of the fluctuation of the river assuming that the most unfavorable conditions were encountered or that the low water flow would occur at the time of peak load. Also the reservoir has capacity to run the plant until the steam auxiliary may be brought into commission, in case of accident to the flume.

As to the permanency of construction, of course in a case of this kind we are dealing with simple units starting from the motors right up to the power house. The average size motor on the system is a 7½ h.p.—you might say that we were doing a peddling business. The old No. 1 flume that Mr. Doble spoke of was put in for an economical reason, it was far cheaper to put in the flume than a ditch or a tunnel. The flume has been in there for twelve years, and, apparently, with the exception of being water-stained, it is still in good shape. It looks as though it had about ten years more life left in it, and there is no maintenance to speak of required on it.

On the No. 2 plant we have put in a concrete ditch. On Tule River plant we have run in a concrete ditch where the slopes would permit. We also, in that plant, have gone further than the ordinary concrete ditch and do not rely at all on the concrete or on the strength of the bank, the high water level in the ditch being just six inches above the ordinary surface of the slope of the hill. Those improvements that we have put in will eventually double the capacity of the plant, when this ditch and bank have settled down. Also, there are two very long stretches of flume on the Tule River, which some day can be cut out by putting in a tunnel. That flume is of pine, not of redwood, and probably will not last as long as the old No. 1 flume, which has been in use for the last fifteen years.

I don't think that economy could be said to figure in on any one thing with the exception of the main power line and the distributing system. They are all light stuff, all light poles, and they last very well in that country. As to the steam plants taking care of the peak loads, I believe that when the system gets a little larger by increasing the capacity of the present hydraulic plant and in carrying over the peak load by steam, that it will work out all right. Roughly, I have figures on it when the plant gets about twice its present size. We have always considered the present steam plant, simply as an auxiliary. That is a pretty heavy investment to use for that purpose, but as mentioned in the last part of the paper, the company has very much of a responsibility. We have a very large community depending upon a comparatively small power system, and if some accident should put a generating station out of business for a year, it would seriously interfere with a crop. You have to keep some auxiliary ready for all emergencies. Little interruptions do not make any difference. If the Pacific Gas and Electric Company should have its lights go out for fifteen minutes between six and seven o'clock at night, it would be a serious matter. For ours to go out between six and seven at night about half of one per cent of the consumers would pay their bill next month and make a "kick" about it.

As to the protection of the motors: That has been one of the things we have been trying very hard to arrange for, and the only practicable apparatus we can furnish is just a straight circuit-breaker, so that when the current goes off, the motor stops, and when the power comes on again, it will trip the circuit-breaker. The average farmer objects to even putting that protection on. All he wants is a fuse. In fact, last year some of our consumers held an indignation meeting because they understood we were obliging them to put on circuit breakers, and they said they would not do it. They held a meeting, and decided that we were trying to get $36 more out of them and they would not stand for it. In fact, we had more trouble with them about that, than we have with them about the contracts. We get them to sign the contracts, sometimes they object, but the contract is absolutely fair. We have to give them a cheap rate, but we work on practically a cash basis. The penalty of one per cent per month provided in the contract is no joke. We actually enforce it, and yet it is not an unusual thing for a man to wait until the end of the year before he pays his bill. Some consumers prefer to pay that one per cent per month interest, and so we allow them to wait until the end of the year.

In operating a pump station I don't know of a single instance in that section where labor costs have been counted. A man generally does the work himself, oils up his pump and looks at his motor about twice a day, goes down into the field, and if the water stops he goes back and finds out what is the matter.

As to the secretary's reference to the underground water, I will say that I do not know of any cases in that section where they have dug for water and did not find it. Some of the growers tried to go up too far into the mountains and there were some wells there that were abandoned after they struck rock, bed rock and granite, and some of them, I presume, never would have reached water.

We have something better for the eastern tenderfoot than the dry lands. We have the "white ash" land, or that which is generally known as alkali land down there, and that sells very well to easterners, and there is more profit in it.

A paper presented at the 248th meeting of the American Institute of Electrical Engineers, San Francisco, Cal., May 6, 1910.

PARALLEL OPERATION OF THREE-PHASE GENERATORS, WITH THEIR NEUTRALS INTERCONNECTED

BY GEORGE I. RHODES

The difficulty of operating three-phase star-connected generators, with their neutrals in parallel, was most forcibly brought to the attention of the engineering profession when the company with which the writer is connected attempted to operate its plants in that manner. The various phenomena of that attempt have been fully described by C. W. Ricker (Experience with a Grounded Neutral on a High-Tension Plant, *Electric Journal*, September, 1906) and by the writer (Experience with a Grounded Neutral on the High Tension System of the Interborough Rapid Transit Company, TRANSACTIONS of American Institute of Electrical Engineers, Vol. XXVI, Part II, page 1605).

The subject of neutral currents has been discussed considerably. It is generally understood that they are of triple frequency and are produced by those harmonics of e.m.f. which cannot exist between the lines of a three-phase system. A general review of the theory of these phenomena may not be out of place.

Consider a three-phase star-connected generator (Fig. 1) in whose windings e.m.fs. are generated containing triple harmonics. The e.m.fs. in the coils differ in phase 120 fundamental degrees. The third harmonics differ $3 \times 120 = 360$ third harmonic degrees; the ninth harmonics, $9 \times 120 = 1080$ ninth harmonic degrees. The triple harmonics are thus in phase in all three coils. Since the potential difference between the outer terminals of two windings is equal to the vector difference between the e.m.fs. generated in the coils, the triple harmonics being in phase, will disappear. Thus, in a three phase star-connected system no triple harmonic voltages can exist between the lines.

The higher harmonics, other than multiples of the third, are not eliminated in the voltage between phases. They appear in the same relative magnitudes as in the coil voltages.

If this generator is connected to a balanced star-connected load, currents will flow in the lines of such wave form and magnitude that the potential differences between the terminals and the neutral point will differ from the coil e.m.fs. only by containing no triple harmonics. There can be no currents of these frequencies because they would be in phase in all three lines and hence could have no return path. It is evident that there will exist between the neutral of the generator and that of the load a voltage made up of the triple harmonics generated in the coils of the alternator. If these points are connected, currents of corresponding frequency will flow. The current in this interconnection will be three times the triple frequency current in the lines.

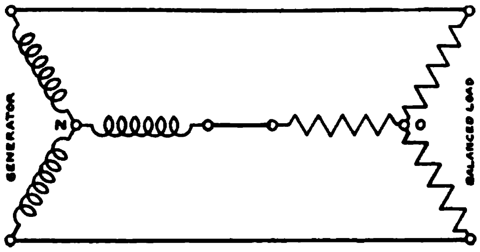


FIG. 1

If, instead of a load, another generator is connected to the first, a difference of potential will exist between their neutrals, equal to the vector difference between their coil e.m.fs. With the neutrals interconnected, a current will flow, limited by the impedances of the machines to triple harmonics. These impedances are in general much smaller than the synchronous impedances.

If the triple frequency e.m.fs. in the two machines are equal and in phase, there can be no neutral potential or current. This ideal condition can exist in general only when one or more of the following conditions are observed.

1. Equal instantaneous angular velocities.
2. Similar wave forms.

3. Equal loads.
4. Excitations corresponding to the loads.
5. Absence of all triple harmonics.

In all reciprocating machines the angular velocity pulsates to a greater or less extent. It has been found by experience that this surging is more troublesome in producing neutral currents than interchange between the phases. Machines that will operate very satisfactorily without neutral connections have caused serious trouble when operated with them. The obvious preventative for trouble of this kind is more uniform rotation, namely, the use of steam turbines or water driven prime movers.

Machines frequently differ considerably in wave form. They may be similar at no load, but differ when loaded on account of armature reaction. Attempts to operate generators thus differing, have resulted in enormous neutral currents. The preventative in this case is careful adjustment of wave forms.

Generators may have e.m.fs. similar to each other at all loads, yet the wave forms at any two different loads may be dissimilar. Machines thus operated at unequal loads will show neutral voltages or currents. These load differences are easily controlled, except in the case of surging mentioned above, so that no trouble should arise. At the instant of synchronizing, however, the load difference is a maximum and serious trouble may occur. Difficulty of this kind has made the operation of synchronizing impossible with several generators on the line. The obvious preventative is to close the neutral connection after the loads are adjusted.

Another cause of dissimilarity in wave form is that excitations, or field currents, are not correctly adjusted to the loads. These differences are of small magnitude and the neutral currents are of no importance under ordinary conditions. They may be reduced by a careful adjustment of excitation.

In all of the above cases the interchange of triple harmonic current may be reduced by the insertion of impedances in the neutral connections. These impedances may be undesirable on account of their size, or on account of the voltage drop in case of unbalanced load. The neutral currents may be eliminated by the connection of but a single generator to the neutral bus, but this method has its limitations. If more than one generator must be operated with a neutral connection, and if impedances are undesirable, then the only remedy is to obtain machines generating no triple harmonic e.m.fs.

It is the purpose of the following discussion to show the real cause of triple harmonics, to indicate a method of computing them, a method of measuring them, and finally to suggest certain elements of design which will reduce them to a negligible amount.

GENERAL EQUATIONS

In any alternator the field or excitation m.m.f. at any point in the air gap may be represented by the following equation:

$$\mathfrak{F}_f = f_1 \sin \alpha + f_3 \sin 3\,\alpha + \;.\;.\;.\;.\;.\; + f_m \sin m\,\alpha$$

$$+ g_1 \cos \alpha + g_3 \cos 3\,\alpha + \;.\;.\;.\;.\;.\; + g_m \cos m\,\alpha$$

$$= \sum_1^m f_m \sin m\,\alpha + \sum_1^m g_m \cos m\,\alpha$$

where

$\mathfrak{F}_f$ = excitation m.m.f. at any point along air gap

$f_1, f_3, \;.\;.\;.\;.\;.\; f_m$ = coefficients of sine terms.

$g_1, g_3, \;.\;.\;.\;.\;.\; g_m$ = coefficients of cosine terms

m = index of harmonic.

α = angular distance of point from interpolar axis (Fig. 2).

It is evident that this equation takes into account all cases where the excitations of the poles are equal, whether the windings are concentrated in a single field coil or are distributed over the polar surface.

A similar equation represents the average value of the m.m.f. of armature reaction of any polyphase alternator, thus

$$\mathfrak{F}_a = a_1 \sin \alpha + a_3 \sin 3\,\alpha + \;.\;.\;.\;.\;.\; + a_n \sin n\,\alpha$$
$$+ b_1 \cos \alpha + b_3 \cos 3\,\alpha + \;.\;.\;.\;.\;.\; + b_n \cos n\,\alpha$$

$$= \sum_1^n a_n \sin n\,\alpha + \sum_1^n b_n \cos n\,\alpha$$

where

$\mathfrak{F}_a$ = armature reaction m.m.f. at any point along air gap.

$a_1, a_3, \;.\;.\;.\;.\;.\; a_n$ = coefficients of sine terms.

$b_1, b_3, \;.\;.\;.\;.\;.\; b_n$ = coefficients of cosine terms

n = index of harmonic.

α = angular distance of point from interpolar axis.

This equation does not take into account the fluctuations of reaction which are present in all armatures except the ideal with an infinite number of phases.

In most alternators a suitable wave form is secured by a greater or less variation in the shape of the pole pieces and hence, in the length of the air gap. This variation in reluctance at different points may be represented by the following equation.

$$K = \pm k_1 \sin \alpha \pm k_3 \sin 3\,\alpha \pm \;.\;.\;.\;.\;.\; \pm k_p \sin p\,\alpha$$

$$\pm l_1 \cos \alpha \pm l_3 \cos 3\,\alpha \pm \;.\;.\;.\;.\;.\; \pm l_p \cos p\,\alpha$$

$$= \pm \sum_1^p k_p \sin p\,\alpha \pm \sum_1^p l_p \cos p\,\alpha$$

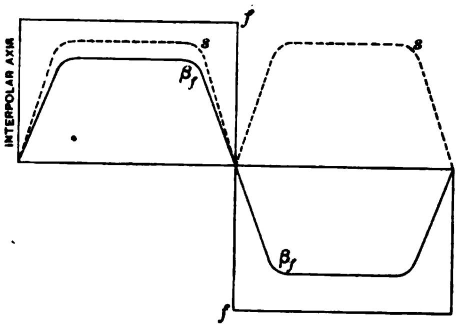


FIG. 2

where

K = magnetic conductivity or permeance per unit angle at any point along air gap.

k_1, k_3, ... k_p = coefficients of sine terms.

l_1, l_3, ... l_p = coefficients of cosine terms.

p = index of harmonic.

α = angular distance of point from interpolar axis.

In this equation the positive sign holds from $\alpha = 0$ to $\alpha = \pi$ and the negative from $\alpha = \pi$ to $\alpha = 2\pi$ etc. This change of sign is necessary as the permeance must be positive in value at all points.

We now have three general equations representing the variation in permeance and in magnetomotive forces of excitation and armature reaction along the air gap of the ideal polyphase alternator.

The corresponding flux densities may be computed by multiplying the magnetomotive forces into the permeance and reducing to new series. These series are here given for future reference.

No load flux

$$\beta_f = \sum_1^m \sum_1^p \sum_1^M \left\{ \frac{2\,M f_m k_p}{\pi} \left[\frac{1}{M^2-(m-p)^2} - \frac{1}{M^2-(m+p)^2} \right] + \frac{2\,M g_m l_p}{\pi} \left[\frac{1}{M^2-(m-p)^2} + \frac{1}{M^2-(m+p)^2} \right] \right\} \sin M\alpha$$

$$+ \sum_1^m \sum_1^p \sum_1^M \left\{ \frac{2\,g_m k_p}{\pi} \left[\frac{m+p}{(m+p)^2-M^2} - \frac{m-p}{(m-p)^2-M^2} \right] + \frac{2 f_m l_p}{\pi} \left[\frac{m+p}{(m+p)^2-M^2} + \frac{m-p}{(m-p)^2-M^2} \right] \right\} \cos M\alpha \qquad \text{(I)}$$

Armature reaction flux

$$\beta_a = \sum_1^n \sum_1^p \sum_1^N \left\{ \frac{2\,N a_n k_p}{\pi} \left[\frac{1}{N^2-(n-p)^2} - \frac{1}{N^2-(n+p)^2} \right] + \frac{2\,N b_n l_p}{\pi} \left[\frac{1}{N^2-(n-p)^2} + \frac{1}{N^2-(n+p)^2} \right] \right\} \sin N\alpha$$

$$+ \sum_1^n \sum_1^p \sum_1^N \left\{ \frac{2\,b_n k_p}{\pi} \left[\frac{n+p}{(n+p)^2-N^2} - \frac{n-p}{(n-p)^2-N^2} \right] + \frac{2\,a_n l_p}{\pi} \left[\frac{n+p}{(n+p)^2-N^2} + \frac{n-p}{(n-p)^2-N^2} \right] \right\} \cos N\alpha \qquad \text{(II)}$$

where all symbols have the same significance as above, with the addition of

M = index of harmonic in field flux.

N = index of harmonic in reaction flux.

These equations may be transformed to represent voltages by a method explained in great detail by Comfort A. Adams in his paper " The Voltage Ratio in Synchronous Converters with Special Reference to the Split Pole Converter," TRANSAC-

TIONS A.I.E.E., Vol. XXVII, Part II, page 959, and "Electromotive Force Wave Shape in Alternators," TRANSACTIONS A.I.E.E., Vol. XXVIII, Part II, page 1053.

In brief, the method is as follows. A single conductor passing at a uniform velocity through a flux whose distribution may be represented by a Fourier's Series, a wave of e.m.f. is generated exactly similar in form. The relative values of the different harmonics are the same in the e.m.f. wave as in the flux distribution wave. If, however, instead of a single coil, a number of similarly distributed windings are passed through the flux, the net e.m.f. generated is the vector sum of the e.m.fs. in the individual coils. This vector sum is less than the arithmetical sum by a proportion depending on the angular space over which the coils are distributed; the greater the space the greater the reduction. In the case of the higher harmonics the angular distribution of the conductors is multiplied by the index of the harmonics. Hence in a distributed winding the relative values of the harmonics in the e.m.f. wave differ from those in the flux distribution wave. The corresponding reduction factors may be obtained from the above mentioned papers.

EQUATIONS FOR PURE SINE NO LOAD VOLTAGE

Up to this point the discussion has been very general. The equations show that in addition to a third harmonic in the no load e.m.f. wave, there may also be a similar harmonic generated by the armature reaction.

In order that there may be gained an idea of the real magnitudes of the neutral voltages, it is desirable to assume conditions existing in machines which have caused trouble and to compute figures which may be checked by actual measurement.

These conditions are as follows:

1. Concentrated field windings.
2. Armature windings distributed over 60 electrical degrees per phase.

The first condition obtains in by far the greater number of machines. The second in most machines of large size, where it has been found desirable to use a full pitch winding.

For preliminary computations, it will be assumed that no triple harmonic exists in the no load coil e.m.f. wave of the generator; that is, the potential between line and neutral is purely sinusoidal. It will also be assumed that the armature reaction m.m.f. is purely sinusoidal, as would be the case with a machine of an infinite number of phases.

We thus have for the m.m.f. due to excitation,

$$\mathfrak{F}_f = \pm f$$

That is, the magnetomotive force is uniform over the polar space, being positive between $\alpha = 0$ and $\alpha = \pi$ and negative from $\alpha = \pi$ to $\alpha = 2\,\pi$. This assumption is not completely borne out in practice, but it is near enough for purposes of approximation.

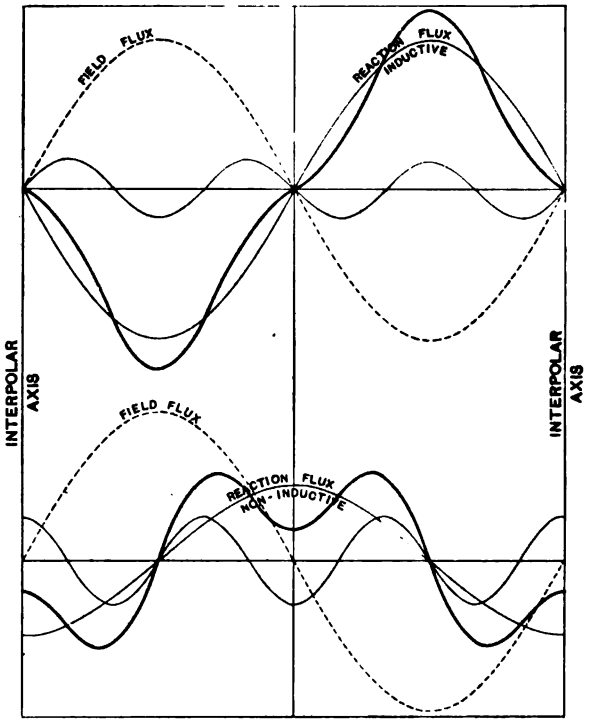


FIG. 3

The m.m.f. due to armature reaction is

$$\mathfrak{F}_a = a_1 \sin \alpha + b_1 \cos \alpha$$

$$a_1^2 + b_1^2 = A_1^2$$

The sine terms represent the effect of current in quadrature with the internal e.m.f. and the cosine terms that of current in phase with it. Thus

$$\mathfrak{F}_a = A_1 \sin \phi \sin \alpha - A_1 \cos \phi \cos \alpha$$

where ϕ = angle between current and internal e.m.f.

The magnetic conductance or the permeance in the air gap is represented as follows:

$$K = \pm k_1 \sin \alpha$$

The field flux is easily obtained as follows:

$$\beta_f = \mathfrak{F}_f \, K = f \, k_1 \sin \alpha$$

The reaction flux distribution is derived by substituting in equation (II).

$$n = 1, \; p = 1, \; l = 0 \text{ and } N = 1, 3$$

$$\beta_a = k_1 A_1 \sin \phi \, (0.848 \sin \alpha - 0.170 \sin 3\,\alpha \; . \; . \; . \; . \; .)$$

$$- k_1 A_1 \cos \phi \, (0.424 \cos \alpha - 0.254 \cos 3\,\alpha \; . \; . \; . \; . \; .)$$

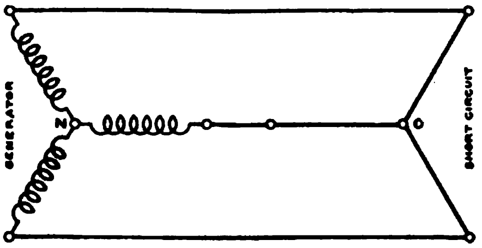


FIG. 4

The relative values and phases of these reaction fluxes are shown in Fig. 3. The upper curves show the reaction due to a current lagging 90 deg. behind the internal voltage and the lower curves that due to an equal current in phase therewith. It will be seen that the armature reaction causes triple harmonic fluxes of from 20 per cent to 60 per cent of the total.

Considering the case of a machine running under short circuit conditions as represented in Fig. 4, the current lags practically 90 deg. behind the internal e.m.f. generated by the excitation flux. A triple harmonic voltage appears between the neutral of the generator and the short circuit point. That portion of the field flux of fundamental distribution not required to generate e.m.fs. overcoming the leakage impedance drop, is neutralized by the corresponding reaction flux.

We thus have the following relation

$$f\,k_1\,\frac{X_r}{X_s}\;.\;+0.848\,k_1\,A_1\sin\,(-90°)=0$$

$$A_1=\frac{f\,X_r}{0.848\,X_s}$$

where X = leakage reactance.
X_r = reaction reactance.
X_s = synchronous reactance.
Under conditions other than short circuit if
I = current.
I_s = short circuit current.

$$A_1=\frac{I\,X_r\,f}{0.848\,I_s\,X_s}$$

Thus the reaction flux becomes

$$\beta_a=\frac{I\,X_r\,f\,k_1\sin\phi}{0.848\,I_s\,X_s}\,(0.848\sin\alpha-0.170\sin 3\,\alpha+\;.\;.)$$

$$-\frac{I\,X_r\,f\,k_1\cos\phi}{0.848\,I_s\,X_s}\,(0.424\cos\alpha-0.254\cos 3\,\alpha+\;.\;.)$$

This may be transformed into an e.m.f. equation by the method referred to above, with a reduction factor of ⅔ for the third harmonic.

If e_f = instantaneous value of internal e.m.f.
E_f = effective value of internal e.m.f.
e_a = instantaneous value of reaction.
E_a = effective value of reaction e.m.f.
$\omega = 2\,\pi$ times frequency.
t = time.
Since

$$e_f=\sqrt{2}\;E_f\sin\omega\,t$$

$$e_a=\frac{\sqrt{2}\,E_f\,I\,X_r\sin\phi}{0.848\,I_s\,X_s}\,(0.848\sin\omega\,t-0.113\sin 3\,\omega\,t+\;.\;.)$$

$$-\frac{\sqrt{2}\,E_f\,I\,X_r\cos\phi}{0.848\,I_s\,X_s}\,(0.424\cos\omega\,t-0.169\cos 3\,\omega\,t+\;.\;.)$$

Since $I_s X_s = E_f$

$$e_a = 1.18 \sqrt{2}\, I\, X_r \left[(0.848 \sin \omega t - 0.113 \sin 3\, \omega t) \sin \phi \right.$$

$$\left. - (0.424 \cos \omega t - 0.169 \cos 3\, \omega t \ldots) \cos \phi \right]$$

The magnitude of the triple harmonic voltage may be calculated readily from this equation. For instance, in a machine whose load current is one-half the short circuit current and whose leakage reactance is negligible, its value may readily reach at unity power factor.

$$\frac{1.18 \times 0.169\, E_f}{2} = 0.10\, E_f$$

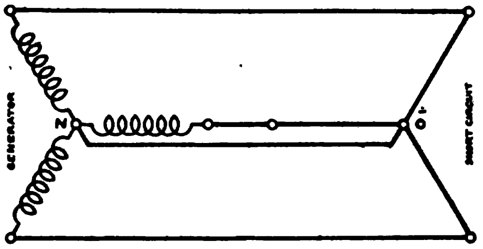


FIG. 5

With the machine running under the short circuit conditions shown in Fig. 5, a triple harmonic current flows in the neutral connection.

The impedance which the armature winding offers to the flow of this current is made up of two items; that due to leakage flux and that due to reaction flux. It is evident that the leakage flux is the same, irrespective of whether the current is of fundamental or of triple frequency. The distribution and the magnitude of the reaction flux produced by triple harmonic currents, differ in a marked degree from that produced by a fundamental current.

If X_{III} = leakage reactance to third harmonic current.

X_{rIII} = reaction reactance of third harmonic current.

X_{sIII} = total reactance of third harmonic current.

The leakage flux is independent of the frequency, thus

$$X_{III} = 3\, X$$

Since the triple harmonic currents are in phase in all three armature coils, the reaction m.m.f. has a triple distribution corresponding to three times the normal number of poles (Fig. 6). This magnetomotive force may be represented by the following equation.

$$\mathfrak{F}_{a\,\text{III}} = \sum_1^n a_{n\,\text{III}} \sin 3\,n\,\alpha + \sum_1^n b_{n\,\text{III}} \cos 3\,n\,\alpha$$

The m.m.f. multiplied into the permeance gives the reaction flux produced by the triple harmonic.

Considering only the simple conditions enumerated in the foregoing computations

$$\mathfrak{F}_{a\,\text{III}} = a_{1\,\text{III}} \sin 3\,\alpha + b_{1\,\text{III}} \cos 3\,\alpha$$

$$= A_{1\,\text{III}} \sin \phi_{\text{III}} \sin 3\,\alpha - A_{1\,\text{III}} \cos \phi_{\text{III}} \cos 3\,\alpha,$$

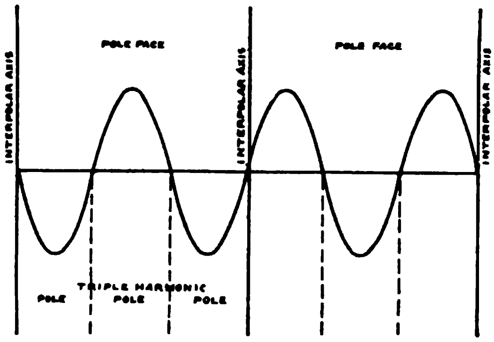


FIG. 6

where ϕ_{III} = the angle between third harmonic current and internal e.m.f.

$$K = \pm k_1 \sin \alpha$$

Substituting in equation (II) $n = 3$, $p = 1$, $l_p = 0$ $N = 1, 3$,

$$\begin{aligned}\beta_{a\,\text{III}} &= k_1 A_{1\,\text{III}} \sin \phi_{\text{III}} \,(-0.170 \sin \alpha + 0.655 \sin 3\,\alpha)\\ &\quad - k_1 A_{1\,\text{III}} \cos \phi_{\text{III}} \,(-0.255 \cos \alpha + 0.618 \cos 3\,\alpha)\end{aligned}$$

On account of the triple distribution of the m.m.f., the magnitude of this flux, is but ⅓ of that produced by an equal fundamental current. The increased angular distribution of the armature windings has a similar influence on the flux as on the e.m.f. This increase is from 60 deg. to 180 deg, with a corresponding reduction factor of approximately ⅔.

Thus

$$A_{1\,\text{III}} = \frac{2}{9} A_1,$$

With the neutrals short circuited, the triple harmonic reaction flux distribution is

$$\beta_{a\text{III}} = \frac{2}{9}\, k_1 A_1\, (0.655 \sin 3\,\alpha)$$

An equal fundamental current produces a reactance flux distribution

$$\beta_a = k_1 A_1\, (0.848 \sin \alpha)$$

The relative values of reaction reactances are the same as those of the corresponding fluxes, thus

$$\frac{X_{r\text{III}}}{X_r} = \frac{2\, k_1 A_1 \times 0.655}{9\, k_1 A_1 \times 0.848}$$

$$X_{r\text{III}} = 0.171\, X_r$$

It will be noted that the triple harmonic current develops a small fundamental reaction aiding the excitation. This is negligible, however, for a neutral current three times the line short circuit current has an effect of only $2/9 \times 0.170 = 3.8$ per cent of the excitation.

Summarizing the equations which have thus far been deduced, we have for conditions of pure sine distribution of no load flux,

Triple harmonic or neutral e.m.f.

$$e_{\text{III}} = -1.18 \sqrt{2}\, I\, X_r\, [0.113 \sin \phi \sin 3\,\omega\, t - 0.169 \cos \phi \cos 3\,\omega\, t]$$

Reactance per phase for neutral current.

$$X_{s\text{III}} = 3\, X + 0.171\, X_r$$

EQUATIONS FOR MACHINE WHOSE NO LOAD VOLTAGE CONTAINS A THIRD HARMONIC

In most alternators there is present at no load a triple frequency e.m.f. which flattens the wave form symmetrically. This harmonic thus has a positive value, as referred to the fundamental. The following equations represent the various quantities taking into account this no load neutral voltage.

Excitation m.m.f.

$$\mathfrak{F}_f = \pm f$$

Armature reaction m.m.f.

$$\mathfrak{F}_a = A_1 \sin \phi \sin \alpha - A_1 \cos \phi \cos \alpha$$

Permeance of air gap

$$K = \pm k_1 \sin \alpha \pm k_3 \sin 3\alpha = \pm k_1 \left(\sin \alpha + \frac{k_3}{k_1} \sin 3\alpha \right)$$

Reaction flux distribution

$$\begin{aligned} \beta_a = k_1 A_1 \sin \phi & \left[\left(0.848 - 0.17 \frac{k_3}{k_1} \right) \sin \alpha \right. \\ & \left. - \left(0.170 - 0.65 \frac{k_3}{k_1} \right) \sin 3\alpha \right] \\ - k_1 A_1 \cos \phi & \left[\left(0.424 + 0.60 \frac{k_3}{k_1} \right) \cos \alpha \right. \\ & \left. - \left(0.254 - 0.11 \frac{k_3}{k_1} \right) \cos 3\alpha \right] \end{aligned}$$

Relation between A_1 and f_1

$$A_1 = \frac{f_1 X_r}{\left(0.848 - 0.17 \frac{k_3}{k_1} \right) X_s}$$

Open circuit or internal voltage

$$e_f = \sqrt{2}\, E_f \left(\sin \omega t + \frac{E_{f\,\mathrm{III}}}{E_f} \sin 3\omega t \right)$$

Now

$$\frac{k_3}{k_1} = \frac{3\, E_{f\,\mathrm{III}}}{2\, E_f}$$

on account of the voltage reduction factor.

Armature reaction voltage,

$$e_a = \frac{\sqrt{2}\, I\, X_r}{0.848 - 0.25\,\frac{E_{f\,\mathrm{III}}}{E_f}} \left\{ \left[\left(0.848 - 0.25\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \sin \omega t \right.\right.$$

$$\left. - \left(0.113 - 0.65\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \sin 3\,\omega t \right] \sin \phi$$

$$- \left[\left(0.424 - 0.90\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \cos \omega t \right.$$

$$\left.\left. - \left(0.170 - 0.11\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \cos 3\,\omega t \right] \cos \phi \right\}$$

Third harmonic reaction flux

$$\beta_{a\,\mathrm{III}} = k_1\, A_{\mathrm{III}} \left\{ \left[\left(-0.170 + 0.97\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \sin \alpha \right.\right.$$

$$\left. + \left(0.655 + 0.42\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \sin 3\,\alpha \right] \sin \phi_{\mathrm{III}}$$

$$- \left[\left(-0.255 + 0.17\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \cos \alpha \right.$$

$$\left.\left. + \left(0.618 + 0.21\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \cos 3\,\alpha \right] \cos \phi_{\mathrm{III}} \right\}$$

Total third harmonic reactance

$$X_{s\,\mathrm{III}} = 3\,X + \frac{2\left(0.655 + 0.42\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) X_r}{9\left(0.848 - 0.25\,\frac{E_{f\,\mathrm{III}}}{E_f}\right)}$$

Summarizing the equations, triple frequency e.m.f.

$$e_{\mathrm{III}} = \sqrt{2}\, E_{f\,\mathrm{III}} \sin 3\,\omega t - \frac{\sqrt{2}\, I\, X_r}{0.848 - 0.25\,\frac{E_{f\,\mathrm{III}}}{E_f}} \left\{ \right.$$

$$\left(0.113 - 0.65\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \sin 3\,\omega t \sin \phi$$

$$\left. - \left(0.170 - 0.11\,\frac{E_{f\,\mathrm{III}}}{E_f}\right) \cos 3\,\omega t \cos \phi \right\} \qquad \text{(III)}$$

Triple frequency reactance per phase

$$X_{s\text{III}} = 3\,X + \frac{2\left(0.655 + 0.42\,\frac{E_{f\text{III}}}{E_f}\right) X_r}{9\left(0.848 - 0.25\,\frac{E_{f\text{III}}}{E_f}\right)} \tag{IV}$$

Where

e_{III} = instantaneous value of neutral voltage.
$E_{f\text{III}}$ = effective value of no load neutral voltage.
E_f = effective value of no load coil voltage.
I = load current.
ϕ = angle between current and internal voltage.
X = leakage reactance per phase fundamental.
X_r = reaction reactance per phase fundamental.

These equations apply to all generators having full pitch coils distributed over 60 electrical degrees per phase, with a wave form secured by varying the air gap. This type of machine is quite common.

DETERMINATIONS OF ANGLE BETWEEN LOAD CURRENT AND INTERNAL E.M.F.

In all of the above equations for triple harmonic voltages there is present the undetermined angle between the load current and the internal e.m.f. due to excitation. Referring to Fig. 3 it will be noted that the reaction due current in phase with the internal e.m.f. is practically one-half that due to an equal current in quadrature therewith. Under these conditions the terminal voltage is approximately

$$P\,D = E_f\left(1 + \frac{I}{I_s}\sin\phi - j\,\frac{I}{2\,I_s}\cos\phi\right)$$

If ψ = the angle between the terminal and the internal e.m.f.s

$$\psi = \tan^{-1}\frac{-\frac{I}{I_s}\cos\phi}{2\left(1 + \frac{I}{I_s}\sin\phi\right)}$$

If θ = the angle between the current and the terminal voltage

$$\theta = \phi - \psi$$

These equations may be solved to get ψ when the load and power factor are known. The approximate values may be obtained readily from Fig. 7. In this figure the abscissæ represent angles between the current and the terminal voltage and the ordinates angles between the terminal and internal voltages. Negative angles signify that the current lags behind the terminal voltage or the terminal voltage behind the internal voltage.

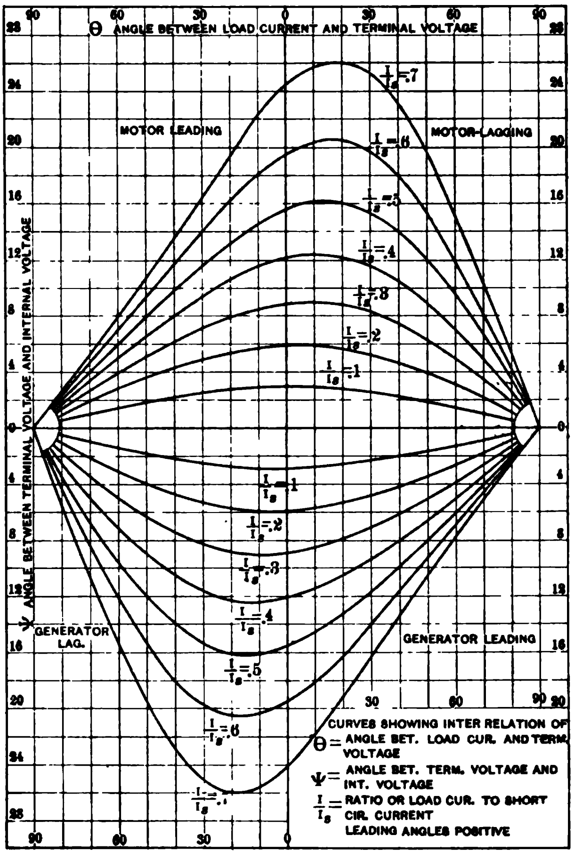


Fig. 7

Measurement of Triple Harmonics

In the foregoing discussion it is assumed that we have a means of measuring the no load third harmonic. The method is as follows. (Fig. 8). Connect three transformers with the primaries in star and the secondaries in delta. The triple harmonic necessary for the magnetizing currents cannot flow in the lines; they appear as circulating currents in the delta windings. The delta connection also equalizes the voltages on all three transformers, so that the neutral of the primary connection is the true neutral of the system. A voltmeter, either alone or with a potential transformer connected between the transformer neutral and the generator neutral, will indicate the magnitude of the triple harmonic voltages. An oscillograph will give the phase relations.

The short circuit neutral voltages appear between the short circuit point and the neutral of the generator.

APPLICATION OF EQUATIONS TO A GENERATOR OF KNOWN CHARACTERISTICS

The application of the equations developed above to a generator which is unsuitable for parallel operation with interconnected neutrals, will serve to make them clearer.

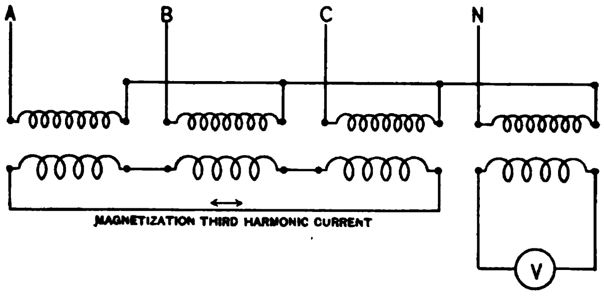


FIG. 8

In Figs. 9 and 10 are shown the no-load characteristics of such a generator. The winding is a distributed full pitch winding of usual type. It will be observed that the open circuit triple harmonic is symmetrical with the coil voltage and positive in value.

Applying the constants of this generator to equations III and IV, we get a triple frequency e.m.f.

$$e_{\text{III}} = 0.085\, E_f \sqrt{2} \sin 3\,\omega\, t - \frac{I\, X_r \sqrt{2}}{0.848 - 0.25 \times 0.085} \left\{ \begin{array}{l} (0.113 - 0.65 \times 0.085) \sin 3\,\omega\, t \sin \phi \\ -(0.170 - 0.11 \times 0.085) \cos 3\,\omega\, t \cos \phi \end{array} \right\}$$

$$= 0.085\, E_f \sqrt{2} \sin 3\,\omega\, t - 0.069\, I\, X_r \sqrt{2} \sin 3\,\omega\, t \sin \phi$$

$$+ 0.195\, I\, X_r \sqrt{2} \cos 3\,\omega\, t \cos \phi$$

Triple frequency reactance per phase

$$X_{sIII} = 3\times 0.8 + \frac{2\,(0.655+0.42\times 0.085)\,X_r}{9\,(0.848-0.25\times 0.085)} = 2.4+0.185\,X_r$$

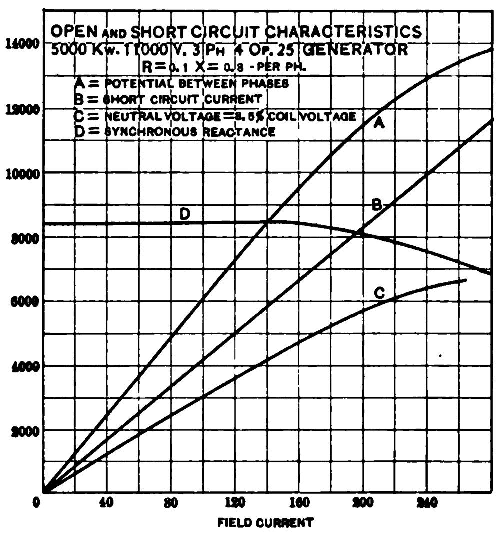


FIG. 9

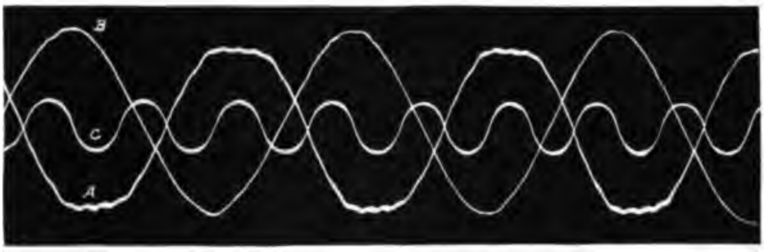


FIG. 10.—Open circuit wave forms of 5000 kw., 11,000-volt, three-phase, Y-connected generator

A = Line to neutral of generator

B = Line to line

C = Neutral of generator to neutral of system

If this machine had no neutral voltage on open circuit, these equations would be

$$e_{III} = -0.133\,I\,X_r\,\sqrt{2}\sin 3\,\omega\,t\sin\phi + 0.200\,I\,X_r\,\sqrt{2}\cos\omega\,t\cos\phi$$

$$X_{sIII} = 2.4+0.174\,X_r$$

Figs. 11, 12 and 15 show the effective values of voltage and current as represented by these equations, together with observed values. In Fig. 11, *A* represents the computed values of neutral voltage when the machine is short circuited in the usual manner; *A′* gives observed values with an encouraging agreement. *B* and *B′* similarly show computed and observed values of neutral current when the neutral also is connected to the short circuit point. The agreement here is not quite as good, but is still quite satisfactory.

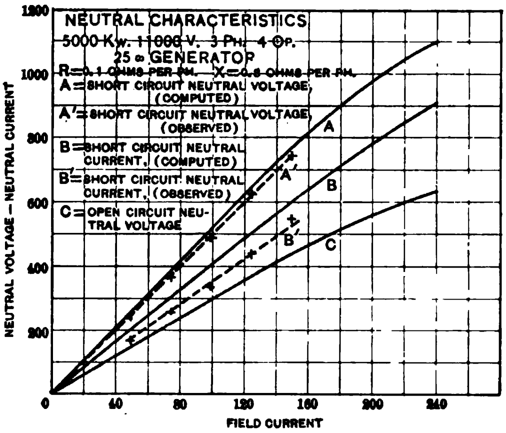


FIG. 11

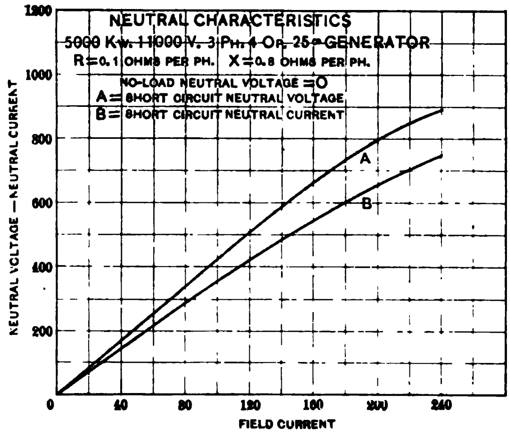


FIG. 12

Fig. 12 shows the magnitudes of neutral voltage and current that would have obtained in this machine, had its pole faces been shaped to give a sine wave when run on open circuit.

Figs. 13 and 14 are reproductions of oscillograph records taken under short circuit conditions. They are self-explanatory.

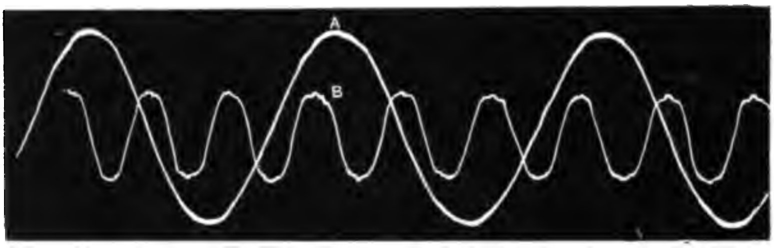


FIG. 13.—Short circuit wave forms of 5000-kw., 11,000-volt, three-phase, Y-connected generator
A = Line current
B = Neutral voltage

In Fig. 15, A represents the computed neutral voltage of the machine with different loads at unity power factor. Observed values are represented by crosses and the dotted line. B shows what these voltages would be in a similar machine with a perfect wave form at no load.

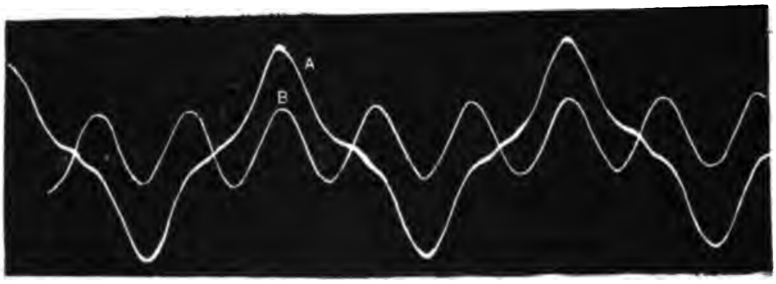


FIG. 14.—Short circuit wave forms of 5000-kw., 11,000-volt, three-phase, Y-connected generator
A = Line current
B = Neutral current

The discrepancy at overloads is probably due to the fact that the air gap between the poles has a greater permeance in actual machines than in the ideal machine upon whose characteristics the equations are based. This increased permeance has the result of greatly reducing the triple harmonic caused by the reaction of current in phase with the internal voltage. The reduction is to approximately one-third of the calculated value, which magnitude gives calculated curves corresponding to the observed values.

The above comparisons of observed and computed results are given as a test of the theory and methods. The further application to difference in potential, etc., between the neutrals of machines in parallel will serve as a measure of trouble to be expected.

In Fig. 15, curves *C* and *B* show the calculated voltage between the neutrals of two machines, one of which is running without load and the other of which is running loaded. The voltage between neutrals of two machines is governed principally by the reaction of inductive load, hence the effect of the reduction of interpolar triple harmonics mentioned in connection with Fig. 15 is of comparatively little importance.

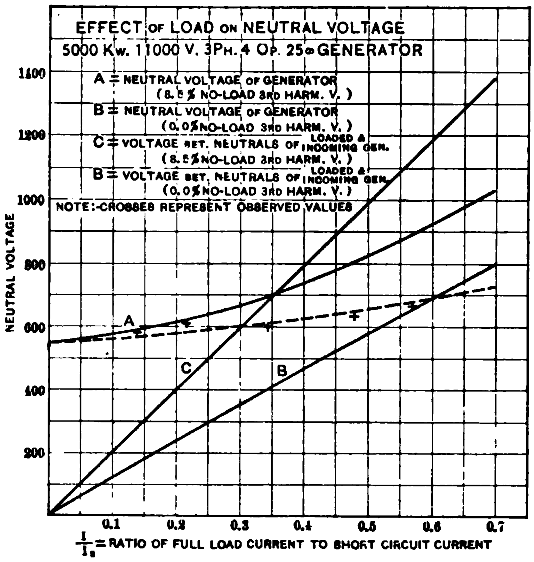


FIG. 15

Fig. 16 shows the calculated angular displacement of voltages due to load. *A* shows the angular displacement of the internal voltage; *B* the angular displacement of the neutral voltage and *C* the angular displacement of neutral voltage in a machine having zero no load triple harmonic.

It will be observed that the triple harmonic is displaced by an angle several times as great as is that of the fundamental. It will also be observed that at large loads the voltage between neutrals of loaded and unloaded generators may be larger than the neutral voltage of either, due to the very large angular displacement.

Figs. 17 and 18 are oscillograph records taken on a machine running at loads of 5000 and 9000 kw. These loads correspond to ratios of approximately 0.32 and 0.58. These records show a reasonably close agreement with theory as to the angular displacement of the neutral voltage.

In the early part of the paper it was mentioned that the causes of trouble with similar machines were non-uniform angular velocities and unequal loads. Referring to Fig. 15, curve *C*, it is seen that the voltage between the neutral of a loaded generator and that of an unloaded generator is practically a linear function of the load. Thus, two machines running with different loads would have about the same neutral potential difference as though one of them were loaded by an amount equal to the load difference and the other was running unloaded.

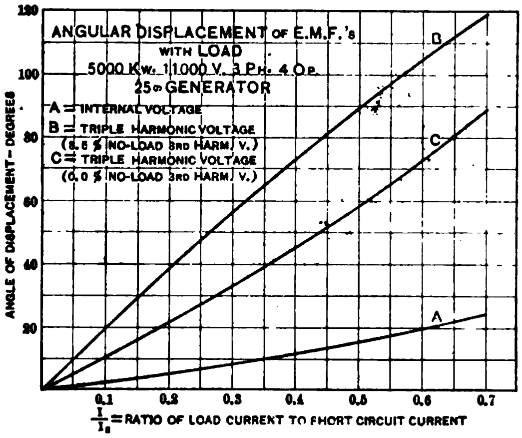


FIG. 16

Unequal instantaneous velocities result directly in a surging of load between two machines. This surging at times amounts to a load corresponding to $I/I_s = 0.25$. This is unusual, but nevertheless is encountered even in well designed plants having reciprocating engines. With generators, such as have given trouble, this causes a neutral potential difference of 500 volts.

The triple frequency reactance being 3.7 ohms per phase, there would flow in the interconnected neutrals of two machines a current of $\frac{500 \times 3}{2 \times 3.7} = 202$ amperes. With a large number of machines interconnected, this current could amount to 400 amperes.

Currents of these magnitudes are not in themselves large enough to cause serious trouble, but since they are always present as surges their possible effects on a large system are somewhat alarming.

It has been found in practice that at times there would be a more or less sudden excessively large rush of current, due possibly to the valve mechanism of the engine. Any such sudden large variation in angular velocity would produce a current limited, not by reactance computed above, but by the leakage reactance without iron. This may not exceed 20 per cent of the leakage reactance, or, in the machines considered above, 0.48 ohms per phase. Under these conditions surges may occur as large as $\frac{500 \times 3}{0.48} = 3100$ amperes.

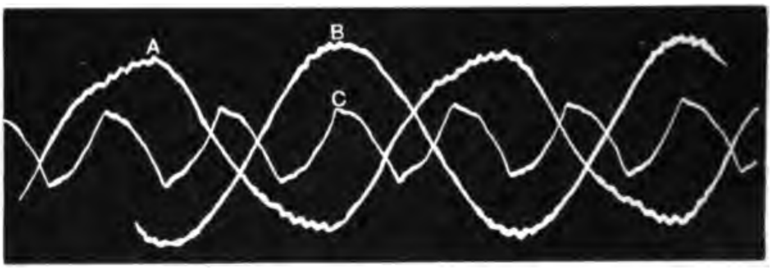


FIG. 17.—Voltage wave forms at 5000-kw., load (non-inductive) 5000-kw., 11,000 volts, three-phase, Y connected generator
A = Line to neutral generator
B = Line to line
C = Neutral of generator to neutral of system

An inspection of Fig. 15 shows that little improvement may be expected by designing the machine with a perfect no load voltage.

Most serious difficulty in the operation of generators with interconnected neutrals has been during the operation of synchronizing. At this time there is a very large difference in loads and at the instant of closing the switch there is a sudden short circuit of the neutral voltage. Loads may differ at this time as much as $I/I_s = 0.6$. corresponding to a neutral voltage of 1190 volts. The first rush of neutral current with several machines running, may reach $\frac{1190 \times 3}{0.48} = 7450$ amperes, which would settle down to a final value of $\frac{1190 \times 3}{3.7} = 965$ amperes. These figures indicate that great synchronizing difficulty is to be expected, especially with several machines running. Evidently all neutral currents at this time may be avoided by connecting the neutral of the incoming machines only after an adjustment of the load.

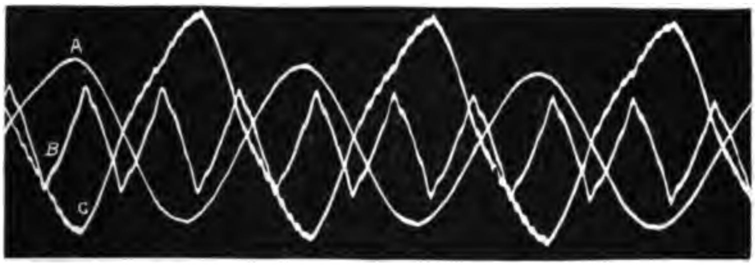


FIG. 18.—Voltage wave forms at 9,000 kw. load (non-inductive) 5000 kw., 11,000-volts., three-phase Y-connected generator
A = Line to neutral generator
B = Line to line
C = Neutral of generator to neutral of system

REMEDIES

Practice and the computations made above show beyond question that with certain types of generators parallel operation with interconnected neutrals is impracticable and dangerous to continuity of service.

The best remedy is to build machines in which no triple harmonic voltages can exist. These troublesome harmonics may be eliminated at no load by the proper shaping of the pole pieces. There are in addition, however, triple harmonics due to armature reaction which are increased by a decrease in no load neutral voltage.

The remedies possible are two; the distribution of the excitation m.m.f. sinusoidly over a uniform air gap so that the armature reaction will be without higher harmonics; or the design of the armature winding so that no triple harmonics may be generated therein. Comfort A. Adams shows in the above mentioned papers that this latter condition may be obtained by a winding distributed over 120 consecutive electrical degrees of armature space.

It is probably impossible to reduce neutral voltages and currents to zero, but there should be no trouble in reducing them to negligible magnitudes.

CONCLUSION

In conclusion then, it appears that alternators as usually built, are unsuited for parallel operation with interconnected neutrals. The difficulty is greatest during the operation of synchronizing, but may be considerable at other times unless the prime movers have uniform driving torques. However, it is perfectly feasible to build alternators that will give no such trouble. When such machines are required, it should be specified that the neutral voltages both on open and short circuit, shall not exceed 1 to 2 per cent of the corresponding fundamental coil voltages, instead of from 10 to 15 per cent, as is now frequently the case. It should further be specified that the short circuit neutral currents shall not exceed 10 to 15 per cent of the full load coil current, instead of 100 per cent as is now common.

Machines built to meet these specifications will operate with complete satisfaction with their neutrals solidly connected together.

DISCUSSION ON "PARALLEL OPERATION OF THREE-PHASE GENERATORS WITH THEIR NEUTRALS INTERCONNECTED". SAN FRANCISCO, CAL., MAY 5, 1910.

H. J. Ryan: The author of this paper defines the factors that cause undesirable currents to circulate among the common neutrals of large Y-connected alternators operated in parallel. He develops analytically the relations of those factors so that the magnitude of the circulating currents may be predetermined with a fair degree of accuracy. To be able to do this is half the battle that must be fought to reduce them to harmless proportions.

In the Interborough and similar plants, the alternator neutrals are paralleled and grounded so that an underground cable feeder in which a fault through the insulation to ground develops will be automatically disconnected before the fault grows into a complete and destructive short circuit. This mode of operation developed troublesome circulating currents among the paralleled neutrals of the alternators. The remedy finally adopted was to ground the neutral of but one alternator. in each of the two Interborough stations operating in parallel. The proportions employed in setting the feeder circuit-breakers, resistance of ground connections, etc., are such as to secure maximum effectiveness of the protection thus accorded the underground system.

This eliminates the paralleled neutrals and constitutes one remedy that has been put into practice with rather good results.

At the close of this paper the author proposes two additional remedies:

1. The distribution of each armature phase over 120 deg. fundamental, in lieu of 60 deg.

Each pair of actual or fundamental poles have as third harmonic components six small poles. These proposed broad armature coils cut such third harmonic poles in opposing pairs. Phase opposition occurs in developing the corresponding third harmonics e.m.fs. with a net result of zero for such e.m.fs., no matter to what extent the third harmonic poles may be produced by armature reaction.

2. A uniform distribution of air-gap reluctance and a polar distribution of field excitation m.m.f. so as to match the distribution of armature reaction m.m.f.

This practically implies an alternator modeled structurally much like an induction motor or generator.

These are features that the factories can very likely find a way to meet. Doubtless generators of this character should be somewhat less desirable in other respects, because they are not now found in practice. As against the compromise method now in use designated above as No. 1, is either method, No. 2 or No. 3, desired sufficiently to offset the manifest disadvantages that must exist somewhere for the reason just given? One hopes that the discussion of this paper will throw some light hereon.

The author of the paper has done the profession a real service in demonstrating that all problems which owe their origin to non-sine wave conditions may be solved by the sine-wave methods applied to the multi-frequency components of the original irregular alternating waves. The method looks complicated because of the many terms that the several frequencies introduce. Inherently it is nothing more than an extension of our common methods.

S. J. Lisberger: In paralleling the two alternators, Mr. Rhodes speaks of alternating the two; does he leave the neutral of the alternator that is to be grounded, when the two are in final parallel, open until the two are synchronized, or is it closed at the moment of synchronizing the two alternators?

G. I. Rhodes: We have little occasion to parallel two generators with their neutrals interconnected. Normally, one unit in each plant is connected to the neutral bus. When this grounded machine is to be taken out of service the neutral of a second is grounded and then that of the first cleared. This procedure allows the two machines to run for a short time with their neutrals in parallel.

When the two stations have to be synchronized the operation is performed with the neutral of each grounded. The rheostats however, limit the interchange of current to a small value.

The primary object of the ground resistance is to limit the flow of current to a grounded cable. This is the sole object where a single rheostat is used. Where a separate resistance is inserted in the neutral connection of each generator it has the added function of greatly reducing the interchange of triple harmonic currents between machines.

C. L. Cory: On the Pacific Coast we have had some experience in operating high-voltage Y-connected generators, and the resultant higher harmonic e.m.fs. There are one or two things I may add to the paper, not so much regarding the operation of the generators in the station but the results on outside circuits of grounding the neutral.

There are in the Redondo Station of the Pacific, Light & Power Company three 5000-kw., 18-000-volt, Y-connected generators directly driven by reciprocating engines and during a fifteen day test of one of the units, as well as during the regular operation of the plant, the presence of these higher harmonics was observed in a manner somewhat similar to that outlined in the New York station. I do not know exactly what was done regarding the neutral connections to the ground after the test was completed, but during the test ammeters were connected in the neutral circuit to the ground from each of the three generators. It was observed that the ground currents varied with the relative loads upon the generators.

I do not recall at this time what arrangement was made regarding the neutral connections during the synchronizing of the generators, but the three generators were operated in synchronism during the test and the plant as a whole was run in synchronism with water power and other steam driven stations many miles away.

One thing which was observed, of which you unquestionably have knowledge in the operation of such machines, was the impossibility of connecting the secondaries of the transformers in delta with their primaries connected Y since there is a current due to the e.m.f. of the higher harmonic waves which manifests itself in the delta connection of the secondary side. There is another point, and if I am wrong, Mr. Rhodes, I will be very glad to have you correct me, is that the magnitude of the current from the neutrals to the ground due to the higher harmonics, principally the third, depends directly upon the voltage of the generators.

G. I. Rhodes: Yes. The current flowing to ground on account of the electrostatic capacity of the lines is directly proportional to the voltage. The interchange of current between machines is the same proportion of full-load current irrespective of the voltage.

C. L. Cory: Therefore, if we should reduce the voltage of these generators from 18,000 volts down to 2300 volts the magnitude of the ground currents would be correspondingly reduced, which reduction of voltage, while not a complete solution, would reduce the trouble.

The principal difficulty which was found in this case was the interference with the telephone and telegraph lines wherever there was an exposure of such circuits near the high-voltage transmission lines connected with the system. Telephone lines that operated very satisfactorily before the neutral was connected with the earth were, after this connection was made at the station, practically rendered inoperative. We have here to-day, Mr. President, the engineers of the telephone company and since they have to a great extent inoperative the conditions produced by the operation of high tension transmission systems on the coast, this side of the matter should I think be given due consideration. It is apparent, as set forth in Mr. Rhode's paper, that telephone and telegraph line interference may be of considerable magnitude during the time when the generators are being started and synchronized and that the conditions would not be so severe during the normal operation of the generators, although with the changing loads on the generators serious troubles might be encountered.

In this connection it is worth remembering that very little difficulty, comparatively, has resulted from grounding the neutrals of the 60,000 volt and 100,000 volt transmission lines where the generators are operated at comparatively low voltage and the high line voltage is obtained by step-up transformers.

There is another instance in Southern California where a large steam turbine with a Y-connected high-tension generator had the neutral grounded. In this case the higher harmonics interferred seriously with the operation of the telegraph system. the telegraph and transmission lines running parallel along the right of way of the Southern Pacific Company for a number of miles.

In the general solution of the problems which have arisen and will continue to arise in connection with transmission lines and telegraph and telephone lines, there is no question but that the equations and discussions as set forth in the paper, as well as the conclusions of the author, will be of material advantage.

President Stillwell: I would ask Mr. Rhodes whether he, during his investigation, measured or approximately measured the variation.

G. I. Rhodes: No such measurements have been made.

President Stillwell: Did you form any impression as to whether the variation in angular velocity in the case of the reciprocating engine was quantitatively a serious matter as affecting the interchange of current? In other words, is there serious disadvantage, in your judgment in using a reciprocating engine as compared with a water or steam driven turbine, assuming that armatures are similarly wound?

G. I. Rhodes: The difficulty of operating the plant with the neutrals in parallel was due primarily to the variation in angular velocity of the engines; the trouble during the operation of synchronizing could have been avoided by closing the neutral afterwards. Where turbines are used there is no appreciable surging in the neutral connections.

It is possible to introduce triple harmonic current by unequal excitations, but under normal conditions these currents are negligible.

President Stillwell: The point I have in mind is, would the variation of angular velocity, in the case of a winding having two slots per phase per pole, be serious from a practical operating standpoint?

If you had *no* third harmonic would it be serious?

G. I. Rhodes: The number of slots per pole has no direct influence on the neutral current. If the alternators had been designed to be without triple harmonics under all conditions of load, the variations in angular velocity would not have been serious. It would have been possible to operate the machines with their neutrals in parallel, without any interchange of current other than that which would occur with the neutrals disconnected.

C. F. Adams: In connection with this question, I do not think the question of circulating currents in grounded neutrals has ever been an issue as far as the apparatus of the Pacific Gas and Electric Corporation has been concerned until possibly within the last few months. Many of the generators at the power stations are Y-connected, others are delta-connected. I don't think the question of the circulating current in neutrals has ever become anything of a factor. At the Oakland station the high potential transformers are of course star-connected on the 2,300-volt side. With synchronous motors of the Stanley type, running connected in the same manner with grounded neutral, there is absolutely no flow of current through the neutral that is noticeable. With the turbines floating on the line, there is no appreciable flow of current through any of the meters, but there is present a circulating current through the neutral of approximately 300 amperes. The speed of the turbines is 720 revolutions, and with practically all of the rest of the system being water-driven, this question of angular velocity would not seem to be much of a factor. I think the matter of current flow is probably due to the variation in the type of pole face used in the generators. That is my opinion and belief at the present time. Mr. Downing has made some experiments in that line, and possibly he can give us some information.

Paul Downing: We have made some tests along the lines which Mr. Adams has indicated, but have not as yet reached any definite conclusion. We have a circulating current there, which is practically constant, regardless of the load carried by the turbines. This particular turbine runs in connection with the transmission line, which is supplied with power from hydroelectric plants. A great deal of the time that particular turbine carries no load, simply floating on the line. As I say, we have not progressed quite far enough with our experiments yet to arrive at any definite conclusion.

Along this same line I would ask Mr. Rhodes if it is common practice to operate different stations in parallel on a given network, and if so, whether or not the current on the neutral of one machine in each station, or one machine, feeds in to a given network.

G. I. Rhodes: The system with which I am connected, consists of two plants operated in parallel with a single generator in each station grounded through a resistance. These resistances practically eliminate trouble from the neutral currents. There is no reason why a network having several power stations could not be operated in this manner.

E. F. Scattergood: Mr. Rhodes speaks of several machines operating in parallel and suddenly one of these machines dropping out. I would ask if that occurs with the turbines or only with the reciprocating engines, or with both?

G. I. Rhodes: There was no definite indication of why a machine would drop out suddenly. It was probably due to the valve motion on the engines. When the machines were operated in parallel with their neutrals interconnected, the surging was very irregular. At times an especially heavy surge would occur on a machine without cutting it out, but this was frequently a preliminary signal of trouble. There should be no trouble of this kind in steam-turbine or in hydraulic plants.

W. F. Lamme: I would like to ask about the regulation of the machine. I have had some experience in paralleling alternators and have noticed that where a machine would run perfectly parallel up to 400 volts, at 2000 volts you could not get satisfactory work out of it at all.

G. I. Rhodes: The inherent regulation of these generators figures out at about four and one-half per cent.

P. M. Lincoln: My judgment of the value of this paper is based entirely upon the conclusions which are mentioned in the last few paragraphs and particularly to the one conclusion which is mentioned in the first sentence of the concluding paragraph. This reads as follows:

> In conclusion then it appears that alternators as usually designed and built are not suited for parallel operation with their neutrals interconnected.

Judging from this it seems that Mr. Rhodes has attempted to demonstrate something contrary to actual facts.

I am familiar with the designs and practice of alternating-current generators as made by the company with which I am connected, and quite a considerable number of the generators made by this company has been operated on four-wire three phase systems with the neutrals of the generators solidly connected to the neutral of the system operated, thus forming the systems with interconnected neutrals such as Mr. Rhodes discusses. In no case where such practice is in use has any particular attention been paid to the design of the generators with a view of reducing any disturbances which might arise from these interconnected neutrals. In the operation of such generators as have been used with interconnected neutrals there has never been any reason for complaint on account of this connection with the single exception of the plant with which Mr. Rhodes is connected. In view of the fact, therefore, that quite a large number of plants are using this method of operation and the further fact that this method is becoming more and more popular as time goes on, I do not think that Mr. Rhodes' broad conclusion is in any sense justified.

The question of circulating currents between various generators operated in parallel is by no means a question of the generators only. The prime movers which operate these generators have a great deal more to do with the magnitude of these circulating currents than has the generator itself. In any plant where alternating current generators are paralleled, currents are bound to circulate between the various units in parallel. The magnitude of these circulating currents is dependent to a very large degree upon the uneven driving torque which is a necessary accompaniment of reciprocating engines. It is well known that the power output of any reciprocating engine is not constant at all times. It rises to a maximum at the beginning of the piston stroke when the pressure within the cylinder is nearly boiler pressure and falls to a minimum at the end of the stroke, when there is no effective pressure within the cylinder. On the other hand the power output of an electric polyphase generator into its circuit is constant, and is the same at each instant of time. The average power output of an engine is equal to the average power output of the generator plus the losses. The excess or deficiency of power in the engine cycle therefore is devoted to two things—first, the speeding up or slowing down of the flywheel which is attached to the generator, and second, a somewhat increased or decreased power output from that particular generator on account of the fact that its e.m.f. wave is forced somewhat ahead or lags somewhat behind the e.m.f. waves of the other units in circuit at the same time. This fact that the e.m.f. wave of one generator is ahead or lags behind the e.m.f. wave of the other generators in circuit at the same time is largely responsible for circulating currents. So long as the various generators are three-phase and are connected together on the outside terminals only it is impossible for triple harmonics or multiples thereof to constitute any part of the currents which circulate between the various units. This is on account of the fact that in the outside terminals of no three-phase generator is it possible for triple harmonic e.m.fs. to appear. As soon, however, as the neutrals of the various generators are interconnected the triple harmonic current can flow and under some conditions this triple harmonic current becomes a very large proportion of the total circulating current that appears between the various units. The flow of this triple harmonic current can be readily determined by placing a meter in the neutral connection between the various units in parallel. It should be borne in mind, however, that the current circulating through the windings of the generator is only one-third of the current which is thus measured as coming from the neutral of the generator. The triple harmonic current in each of the three phases of the generator windings are all in phase and thus the triple harmonic current in the neutral is three times that in the generator winding itself. For instance a triple harmonic of 75 per cent of full load measured in the neutral wire means that only 25 per cent of full load current is circulating through the generator windings. The heating effect of such a 25 per cent triple harmonic superposed upon full load fundamental current would increase the total effect only by 3 per cent. It is quite easy therefore to obtain from measurements made in the neutrals of three-phase generators in parallel an exaggerated idea of the importance of circulating triple harmonic current that may be found between these various units. I do not know of any case where so much as 75 per cent of full load current has been found as a normal condition but I cite an example having an excessive triple harmonic current so as to show how unimportant a part such a circulating current really plays so far as heating of the armature winding is concerned.

Another condition has a very important effect upon this circulating current and that is the amount of armature reaction.

In general the greater the armature reaction (that is the poorer a given machine regulates) the less will be the circulating currents which will be caused by a given departure of the prime mover from uniform rotation. The generators of the Interborough Rapid Transit Company, with which Mr. Rhodes is familiar, have very close regulation. Their short-circuit ratio is over three. In other words, this simply means that a given amount of armature current has less influence over the field than the same amount of armature current would have in a generator whose short circuit ratio is, say, two. Conclusions, therefore, which are reached from a study of machines whose short-circuit ratio is three or more, such as the Interborough machines, do not necessarily hold when the short-circuit ratio is considerably less as is the usual practice in more modern machines.

With recent type machines there may be even a considerable departure from uniform rotation in the prime movers and still the circulating current with interconnected neutrals will not reach a value sufficient to cause the slightest inconvenience. A case in point is the experience of a lighting company in Pittsburg. This company operates a number of 4000-volt generators in parallel with neutrals solidly interconnected. The voltage from the neutral to each outside is about 2200 and all of the lighting by this company is done from neutral to outside. These particular machines are driven by gas engines and the plant has been in operation for a number of years. It is well known that the gas engine has about as great a departure from uniform rotation as any prime mover, but in the case cited above there has not been the slightest disturbance of any kind and neither has there been any question concerning the desirability or advisability of operating their machines in this manner. Quite a number of other plants are using the four-wire, three-phase system of distribution and are connecting the neutrals of their generators direct to the neutral of their systems. This method of operation is becoming more and more favored as time goes on and so far as ordinary generator design is concerned there is nothing to prevent it. This has been proven by the experience of quite a large number of plants.

It is quite evident therefore that experience has proven quite the contrary of the broad conclusions laid down in Mr. Rhodes' paper. It is both unnecessary and inadvisable to follow out the suggestion of making more or less freak generators such as Mr. Rhodes suggests for the overcoming of a difficulty which in actual practice does not exist.

G. I. Rhodes: I believe I have answered most of the questions that have been asked of me, so I will say a few words with respect to Mr. Lincoln's remarks. I also know of a plant of large size operating with neutrals solidly connected together, that did not have any trouble. Some months ago an attempt was made to get a manufacturing company to build generators which it would guarantee as to operation with the neutrals in parallel. No such guarantee could be obtained. It is hard to say why there has been no trouble with the plants Mr. Lincoln mentioned, but if I knew more about the details of the machines, I might be able to explain it.

In response to what Mr. Cory has said about telephone lines, I might bring up an instance of some difficulties experienced with triple frequency current. I have in mind some special tests we made on one of our small turbines, and during this test we had occasion to put in circuit some 35 miles of underground cable operating at 11,000 volts between phases. There was a triple-frequency component of 500 volts in the potential to ground. The neutral current was considerably larger than the line current. The oscillograph record taken during that test was published by Mr. H. G. Stott two years ago. TRANSACTIONS A. I. E. E., Vol. XXVII Part II, page 1536.

C. A. Adams (by letter): As this subject is one in which the writer is greatly interested, he cannot refrain from expressing his admiration for the author's courage in attacking and skill in carrying out even a roughly quantitative solution of this problem. The approximations are necessarily rather gross, but the results should be, and in fact seem to be, close enough to be of great practical value.

There is much food for thought and discussion in connection with the method of analysis and the approximations involved, but as most readers of the TRANSACTIONS are more interested in the remedies for the difficulty, I will stop here to question only one of the author's assumptions, namely that the effective third harmonic reactance at the instant of short circuit " is not over 20 per cent of the (third harmonic) leakage reactance ", if the slot leakage were entirely neglected the coil end leakage alone would ordinarily amount to more than 20 per cent of the total, especially in a 25-cycle turbo-alternator.

Coming now to the remedies, the author has neglected entirely the consideration of fractional pitch windings,[1] although his suggestion of a 120 degree belt span is in some respects equivalent to a two-thirds pitch. A two-thirds pitch with a 60 degree belt would eliminate the third harmonic entirely under all conditions of load, and would save considerable copper and overall length of machine, as compared with the 120 degree belt at full pitch.

Other things being equal the two-thirds pitch winding would require about 15 per cent more slot copper, but a little less coil end copper than the full pitch winding; but as the coil end copper at full pitch is frequently more than 50 per cent of the total, the increase in total armature copper would be only 6 or 7 per cent, which could be neutralized by a slight increase in peripheral velocity. The saving as compared with the 120 degree belt full pitch winding would be 8 or 9 per cent.

It should be noted that the reducing effect of the two-thirds pitch upon other than the triple harmonics is the same as upon the

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[1] " E.m.f. Wave Shape in Alternators ", TRANSACTIONS A.I.E.E., Vol. 28 (1909) p. 802; " Fractional Pitch Winding for Induction Motors ", TRANSACTIONS A.I.E.E., Vol. 26 (1907), p. 1485.

fundamental, so that the relative magnitudes of these other harmonics remain the same. But the belt differential factor reduces each of these, say the nth harmonic, to 1-nth of its value in the flux distribution curve. Thus with any reasonable shaping of the pole face, the 5th, 7th, 11th, 13th, etc., harmonics will be reduced to comparatively small values. However, if it were important to reduce them still farther, it could be done by a double winding in two layers connected in series, each of the two layers giving the same e.m.f. wave-shape as the original winding and the two layers displaced in phase enough to largely eliminate the more important harmonics. The best phase displacement for this purpose is 30 degrees in a three phase machine, see Fig. 9 of the writer's article on " Alternator Wave Shape " referred to above.

This last suggestion would involve considerable additional insulation and complication in winding, and should not be necessary with any reasonably good flux distribution curve.

The author's second suggestion for a remedy, namely a uniform gap and distributed field winding, seems to be quite feasible, although it would be better when combined with a moderate pitch reduction. It should not be difficult with distributed field windings, such as now in considerable use, to obtain a flux distribution of trapezoidal form in which the third harmonic is negligibly small, but with a moderate fifth harmonic. The latter could then be eliminated from the e.m.f. by a coil pitch of 80 per cent or thereabouts.

S. B. Charters Jr., W. A. Hillebrand (by letter): It may be of interest to know that the phenomena described by Mr. Rhodes can be duplicated under laboratory conditions.

Two identical 7½-kw., three-phase, Y-connected alternators, 380 volts per phase, were operated in parallel on a non-inductive load, with the following results:

Line E.	Load I.	Current delivered by one alternator.		Neutral current.	Neutral Potential.
		Neutral, out or open.	Neutral, in or closed.		
Load... 349.	5.4	3.15	3.35	2.7	2.1
No load 379.	0	3.75	4.1	4.1	3.1

Excitation was adjusted for minimum cross currents between the two machines.

Armature impedance for each leg of the Y-connection, 2.6 ohms at 60 cycles.

$$3 \times 2.6 = 7.8 \text{ ohms, at 180 cycles.}$$

Synchronous reactance per phase of each alternator, 3.5 ohms.

Assuming a synchronous reactance to the third harmonic of 2/9 that to the fundamental, as given by Mr. Rhodes, the neutral current for each of the above cases is computed as follows, dividing the measured neutral potential by the impedance of two phases in series.

Load

$$I_n = 3\times\frac{2.1}{2\times 7.8+2\times 2/9\times 3.5} = 0.367 \text{ amp.}$$

No load

$$I_n = 3\times\frac{3.1}{2\times 7.8+2\times 2/9\times 3.5} = 0.542$$

Ratio, observed to computed neutral currents,

Load

$$\frac{2.7}{0.367} = 7.36$$

No load

$$\frac{4.1}{0.542} = 7.57$$

The discrepancy between observed and computed values for the neutral current seems to be due to an amplification of the third harmonic e.m.f. introduced by the third harmonic itself. This was checked by measuring the circulating current in one of the machines operating no load, delta connected, as follows:

Line E	3d Harmonic E with delta open.	3d Harmonic circulating current.
220	17.8	5.0

By computation the third harmonic should be

$$I_3 = \frac{17.8}{3\times 7.8+3\times 2/9\times 3.5} = 0.693$$

Ratio of observed to computed current,

$$\frac{5}{0.693} = 7.22$$

This is a reasonable agreement with the previous ratios 7.36 and 7.57.

The oscillograph showed that the current circulating in the delta was practically a pure third harmonic.

G. I. Rhodes: The apparent discrepancy between calculated and observed neutral currents as given by Messrs. Charters and Hillebrand may possibly be explained as follows: The value of the reactance to triple harmonic current is given in the paper as the sum of three times the leakage reactance plus 2/9 of the reaction reactance. This latter quantity is defined as the difference between the synchronous and the leakage reactances. The figure given for leakage reactance is abnormally high and on that account is open to some question. It is probable that there was a misunderstanding as to the definitions of the reactances to be used in calculating neutral current.

Mr. Lincoln's adverse criticism of the paper deserves attention. His chief objection appears to be based solely on the wording of the conclusion, without any reference to the subject matter leading up to it. His discussion seeks to establish the fact that alternators as usually designed and built are suitable for operation with interconnected neutrals, without special consideration to design.

The fact that some machines have proved incapable of operation with paralleled neutrals indicates beyond a doubt that design has a great deal to do with it, and the cause of this trouble should be investigated rigidly so that it may be avoided in future installations. This paper has investigated the cause and suggested a remedy.

Mr. Lincoln offers in support of his criticism, the satisfactory operation of certain plants with solidly interconnected neutrals. He gives absolutely no details to indicate whether or not these generators embodied any elements of design tending to reduce neutral currents, or as to their size, number, or conditions of operation. He specifically mentions the generators which have caused trouble, as special, on account of their low armature reaction.

The writer has investigated the only plant mentioned with sufficient detail to afford identification. This plant consists of two 200-kw. 4000-volt, three-phase, Y-connected, gas-engine-driven generators. They are designed with large armature reaction and large leakage reactance, to limit interchange of current. The neutrals are solidly connected together as are also the lines as far as automatic switches are concerned.

What is satisfactory operation?

At the time the writer was in the plant there were occasional surges between the generators sufficient to cause the wattmeter on one to fall to zero, and that on the other to rise to double the load with violent oscillations. The engineers seemed not in the least worried. It was evidently not an uncommon occurrence. Such conditions which were "satisfactory" in this 400-kw. plant would have been disastrous in a plant of 40,000 kw.

This small plant consisted of but two units. It has been found quite possible to operate two units in the plants with which the writer is connected. It was sometimes possible to operate even three, but it was absolutely impossible to operate more than this number. If this gas-engine plant had consisted of eight to ten units as is frequently the case in larger systems, it is probable that there would have been trouble.

Mr. Lincoln makes a statement as to the unimportance of the heating effect of the neutral current. He states that a 75 per cent current corresponds to a 25 per cent triple harmonic coil current. He states the increased heating effect is 3 per cent. This figure should be 6 per cent, for the increased loss is proportional to the square of the current value of non-fundamental frequency. Thus, the heating with 75 per cent neutral current is $1.00^2 + 0.25^2 = 1.063$. The extreme figure given by Mr. Lincoln for neutral current is very much too small. The writer has knowledge of a case in which the current was several times full load. It is thus evident that the heating effect of neutral current is not always negligible.

Mr. Lincoln's reference to the low armature reaction of the machines which have proved incapable of satisfactory operation with interconnected neutrals indicates his belief that this low reaction was responsible for the trouble.

If he had studied the paper instead of the conclusion he would have observed the following:

1. Neutral potential is directly proportional to armature reaction.

2. Neutral current is independent of armature reaction.

3. Neutral current is in the inverse ratio to leakage reactance.

That is, the small reaction had nothing whatever to do with the interchange of neutral current which proved dangerous.

Mr. Lincoln, after attempting to demonstrate the non-existence of a condition proved in the paper without pointing out a flaw affecting the value of the work, criticises the proposed remedies as " freak." That is, a winding occupying 120 consecutive electrical degrees per phase or a smooth rotor with distributed field winding is a " freak." Every two-thirds pitch winding having a belt span of 60 degrees fulfills the first specification. This type of winding is by no means rare, as may be discovered by an inspection of some of the armatures in the shops of the large manufactuing companies. It is frequently used to obtain the best copper economy under certain conditions of design. It is by no means improbable that some of Mr. Lincoln's satisfactory generators which have given no cause for complaint contain such windings, although those examined by the writer had full pitch coils. Many turbo-alternators are now built with uniform air gaps and field windings distributed to give a good wave form. It is safe to say that there are in existence alternators in which the triple harmonic potentials or currents generated are of very small value. They have never before been branded as " freak."

The conclusion given in the paper still stands. It is unsafe to depend on satisfactory operation of alternators with interconnected neutrals unless triple harmonics are eliminated by proper design. Such machines are entirely practicable and should be specified whenever paralleling of the neutrals is required.

Ralph D. Mershon (by letter): The papers by G. I. Rhodes and J. J. Frank, are closely related. Their correspondence becomes evident when we consider some of the consequences of operating generators in parallel with their neutrals interconnected. With such connection it is possible to safely and effectively operate all transforming equipment with both windings connected in Y and with all neutrals interconnected. Under these conditions, the dangerous third harmonic voltage, of which Mr. Frank's paper treats, disappears, and might therefore be ignored in general engineering practice, except where connections other than Y become necessary.

But the elimination of the third harmonic voltage, due to the exigencies of iron magnetization, is not the only advantage of Y connection. There is another advantage, though the importance of it in transmission work does not seem to be generally realized.

If a transmission system be supplied from generators operating with their neutrals connected to a neutral busbar, and with all transformer windings connected in Y, the system is simpler and more flexible than one in which any delta connections are employed. We may say that it is a system made up of three independent, or nearly independent, single phase circuits 120 deg. apart. This is not true of a three phase circuit in which the three phases are inter-related through delta-Y or delta-delta connections.

Let us consider a transmission system on which the generators are run with a neutral busbar and of which the step-up transformers are run in Y on both high and low voltage sides. Then each transformer will require only two switches to cut it clear of all voltage, one in one high voltage lead and one in one low voltage lead. Each of the other two leads will be connected to a neutral bus which may be grounded. This latter connection may be made by any suitable connector, since it will seldom have to be distrubed and will be perfectly safe to handle at all times. On the other hand, with transformers in delta-Y three switches (two for one winding and one for the other) are required, and with them in delta-delta four (two for each winding) are necessary to perform the same service.

Again, a spare step-up transformer will, for delta-Y connection, require nine switches, and for delta-delta connection twelve switches, to enable its use to replace any of the operating transformers. With Y-Y connection, only six switches are necessary for the same service.

The same simplification applies to the step-down transformers, if the high voltage neutral of both step-up and step-down transformers be dead grounded or grounded through a resistance of relatively moderate value. If either of them be ungrounded or grounded through a high resistance, the step-down transformers must be connected in delta on at least one set of windings in order to avoid the possibility of collapse of the voltage triangle.

There have been some remarks in the previously published discussion of Mr. Rhodes' paper to the effect that such a paper has no particular bearing on present practice, since generators are already in practice operated with their neutrals interconnected. These remarks give the impression that satisfactory operation under such conditions can be readily attained, and that there is no reason why it should not be a usual thing without any particular precautions in design and operation of the generators. This is quite contrary to my experience. When endeavoring to obtain generators for operation on a neutral busbar I have found that the manufacturers refused to extend the usual guarantees to operation in this manner. I am glad to know that generators for such operation can now be readily obtained, and hope that when next the demand for them arises I shall find them obtainable without the exception that has been imposed heretofore.

These two papers strike me as valuable and important ones. I think they will hereafter furnish a starting point for the explication of many of the phenomena of alternating current transmission systems.

H. Y. Hall (by letter): There are three schemes for the operation of grounded neutral systems, as exemplified by the practice of the Manhattan Railway Co., New York Central Railway and Southern Pacific Co.

At the Manhattan Railway plant, see Fig. 1, only one machine at a time is grounded. The advantage of the scheme is that the resistance between neutral and ground does not vary with the number of generators in operation, but is fixed and practically constant, thus allowing a sufficient current to flow to the ground to trip the relay in case a feeder becomes grounded. The disadvantage of this scheme is that during the time consumed in transferring the ground connection from one generator to another the system is ungrounded. This scheme has proven satisfactory during six years of service.

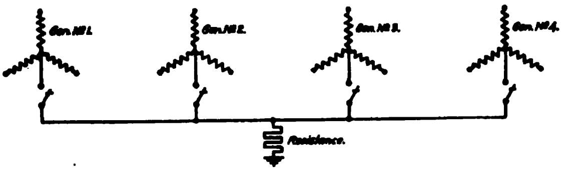


FIG. 1.—Manhattan Railway Co. practice

As will be seen from Fig. 2 the scheme used by the Southern Pacific Co., at its Fruitvale plant is the same as that used by the Manhattan Railway Co., except the use of single-pole double-throw switches instead of single-pole, single-throw switches for the neutrals and the sectioning of the neutral bus. The practice will be to run with all neutral switches in the down position, except that for the grounded machine which will be in the up position. When it is desired to shift the neutral connection, the switch on the generator to be grounded is thrown up, after which the switch for the generator to be disconnected from ground is thrown to the down position. the system would be ungrounded during only the time it takes to throw a switch from the up to the down position. The neutral resistance is a grid type rheostat having a resistance of 13 ohms and capable of dissipating 6000 kw.

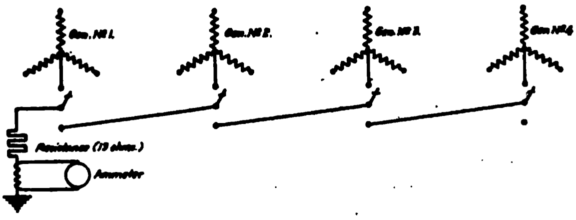


FIG. 2.—Southern Pacific Company practice

for 30 seconds without injurious heating. With a dead ground on one phase of a feeder, this resistance would limit the current to 500 to 600 amperes which is sufficient to operate the automatics on the feeders; there are no automatic devices on the generators.

At the N. Y. C. power stations, see Fig. 3, it would be safe to operate with the neutral switches closed on all four machines, if the two interconnecting switches were open, as there would be very little current flowing in the neutrals. It is not advisable

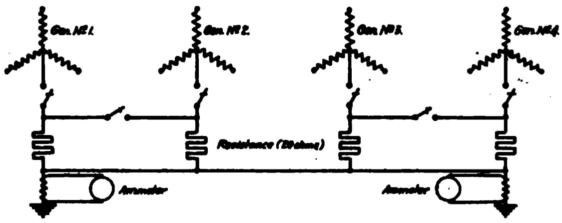


FIG. 3.—N. Y. C. & H. R. R. R. practice

to operate with all neutral switches closed as there would be only five ohms resistance between neutral and ground, which would allow too much current to flow, in case of a ground on one leg of a feeder. Two sets of resistances should be kept connected in whether one or all generators are being operated.

In connection with the installation and operation of grounded neutral systems, another point to be borne in mind is the method of connection of potential transformers. If star connected potential transformers are to be used they should be connected to the neutrals of the machine, instead of to the neutral bus or the ground bus, for the neutral connection. If they are connected to the ground or neutral bus, whenever the system is running ungrounded the potential transformer voltages will be greatly unbalanced due to the difference in the loading of the potential transformers. At the Port Morris plant of the New York Central there have been potential transformer burn-outs, due to 50 per cent over-voltage on potential transformers. The system at the time was not grounded as the operator forgot to put in the neutral switch on the machine in service. For feeders, potential transformers should be connected between phases and not to the neutral or ground.

A paper presented at the 248th meeting of the American Institute of Electrical Engineers, San Francisco, Cal., May 6, 1910.

OBSERVATION OF HARMONICS IN CURRENT AND IN VOLTAGE WAVE SHAPES OF TRANSFORMERS

BY JOHN J. FRANK

INTRODUCTION

Ever since Professor Ryan presented his famous paper on "Transformers" before the Institute, in which attention was called to the lack of symmetry between curves of instantaneous values of current and potential applied to the transformer, numerous writers have discussed the subject from various view points.

One writer on the subject, Mr. Charles K. Huguet, draws the conclusion that the distortion is due entirely to the variations in the permeability of the iron core since hysteresis is essentially unsymmetrical with respect to the magnetization.

Dr. Bedell and Mr. Elbert C. Tuttle, in a more recent paper, present the subject from a purely theoretical view point. In their discussion, they show how complex current waves may be formed by the combination with a fundamental of triple harmonic wave shapes of different amplitude and phase relation. The significance of the resultant wave distortion and of the various hysteresis loops plotted are fully discussed and the following conclusions drawn:

1. When a sinusoidal electromotive force is applied to a coil of wire embracing iron, an alternating current will flow distorted by the presence of a third harmonic.

2. This harmonic is in advance of the fundamental by an angle ψ, which is greater than 30 deg. and less than 180 deg.

3. Considering the maximum of the fundamental as unity, the maximum of this harmonic cannot exceed a definite value of about 0.192 for $\psi = 30$ deg. and 0.333 for $\psi = 180$ deg. (See following table).

LIMITING VALUES OF β AND ψ FOR VARIOUS VALUES OF ϕ

ϕ	β	ψ	ϕ	β	ψ
0°	0.111	0°	40° 6′	0.211	29° 34′
	0.112	5° 41′	45° 14′	0.220	29° 6′
	0.113	7° 59′	46° 34′	0.222	27° 43′
	0.116	11° 8′	57° 44′	0.240	27° 28′
1° 17′	0.120	16° 20′	60° 42′	0.244	27° 1′
1° 45′	0.122	16° 54′	71° 44′	0.260	25° 8′
4° 48′	0.133	22° 30′	76° 48′	0.267	24° 9′
6° 55′	0.140	24° 28′	87° 47′	0.280	21° 56′
8° 34′	0.144	25° 35′	95° 54′	0.289	20° 12′
12° 52′	0.156	27° 40′	107° 16′	0.300	18° 4′
14° 15′	0.160	28° 15′	120° 40′	0.311	14° 34′
17° 37′	0.167	28° 57′	134° 4′	0.320	11° 22′
22° 44′	0.178	29° 41′	143° 35′	0.322	10° 23′
23° 47′	0.180	29° 47′	157° 18′	0.330	5° 43′
30° 39′	0.192	30° 00′	180°	0.333	0°
33° 59′	0.200	29° 56′			

DATA RELATIVE TO COMPLEX CURVES

ϕ	β	α	ψ	I	I′
0°	0.111	0°	0°	1.006	0.8890
2°	0.122	16° 54′	17°	1.007	0.8832
5°	0.135	22° 48′	23°	1.009	0.8833
20°	0.172	29°	29° 30′	1.015	0.9250
30°	0.193	29° 33′	30°	1.019	0.9624
45°	0.220	28° 38′	29° 22′	1.024	0.9868
90°	0.283	19° 36′	20° 30′	1.039	1.1850
135°	0.321	10° 12′	10° 45′	1.050	1.2850
180°	0.333	0°	0°	1.053	1.3330

ϕ is the phase relation of the third harmonic to the fundamental at the origin.
β is the ratio of the maximum ordinates of the fundamental and third harmonic (critical value).
ψ is the phase difference between the maxima of the distorted and fundamental curves.
$90 - \phi$ is lag of fundamental component of current behind e.m.f.
$90 - \alpha$ is lag of equivalent sine current behind e.m.f.
I and I′ are the maxima of the equivalent sine curve and distorted curve, respectively, the maximum value of the fundamental being unity.

4. The angle of hysteretic advance due to the third harmonic cannot exceed 30 degs.

To these may be added also the following conclusions:

5. That if a sinusoidal electromotive force is impressed upon a coil, the magnetic flux threading the coil will likewise be

sinusoidal, and in phase 90 deg. behind the electromotive force, whether the coil embraces iron or not.

6. That the maximum of the current wave must coincide with the maximum of the flux. If the coil embraces iron, the maximum flux coincides with the maximum of the complex wave; if the coil does not embrace iron, the flux coincides with the sinusoidal current wave.

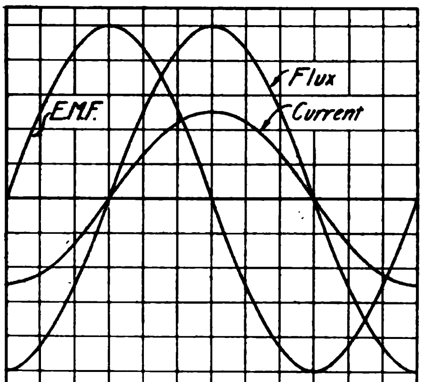


Fig. 1.—Phase relation of current, voltage and flux in a coil not encircling iron

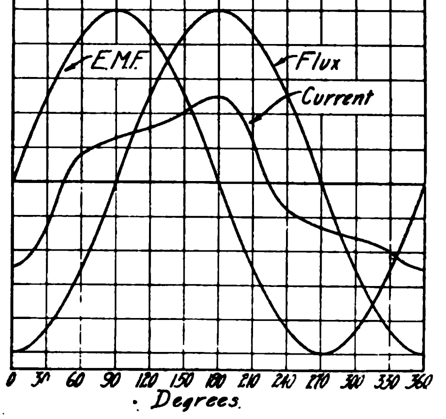


Fig. 1A.—Phase relation of current, voltage and flux in a coil encircling iron

The first four conclusions are drawn from figures given in the preceding tables taken from the paper referred to.

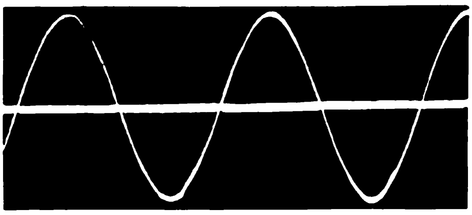
Conclusions 5 and 6 are illustrated in Fig. 1, "Phase relation of current, voltage and flux in a coil not encircling iron", and in Fig. 1 A, "Phase relation of current, voltage and flux in a coil encircling iron."

From the writer's experience, he was led to believe that the value of the third harmonic was not limited to the figures given

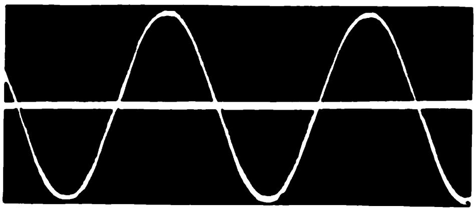
SHEET I.

Oscillograms observed on three single-phase 60-cycle, 150-kw., 4150 volt, Y-connected primary, 480-volt secondary transformers, installed in substation No. 34 of the Rochester Railway and Light Company, Rochester, N. Y.

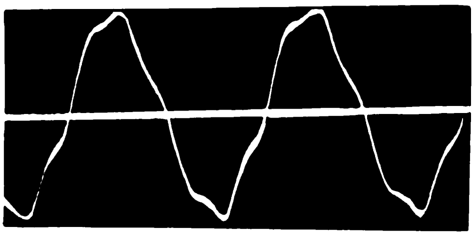
Neutral Isolated—Delta Closed



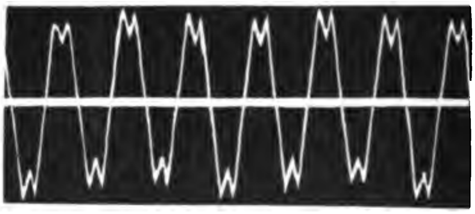
Curve No. 1
Potential, line to line, 4293 volts.



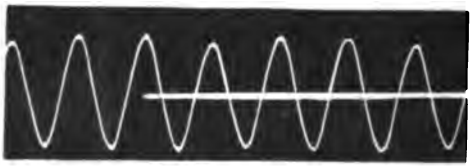
Curve No. 2
Potential across one transformer (*i.e.*, line to neutral), 2422 volts.



Curve No. 3
Current in line (*i.e.*, in transformer), 1.2 amperes.



Curve No. 4
Potential across isolated neutral (*i.e.*, neutral to ground), 125 volts

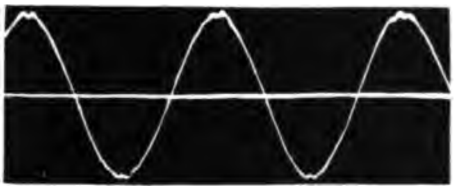


Curve No. 5
Current in closed secondary delta, 2.35 amperes.

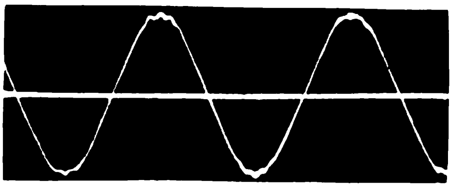
SHEET 2

Oscillograms observed on three single-phase, 60-cycle, 185-kw., 4150-volt Y-connected primary, 480-volt secondary transformers, installed in substation No. 34 of the Rochester Railway & Light Co., Rochester, N. Y.

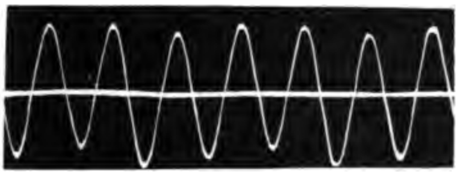
Neutral Connected—Delta Closed



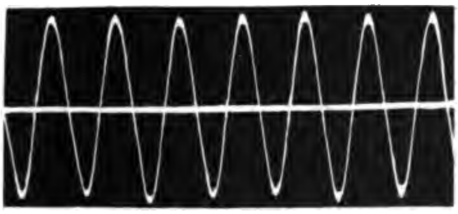
CURVE No. 6
Potential, line to line, 4342 volts.



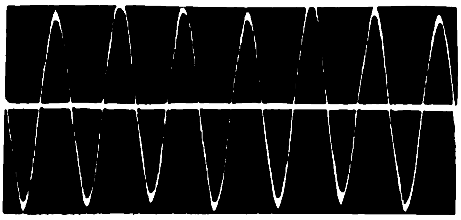
CURVE No. 7
Potential across one transformer, 2540 volts.



CURVE No. 8
Current in line, 39.5 amperes.



CURVE No. 9
Current in connected neutral, 122 amperes.

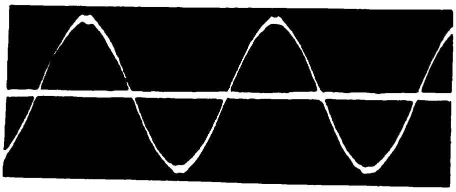


CURVE No. 10
Current in closed secondary delta, 180 amperes.

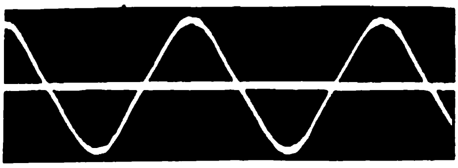
SHEET 3

Oscillograms observed in three single-phase, 60-cycle, 185-kw., 4150-volt Y-connected primary, 480-volt secondary transformers, installed in substation No. 34 of the Rochester Railway & Light Co., Rochester, N. Y

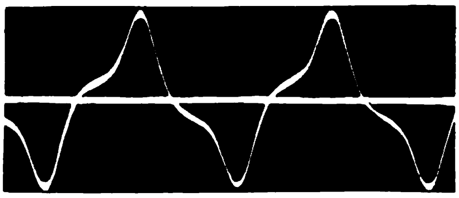
Neutral Connected—Delta Open



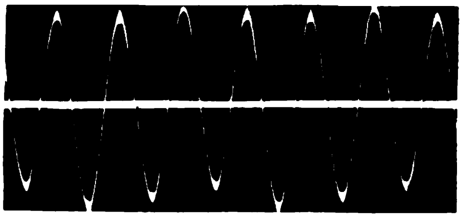
Curve No. 11
Potential, line to line, 4233 volts.



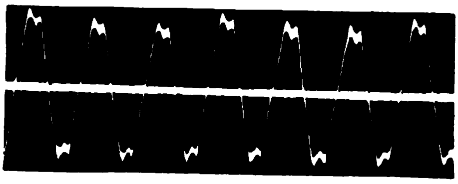
Curve No. 12
Potential across one transformer, 2453 volts



Curve No. 13
Current in line, 1.65 amperes.



Curve No. 14
Current in connected neutral, 1.45 amperes.

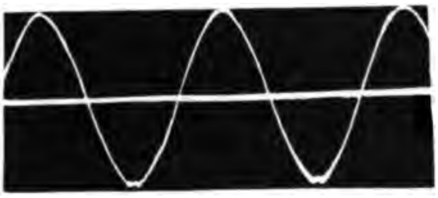


Curve No. 15
Potential across open secondary delta, 73 volts

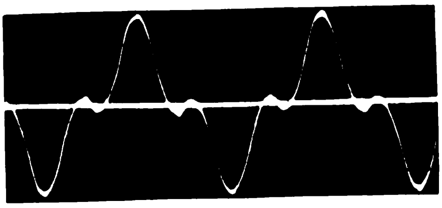
SHEET 4

Oscillograms observed on three-single phase, 60-cycle, 185-kw., 4150-volt Y-connected primary, 480-volt secondary transformers, installed in substation No. 34 of the Rochester Railway & Light Co., Rochester, N. Y.

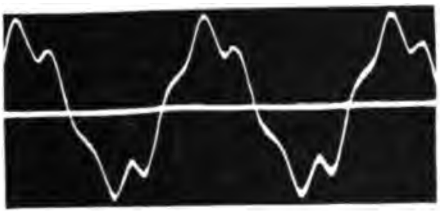
Neutral Isolated—Delta Open



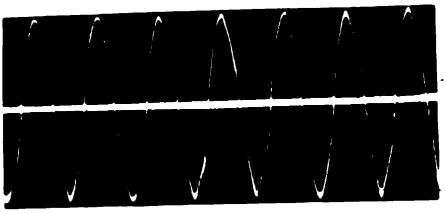
CURVE No. 16
Potential, line to line, 4250 volts.



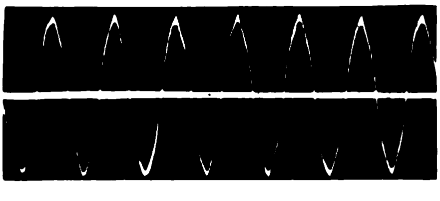
CURVE No. 17
Potential across one transformer, 2705 volts.



CURVE No. 18
Current in line, 1.1 ampere.



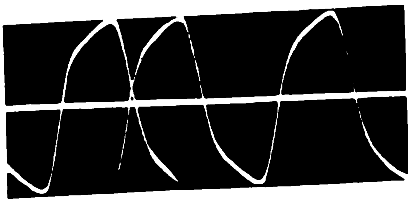
CURVE No. 19
Potential across isolated neutral, 1041 volts.



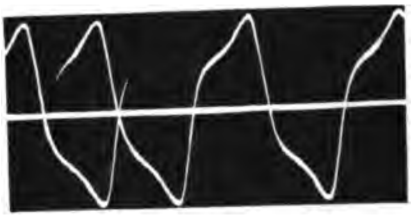
CURVE No. 20
Potential across open secondary delta, 720 volts.

SHEET 5

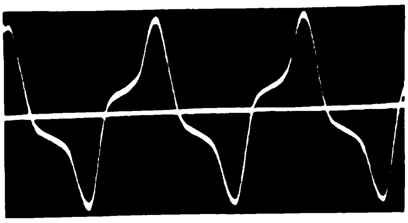
Oscillograms taken on one single-phase, core-type, 25-cycle, 185-kw. 33,000-volt primary, 430-volt secondary transformer, connected single-phase.



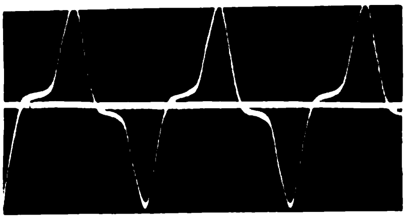
Curve No. 21
Current at 22.6 kilolines.
3.48 amperes.



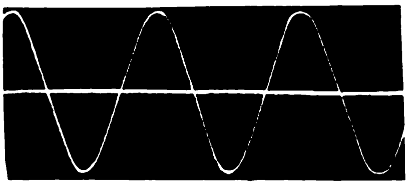
Curve No. 22
Current at 45.2 kilolines,
5.49 amperes.



Curve No. 23
Current at 67.9 kololines,
12.5 amperes.



Curve No. 24
Current at 90.5 kilolines,
35.8 amperes.



Curve No. 26
Potential at 90.5 kilolines
430 volts.

SHEET 6

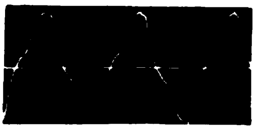
Oscillograms taken on one three-phase, core-type, 25-cycle, 40-kw., 2300-volt Y-connected primary, 460-volt delta-connected secondary transformer. Density, 106.4 kilolines.

Isolated Neutral—Closed Delta

CURVE No. 28
Potential, line to line, 2875 volts.

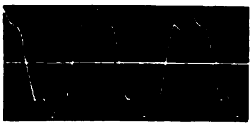
CURVE No. 29
Potential across leg 1, (*i.e.*, line 1 to neutral) 1650 volts.

CURVE No. 30
Potential across leg 2, 1650 volts.



CURVE No. 31
Potential across leg 3, 1650 volts.

CURVE No. 32
Current in line 1 3.36 amperes.



CURVE No. 33
Current in line 2, 2.76 amperes.

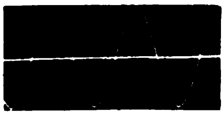
CURVE No. 34
Current in line 3, 3.0 amperes.

CURVE No. 35
Current in closed secondary delta, 2.93 amperes.

SHEET 7

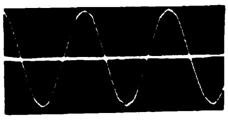
Oscillograms taken on one three-phase, core-type, 25-cycle, 40-kw., 2300-volt Y-connected primary, 460-volt delta-connected secondary transformer. Density, 106.4 kilolines.

Connected Neutral—Closed Delta

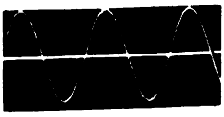


CURVE No. 36
Potential line to line, 2875 volts.

CURVE No. 37
Potential across leg 1, 1652.5 volts. (42.55 kilolines, 662 volts.)



CURVE No. 38
Potential across leg 2, 1652.5 volts.



CURVE No. 39
Potential across leg 3, 1652.5 volts.

CURVE No. 40
Current in line 1, 3.16 amperes.

CURVE No. 41
Current in line 2, 2.56 amperes.

CURVE No. 42
Current in line 3, 3.26 amperes.

CURVE No. 43
Current in connected neutral, 0.7 amperes.

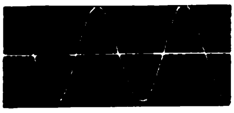
CURVE No. 44
Current in closed secondary delta, 3.0 amperes

SHEET 8

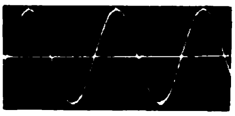
Oscillograms taken on one three-phase, core-type, 25-cycle, 40-kw., 2300-volt Y-connected primary, 460-volt delta-connected secondary transformer. Density, 106.4 kilolines.

Connected Neutral—Open Delta

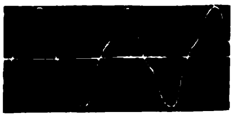
CURVE No. 45
Potential, line to line, 2875 volts.



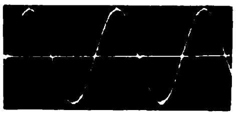
CURVE No. 46
Potential across leg 1, 1652.5 volts.



CURVE No. 47
Potential across leg 2, 1652.5 volts.

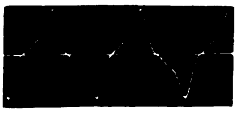


CURVE No. 48
Potential across leg 3, 1652.5 volts.



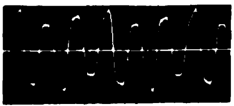
CURVE No. 49
Current in line 1, 2.96 amperes.

CURVE No. 50
Current in line 2, 2.76 amperes.



CURVE No. 51
Current in line 3, 3.16 amperes.

CURVE No. 52
Current in connected neutral, 3.25 amperes.



CURVE No. 53
Potential across open secondary delta, 4 volts.

SHEET 9

Oscillograms taken on one three-phase, core-type, 25-cycle, 40-kw., 2300-volt Y-connected primary, 460-volt delta-connected secondary transformer. Density, 106.4 kilolines.

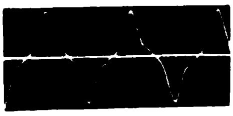
Isolated Neutral—Open Delta

Curve No. 54
Potential, line to line, 2875 volts.

Curve No. 55
Potential across leg 1, 1655 volts.

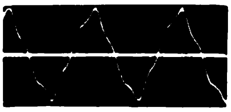
Curve No. 56
Potential across leg 2, 1655 volts.

Curve No. 57
Potential across leg 3, 1655 volts.



Curve No. 58
Current in line 1, 3.32 amperes.

Curve No. 59
Current in line 2, 2.64 amperes.



Curve No. 60
Current in line 3, 2.94 amperes.

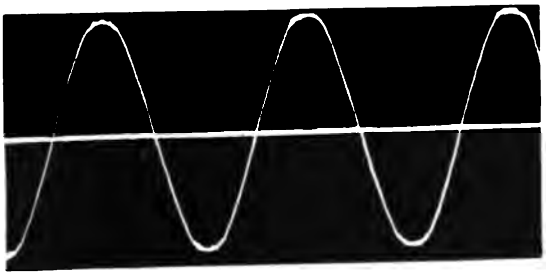
Curve No. 61
Potential across isolated neutral, 135 volts.

Curve No. 62
Potential across open secondary delta, 150 volts.

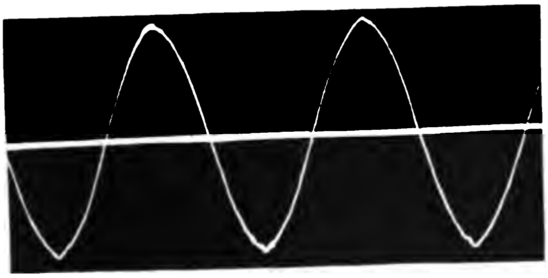
SHEET 10

Oscillograms taken on three single-phase, core-type, 25-cycle, 25-kw., 2300-volt delta-connected primary, 460-volt Y-connected secondary transformers.

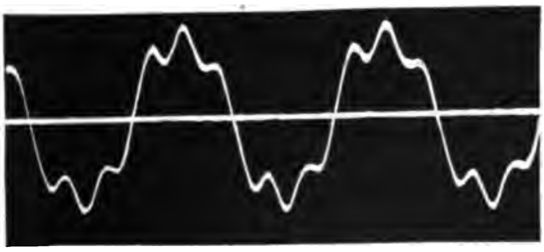
Isolated Neutral—Closed Delta



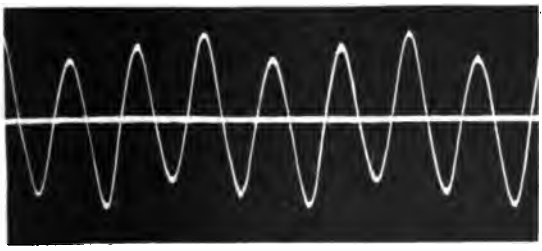
Curve No. 63
Potential line to line, 795 volts.



Curve No. 64
Potential across one transformer (*i.e.*, line to neutral), 462.5 volts.



Curve No. 65
Current in line (*i.e.*, in transformer), 5.81 amperes.

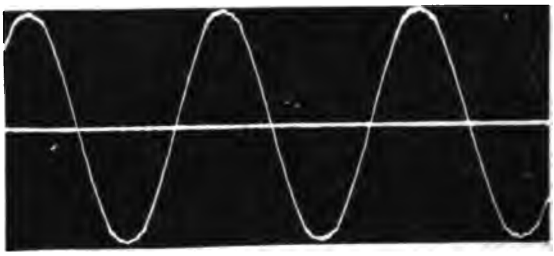


Curve No. 66
Current in closed primary delta, 0.63 ampere.

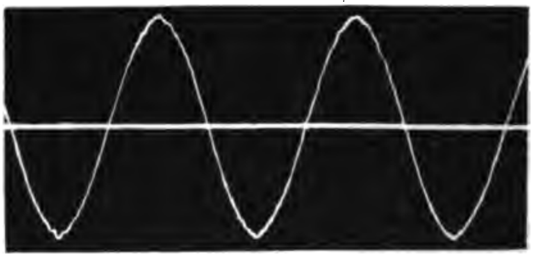
SHEET 11

Oscillograms taken on three single-phase core-type, 25-cycle, 25-kw., 2300-volt delta-connected primary, 460-volt Y-connected secondary transformers.

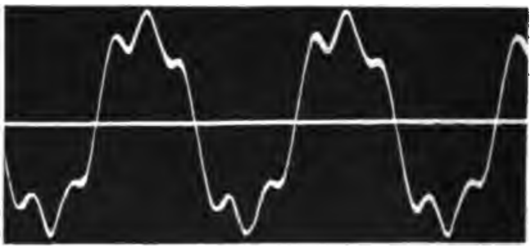
Connected Neutral—Closed Delta



CURVE No. 67
Potential line to line, 795 volts.



CURVE No. 68
Potential across one transformer, 462.5 volts.



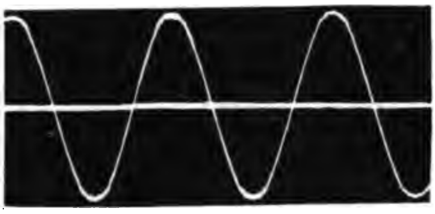
CURVE No. 69
Current in line, 3.88 amperes.

CURVE No. 70
Current in connected neutral, 0.76 ampere.

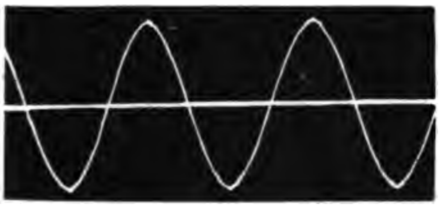
SHEET 12

Oscillograms taken on three single-phase, core-type, 25-cycle, 25-kw., 2300-volt delta-connected primary, 460-volt Y-connected secondary transformers.

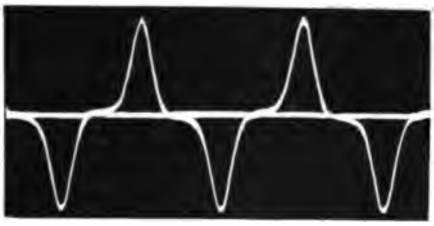
Connected Neutral—Open Delta



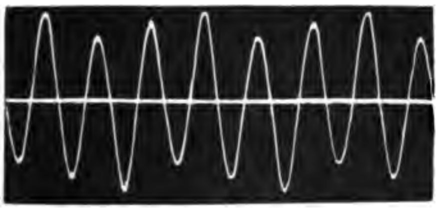
Curve No. 71
Potential line to line, 795 volts.



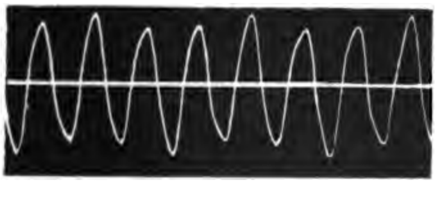
Curve No. 72
Potential across one transformer, 462.5 volts.



Curve No. 73
Current in line, 5.94 amperes.



Curve No. 74
Current in connected neutral, 9.45 amperes.

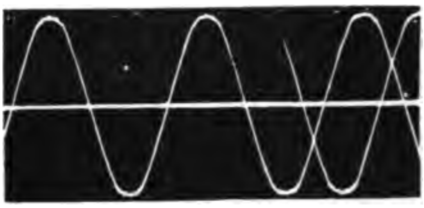


Curve No. 75
Potential across open primary delta, 24.5 volts.

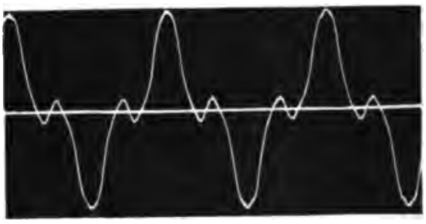
SHEET 13

Oscillograms taken on three single-phase, core-type, 25-cycle, 25-kw, 2300-volt delta-connected primary, 460-volt Y-connected secondary transformers.

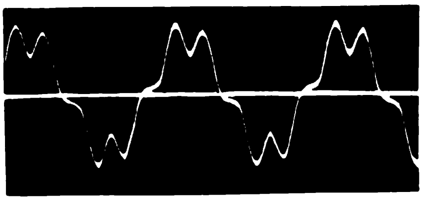
Isolated Neutral—Open Delta



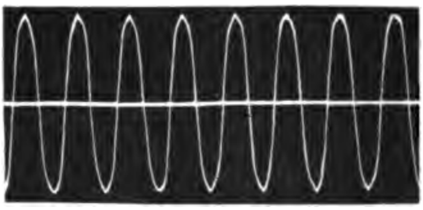
Curve No. 76
Potential line to line, 795 volts.



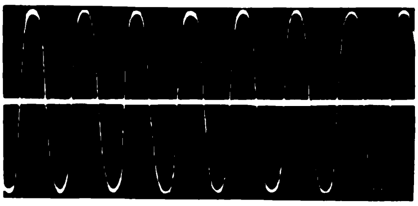
Curve No. 77
Potential across one transformer, 525 volts.



Curve No. 78
Current in line, 3.37 amperes.



Curve No. 79
Potential to isolated neutral, 257 volts.

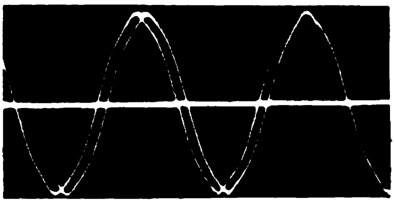


Curve No. 80
Potential across open primary delta, 3780 volts.

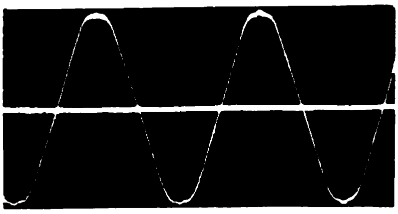
SHEET 14

Oscillograms taken on one three-phase, shell-type, 60-cycle, 330-kw., 13,200-volt delta-connected primary, 430-volt Y-connected secondary transformer.

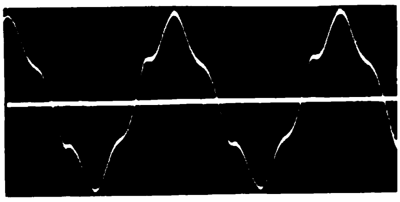
Isolated Neutral—Closed Delta



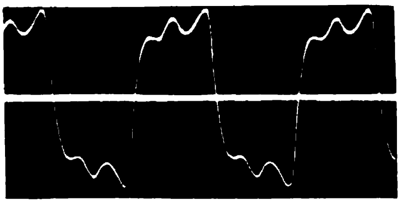
Curve No. 81
Potential, line to line, 745 volts.



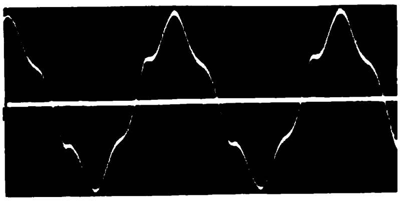
Curve No. 82
Potential across one leg (*i.e* line to neutral), 430 volts.



Curve No. 83
Current in line 1, 58.8 amperes.



Curve No. 84
Current in line 2, 44.6 amperes.

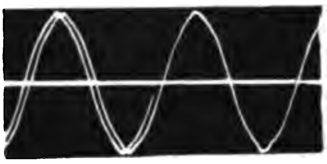


Curve No. 85
Current in line 3, 57.8 amperes.

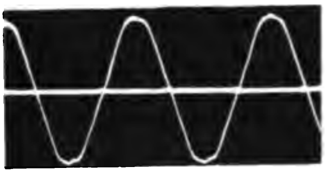
SHEET 15

Oscillograms taken on one three-phase, shell-type, 60-cycle, 330-kw., 13,200-volt delta-connected primary, 430-volt Y-connected secondary transformer.

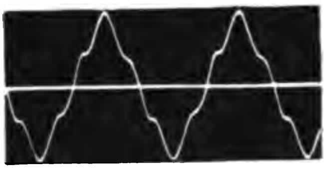
Connected Neutral—Closed Delta



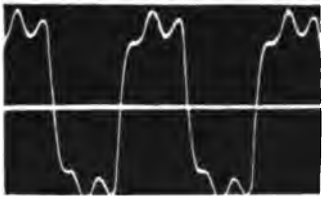
CURVE No. 86
Potential, line to line, 745 volts.



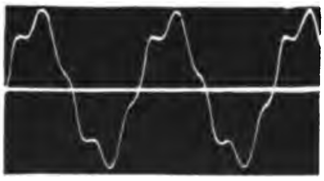
CURVE No. 87
Potential across one leg, 430 volts.



CURVE No. 88
Current in line 1, 60 amperes.



CURVE No. 89
Current in line 2, 45.6 amperes.



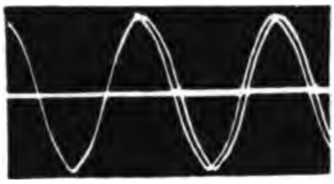
CURVE No. 90
Current in line 3, 57.8 amperes.

CURVE No. 91
Current in connected neutral, 3.5 amperes .

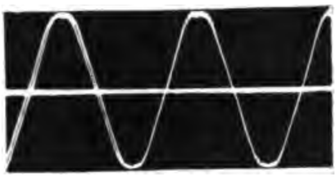
SHEET 16

Oscillograms taken on one three-phase, shell-type, 60-cycle, 330-kw., 13,200-volt delta-connected primary, 430-volt Y-connected secondary. transformer.

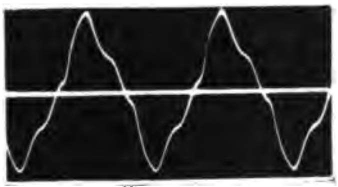
Connected Neutral—Open Delta



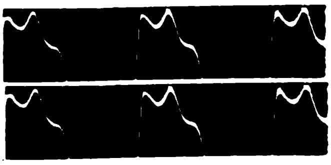
Curve No. 92
Potential, line to line, 745 volts.



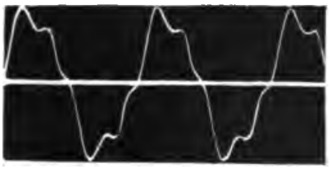
Curve No. 93
Potential across one leg, 430 volts.



Curve No. 94
Current in line 1, 64.2 amperes.



Curve No. 95
Current in line 2, 57.8 amperes.



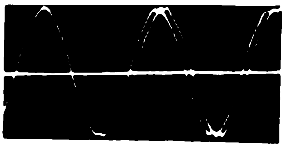
Curve No. 96
Current in line 3, 60 amperes.

Curve No. 97
Current in connected neutral, 24.9 amperes.

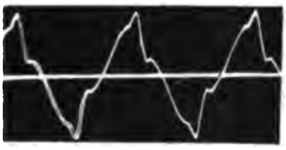
SHEET 17

Oscillograms taken on one three-phase, shell-type, 60-cycle, 430-kw., 13,200-volt delta-connected primary, 430-volt Y-connected secondary transformer.

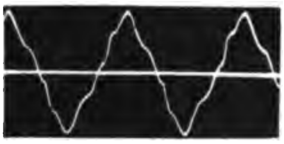
Isolated Neutral—Open Delta



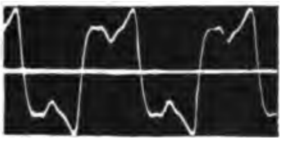
Curve No. 98
Potential, line to line, 745 volts.



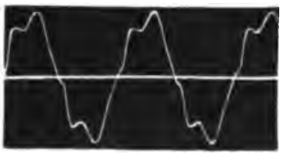
Curve No. 99
Potential across one leg, 460 volts.



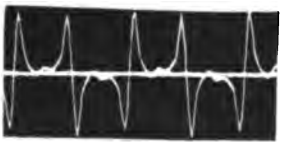
Curve No. 100
Current in line 1, 53.7 amperes.



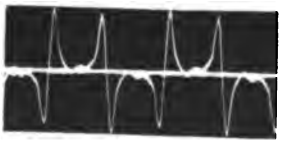
Curve No. 101
Current in line 2, 36.6 amperes.



Curve No. 102
Current in line 3, 53.7 amperes.



Curve No. 103
Potential to isolated neutral, 102.2 volts.

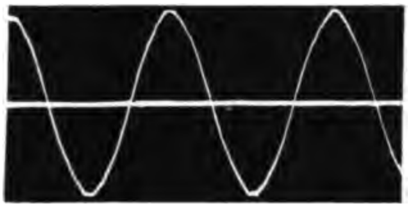


Curve No. 104
Potential across open primary delta, 9580 volts.

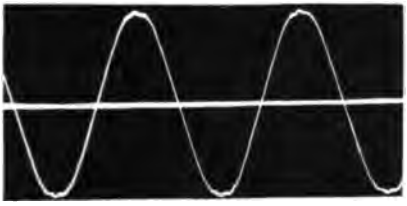
SHEET 18

Oscillograms taken on one three-phase, balanced core-type, 60-cycle, 200-kw., 4600-volt delta-connected primary, 2300-volt Y-connected secondary transformer.

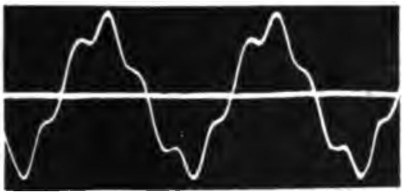
Isolated Neutral—Closed Delta



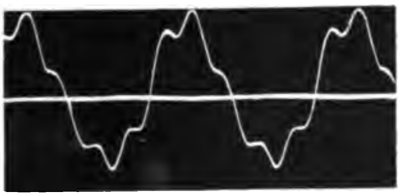
Curve No. 105
Potential, line to line, 3980 volts.



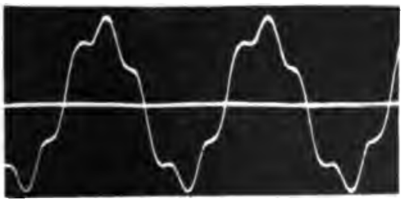
Curve No. 106
Potential across one leg (*i.e.*, line to neutral), 2275 volts



Curve No. 107
Current in line 1, 2.0 amperes.



Curve No. 108
Current in line 2, 1.92 amperes.

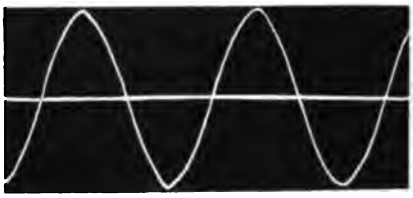


Curve No. 109
Current in line 3, 2.0 amperes.

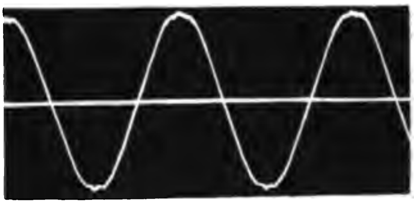
SHEET 19

Oscillograms taken on one three-phase, balanced core-type, 60-cycle, 200-kw., 4600-volt delta-connected primary, 2300-volt Y-connected secondary transformer.

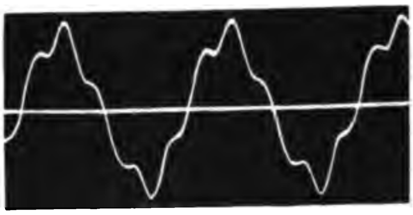
Connected Neutral—Closed Delta



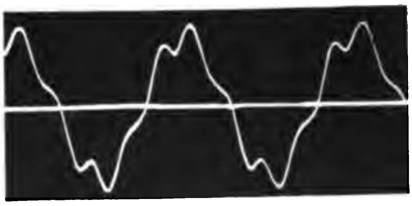
Curve No. 110
Potential, line to line, 3980 volts.



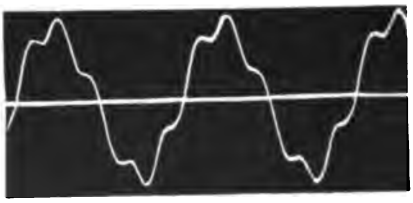
Curve No. 111
Potential across one leg, 2275 volts.



Curve No. 112
Current in line 1, 1.97 amperes.



Curve No. 113
Current in line 2, 1.88 amperes.

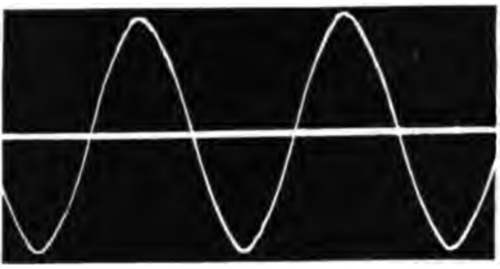


Curve No. 114
Current in line 3, 1.97 amperes.

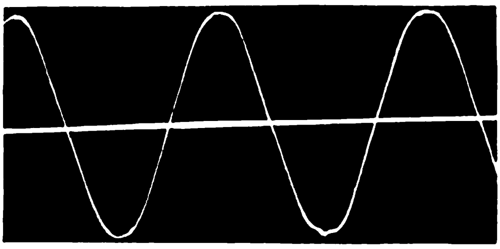
SHEET 20

Oscillograms taken on one three-phase, balanced core-type, 60-cycle, 200-kw., 4600-volt delta-connected primary, 2300-volt Y-connected secondary transformer.

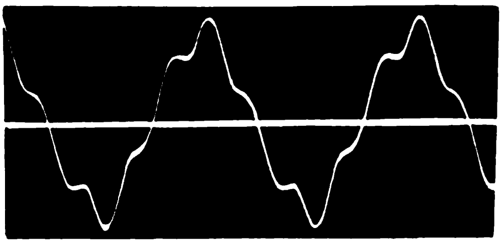
Connected Neutral—Open Delta



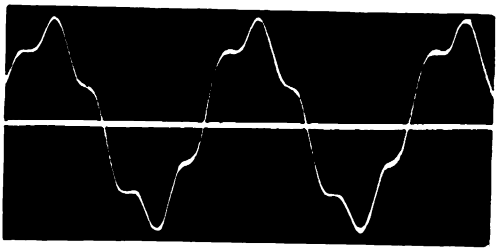
CURVE No. 115
Potential, line to line, 3980 volts.



CURVE No. 116
Potential across one leg, 2275 volts.



CURVE No. 117
Current in line 1, 1.58 amperes.

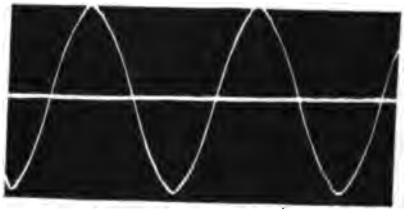


CURVE No. 118
Current in line 3, 1.6 amperes.

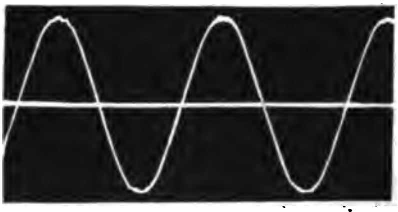
SHEET 21

Oscillograms taken on one three-phase, balanced core-type, 60-cycle, 200-kw., 4600-volt delta-connected primary, 2300-volt Y-connected secondary transformer.

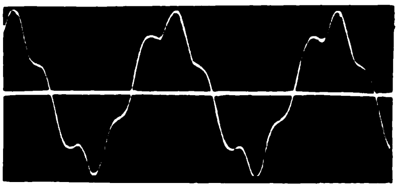
Isolated Neutral—Open Delta



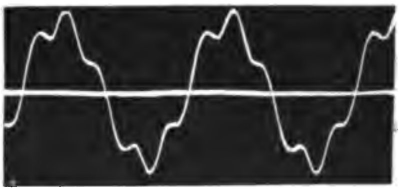
Curve No. 119
Potential, line to line, 3980 volts.



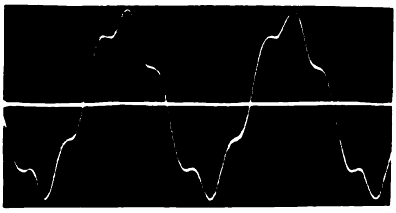
Curve No. 120
Potential across one leg 2275 volts.



Curve No. 121
Current in line 1, 1.82 amperes.



Curve No. 122
Current in line 2, 1.70 amperes.

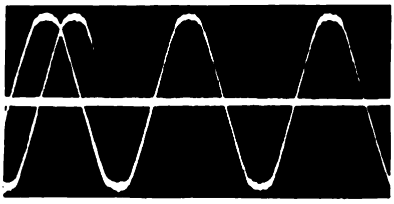


Curve No. 123
Current in line 3, 1.80 amperes.

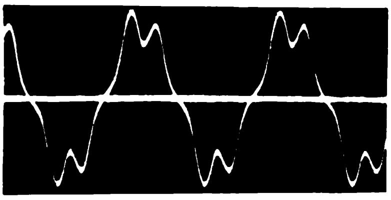
SHEET 22

Oscillograms taken on three single-phase, core-type, 25-cycle, 25-kw., 2300-volt delta-connected primary, 460-volt delta-connected secondary.

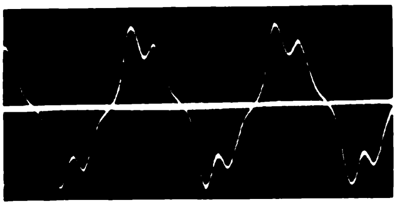
Primary, Closed Delta—Secondary, Closed Delta



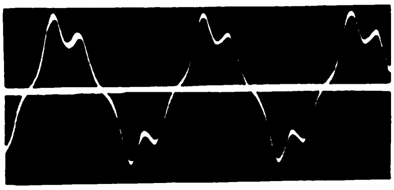
CURVE No. 124
Potential, line to line, 460 volts.



CURVE No. 125
Current in line 1, 11.4 amperes.



CURVE No. 126
Current in line 2, 9.95 amperes.



CURVE No. 127
Current in line 3, 9.7 amperes.

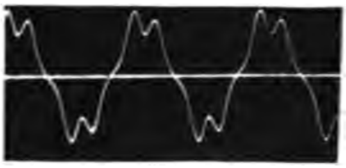
CURVE No. 128
Current in primary delta, 7.1 amperes.

SHEET 23

Oscillograms taken on three single-phase, core-type, 25-cycle, 25-kw., 2300-volt delta-connected primary, 460-volt delta-connected secondary.

Primary, Closed Delta—Secondary, Open Delta

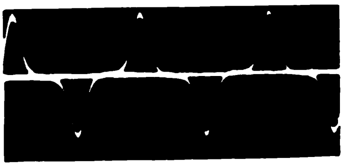
CURVE No. 129
Potential, line to line, 460 volts.



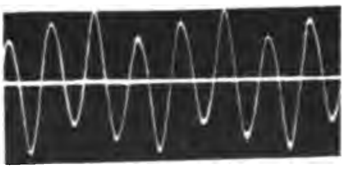
CURVE No. 130
Current in line 1, 11.4 amperes.

CURVE No. 131
Current in line 2, 9.95 amperes.

CURVE No. 132
Current in line 3, 9.7 amperes.



CURVE No. 133
Current in primary delta, 7.1 amperes.

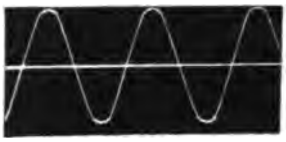


CURVE No. 134
Potential across open secondary delta, 4.7 volts.

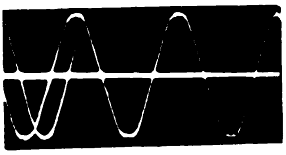
SHEET 24

Oscillograms taken on three single-phase, core-type, 25-cycle, 25-kw., 2300-volt delta-connected primary, 460-volt delta-connected secondary.

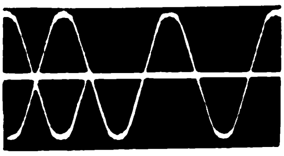
Primary, Open Delta—Secondary, Open Delta



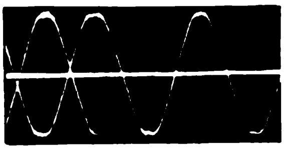
Curve No. 135
Potential across one leg of primary 2280 volts.



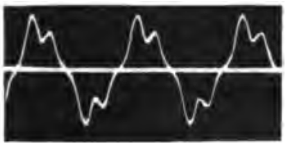
Curve No. 136
Potential, line 1 to line 3, 460 volts.



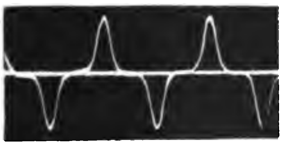
Curve No. 137
Potential, line 1 to line 2, 460 volts.



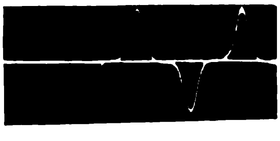
Curve No. 138
Potential, line 2 to line 3, 460 volts.



Curve No. 139
Current in line 1, 10.0 amperes.



Curve No. 140
Current in line 2 7.5 amperes.

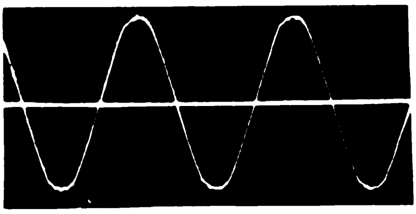


Curve No. 141
Current in line 3, 5.7 amperes.

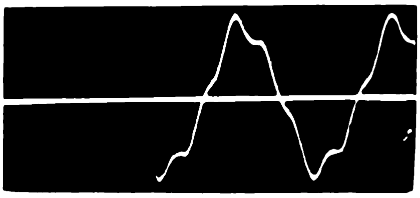
Sheet 25

Oscillograms taken on one three-phase, core-type, 25-cycle, 40-kw., 2300-volt delta-connected primary, 460-volt delta-connected secondary.

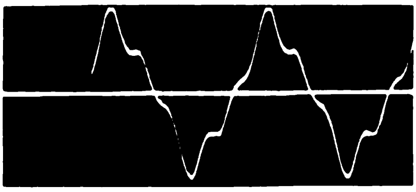
Primary, Closed Delta—Secondary, Closed Delta



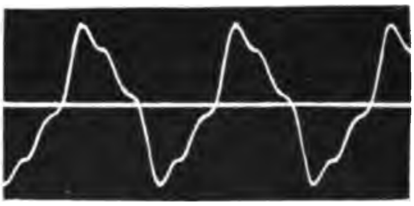
Curve No. 142
Potential, line to line, 430 volts.



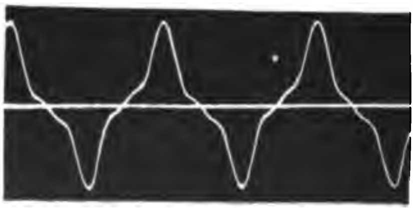
Curve No. 143
Current in line 1, 5.0 amperes.



Curve No. 144
Current in line 2, 4.05 amperes.



Curve No. 145
Current in line 3, 3.6 amperes.

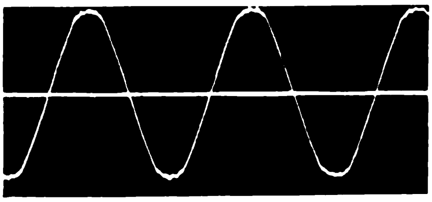


Curve No. 146
Current in primary delta, 2.98 amperes.

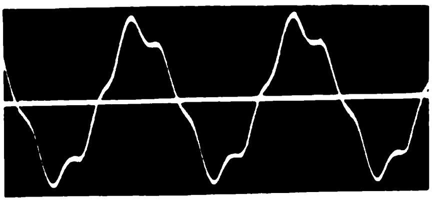
SHEET 26

Oscillograms taken on one three-phase, core-type, 25-cycle, 40-kw., 2300-volt delta-connected primary, 460-volt delta-connected secondary.

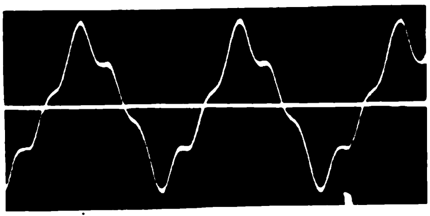
Primary, Closed Delta—Secondary, Open Delta



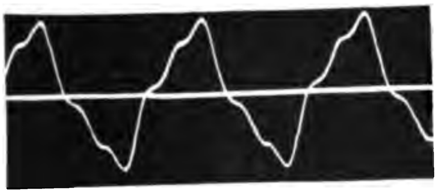
Curve No. 147
Potential, line to line, 430 volts.



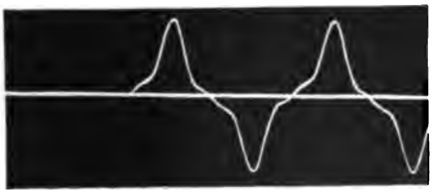
Curve No. 148
Current in line 1, 5.0 amperes.



Curve No. 149
Current in line 2, 3.6 amperes.



Curve No. 150
Current in line 3, 4.05 amperes.

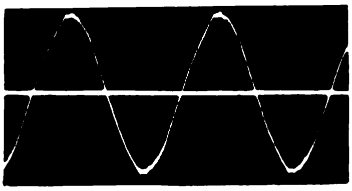


Curve No. 151
Current in primary delta, 2.98 amperes.

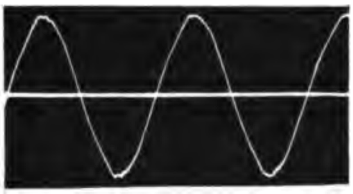
SHEET 27

Oscillograms taken on one single-phase, core-type, 25-cycle, 25-kw 2300-volt primary, 460-volt secondary transformer.

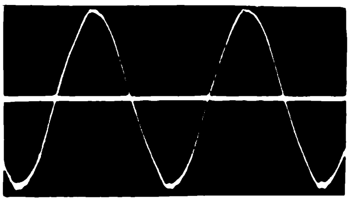
Single Phase



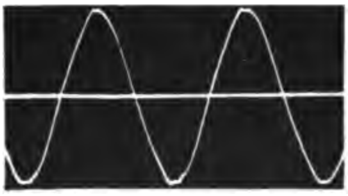
Curve No. 152
Potential at 22.5 kilolines, 115 volts.



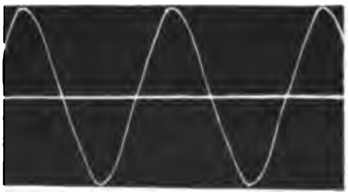
Curve No. 153
Potential at 45.0 kilolines, 230 volts.



Curve No. 154
Potential at 90 kilolines, 460 volts



Curve No. 155
Potential at 112.5 kilolines, 575 volts.

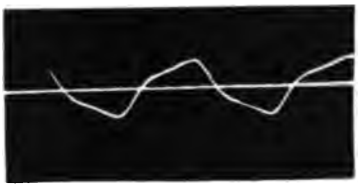


Curve No. 156
Potential at 135 kilolines, 675 volts.

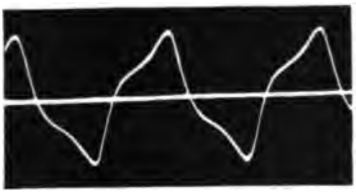
SHEET 27A

Oscillograms taken on one single-phase, core-type, 25-cycle, 25-kw., 2300-volt primary, 460-volt secondary transformer.

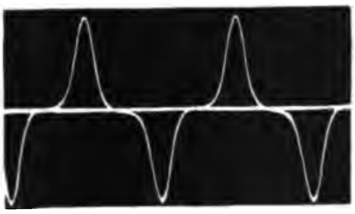
Single Phase



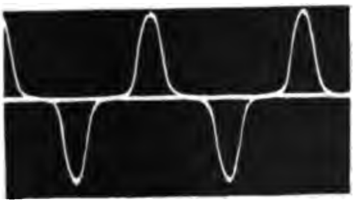
CURVE No. 157
Current at 22.5 kilolines, 0.402 amperes.



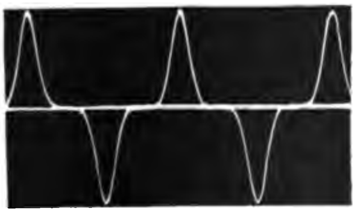
CURVE No. 158
Current at 45.0 kilolines, 0.75 amperes.



CURVE No. 159
Current at 90 kilolines, 6.05 amperes.



CURVE No. 160
Current at 112.5 kilolines, 27.2 amperes.

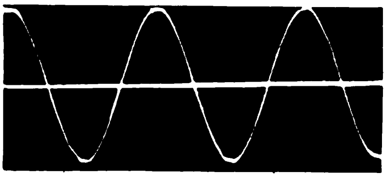


CURVE No. 161
Current at 135 kilolines, 113.4 amperes.

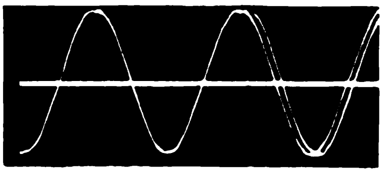
SHEET 28

Oscillograms taken on one alternator at Station No. 3, Rochester Railway and Light Co., Rochester, N. Y. Connected neutral, 24 poles, 2100-kw., 300 rev. per min., 4150 volts.

Load 1500 kw.

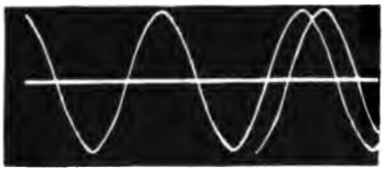


CURVE No. 162
Potential wave, line *A* to line *B*, 4440 volts.

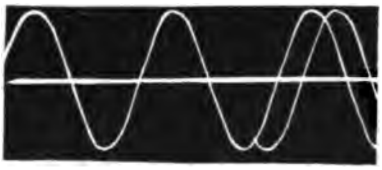


CURVE No. 163
Potential wave, neutral to line *C*, 2560 volts.

Isolated neutral, 80 poles, 1360 kw., 90 rev. per min., 2500 volts



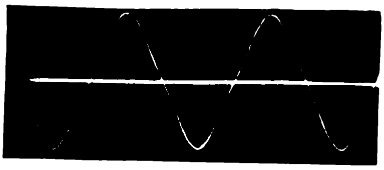
CURVE No. 164
Potential wave, line *A* to line *B* (no load), 4357 volts.



CURVE No. 165
Potential wave, neutral to line *A* (no load), 2455 volts.

CURVE No. 166
Potential wave, neutral to line *C* (no load), 2455 volts.

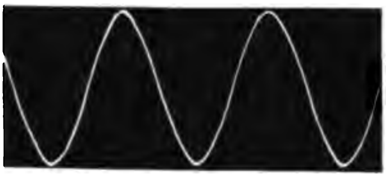
Isolated neutral, 10 poles, 3000 kw., 720 rev. per min., 4150 volts



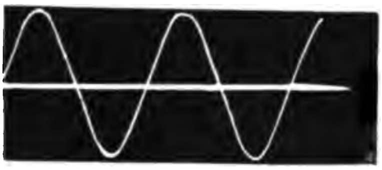
CURVE No. 167
Potential wave, neutral to line *C* (no load), 2487 volts.

SHEET 29

Oscillograms taken on one alternator at Station No. 5, Rochester Railway and Light Co., Rochester, N. Y. **Isolated neutral, 22 poles, 1200-kw.,** 327 rev. per min , 4150 volts.



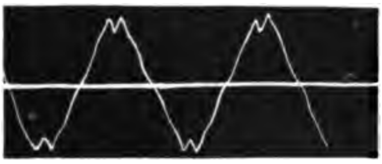
CURVE No. 168
Potential wave, line to line (no load), 4230 volts.



CURVE No. 169
Potential wave, neutral to line (no load), 2718 volts.

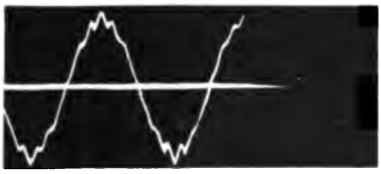
Isolated neutral, 16 poles, 350 kw., 450 rev. per min., 2500 volts

CURVE No. 170
Potential wave, line to line (no load), 4457 volts.



CURVE No. 171
Potential wave, neutral to line (no load), 2540 volts.

Isolated neutral, 24 poles, 530 kw., 300 rev. per min., 4150 volts. Frequency Changer

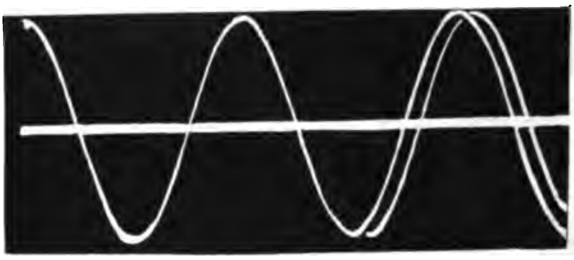


CURVE No. 172
Potential wave, line to line (no load), 4083 volts.

CURVE No. 173
Potential wave, neutral to line (no load), 2277 volts.

SHEET 30

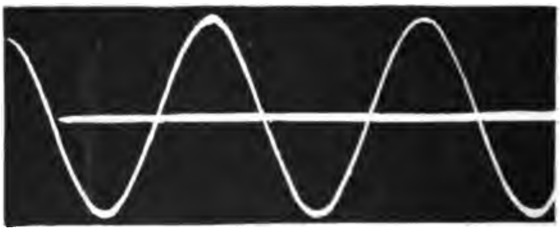
Oscillograms taken on one alternator at Station No. 15, Rochester Railway and Light Co., Rochester, N. Y. Connected neutral, 36 poles, 500 kw., 200 rev. per min., 4150 volts.



CURVE No. 174
Potential wave, line *A* to line *B* (no load), 4,373 volts.

CURVE No. 175
Potential wave, neutral to line *C* (no load), 2,400 volts.

Feeders at Station No. 34, Rochester Railway and Light Co., Rochester, N.Y. Transformers disconnected



CURVE No. 176
Potential wave, line to line (no load), 4313 volts.

CURVE No. 177
Potential wave, ground to line (load, 500 kw.), synchronous motor and 450-kw. transformer, 2473 volts.

in the above tables, as these conclusions were drawn without consideration of any harmonics higher than the third which might be present in the wave shape of the exciting current of the average commercial transformer. A series of tests and investigations with the oscillograph was, therefore, undertaken to check this opinion on the subject and at the same time to make evident, if possible, that the investigation and discussion of current and potential wave shapes has scientific value not only from a theoretical view point, but has great practical value from the operating standpoint as well. It has great bearing on the successful operation of every large alternating current distributing system and must be so considered, as a disregard of the importance or effect of this distortion may lead to dangerous conditions and disastrous results.

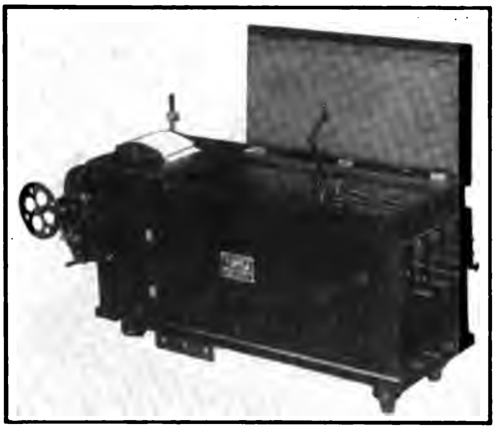


Fig. 2.—Oscillograph showing photographic and tracing attachment

Oscillograms of current and potential wave shapes discussed in the succeeding pages of the paper were taken by an oscillograph similar to that described in the paper by L. T. Robinson, Transactions of the American Institute of Electrical Engineers, Vol. 24, and shown in Figs. 2 and 3.

As the two half cycles of the oscillograph curve are symmetrical, it is necessary for the analysis and subsequent discussion to consider only the first half cycle, which part on an enlarged scale has been transferred by means of a dividing engine to coördinate paper, and resolved into its component curves, of the first, third and fifth, etc., frequencies, by the method described by Professor S. P. Thompson in his book on Dynamo Electric Machinery, Vol. II, and which is given in the appendix to this paper, together with a complete analysis of curve No. 78, Sheet 13, the analysis of which is shown in Fig. 17. The accuracy of the method has been tested by comparing the original complex wave with the complex wave formed by combining the several component curves. In every case, the two complex waves are almost identical.

PLOTTING OF HYSTERESIS LOOP

As a basis for discussion, and as representative of a size and voltage commonly found in practice, a 25-cycle, 185-kw., 33,000-volt primary, 430-volt secondary transformer was selected, on which oscillograms of exciting current were taken with strictly sinusoidal potential applied. Sheet 5 shows the oscillograms corresponding to different densities. The analysis of these curves, given in Figs. 4, 5, 6 and 7, show the characteristic distortion due to the presence of the harmonics. In these figures, the curves marked " complex wave " correspond to the oscillograms on Sheet 5. These complex waves, by the method previously referred to, have been resolved into their component sine waves. The following table gives the values of the maxima of these several curves in terms of the maximum of the complex and also in terms of the maximum of the fundamental wave.

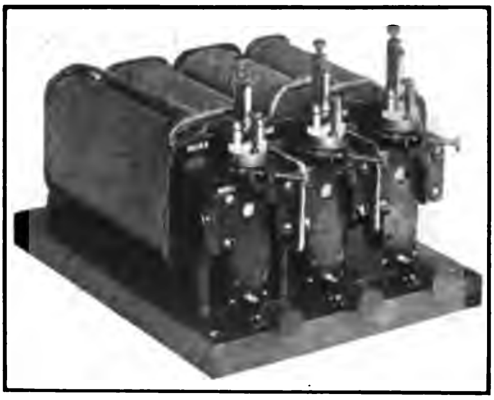
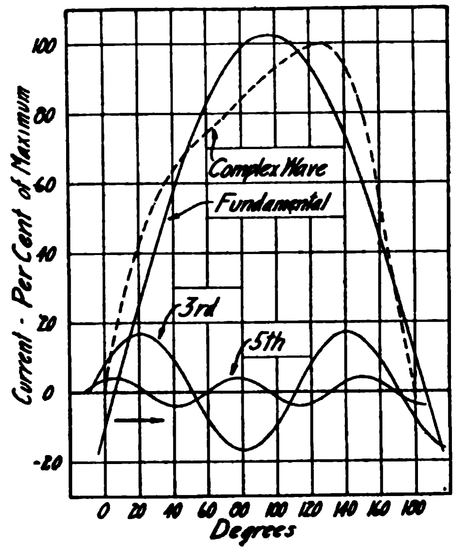


FIG. 3.—Oscillograph galvanometer



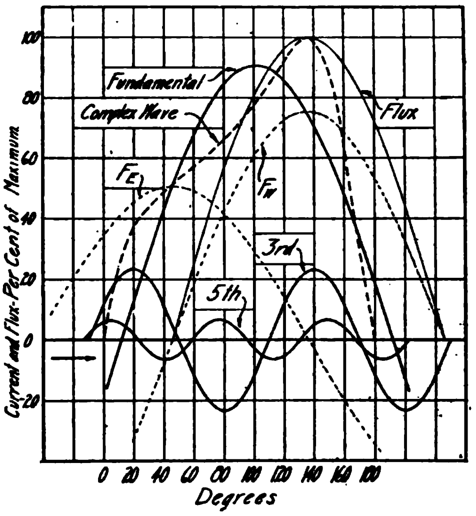
Max. complex wave = 100

R_1 = 102.6 ϕ_1 = − 6° 16′

R_3 = 17.0 ϕ_3 = 27° 9′ 25% excitation

R_5 = 4.0 ϕ_5 = 58° 38′

FIG. 4.—Analysis of oscillogram No. 21 Sheet No. 5



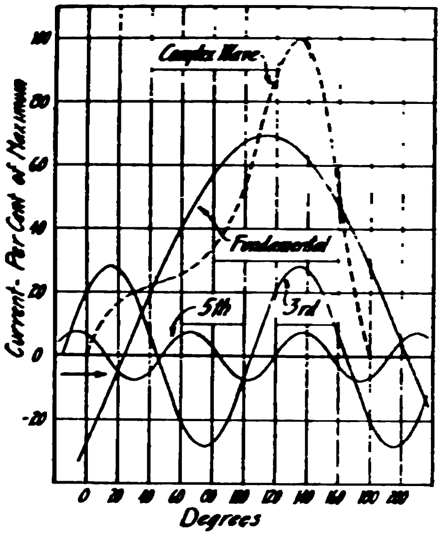
Max. complex wave = 100

R_1 = 90.7 ϕ_1 = −11° 52′

R_3 = 23.3 ϕ_3 = 30° 43′ 50% excitation

R_5 = 6.6 ϕ_5 = 66° 52′

FIG. 5.—Analysis of oscillogram No. 22 Sheet No. 5



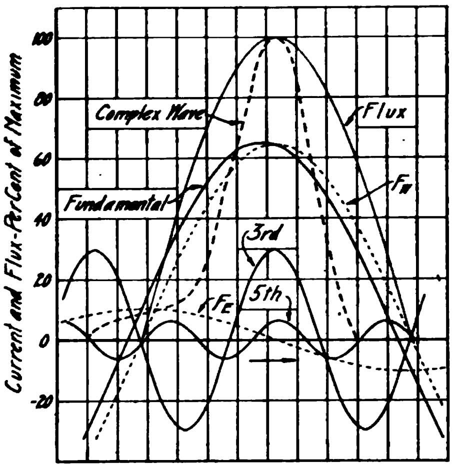
Max. complex wave = 100

R_1 = 69.4 ϕ_1 = −23° 50′ 75 per cent excitation

R_3 = 28.2 ϕ_3 = 45° 30′

R_5 = 7.7 ϕ_5 = 120° 0′

Fig. 6.—Analysis of oscillogram No. 23 Sheet No. 5



Max. complex wave = 100

R_1 = 65.0 ϕ_1 = −27° 1′ 100 per cent excitation

R_3 = 29.9 ϕ_3 = 73° 56′

R_5 = 6.2 ϕ_5 = 170° 24′

Fig. 7.—Analysis of oscillogram No. 24 Sheet No. 5

TABLE I.

DATA RELATIVE TO CURVE IN FIGS. 4–7

25-cycle, 185-kw., 33,000-volt primary, 430-volt secondary, single-phase transformer

	Relative values of maxima in terms of complex wave				Relative value of maxima in terms of fundamental wave							
Density per sq. in. kilolines	Complex wave per cent	Fundamental per cent	Third harmonic per cent	Fifth harmonic per cent	Fundamental per cent	Third harmonic per cent	Fifth harmonic per cent	Complex wave per cent	Amperes effective	Core loss watts	Angle of advance of 3d over fund in terms of fundamentals	Angle of hysteretic advance
22.6	100	102.6	17	4.0	100	16.6	3.9	97.5	3.48	233	15°	31°
45.25	100	90.7	23.3	6.6	100	25.5	7.3	110.0	5.49	730	22°	34°
61.9	100	69.2	28.8	7.7	100	41.6	11.1	144.5	12.5	1488	39°	21°
90.5	100	65.0	29.9	6.2	100	46	9.6	154	35.8	2575	52°	9°

Fig. 8 gives the square root of the mean square value of exciting current and core loss on this transformer at different densities.

It will be seen that these figures do not bear out the conclusion drawn by Dr. Bedell and Mr. Tuttle. It will be noted that ϕ, the angle between the third and the fundamental at the origin, is not limited to values between 30 degs. and 180 degs., but may vary between greater ranges of value. The angle of hysteretic advance, or the angle between the maximum of the fundamental and the maximum flux, may be larger than 30 degs., as shown in Fig. 5. No doubt the explanation for this is due to the fact that in the former discussion, only the fundamental and the third harmonic were considered as forming the complex wave, whereas in the present instance, it is shown that at least the fifth, in addition to the fundamental and the third, is found in the complex waves.

From these curves and the table given above, the conclusion may be drawn that the amplitude of the third harmonic increases with the density in the core, the limiting value being dependent, to a certain extent, on the value of the other higher harmonics also present in the current wave.

In Figs. 5 and 7, curves have been added to represent the flux and, in accordance with conclusion 6, page 667, the maximum of the flux is shown in phase with the maximum of the complex wave. In Fig. 5, the maximum of this flux wave represents a density equal to 45.2 kilolines per square inch, while in Fig. 7, it represents a density of 90.5 kilolines per square inch.

For a further discussion of the curves, the fundamental wave has been resolved into two sinusoidal curves whose maxima are 90 deg. apart; one F_e in phase with the voltage, and one F_w in phase with the flux. The former, in phase with the voltage, represents energy given to the core; that is, hysteretic loss. The latter, 90 deg. out of phase with the voltage and consequently in phase with the flux, represents no power; that is, wattless or that part of the current required merely to magnetize the core. The complex wave, *i.e.*, the oscillogram, has, therefore, been resolved into four component parts; two of fundamental frequency—one, F_w in phase with the flux, the other, F_e in phase with the voltage—and one curve of three times fundamental frequency and one curve of five times fundamental frequency.

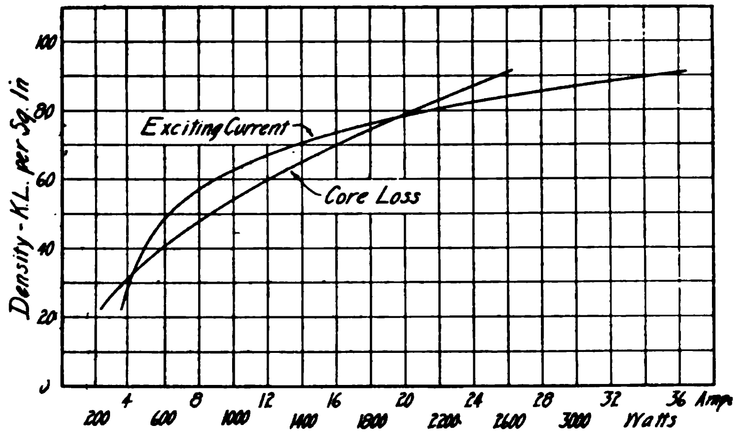


FIG. 8.—Curve of exciting current and losses single-phase core type 25-cycle, 185-kw. 33,000-volt primary, 430-volt secondary transformer.

Using a system of rectangular coördinates, and plotting loops with these various curves in conjunction with the curve of flux, some interesting results follow:

1. Using the complex current and the sinusoidal flux wave, the well-known hysteresis loop may be plotted whose area is equal to, or rather represents, the energy given to the core for any particular induction. In Figs. 9 and 12, the loop marked L_c, is shown corresponding to a density in the core of 45.2 kilolines and 90.5 kilolines per sq. in. respectively.

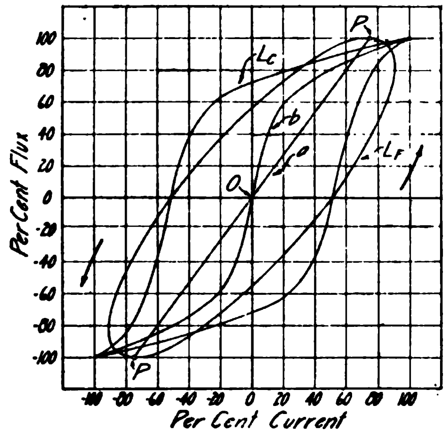


FIG. 9.—Loops plotted from oscillogram No. 21 sheet No. 5 and oscillogram No. 26 Sheet No. 5

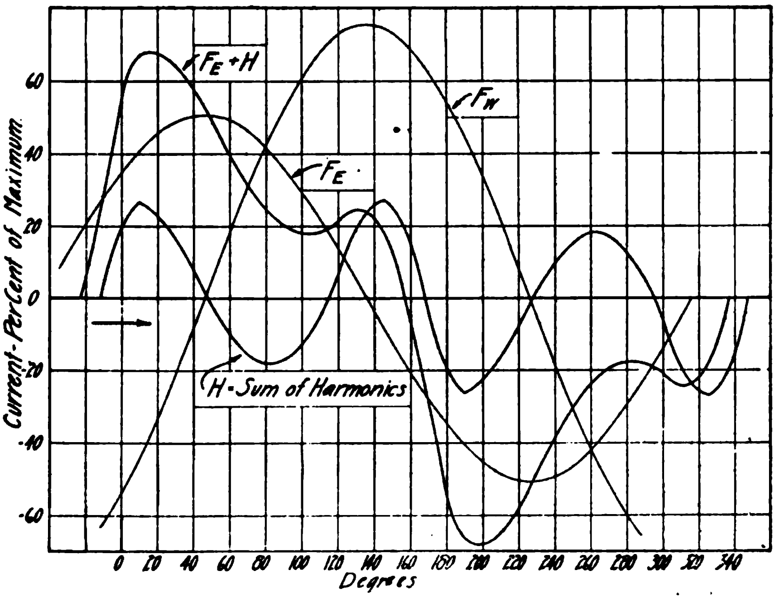


FIG. 10.—Curves obtained from oscillogram No. 22 Sheet No. 5 d oscillogram No. 26 sheet No. 5

2. Using the fundamental component of the current wave instead of the complex wave, *i.e.*, the complex wave minus the higher harmonics, and the sinusoidal flux curve, an elliptical loop, marked L_f, results, of the same area as the distorted loop. This indicates that the same energy is given to the core. The conclusion to be drawn is, that with sinusoidal potential applied, the higher harmonics in the current wave are not produced by, or do not produce, the energy loss in the core.

3. Using the wattless component F_w of the fundamental and the sinusoidal flux wave, the straight line curve *a*, Fig. 9, is obtained, passing through zero and intersecting the ellipse at the point *P*. Since the wattless component of the current is used in conjunction with the flux curve, the figure should enclose no area, as it represents no loss. It should be noted that the location or relative position of this line *a* is determined by the magnetizing component of the fundamental of the exciting current. The point *P*, *i.e.*, the intersection of the straight line *a* with the ellipse, may be predetermined by using the amplitude of the

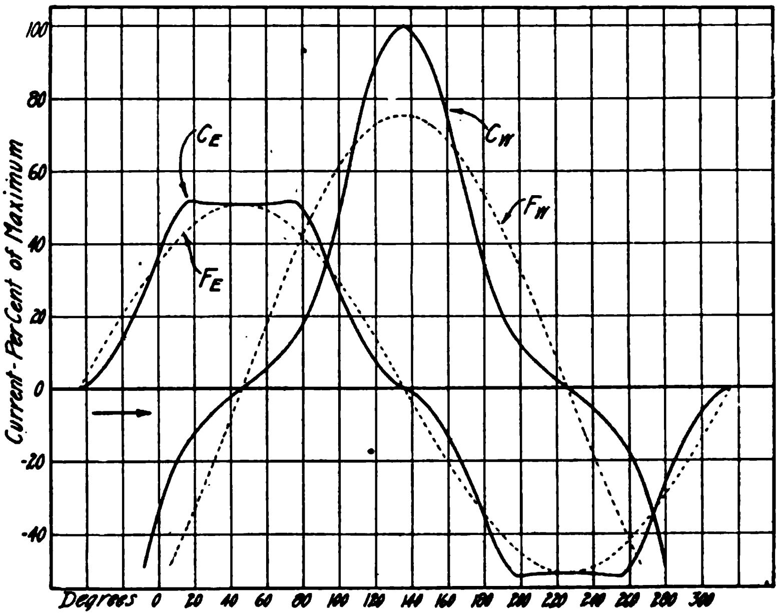


FIG. 11.—Curves obtained from oscillogram No. 22 sheet No. 5 and oscillogram No. 26 sheet No. 5

wattless component of the fundamental as abscissa, plotted against the maximum of the flux as an ordinate. This point *P* and zero determine the direction of the line. If the magnetizing component of the fundamental were small compared with the energy component, the angle made by this line *a* with the vertical axis would be small, and were this component large, the angle made by the line *a* with the vertical would be large. Should it be possible for this component to equal zero, the line *a* would be vertical and would coincide with the vertical axis of ordinates.

4. Uniting the energy component of the fundamental with the higher harmonics, the curve shown in Figs. 10 and 13, marked

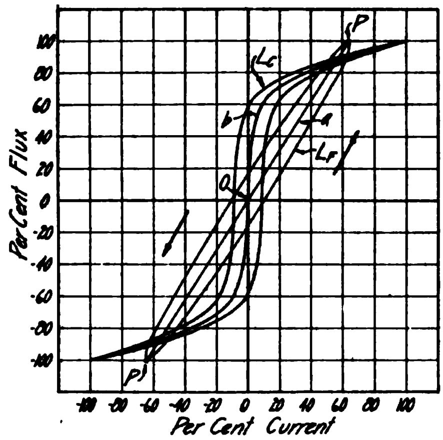


FIG. 12.—Curves plotted from oscillogram No. 24 sheet No. 5 and oscillogram No 26 sheet No. 5

$F_e + H$ follows. F_e is the energy component of the fundamental, as shown in Figs. 5 and 7, and curve *H* is the sum of the harmonics; *i.e.*, the complex wave minus the fundamental. Using ordinates of this curve $F_e + H$ as abscissa, and line *a* as an axis, the original hysteresis loop L_c, Fig. 9 will result. The ordinates of this curve $F_e + H$, Fig. 10, above the zero line are plotted to the right of line *a*, Fig. 9, and the ordinates of $F_e + H$, Fig. 10, below the zero line are plotted to the left of line *a*, Fig. 9. Since the sinusoidal flux wave has again been combined with the energy, wattless, and harmonic components of the current, the resultant figure should be the hysteresis loop originally plotted.

5. Using the energy component F_e of the fundamental, and

the sinusoidal flux wave, an ellipse or circle will result, not shown, but vertical with respect to the axis of coördinates.

6. Using the wattless component of the fundamental F_w, Fig. 10, and all the harmonics in phase with the flux, curve H, Fig. 10, and plotting a curve with the flux, the line b, Figs. 9 and 12 results. This line should enclose no area since only wattless components of the current wave are used. It is analogous to line a, but is bent or distorted, due to the presence of harmonics. It represents also the average current required for rising and falling magnetization.

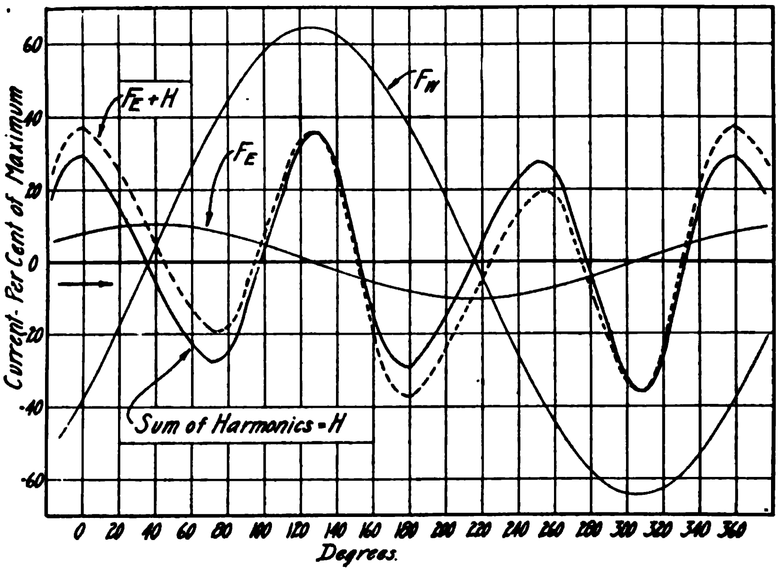


Fig. 13.—Curves plotted from oscillogram No. 24 sheet No. 5 and oscillogram No. 26 sheet No. 5

7. Considering Figs. 5 and 7, attention is called to the fact that the maximum of the third and of the fifth harmonic are not in phase with the maximum of the flux or of the complex wave. If these harmonics are resolved into component parts in phase with the flux and in phase with the voltage, and these components added to similar ones of the fundamental, curves C_w and C_e will result. These curves may also be obtained from curves given in Figs. 5 and 9, as follows:

C_e may be obtained by using as ordinates the abscissa between line b and the hysteresis loop; curve C_w by using as ordinates the abscissa between the vertical axis and the line b.

It is interesting to note that the area enclosed between the curve F_e, Fig. 11, and the horizontal axis, is equal to the area enclosed between the horizontal axis and the curve C_e, Fig. 11. Since this area, in a certain sense, represents the energy supplied the core, we can again conclude that the harmonics do not affect the loss in the core.

The general conclusion to be drawn from these tests and the interpretation of the various curves plotted is that in transformers the distortion of the current wave shape is neither a cause nor an effect of the energy loss in the core, but results only from the varying permeability of the steel. The amount of the distortion varies with the density, since the greater the density the more prominent are the higher harmonics, such as the third, fifth, seventh, ninth, etc.

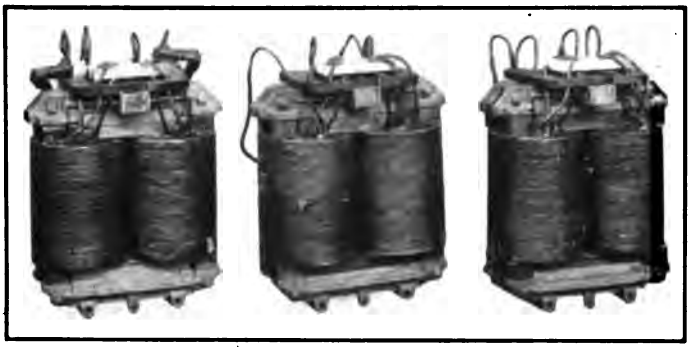


Fig. 14.—Three, single-phase, core-type, 25-cycle, 25-kw. 2300-volt primary, 460 volt secondary transformers used in observing third harmonics

Investigation of Interconnected Transformers

As an extension to the investigation of a single-phase transformer, observations of harmonics in current and potential wave shapes of interconnected transformers were made. With three transformers, the Y-connection is the most common, and without doubt, the most important connection. For these observations, three single-phase, core-type, 25-cycle, 25-kw., 2300-volt primary, 460-volt secondary transformers were selected, and oscillograms taken of current and potential at different densities in the core. The small capacity was selected so that the potential wave shape of the relatively small generator available would not be distorted by the current required for the test; the low voltage to avoid the use of both current and potential transformers in measuring current, voltage, and watts.

As preliminary and for further reference, oscillograms of potential and current at different densities were taken single-phase and are shown on Sheets 27 and 27 A. The only special reference to be made to these current curves is the pronounced flattening at the zero point for the higher densities. Root-mean-square values are give in Table 2.

TABLE 2

25-cycle, 25-kw., 2300-volt primary, 46-volt secondary transformers, connected single-phase

B-Kilolines	Volts	Amperes	Watts
45.0	230	0.75	70
90.0	460	6.05	280
112.5	575	27.2	540

The three transformers were connected as shown in Fig. 15 with the 460-volt winding Y-connected, and the 2,300-volt winding connected with the delta open. Current was supplied by a three-phase generator through three single-phase transformers delta-Y connected, as shown. By means of the switch at *E F*, the neutrals between the step-down transformers and the transformers under test could be connected; with the switch at *B C*, the delta connection of the transformer under test could be closed.

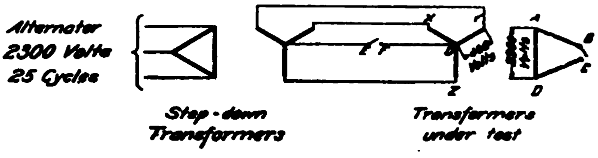


FIG. 15

With the switches at *B C* and *E F* open, root-mean-square values of current in the line and voltage across the *Y*, *i.e.*, across X *Z*, X *Y* and *Y Z*; across the leg, *i.e.*, *O* X, *O Y* and *O Z*; and across the open delta, and across the open neutral are given in Table 3.

TABLE 3

Three 25-cycle, 25-kw., 2,300-volt primary, 460-volt secondary transformers, connected open delta—isolated neutral

Density in core kilolines per sq. in.	Voltage across				Current in line			Watts
	Lines	Leg	Open delta	Isolated neutral	1	2	3	
22.5	397.5	244.6	1,180	100	0.53	0.54	0.54	167.5
90.0	795	525	3,780	257	3.42	3.27	3.42	675
112.5	995	675	5,040	330.5	15.5	14.3	15.7	1,650

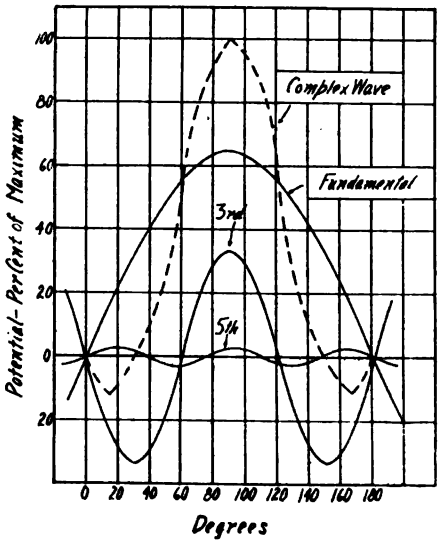
Oscillograms corresponding to a density of 90 kilolines per sq. in. are given in Sheet 13.

Each of the three transformers would require normally for its magnetization a current having a triple frequency component similar to curve No. 159, Sheet 27A. Since the current in a balanced three-phase system cannot contain a triple harmonic (otherwise the sum of the instantaneous values would not equal zero), the current wave shape in Y-connected transformers cannot contain a triple harmonic. Necessarily, the induction in the core must be distorted from the sine shape by an amount corresponding to the value of the triple harmonic component in the current. The resulting induction in the core of each transformer is, therefore, represented by the potential curve No. 77, Sheet 13, and the current flowing in the winding, by curve No. 78, Sheet 13. The analyses of these curves are given in Figs. 16 and 17.

In Fig. 16, attention is called to the relative values of the maximum induction at fundamental, triple, and quintuple frequencies, equal to 64.5 per cent, 33.3 per cent and 2.2 per cent respectively, of the maximum of the complex wave.

In Fig. 17, attention is called to the absence of the triple frequency component of the current and to the pronounced quintuple component. It will be noted also that the sum of the induction at triple and quintuple frequency is equal to 55 per cent of the maximum induction at the fundamental frequency.

Fig. 18 shows the instantaneous values of potential across each of the delta-connected windings of the transformers in their proper phase relation to each other. The triple frequency components in the legs are in phase with each other while the fundamental components are 120 deg. apart and their sum equals zero. The voltage in the delta is, therefore, represented by the curve *C B*, Fig. 18, and measured by curve No. 80, Sheet 13. Both curves show a triple frequency potential equal in ampli-



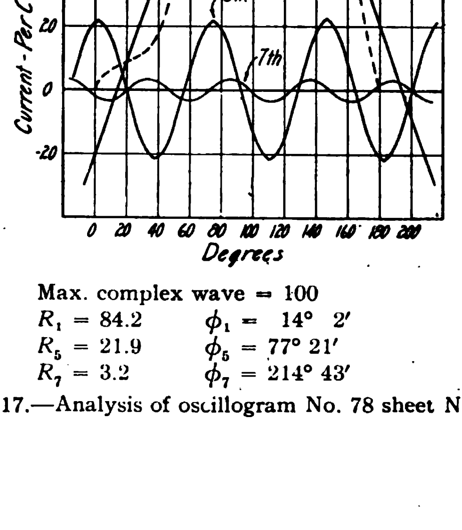
Max. complex wave = 100

$R_1 = 64.5$ $\phi_1 = -\ 0° 32'$

$R_3 = 33.3$ $\phi_3 = 177° 56'$

$R_5 = 2.2$ $\phi_5 = -15° 58'$

FIG. 16.—Analysis of oscillogram No. 77 sheet No. 13



Max. complex wave = 100

$R_1 = 84.2$ $\phi_1 = 14° 2'$

$R_5 = 21.9$ $\phi_5 = 77° 21'$

$R_7 = 3.2$ $\phi_7 = 214° 43'$

FIG. 17.—Analysis of oscillogram No. 78 sheet No. 13

tude to three times that of the triple frequency found in each leg. The root-mean-square voltage read across the open delta is given in Table 3 and confirms the conclusion drawn from the discussion of the curves.

While the sum of the instantaneous current values is equal to zero, the resultant distortion of the potential produces an unbalance in the voltage of the system; *i.e.*, the sum of the instantaneous potential values does not equal zero as is evidenced by the voltage across the open delta and the open neutral.

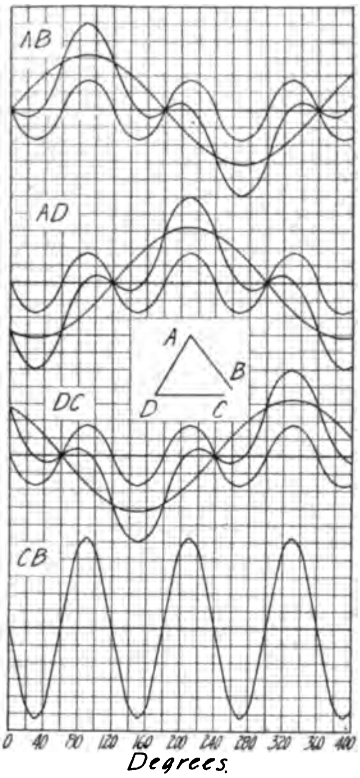


FIG. 18.—Phase relation of voltage across legs and across open delta of delta-connected transformers

In Fig. 19 is shown the instantaneous values of potential across the transformer, *O* X and *O Y*, and across the lines, X *Y* in their proper phase relation. It will be noted that the sum of the instantaneous values of *O* X and *O Y* equals the instantaneous values of X *Y*. The triple frequency components of voltage being 60 degs. fundamental frequency, or 180 degs. triple frequency apart, neutralize each other, and the resultant potential across the *Y* is a sine shape.

The potential across X *Y*, X *Z*, and *Y Z* is a sine curve, as shown by curve No. 76, Sheet 13, and by Fig. 19. By the connections shown in Fig. 15, a sine potential is insured across each leg of the delta-Y step-down transformers. It has just been noted that the potential across each leg, *O* X, *O Y*, and *O Z* is not a sine potential (see Sheet 15), so that the system is unbalanced with respect to the potential across the neutral *E F* by an amount equal to the triple frequency distortion found in each leg. Curve No. 79, Sheet 13, gives the observed shape.

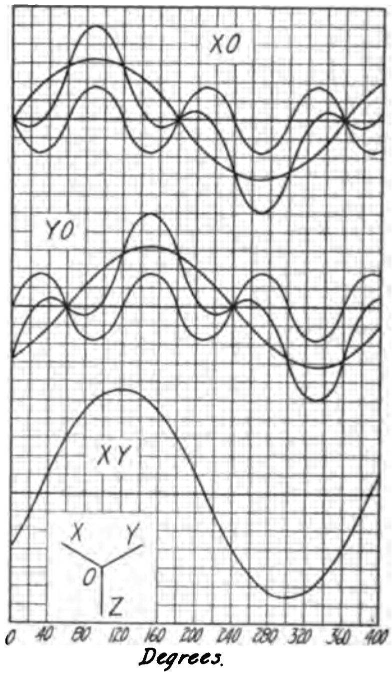


FIG. 19.—Phase relation of voltage across line and across legs of Y-connected transformers

Root-mean-square values given in Table 3 confirm the above conclusions. With 795 volts applied across the *Y*, (*i.e.*, X *Y*) the voltage across each leg is not $\frac{795}{\sqrt{3}}$, (*i.e.*, 460 volts) but 525 volts. Since effective voltages of different frequencies are added in quadrature, the value of the higher harmonic component is $\sqrt{525^2 - 460^2} = 253$ volts, which agrees quite closely with 257 volts actually read across the open neutral. It should be noted also that 253 volts is 55 per cent of 460, agreeing perfectly with the observation in the discussion of Fig. 16.

Since the distortion applied to the primary winding of the transformer must be reproduced on the secondary winding, the triple frequency potential of 253 volts multiplied by the ratio of transformation should appear on each leg of the delta-connected side of the transformers. The ratio of transformation being 5:1, $5 \times 253 = 1265$ volts. This multiplied by 3—since the triple frequency voltage in the three legs is in phase—gives 3795 volts as against 3780 volts actually observed.

It may be noted that with 795 volts applied across the lines, 2620 volts were read across each leg of the delta, indicating a change or error in the ratio of transformation. This fictitious ratio will not be observed if voltages are read across the primary and secondary windings of each transformer. With 525 volts applied to the low tension winding, 2,620 volts is observed on the high tension winding, indicating the correct ratio. As the discrepancy between the actual ratio and this apparent ratio is due entirely to the triple frequency voltage it disappears as soon as the delta is closed.

The discussion of transformers connected as above applies equally well to any connection in which neither winding of the transformer forms a closed delta, or in which the neutrals are isolated. In several instances, the writer has observed a triple frequency voltage equal to 50 per cent of the fundamental appearing on the secondary side of step-down transformers for synchronous converters, so that when the converters were disconnected, the ratio of the transformers was apparently decreased 20 per cent. This decrease in ratio, of course, immediately disappeared as soon as the synchronous converters were put into operation.

The important detail to be noted in the observations made of this Y-delta connection is the increase in the potential strains distributed throughout the winding of the transformer resulting from the distorted potential wave shape. Excepting in small lighting transformers, where the insulation factor of safety is 5 or 10, this increase in the potential strains greatly reduces the reliability of operation of a transformer. In such transformers in which the normal fundamental voltage is 70,000 or 80,000 volts and which have an insulation factor of safety of about two, as indicated by the test voltage of 140,000 to 160,000 volts applied, the application of a triple frequency voltage of 40 per cent or 50 per cent of the fundamental may reduce the insulation factor of safety to 1.3 or 1.4—certainly not large enough to insure reliable operation. It should be noted also, from Table 3 and Fig. 16, that while the root-mean-square value of the potential is increased about 25 per cent, the maximum value of the complex wave is very much more increased and since the maximum is the puncturing voltage, the actual increase in the voltage strain is not truly indicated by the root-mean-square values as given in Table 3.

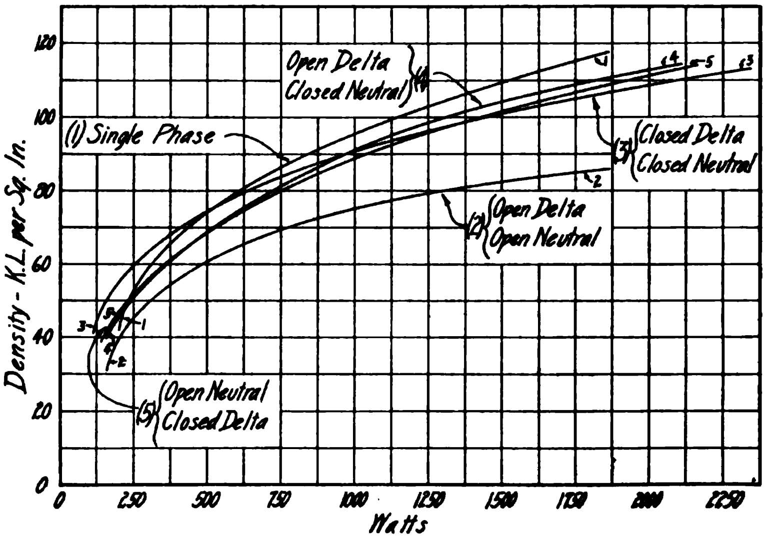


FIG. 20.—Curve of core losses: three single-phase, 25-cycle 25-kw. 2300-volt primary, 460-volt secondary transformers

The distinction between these strains and those resulting from high frequency surges should be clearly noted. The strains resulting from this potential distortion are equally distributed over all parts of the winding, while those resulting from line surges, short circuits or switching may affect only a small portion of the winding. Attention is also called to the difference in the losses in transformers. Referring to Table 1, we note that, under single-phase excitation, the core loss in each transformer at a density of 90 kilolines is 280 watts, or 840 for the three transformers, while with the same effective voltage on the transformers connected three-phase, the total core loss is but 675 watts. This difference or reduction in loss is explained by the difference in the maxima of the density in the core under the different connections. Fig. 20 brings out more clearly this difference in core loss under the different connections.

The next step in the discussion is to observe the results obtained from the elimination of the potential distortion cited above by closing the delta. Oscillograms of current and potential are given on Sheet 10. The root-mean-square values are given in Table 4.

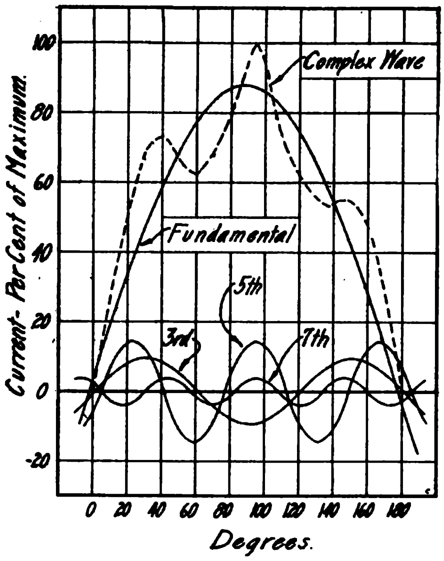
TABLE 4

25-cycle, 25-kw., 2300-volt primary, 460-volt secondary transformers, connected neutral isolated—delta closed.

B-Kilolines	Voltage across			Current in line				Watts
	Lines	Leg	Isolated neutral	1	2	3	Closed delta	
22.5	397.5	234.6	0	0.59	0.58	0.60	0	188
90.0	795	462.5	0	6.30	5.4	5.73	0.63	1,030
112.5	995	575	0	27.7	24.0	27.0	3.2	2,060

It will be noted that the potential wave across the transformers, as well as across the lines *X Y*, has a sine shape and that the voltage across the open neutral has dropped to zero. This is to be expected from our previous discussion, as the triple frequency harmonic of the current has now been supplied. The value of this current necessary to demagnetize the core is indicated by the 0.63 ampere read in the closed delta. Analysis of oscillogram 65, Sheet 10, is given in Fig. 21, and of oscillogram 66, Sheet 10, is given in Fig. 22. It will be noted that upon closing the switch at *C D* with 3780 volts observed across the open delta, only a very small current flows. This is consistent as the current is in no sense a load current, but merely the triple frequency exciting current component necessary to demagnetize the core to eliminate the potential distortion.

If, instead of supplying the triple frequency current component by closing the delta, it is supplied by connecting the neutrals at *E F*, the same general results follow, as is shown by the oscillograms on Sheet 12. It will be noted that practically



Max. complex wave = 100

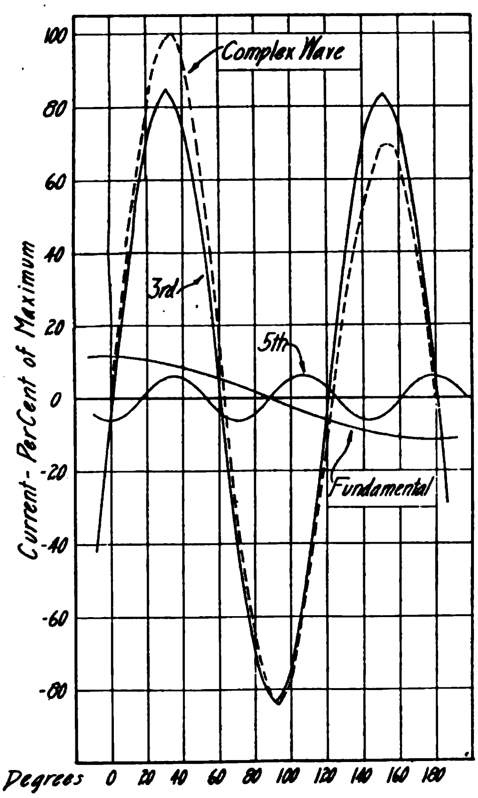
R_1 = 88.1 ϕ_1 = 2° 13′

R_3 = 9.4 ϕ_3 = −3° 32′

R_5 = 14.4 ϕ_5 = −24° 13′

R_7 = 3.8 ϕ_7 = 148° 12′

Fig. 21.—Analysis of oscillogram No. 65 sheet No. 10



Max. complex wave = 100

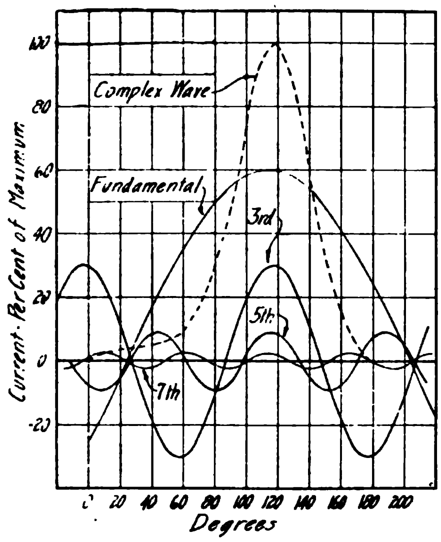
R_1 = 11.2 ϕ_1 = 88° 28′

R_3 = 83.8 ϕ_3 = −3° 24′

R_5 = 6.0 ϕ_5 = −87° 9′

Fig. 22.—Analysis of oscillogram No. 66 sheet No. 10

sine potential is applied to each of the transformers, as shown by oscillogram 72, and that the current wave in the transformers has been restored to practically the identical shape required when excited single-phase. A comparison of curve No. 73, sheet 12, and its analysis given in Fig. 23, should be made with curve No. 159, Sheet 27. It will be noted also that the ratio of triple frequency current in the closed neutral to the triple frequency in the closed delta checks with the ratio of triple frequency voltage across the open neutral to the voltage across the open delta. Root-mean-square values are given in Table 5.



Max. complex wave = 100

$R_1 = 60.0$ $\phi_1 = -23° 39'$

$R_3 = 30.2$ $\phi_3 = 98° 15'$

$R_5 = 9.0$ $\phi_5 = 228° 4'$

$R_7 = 2.5$ $\phi_7 = 20° 43'$

FIG. 23.—Analysis of oscillogram No. 73 sheet No. 12

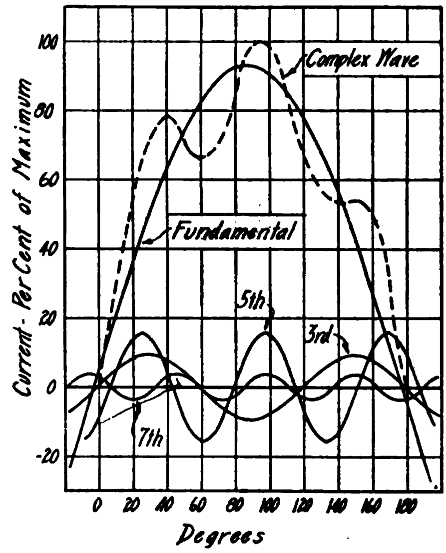
TABLE 5

Three single-phase, core type, 25-cycle, 25-kw., 2300-volt primary, 460-volt secondary transformers, connected delta open—neutral connected

B-Kilolines	Voltage across			Current in line				Watts
	Lines	Leg	Open delta	1	2	3	Con-nected neutral	
22.5	397.5	232.9	0	0.60	0.64	0.59	0.455	185
90.0	795	462.5	24.5	6.51	4.83	6.48	9.45	970
112.5	995	575	135	33	26	31.7	46.5	1,975

The final investigation is to note the condition existing with both the neutral and the delta closed. Oscillograms are given on Sheet 11; analyses of curves No. 69 and No. 70 are given in Figs. 24 and 25. Root-mean-square values are given in Table 6.

In order to bring out more clearly the difference in core loss in the transformers under different excitations and different connections, the observations have been plotted in curves shown in Fig. 20.



Max. complex wave = 100

$R_1 = 93.2$ $\phi_1 = 2° 50'$

$R_3 = 9.4$ $\phi_3 = 1° 49'$

$R_5 = 14.9$ $\phi_5 = -33° 9'$

$R_7 = 3.8$ $\phi_7 = 130° 17'$

FIG. 24.—Analysis of oscillogram No. 69 sheet No. 11

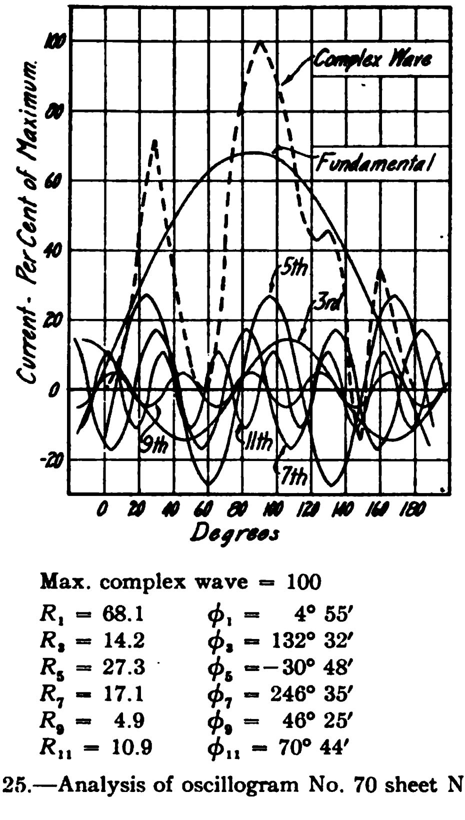
TABLE 6

Three single-phase, core type, 25-cycle, 25-kw., 2300-volt primary, 460-volt secondary, transformers connected delta closed—neutral connected

B-Kilolines	Voltage across		Current in line					Watts
	Lines	Leg	1	2	3	Closed delta	Connected neutral	
22.5	397.5	234.2	0.3	0.28	0.3	0	0	127.5
90.0	795	462.5	4.08	3.45	4.11	0.62	0.76	975
112.5	995	575	27	24.5	27.5	3.2	1.13	2,290

OBSERVATIONS ON A THREE-PHASE CORE TYPE TRANSFORMER

The next step in the investigation was to observe the wave shapes of current and potential on a three-phase core type transformer and to note the influence of the difference in the magnetic circuit of such a transformer as compared with the magnetic circuit of three single-phase transformers. Fig. 26 shows the three-phase core type transformer used in this investigation. As before, a transformer of low voltage and small capacity was selected so that the potential wave shapes applied by the generator would not be distorted by the current required for the test. It should be noted that the magnetization of each of the three legs of the three-phase core is not the result of the current flowing in the coil surrounding it, but is imposed by the resultant effect of the currents around all the legs. The lack of symmetry



Max. complex wave = 100

$R_1 = 68.1$ $\phi_1 = 4° 55'$
$R_3 = 14.2$ $\phi_3 = 132° 32'$
$R_5 = 27.3$ $\phi_5 = -30° 48'$
$R_7 = 17.1$ $\phi_7 = 246° 35'$
$R_9 = 4.9$ $\phi_9 = 46° 25'$
$R_{11} = 10.9$ $\phi_{11} = 70° 44'$

FIG. 25.—Analysis of oscillogram No. 70 sheet No. 11

between the magnetic circuit of the middle leg and either outside leg also affects the results. The reluctance of the air circuit for each leg being many times the reluctance of the iron circuits, considerably more triple frequency current is required to eliminate the potential distortion, so that the marked distortion of current and potential noted in the single-phase transformers under similar connections is, therefore, absent.

Sheets 6, 7, 8 and 9 give oscillograms of current and potential as before. Tables 7, 8, 9 and 10 give the root-mean-square values.

FIG. 26.—Three-phase, core-type, 25-cycle, 40-kw., 2300-volt primary, 460-volt secondary transformer used to investigate third harmonics

TABLE 7

Three-phase, core type, 25-cycle, 40-kw., 2300-volt primary, 460-volt secondary transformers, connected neutral isolated—delta open

B-Kilolines	Voltage across				Current in line			Watts
	Lines	Leg	Open delta	Isolated neutral	1	2	3	
42.6	1150	662	2.5	2.3	0.252	0.234	0.186	210
85.2	2300	1324	50	45	1.34	1.22	1.92	860
106.4	2875	1650	150	135	3.32	2.94	2.64	1960

TABLE 8

Three-phase, core type, 25-cycle, 40-kw., 2300-volt primary, 460-volt secondary transformers, connected isolated neutral—closed delta

B-Kilolines	Voltage across			Current in line				Watts
	Lines	Leg	Isolated neutral	1	2	3	Closed delta	
42.6	1150	662	0	0.234	0.252	0.210	0.076	211.5
85.2	2300	1324	0	1.17	1.32	0.92	0.84	880
106.4	2875	1650	0	3	3.36	2.76	2.93	2040

TABLE 9

Three-phase core type, 25-cycle, 40-kw., 2300-volt primary, 460-volt secondary transformers, connected neutral connected—delta open

B-Kilolines	Voltage across			Current in line				Watts
	Lines	Leg	Open delta	1	2	3	Connected neutral	
42.6	1150	659	0	0.204	0.195	0.171	0.137	213
85.2	2300	1324	0	1.42	1.22	0.92	0.86	880
106.4	2875	1652.5	4	3.16	2.96	2.76	3.25	2040

TABLE 10

Three-phase, core type, 25-cycle, 40-kw., 2300-volt primary, 460-volt secondary transformers, connected delta closed—neutral connected

B-Kilolines	Voltage across		Current in line					Watts
	Lines	Leg	1	2	3	Closed delta	Connected neutral	
42.6	1150	662	1.08	0.096	0.09	0.225	0.223	216
85.2	2300	1324	1.32	1.27	0.82	0.82	0.404	960
106.4	2875	1652.5	3.16	3.26	2.56	3.0	0.7	2120

It should be noted that the potential wave shape across the different legs is not identical, and that the current wave shape in the three legs is also not identical. These differences are explained by the lack of symmetry of the magnetic structure of the different legs and also by the slight difference in the windings of the legs. It will be noted that the same general results follow on the three-phase transformer as were observed in the discussion of the three single-phase transformers.

In Fig. 27, the observed core losses under the different connections are plotted.

The next step in the investigation was the consideration of a three-phase core type transformer with legs symmetrically arranged, as shown in Fig. 28. Oscillograms are given on Sheets 18, 19, 20 and 21, and root-mean-square values at density of 66 kilolines in the core are given in Table 11.

Attention is called to the almost equal values of exciting current for the different windings which was not observed in the unsymmetrical three-phase core type. It will be noted also that as the results of the symmetrical magnetic structure and the inter-relation of the magnetizing effects, the potential wave shape across the different legs under all connections is practically the same. No doubt, at higher densities, some unbalanced effect would be noted, but at the densities at which tests were taken, none were observed.

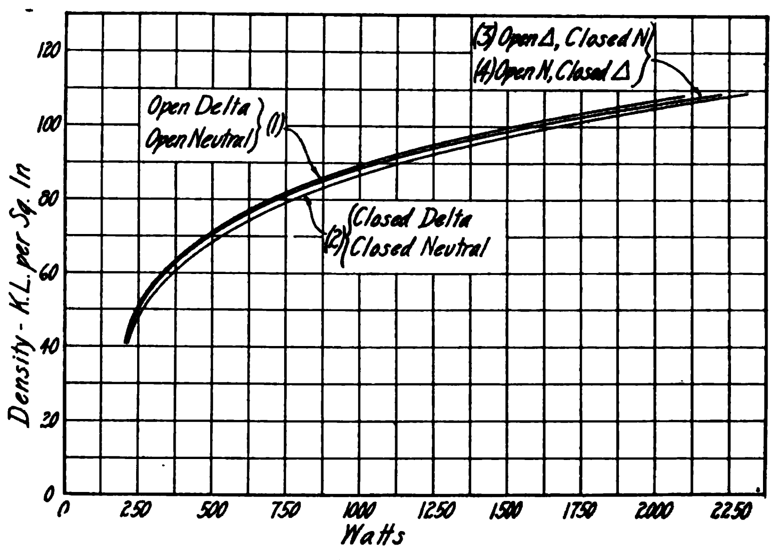


FIG. 27.—Curve of core loss of three-phase, 25-cycle, 40-kw. 2300-volt Y-primary, 460 volt delta secondary

For a final series of observations, a three-phase shell type, 60-cycle, 330-kw., 13,200-volt primary, 430-volt secondary transformer was selected, and oscillograms of current and potential observed as given in Sheets 14, 15, 16 and 17. Root-mean-square values at 43 kilolines and 86 kilolines are given in Tables 12 and 13.

TABLE 11

Three-phase, core type, 60-cycle, 200-kw., 4600-volt primary, 2300-volt secondary transformers.

		Voltage across				Current in line			
	B-Kilolines	Lines	Leg	Neutral	Delta	1	2	3	Watts
(1)	66	3980	2275	0	0	1.82	1.70	1.90	3420
(2)	66	3980	2275	0	0	1.97	1.88	1.97	3820
(3)	66	3980	2275	0	0	1.58	1.42	1.6	3610
(4)	66	3980	2275	0	0	2.0	1.92	2.0	3850

(1) Delta closed—neutral connected.
(2) Delta open—neutral isolated.
(3) Delta closed—neutral isolated.
(4) Delta open—neutral connected.

TABLE 12

Three-phase, shell type, 60-cycle, 330-kw., 13,200-volt primary, 430-volt secondary

		Voltage across				Current in line				
	B-Kilo-lines	Lines	Leg	Delta	Neutral	1	2	3	Neutral	Watts
(1)	43	372.5	215	4500	50.1	6.0	6.2	4.76	—	2225
(2)	43	372.5	215	—	—	5.88	6.00	4.86	0	2250
(3)	43	372.5	215	5	—	5.88	6.31	5.37	2.33	2275
(4)	43	372.5	215	—	0	6.0	6.2	4.76	—	2225

(1) Delta closed—neutral connected.
(2) Delta open—neutral isolated.
(3) Delta closed—neutral isolated.
(4) Delta open—neutral connected.

TABLE 13

Three-phase, shell type, 60-cycle, 330-kw., 13,200-volt primary, 430-volt secondary

		Voltage across				Current in line				
	B-Kilolines	Lines	Leg	Delta	Neutral	1	2	3	Neutral	Watts
(1)	86	745	460	9580	102.2	53.7	53.7	36.6	—	9,000
(2)	86	745	430	—	—	60	57.8	45.6	3.5	10,500
(3)	86	745	430	301.5	—	64.2	57.8	60.0	24.9	10,200
(4)	86	745	430	—	0	58.8	57.8	44.6	—	10,000

(1) Delta closed—neutral connected.
(2) Delta open—neutral isolated.
(3) Delta closed—neutral isolated.
(4) Delta open—neutral connected

Fig. 28.—Three-phase, core-type, 25-cycle, 500-kw., 2300-volt primary 2300-volt secondary transformer used in the investigation of third harmonics

Fig. 29.—Three-phase, shell-type, 60-cycle, 330-kw., 13,200-volt primary, 430-volt secondary transformer used to investigate third harmonics

The general construction of the transformer and diagram of the core structure is shown in Figs. 29 and 30. The unsymmetrical current and potential waves are no doubt explained entirely by the unsymmetrical core structure.

Attention is called to the potential wave shape across the open neutral and open delta, analysis of which is given in Fig. 31. The presence of a fundamental of considerable magnitude is, no doubt, explained by the presence of unbalanced fundamental voltage due to lack of absolute duplication of the windings.

DELTA-CONNECTED TRANSFORMERS

The remaining important connection of interconnected transformers is the delta connection, using either two or three transformers. For this investigation three 25-cycle, 25-kw., 2300-volt primary, 460-volt secondary transformers were selected and connected as shown in Fig. 32. Sheet 22 gives the oscillograms of current and potential, using the three transformers with delta primary and delta secondary. It will be noted that the currents in the line are almost identical in shape. Reference is made to curve No. 78, Sheet 13, and its analysis given in Fig. 17, which shows no third harmonic, but a decided fifth and seventh.

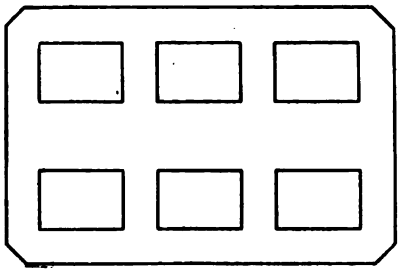
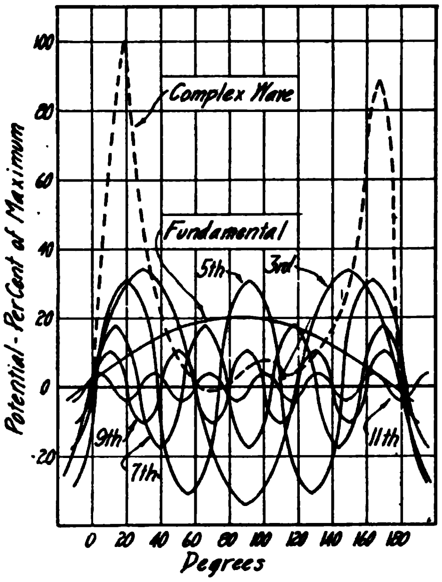


FIG. 30.—Diagram of core structure of three-phase, shell-type, 60-cycle, 330-kw., 13,200-volt primary, 430-volt secondary transformer used to investigate third harmonic

Sheet 23 gives the oscillograms of current and potential with three transformers delta connected on the primary and two transformers on the secondary, a condition which may arise when one of three delta connected transformers becomes open. It will be noted that there is no appreciable change in the current wave shape. The potential across the open delta shows the usual characteristic of triple frequency voltage and a slight fundamental. The current in the primary delta has the characteristic curve of the current in a transformer connected single-phase *i.e.*, has a fundamental and a decided third harmonic. This



Max. complex wave = 100

R_1	= 20.1	ϕ_1 =	4° 49′
R_3	= 33.9	ϕ_3 =	1° 39′
R_5	= 30.8	ϕ_5 =	-7° 35′
R_7	= 17.8	ϕ_7 =	-4° 16′
R_9	= 10.4	ϕ_9 =	-0° 13′
R_{11}	= 4.1	ϕ_{11} =	41° 44′

FIG. 31.—Analysis of oscillogram No. 104 sheet No. 17

naturally follows because the transformer with secondary open is excited by the delta connected primary and calls for a current characteristic corresponding to the sine potential applied.

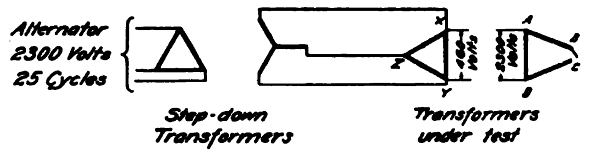


FIG. 32

The next step in the investigation was to open the primary delta as shown in Fig. 33. Sheet 24 gives the oscillograms. It will be noted that the wave shapes across the lines and across each transformer are identical. The current in the two outside legs shows the usual characteristic of the fundamental and a marked third harmonic. The current in the middle leg, however, shows the presence of a fifth and a seventh harmonic and no third; while the current in legs X and Y conforms to that required when a sine potential is applied across the two transformers connected in series.

OBSERVATIONS ON TRANSFORMERS IN ACTUAL SERVICE

To study the conditions found on transformers in actual service, an investigation was made of three transformers connected to the distributing mains of the Rochester Railway & Light Co., Rochester, N. Y. These transformers were rated 60-cycle, 150-kw., 2,400/4,150 Y-volt primary, 480-volt secondary and are similar in their general characteristics to the 25-cycle, 25-kw., 2,300-volt primary, 460-volt secondary transformers previously discussed. The connections to these transformers and the general arrangement of feeders, generators, etc., forming the distributing system are shown in Fig. 34. Transformers are located in substation No. 34, and it will be noted that power is supplied to this substation from alternators in generating stations Nos. 3, 5 and 15, connected in parallel. The following list gives the generators and their prime movers in the different generating stations.

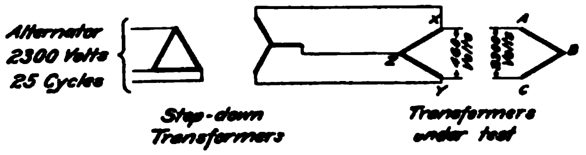


FIG. 33

GENERATING STATION NO. 3

Generators				Prime movers
No. of	Poles	Capacity kilowatts	Speed rev. per min.	
3*	80	1360	90	Reciprocating engine.
1	10	3000	720	Steam turbine.
1	24	2100	300	25-cycle induction motor.
2*	16	350	450	Water wheel.

* Originally two-phase, now three-phase T-connected.

GENERATING STATION NO. 5

Generators				Prime movers
No. of	Poles	Capacity kilowatts	Speed rev. per min.	
3	22	1200	327	Water wheels.
1*	16	350	450	Water wheels.
1	24	2100	300	25-cycle induction motor.

GENERATING STATION NO. 15

Generators				Prime movers
No. of	Poles	Capacity kilowatts	Speed rev. per min.	
2	36	500	200	Water wheel.

Oscillograms of the potential wave shape at no load across the terminals, and from terminal to neutral, of these generators are given on Sheet 29. A study of these curves and the list showing the different types of prime movers of the generators would lead one to conclude that results differing from those observed with a single generator having a sine potential should be expected.

Table 14 gives root-mean-square values of potential, current, and watts, taken as before.

TABLE 14.

Single-phase, core type, 60 cycle, 150-kw, 2400/4150 Y-volt primary, 480 volt secondary

	Voltage across				Current in line					Watts
	Lines	Leg	Delta	Neutral	A	B	C	Delta	Neutral	
(1)	4250	2705	720	1041	1.1	1.11	1.08	—	—	941
(2)	4342	2540	—	—	38.8	40.6	39.1	180	122	3467
(3)	4233	2453	73	—	1.35	2.0	1.6	—	1.45	1012
(4)	4293	2422	—	125	1.26	1.28	1.06	2.35	—	1025

(1) Open delta—isolated neutral.
(2) Closed delta—connected neutral.
(3) Open delta—connected neutral.
(4) Closed delta—isolated neutral.

It should be stated, that these figures could not be as accurately taken as those given in previous tables because of the fluctuations or variations consequent to the varying load of the system.

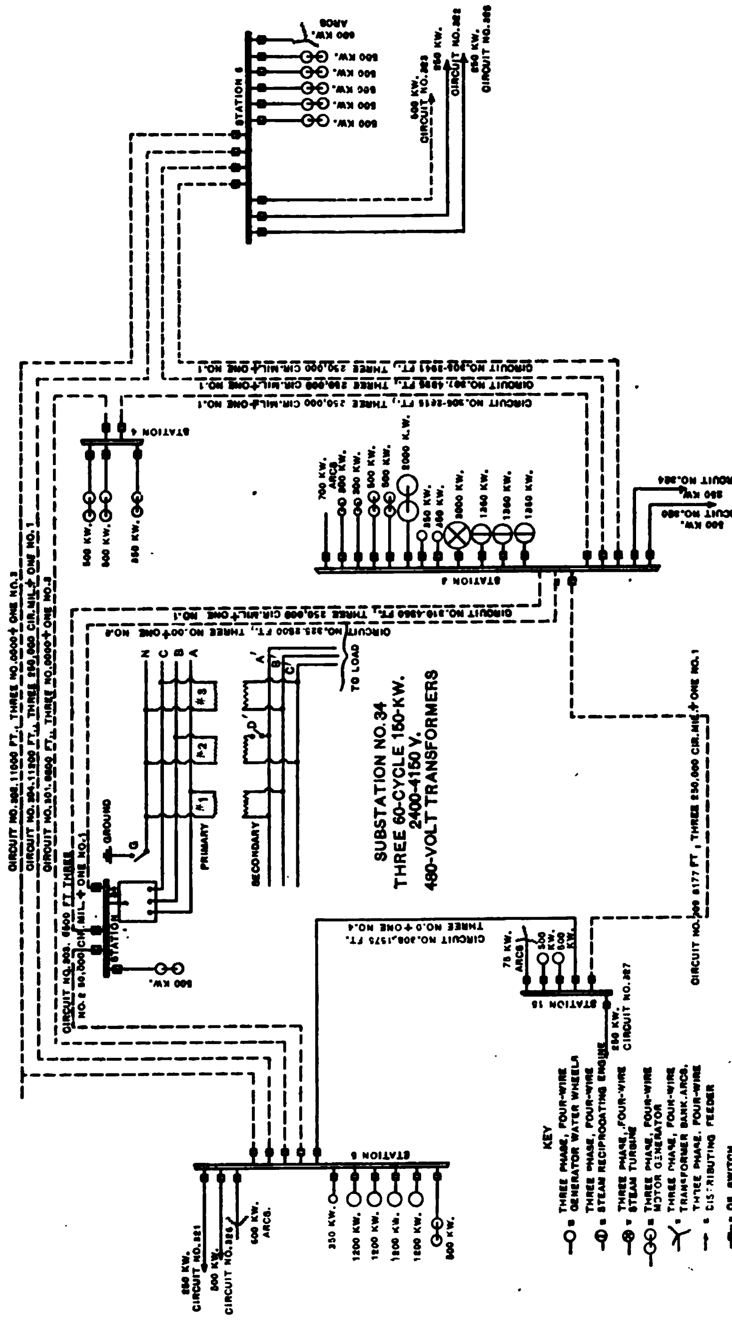


FIG. 34.—Electrical apparatus, the lines and distributing feeders on 4150-volt three-phase system Rochester Railway and Light Company, Rochester, N. Y.

Sheet 4 shows the usual oscillograms of current and potential with the neutral isolated and with the secondary delta open. Curve No. 16, the potential across the lines or mains, is almost a perfect sine wave. Curve No. 17, the potential across each transformer, shows the usual characteristic wave shape distorted due to the third harmonic. (For comparison, see curve No. 77, Sheet 13, and analysis given in Fig. 16.) Curve No. 18, current in the line, shows the presence of the fifth harmonic. (Compare also curve No. 78, Sheet 13, and analysis, Fig. 17). Curves No. 19 and No. 20 show triple frequency across the isolated neutral and open delta.

Sheet 3 gives oscillograms with the neutral connected and the delta open. As previously observed, it is noted that with the neutral closed, allowing triple frequency current to flow in the neutral (curve No. 14), the potential across each transformer is practically a sine wave shape (curve No. 12). The current in the line is changed and has the expected characteristic containing a third harmonic. (Refer to curve No. 23, Sheet 5, and analysis, Fig. 6). The difference in the amplitude of the triple frequency current in the neutral is due to the presence of some fundamental current. Curve No. 15, potential across the open delta, shows in addition to a voltage of triple frequency, a component of the fundamental and a component of higher frequency, presumably the ninth.

Sheet 1 gives oscillograms with the neutral open and the delta closed. It would be expected that the results as observed on Sheet 3, with the neutral closed and delta open, would be reproduced with the neutral open and the delta closed. This is confirmed by the oscillograms. Curves No. 1 and No. 2 show practically a sine potential across the line and across the transformer. Curve No. 3, current in the line, shows the usual distortion. Curve No. 4, the potential across the open neutral, has the same shape as the potential across the open delta, curve No. 15, Sheet 3. Curve No. 5, current in the closed delta, has the same characteristics as curve No. 14, Sheet 3, current in the closed neutral.

Attention is called to the fact that when a path is provided for the circulation of the triple frequency current by either closing the delta or connecting the neutral, the voltage across the open neutral or across the open delta should be zero. The observed fact that there is considerable voltage of triple frequency across the open neutral and open delta would indicate that there is some disturbance on the system which cannot be overcome by the triple frequency magnetizing current supplied to the core.

Oscillograms with both neutral and delta closed are given on Sheet 2 and contrary to the previous observations, it will be noted that a marked triple frequency current is present in the line (curve No. 8) and in the neutral (curve No. 9) and in the closed delta (curve No. 10). The explanation for this is given by the fact that the generating system produces an electromotive force between neutral and line having a triple frequency component, as indicated by the oscillograms on Sheet 29. The potential across the line is free from this triple frequency disturbance. When the neutral of the transformers is connected to the neutral of the generating system, this triple frequency disturbance is applied to the primary of each transformer and is reproduced on the secondary, as evidenced by curve No. 15, Sheet 3. By closing the delta, the triple frequency components in each leg of the secondary delta, being in the same phase, produce an energy current dependent on the resistance and reactance of the mains and of the transformers. This current must be supplied by the primary winding and the ratio of currents in the two windings is practically the same as the ratio of transformation. The current in the neutral of the primary winding should be about three times the current in the line. Reference to Table 14 will confirm this.

The difference between the effect of a triple frequency component forced upon the transformers by the generating system and a triple frequency component created by the magnetization characteristics should be clearly distinguished. Referring to Sheet 3 and Table 14, it will be noted that triple frequency voltage forced upon the transformers by the generating system produced a large current with the delta connected or closed, since these components of each transformer are in phase with each other. Small voltage will call for heavy current, which is only limited by the resistance and reactance of the transformer. The triple frequency voltage created by the magnetic characteristics of the core is suppressed by a very small demagnetizing current, as shown in the various oscillograms previously referred to.

In the present instance, this heavy triple frequency current flowing in the neutral and the line compelled the operating company to disconnect the neutral of the transformers from the neutral of the system. This was practically the only solution to the difficulty without disturbing the whole distributing system. Another solution of the difficulty would have been to use transformers delta-Y connected across each generator, using the neutral of the Y connection for the neutral of the general distributing system.

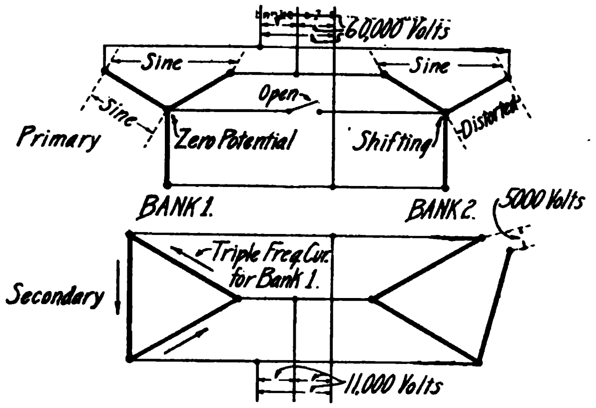


Fig. 35a.—Diagram showing distribution of triple frequency current and voltage in parallel banks of single-phase transformers

As an important example of the confusing conditions occurring in practice resulting from potential wave distortion, the following case may be cited:

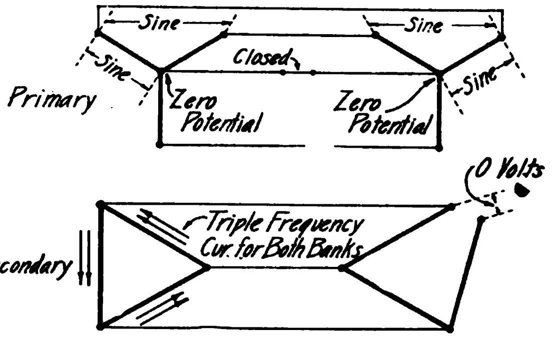


Fig. 35b.—Diagram showing distribution of triple frequency current and voltage in parallel banks of single-phase transformers

Figs. 35*a*, *b*, *c*, *d*, represents two parallel banks of transformers with 60,000-volt Y primary and 11,000-volt delta secondary.

Occasion arose in which it was necessary to disconnect one of the transformers in bank No. 2. In replacing it and attempting to "phase out" the connections, 5,000 volts were measured across the open delta, indicating a very unbalanced condition. A study of the conditions existing will show that this should have been expected. With the neutrals of the two banks isolated and the delta of bank No. 2 open and that of bank No. 1 closed, a sine potential wave shape is maintained across the transformers of bank No. 1 by the triple frequency current supplied by the closed delta. The neutral of this bank should be at zero potential with respect to the ground.

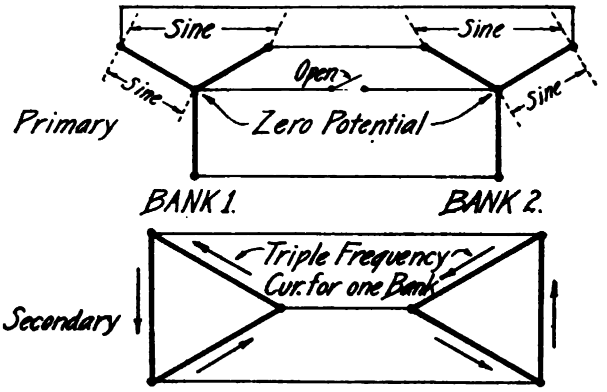


FIG. 35C.—Diagram showing distribution of triple frequency current and voltage in parallel banks of single-phase transformers

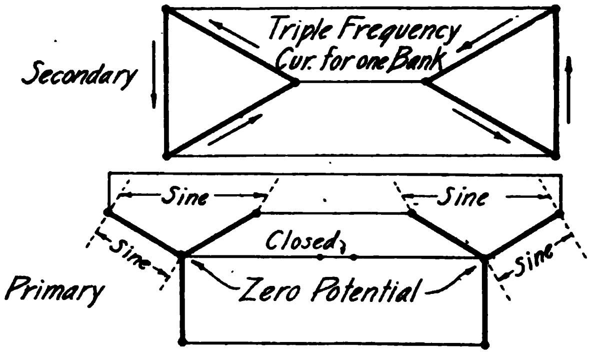
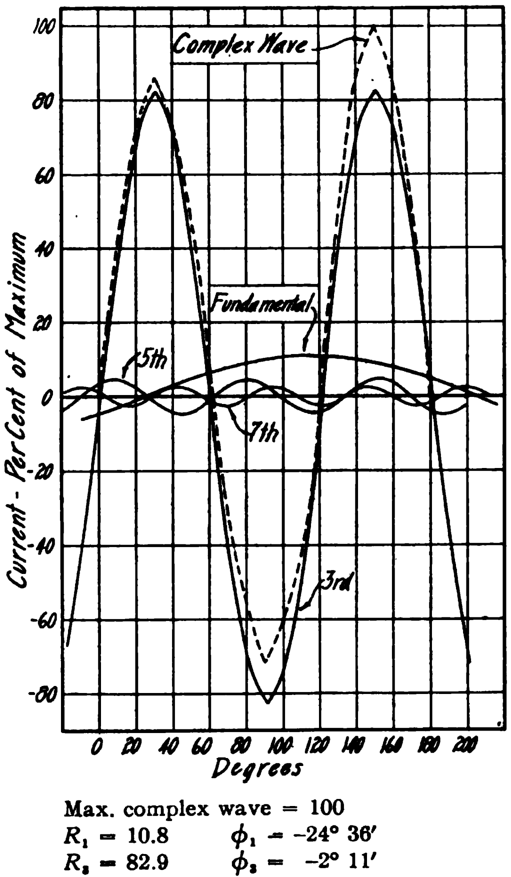


FIG. 35D.—Diagram showing distribution of triple frequency current and voltage in parallel banks of single-phase transformers

With the neutral of bank No. 2 open, while the potential across the 60,000-volt line may be a sine shape, no provision is made to insure a sine potential across each transformer, and consequently the two banks are unbalanced across the neutrals by an amount equal to the distorted potential across each leg of bank No. 2; *i.e.*, the neutral shifts and there is an unbalancing of voltage across the open delta of bank No. 2.



Max. complex wave = 100

R_1 = 10.8 ϕ_1 = -24° 36′

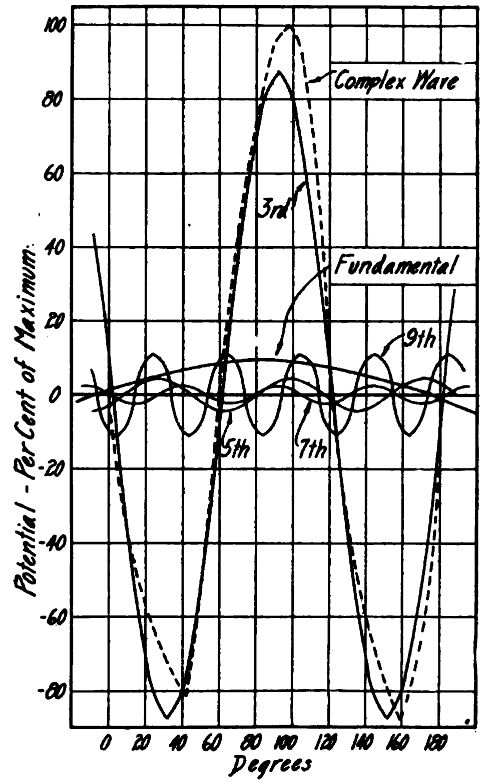
R_3 = 82.9 ϕ_3 = -2° 11′

R_5 = 4.9 ϕ_5 = 48° 19′

R_7 = 2.6 ϕ_7 = 150° 58′

FIG. 36.—Analysis of oscillogram No. 74 sheet No. 12

By connecting the neutrals, all triple frequency disturbances disappear and sine potential is applied to the transformers of both banks, the necessary triple frequency current being supplied for both banks by the closed delta of bank No. 1. Upon closing the delta of bank No. 2, the voltage now read across the open delta will be zero, and the secondary windings of both banks will equally contribute the necessary triple frequency currents to maintain sine potential across the transformers of both banks. Under such conditions, the connection between the neutrals of the primaries of the two banks may be open or disconnected entirely without any disturbance or change in the potential wave shape applied to the transformers.



Max. complex wave = 100

$R_1 = 9.2$ $\phi_1 = 7° \ 1'$

$R_3 = 87.7$ $\phi_3 = 172° \ 32'$

$R_5 = 4.4$ $\phi_5 = -44° \ 3'$

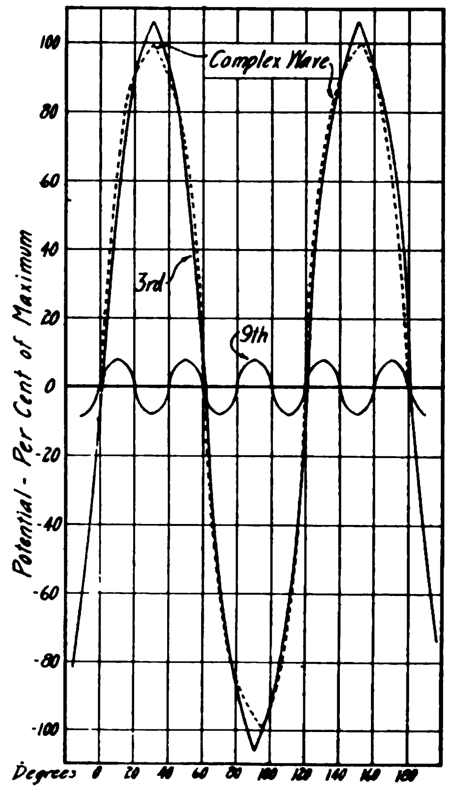
$R_7 = 2.3$ $\phi_7 = 177° \ 43'$

$R_9 = 11.2$ $\phi_9 = 236° \ 8'$

FIG. 37.—Analysis of oscillogram No. 75 sheet No. 12

It is evident that the investigation and observations of the distribution of current and potential has great practical value.

The broadest general conclusion to be drawn from the observations presented in this paper, so far as they relate to transformers, is that in any distributing system disturbances of current and potential are to be expected unless provision is made to maintain sine potential across the individual transformers.



Max. complex wave = 100

$R_3 = 106.0$ $\phi_3 = -2° 26'$

$R_9 = 8.1$ $\phi_9 = 3° 9'$

FIG. 38.—Analysis of oscillogram No. 79 sheet No. 13

The writer takes this opportunity to acknowledge assistance in the discussion and analysis of the curves to Mr. W. W. Lewis.

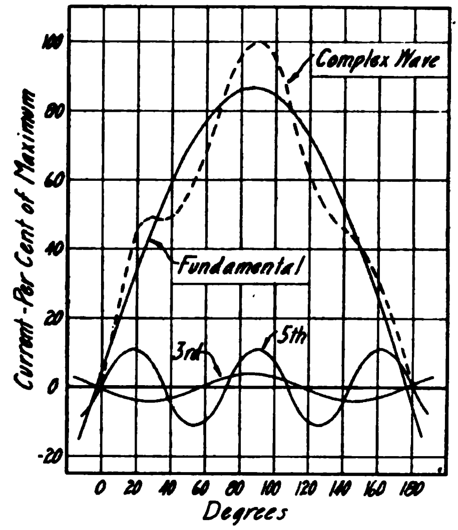
APPENDIX

The analysis of the waves in the foregoing article was carried on by the method of Professor S. P. Thompson, as given in Vol. II of his work on Dynamo Electric Machinery. A brief outline of the method may be of interest.

The following fundamental assumptions are made:

1. Any periodic complex wave, according to the theorem of Fourier, may be considered as built up of a series of harmonic terms, the fundamental one of the series being of the same frequency as the given complex wave. This theorem may be expressed by the following equation:

$$y = R_1 \sin(\theta+\phi_1) + R_3 \sin(3\theta+\phi_3) + R_5 \sin(5\theta+\phi_5) \quad \textbf{(A)}$$
$$+ \ldots \ldots \ldots \ldots \text{ etc.}$$



Max. complex wave = 100

R_1 = 86.8 ϕ_1 = 3° 6′

R_3 = 3.6 ϕ_3 = 189° 46′

R_5 = 11.1 ϕ_5 = 1° 14′

FIG. 39.—Analysis of oscillogram No. 83 sheet No. 14

where R_1, R_3, etc., are the amplitudes of the harmonics, and ϕ_1, ϕ_3, etc., are the angles of lag with respect to the zero of the complex wave.

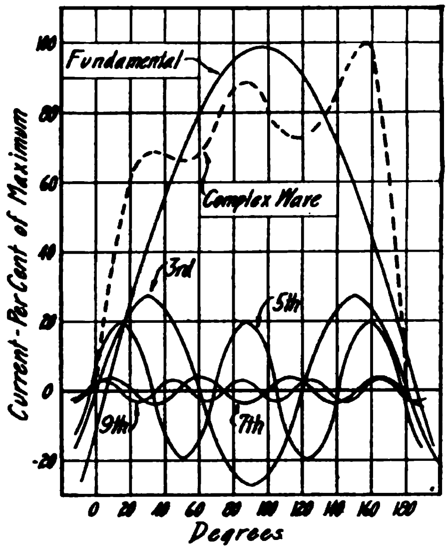
2. As indicated by equation (A), only odd harmonics are present, a well-known characteristic of alternator waves.

3. The lagging harmonics in equation (A) may be resolved into two components; one a sine curve with zero lag and the other a sine curve with a lag of 90 degs.; in other words, a sine curve in

phase with the complex wave and a cosine curve. Equation (**A**) may then be written

$$y = A_1 \sin \theta + B_1 \cos \theta + A_3 \sin 3\,\theta + B_3 \cos 3\,\theta + A_5 \sin 5\,\theta + B_5 \cos 5\,\theta + \ldots \ldots \ldots \text{etc.} \qquad (\mathbf{B})$$

4. The mean horizontal axis of the curve is midway between the highest and lowest points of the curve, and the origin or zero point of the complex wave may be chosen where this curve crosses the horizontal axis.



Max. complex wave = 100

$R_1 = 98.8$ $\phi_1 = -5° 43'$

$R_3 = 27.2$ $\phi_3 = -1° 13'$

$R_5 = 19.9$ $\phi_5 = 15° 32'$

$R_7 = 3.7$ $\phi_7 = 29° 51'$

$R_9 = 3.1$ $\phi_9 = 48° 22'$

FIG. 40.—Analysis of oscillogram No. 84 sheet No. 14

5. The positive and negative portions of the waves under consideration are identical, so that only a half-wave, *i.e.*, 180 degs. need be considered.

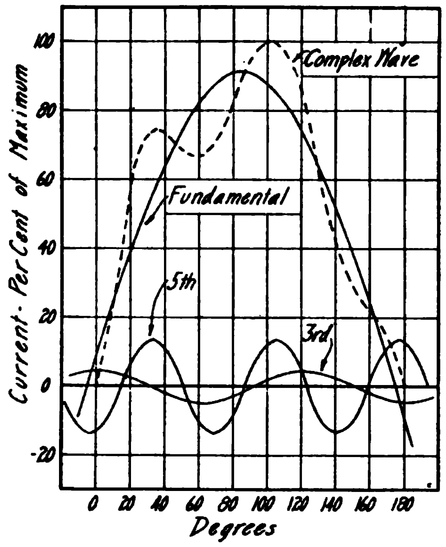
6. If the half-wave is symmetrical to the right and left of 90 degs., only sine terms are present. If not symmetrical in this respect, both sine and cosine terms are present. The latter is the usual case and in general need be the only one considered.

The problem is to find the unknown coefficients A_1, A_3, A_5, etc., and B_1, B_3, B_5, etc. These may then be combined to find R_1, R_3, R_5, etc., by the equation

$$R_1 = \sqrt{A_1^2 + B_1^2} \tag{C}$$

and the angles ϕ_1, ϕ_3, ϕ_5, etc., by the equation

$$\phi_1 = \tan^{-1} \frac{B_1}{A_1} \tag{D}$$



Max. complex wave = 100

$R_1 = 91.0$ $\phi_1 = 5° 22'$

$R_3 = 4.5$ $\phi_3 = 83° 58'$

$R_5 = 13.7$ $\phi_5 = 73° 20'$

$R_7 = 2.6$ $\phi_7 = 238° 24'$

FIG. 41.—Analysis of oscillogram No. 85 sheet No. 14

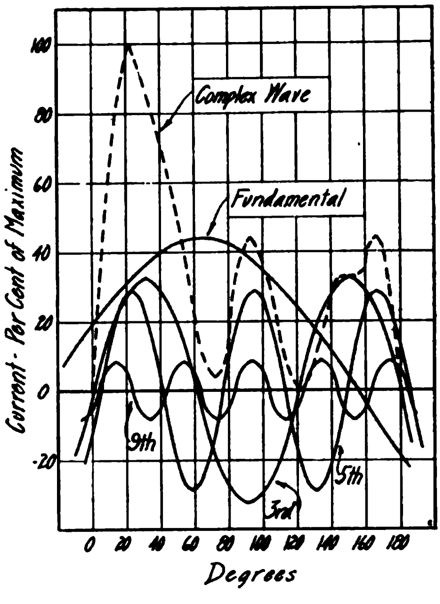
Consider that only the first three harmonics in the series are required, *i.e.*, fundamental, third and fifth. We must then find six unknowns, *viz.*, A_1, A_3, A_5, and B_1, B_3, B_5, and consequently must have six equations. If sine terms only were present, we might choose three convenient points on the wave whose ordinates would then satisfy the following equations:

$$\begin{aligned} y_1 &= A_1 \sin \theta_1 + A_3 \sin 3\,\theta_1 + A_5 \sin 5\,\theta_1 \\ y_2 &= A_1 \sin \theta_2 + A_3 \sin 3\,\theta_2 + A_5 \sin 5\,\theta_2 \\ y_3 &= A_1 \sin \theta_3 + A_3 \sin 3\,\theta_3 + A_5 \sin 5\,\theta_3 \end{aligned} \tag{E}$$

which equations may be solved simultaneously for A_1, A_3 and A_5. Similarly, if cosine terms only were present, three other equations might be formed, *viz.*,

$$\begin{aligned} y_0 &= B_1 \cos \theta_1 + B_3 \cos 3\,\theta_1 + B_5 \cos 5\,\theta_1 \\ y_1 &= B_1 \cos \theta_2 + B_3 \cos 3\,\theta_2 + B_5 \cos 5\,\theta_2 \\ y_2 &= B_1 \cos \theta_3 + B_3 \cos 3\,\theta_3 + B_5 \cos 5\,\theta_3 \end{aligned} \qquad \text{(F)}$$

and solved simultaneously for B_1, B_3, B_5. If both sine and cosine terms are present, then each ordinate chosen is made up



Max. complex wave = 100

$R_1 = 43.8 \qquad \phi_1 = 25° 50'$

$R_3 = 32.4 \qquad \phi_3 = -2° 40'$

$R_5 = 28.7 \qquad \phi_5 = -26° 45'$

$R_9 = 8.5 \qquad \phi_9 = 35° 11'$

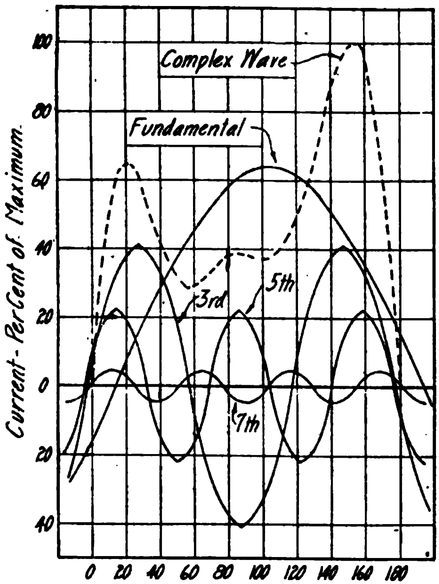
FIG. 42.—Analysis of oscillogram No. 91 sheet No. 15

of two portions, the ordinate of the sine component and the ordinate of the cosine component of the wave at that point, and their separation may be accomplished as follows:

It is known that $\sin \theta = \sin (180° - \theta)$ and that $\cos \theta = -\cos (180° - \theta)$. Take an ordinate y_θ (θ less the 90°) and an ordinate $y_{(180°-\theta)}$. If we add these ordinates, any component parts due to $\cos \theta$, $\cos 3\,\theta$, $\cos 5\,\theta$, etc., will cancel while any component parts due to $\sin \theta$, $\sin 3\,\theta$, $\sin 5\,\theta$, etc., will be doubled. If we subtract $y_{(180^\circ-\theta)}$ from y_θ, the sine components will cancel, leaving the doubled cosine components. That is, expressed algebraically,

$$\begin{aligned} s_1 &= y_\theta + y_{180^\circ-\theta} = 2\,(A_1 \sin\theta_1 + A_3 \sin 3\,\theta_1 + A_5 \sin 5\,\theta_1) \\ d_1 &= y_\theta - y_{180^\circ-\theta} = 2\,(B_1 \cos\theta_1 + B_3 \cos 3\,\theta_1 + B_5 \cos 5\,\theta_1) \end{aligned} \qquad (G)$$

We may thus find a number of ordinates, $\frac{s_1}{2}$, $\frac{s_2}{2}$, $\frac{s_3}{2}$, which may be substituted for y_1, y_2, y_3, in equation (E) and a similar set of ordinates $\frac{d_1}{2}$, $\frac{d_2}{2}$, $\frac{d_3}{2}$, which may be substituted for y_0, y_1, y_2, in equation (F), and equations (E) and (F) solved simultaneously for A_1, A_3, A_5, and B_1, B_3, B_5. The amplitudes R_1, R_3, R_5, and angles ϕ_1, ϕ_3, ϕ_5, may then be found from equations (C) and (D).

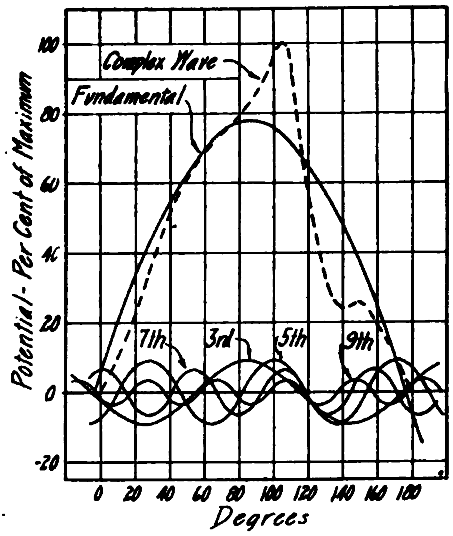


Max. complex wave = 100

$R_1 = 63.9$ $\phi_1 = -14^\circ\ 0'$
$R_3 = 41.0$ $\phi_3 = 8^\circ\ 28'$
$R_5 = 22.1$ $\phi_5 = 21^\circ\ 54'$
$R_7 = 4.8$ $\phi_7 = 10^\circ\ 11'$

FIG. 43.—Analysis of oscillogram No. 97 sheet No. 16

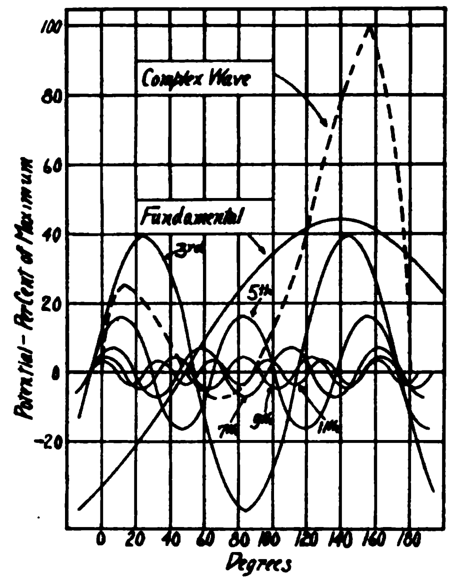
It is apparent that if we consider the complex wave to be made up of a fundamental, third, and fifth harmonics, and there also happens to be a seventh or other higher harmonic present, the amplitudes that we find on the assumption that the first three harmonics only are present, will each contain a portion of the amplitudes belonging to the seventh and higher harmonics, and the analysis is an approximation to that extent. Therefore, the more harmonics for which we strive, the more accurate will be the analysis, also the more complicated the simultaneous equations



Max. complex wave = 100
$R_1 = 77.9$ $\phi_1 = 3° 57'$
$R_3 = 8.9$ $\phi_3 = 195° 26'$
$R_5 = 9.1$ $\phi_5 = -49° 39'$
$R_7 = 6.9$ $\phi_7 = 78° 55'$
$R_9 = 3.6$ $\phi_9 = 203° 28'$

FIG. 44.—Analysis of oscillogram No. 99 sheet No. 17

to be handled. An analysis for all the harmonics up to and including the eleventh is sufficiently accurate for nearly all cases and requires the handling of six simultaneous equations, which is about as many as it is practicable to deal with. For this purpose, the quarter-wave is divided into six intervals of 15 deg. each and the ordinates measured by means of a dividing engine. These ordinates are combined with the ordinates of the supplementary angles in the second quarter of the wave, giving the sums s_1, s_2, etc., and the differences d_1, d_2, etc., to be substituted in the proper equations. By means of a schedule prepared by Professor Thompson and slightly modified for our use, the solution of the simultaneous equations is greatly facilitated. The complete analysis of curve No. 78, Sheet 13, shown in detail in Fig. 17, is appended to show the use of this schedule



Max. complex wave = 100

$R_1 = 44.1$ $\phi_1 = -48° \ 59'$

$R_3 = 39.8$ $\phi_3 = 16° \ 42'$

$R_5 = 16.2$ $\phi_5 = 33° \ 21'$

$R_7 = 7.11$ $\phi_7 = 49° \ 49'$

$R_9 = 4.76$ $\phi_9 = 61° \ 29'$

$R_{11} = 3.48$ $\phi_{11} = 74° \ 36'$

FIG. 45.—Analysis of oscillogram No. 128 sheet No. 22

SCHEDULE FOR THE ANALYSIS OF A PERIODIC CURVE IN WHICH APPEAR ONLY ODD HARMONICS UP TO THE ELEVENTH

(1)	1	2	3	4	5	6
	$y_1 = 7.6$ $y_{11} = 37.3$	$y_2 = 11.2$ $y_{10} = 78.8$	$y_3 = 24.0$ $y_9 = 86.4$	$y_4 = 65.0$ $y_8 = 65.0$	$y_5 = 96.1$ $y_7 = 61.8$	$y_6 = 90.0$
Sum	44.9	90.0	110.4	130.0	157.9	90.0
Dif.	-29.7	-67.6	-62.4	0.0	34.3	
(2)	$s_1+s_3-s_5$		s_2-s_6		$d_1-d_3-d_5$	
	44.9 110.4		90.0 -90.0		29.7 34.3	
	155.3 -157.9				-64.0 62.4	
	$r_1 = -2.6$		$r_3 = 0.0$		$e_1 = -1.6$	

(3) SINE TERMS

Sine	1st and 11th		3rd and 9th		5th and 7th	
0.262	$s_1 = 11.8$				$s_5 = 41.4$	
0.500		$s_2 = 45.0$				$s_2 = 45.0$
0.707	$s_3 = 78.2$		$r_1 = 1.84$		$-s_3 = 78.2$	
0.866		$s_4 = 112.7$				$-s_4 = 112.7$
0.966	$s_5 = 152.3$				$s_1 = 43.4$	
1.000		$s_6 = 90.0$		$r_2 = 0.0$		$s_6 = 90.0$
1st col.	242.3		−1.84		6.6	
2nd col.	247.7		0.0		22.3	
Sum	$6A_1 = 490.0$		$6A_3 = -1.84$		$6A_5 = 28.9$	
Diff.	$6A_{11} = -5.4$		$6A_9 = -1.84$		$6A_7 = -15.7$	
	$A_1 = 81.7$		$A_3 = 0.31$		$A_5 = 4.8$	
	$A_{11} = 0.9$		$A_9 = -0.31$		$A_7 = -2.6$	

COSINE TERMS

0.262		$d_5 = 9.00$				$d_1 = -7.79$
0.500	$d_4 = 0$				$d_4 = 0$	
0.707		$d_3 = -44.1$		$e_1 = -1.13$		$-d_3 = 44.1$
0.866	$d_2 = -58.6$				$-d_2 = 58.6$	
0.966		$d_1 = -28.7$				$d_5 = 33.2$
1.000			$-d_4 = 0$			
1st col	−58.6		0		58.6	
2nd col.	−63.8		−1.13		69.5	
Sum	$6B_1 = -122.4$		$6B_3 = -1.13$		$6B_5 = 128.1$	
Diff.	$6B_{11} = 5.2$		$6B_9 = 1.13$		$6B_7 = -10.9$	
	$B_1 = -20.4$		$B_3 = -0.19$		$B_5 = 21.4$	
	$B_{11} = 0.9$		$B_9 = 0.19$		$B_7 = -1.8$	

(4)

$R_1 = \sqrt{81.7^2 + 20.4^2} = 84.2$	$\tan \phi_1 = \frac{-20.4}{81.7} = -0.25$
$R_3 = \sqrt{0.31^2 + 0.19^2} =$ negligible	$\tan \phi_3 = \quad =$
$R_5 = \sqrt{4.8^2 + 21.4^2} = 21.9$	$\tan \phi_5 = \frac{21.4}{4.8} = 4.46$
$R_7 = \sqrt{2.6^2 + 1.8^2} = 3.2$	$\tan. \phi_7 = \frac{-1.8}{-2.6} = 0.693$
$R_9 = \sqrt{0.31^2 + 0.19^2} =$ negligible	$\tan \phi_9 = \quad =$
$R_{11} = \sqrt{0.9^2 + 0.9^2} =$ negligible	$\tan \phi_{11} = \quad =$
$\phi_1 = 14° 2$	$\phi_7 = 214° 43'$
$\phi_3 =$	$\phi_9 =$
$\phi_5 = 77° 21'$	$\phi_{11} =$

DISCUSSION ON "OBSERVATION OF HARMONICS IN CURRENT AND IN VOLTAGE WAVE SHAPES OF TRANSFORMERS", SAN FRANCISCO, CAL., MAY 6, 1910.

H. J. Ryan: I don't know that there is anything I can add in an effective way to a paper of such great value. Any knowledge of anything that is so fundamental in engineering as the transformer, is of great value, and anything that tends to bring that knowledge up to date, and that has been done in this paper and has been done handsomely, is also of great value.

In the fundamental theory for the treatment of things of this kind use of two principles is made; one is the conservation of energy, and the other is that the average product of two alternating quantities that differ in frequency is zero. Thus by theoretical methods we arrive at the same conclusion, *viz.*, that the harmonics which develop in the exciting current of a transformer do not convey any of the core loss energy.

However, what we come to by theoretical reasoning is generally of very little value until a way has been found to check the result in the laboratory or in practice. It is right here that this paper is of such high value.

The facts brought out in this paper and in Mr. Faccioli's recent tests on a long distance high-tension transmission line show beyond all doubt that it is a matter of great importance to understand properly the causes of wave-form distortion and the methods that should be employed to accomplish their elimination.

We know that a 200-mile, 60-cycle, high-tension transmission line with its receiver circuit open delivers a terminal pressure that is considerably higher than the pressure at the source. With sine wave pressure at normal frequency applied at the source this terminal pressure rise will be a certain amount. Now assume the use of a non-sine wave source pressure made up of one part at normal frequency and a second part at ten per cent of the value of, and at a frequency of three times the first part, being different in frequency each of these pressure parts will work upon the line independently to produce a rise in the terminal pressure. The rise in value and shift in phase will be much greater in proportion for the third harmonics than the fundamental. The result will be to change and to distort greatly the wave form of the open circuit terminal pressure. There will be a corresponding increase in certain instantaneous values of the pressure accomplished by increase of the electric strain on the insulation and such other disorders as follow because of the use of the irregular wave forms.

Mr. Faccioli's transmission experiments and investigations have checked the above theoretical reasoning. It is, therefore, decidedly evident that all wave distortions introduced by three-phase source star-connected transformers, neutrals free, or by any other means should be carefully avoided in high-tension long distance transmission.

G. Faccioli: Professor Ryan brought out the point of the influence of harmonics on the core losses.

This is a very interesting problem. It is true that the high frequency component of the exciting current of a transformer is wattless, but I do not agree with the author of the paper in his conclusion that the distortion of the current is neither a cause nor an effect of the energy loss in the core.

The figures below are respectively a reproduction of Fig. 9 and Fig. 10. The straight line *a* is the loop obtained by plotting the values of the flux in function of the values of the wattless component of the fundamental of the exciting current. This condition of affairs would be possible if we used in the transformer core a material of constant high permeability. Curve *b* is obtained by taking as abscissæ the values of the fundamental and harmonics of the exciting current in phase with the flux. Both *a* and *b* presuppose no losses, but while *a* assumes constant permeability, *b* admits a change in permeability.

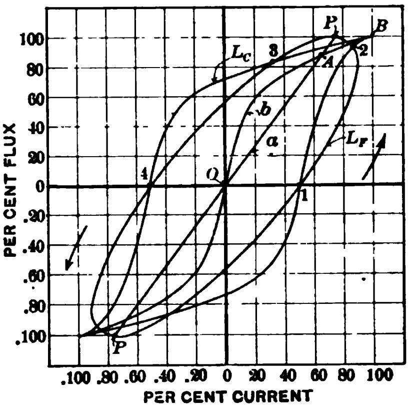


Fig. 9

It is interesting to note that the line *a* crosses the curve *b* in one point only, *A*. This means that if we increase the flux from zero to maximum positive in the case of constant permeability and no losses, the current should be a sine wave in phase with the flux. If the permeability is not constant, then while the flux increases from zero to the point corresponding to *A*, the values of the current are smaller than the values of the sine wave. From the point corresponding to *A* to the maximum value of the flux *B*, the current is higher than the values of the sine wave. Decreasing the flux from maximum positive to zero, we repeat the phenomenon in a reverse direction.

It follows that the change in permeability has caused the current to be less than the value of the sine wave for part of a half cycle; then for another part of a half cycle the current becomes higher than the values of the sine wave, and finally, for the rest of the half cycle, the current is again smaller than the sine values. It is apparent, therefore, that the distortion of current introduced by the change of permeability, crosses the zero line in two points during a half cycle, and is symmetrical with respect to a vertical axis drawn through the maximum value of the flux.

The change of permeability introduces then a high harmonic in the current, whose fundamental wave is of triple frequency. This does not mean that this extra current is a triple frequency sine wave, but it shows clearly, in my opinion, that the disturbance has a large triple frequency component, and is symmetrical with respect to the flux wave.

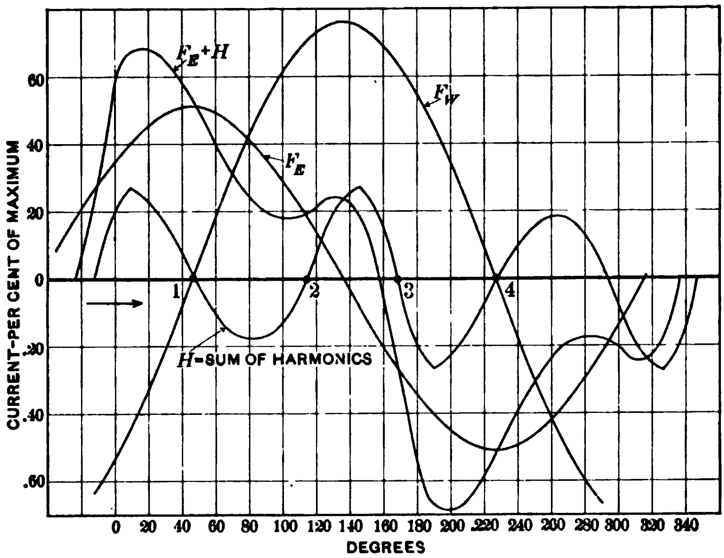


FIG. 10

If now, we take losses into consideration, the line *a* is expanded into an ellipse, and the curve *b* becomes the regular hysteresis loop.

Following the same reasoning as before, we see that in the first quarter cycle of the flux (while the flux grows from zero to maximum positive) the hysteresis loop, starting from point 1, crosses the ellipse at the point 2. It follows that from 1 to 2, the presence of the iron causes the current to be less than the values of the sine wave, (Fig. 10.) From 2 to 3, the current is larger than the sine values, and finally from 3 to 4, the extra current introduced by the iron has again negative values.

It follows immediately that the total distortion introduced by the iron, including losses, is fundamentally of triple frequency, as in the former case, where losses were neglected, but when losses are considered, the distortion is no longer symmetrical with respect to the vertical axis drawn through the maximum value of the flux, as shown by the unsymmetrical position of the points two and three.

We may therefore draw the conclusion that the presence of losses has modified the distortion of current, which would be introduced by a mere change of permeability. The high frequency components of the current are wattless for the whole cycle, but they are active in distributing the losses throughout the cycle, and part of the distortion is a consequence of the presence of these losses.

It seems to me that a glance at Figs. 9 and 10 will show why the distortion of the current due to iron is fundamentally a triple frequency wave. It shows, furthermore, which is the phase position of the high frequency waves. In fact, if we locate such phase position with respect to the flux wave, we see that at points 1 and 4, which are the points of zero flux, the value of the resulting high frequency wave is zero. This is shown in Fig. 10 where the curve *H*, which is the sum of the harmonics, crosses the zero line at the zero point of flux. This happens also in Fig. 12.

In conclusion, it appears clear why the high harmonics introduced by the iron are fundamentally of triple frequency, and it is easy to find their phase position, if they are referred to the wave of flux.

W. A. Hillebrand: Mr. Faccioli's conclusions, that the presence of the higher harmonics, redistributes the losses, strikes me as self-evident. In any circuit it is impossible at any time to know of both currents electromotive forces without having power. It simply means that the term wattless current for wattless volt-amperes, and that the voltage of the other products throughout, is fundamentally higher, and in that instance is zero.

C. A. Copeland: All of this discussion has been based on the assumption that we start out with a sine curve. It would be rather interesting to find out either theoretically or practically what are the worst conditions we would find by starting out with a curve which was a little flat topped or peaked. I was wondering whether there had been any oscillograms taken, starting out with either a flat top or peaked top wave, so as to show what the worst condition would be that we might have, under these conditions.

G. Faccioli: Of course, in a paper of this kind, it was necessary to apply sine waves to the transformers in order to obtain comparable results.

We can deduce the effect of the wave form on the triple frequency component of the exciting current by remembering that in a Y-connected system (neutral disconnected, secondary open) the electromotive force across each individual transformer is distorted as a consequence of the fact that triple frequency currents cannot flow in the Y.

Then, if we apply to a transformer an electromotive force, as the one represented, for instance, in curve 17, sheet 4, we must expect that this electromotive force will not call for a triple frequency exciting current. Now this electromotive force contains a triple frequency conponent itself. If we reverse this component 180 deg., we should expect to reach the conditions where the triple frequency exciting current will be maximum.

President Stillwell: I think it might be interesting if you would explain to what extent the use of the silicon steel affects the triple frequency current.

G. Faccioli: The new silicon steel has a hysteresis loop which is different from the loop of iron used previously. It is well known that the losses per cycle are smaller, and that the permeability at high densities is lower in the silicon steel. We should then naturally expect a somewhat different distortion of exciting current due to silicon steel.

C. L. Cory: It is interesting to contrast the methods which Professor Ryan used twenty years ago in obtaining the curves, point by point, not upon single waves but upon succeeding waves, using a 133-cycle generator, with the results that are shown in the paper read to-day. The three papers, that of Professor Ryan twenty years ago, that of Mr. Rhodes read yesterday, and this paper of Mr. Frank's presented to-day are all of the same type, and the results obtained from the experimental work done are of great value. The things that Professor Ryan really discovered are the things that have now been completely developed and are so clearly shown in the oscillograms so well reproduced in the paper.

From what we heard yesterday morning and also here to-day it is possible that we may conclude that the third harmonic and the higher harmonics, the fifth, seventh, ninth, etc., introduce only difficulties in connection with the generation and use of alternating currents. I do not believe that that conclusion necessarily follows. It was shown yesterday by Mr. Rhodes that the triple and higher harmonics are produced by generators under certain circumstances and this morning by Mr. Frank it has been shown that, no matter what kind of a curve we start with from the generator, somewhere in our transmission system we will find the conditions which are shown by these curves and we cannot avoid the distortion from the true sine wave.

The presence of the higher harmonics have been found troublesome and have almost always lead to difficulties. To-day in the transmission of power we are still using a relatively high frequency. From the beginning of the use of alternating currents the frequency has been reduced from 133 and 120 cycles down to 60, 50, 40 and even 25 cycles, and when we begin to transmit still larger quantities of power over distances three or four times as great as ordinarily found at the present, or up to 500 or 600 miles, perhaps lower frequencies such as 10 12½ or 15 cycles will be found, under certain circumstances to be decidedly preferable.

Is it not possible therefore as the art of the generation and application of electricity still further develops that we may generate by a single generator currents of more than one frequency, or, what would be equivalent, one current of two or more frequencies? We really produce such currents in the generators that were described by Mr. Rhodes, although we do not want them, and as shown by Professor Bedell greater economy of copper results when two currents of differing frequencies are transmitted over the same conductor, and ultimately we may to advantage make use of the combination for more efficiently transmitting power than is possible using current of only one frequency in each conductor.

Silvanus P. Thompson (by letter): Mr. Frank's paper is of particular interest to me, because I happen to have just prepared for the Physical Society of London a yet unpublished note on Hysteresis Loops and Lissajous Figures, the substance of which is as follows. Just as any wave curve, whether of current or of voltage, can be analyzed according to Fourier's theorem into a harmonic series of sine and cosine terms containing only odd terms in the series, so any hysteresis loop can be analyzed into a harmonic series of Lissajous figures, (in sine and cosine terms) containing only odd terms in the series.

The area of the hysteresis loop represents the energy spent in a cycle of magnetizing operations. If we represent the impressed electromotive force as a sine-function of the time, it is known that the wave-form of the flux will be a pure cosine function of the time, and that the wave-form of the reactive electromotive force will be a pure (negative) sine function of the time. Now, if there are present hysteresis and eddy-currents, the current curve will, as known ever since Ryan's classical researches of 1890, not have a simple wave form. It may contain terms of the following orders:

1. $A_1 \sin p\,t$
2. $B_1 \cos p\,t$
3. $A_3 \sin 3\,p\,t$
4. $B_3 \cos 3\,p\,t$
5. $A_5 \sin 5\,p\,t$
6. $B_5 \cos 5\,p\,t$

with possibly other terms of higher orders. Now as the impressed voltage has a form expressed by $V_1 \sin p\,t$, the total energy expended in a cycle will be represented by the result of multiplying $V_1 \sin p\,t$ into each of the above terms, and integrating each such product around a whole cycle, or from $t = 0°$ to $T = 360°$. But, as is well known, the following integrals all have zero value if integrated over a whole period:

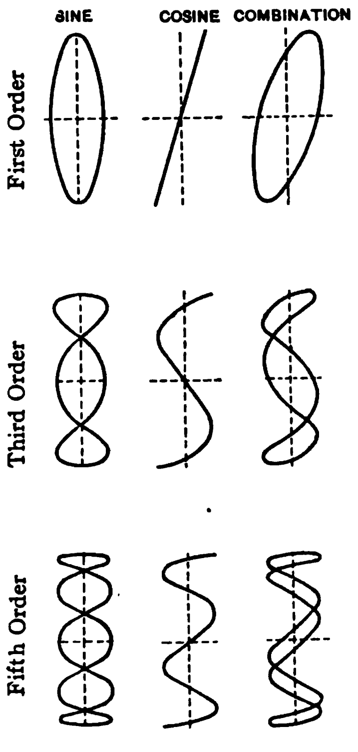
$$\int \sin pt \cos pt,$$

$$\int \sin pt \sin n\, pt$$

$$\int \sin pt \cos n\, pt;$$

where n is any whole number. The only product that remains is therefore the fundamental, *viz*:—

$$\int_0^T \sin^2 pt$$



That is to say the only component which involves the expenditure of any energy in the cycle is the sine-component of the first order; that is so much of the current wave as in phase with the impressed voltage. All other components may distort the form of the current wave, and therefore of the hysteresis loop, but alter the amount of the area of the loop in nowise. The area of the loop is equivalent under all cases to that of an ellipse, the principal axes of which are respectively the maximum flux-density the value of $\mathcal{H}$ due to the maximum value of the first-order sine component of the current curve.

The effect of magnetic leakage, or of an air-gap in the iron core is to shear over the hysteresis loop, that is to introduce as a component a first-order cosine term.

The above are the Lissajous figures which correspond to the several terms:

The total areas of Lissajous figures, of all orders except the first is zero; their negative and positive portions being always equal.

Eddy currents will invariably give sine-components of the first order, and add a further elliptical component to the ellipse. Eddy-currents of the third order, which will be present only if there are third order components in the voltage curve, will tend to distort in the form containing both sine and cosine components of the third order, resembling the letter S.

The ordinary hysteresis loops with acute peaked forms at their ends, obtained when the flux-density is pushed to high values, contain negative cosine terms of third, fifth, and higher orders, and cannot be adequately represented without going to terms higher than the eleventh.

I am able to confirm Mr. Frank's conclusion that the distortion of the form of the current wave curve is neither a cause nor an effect of energy loss in the core, but depends only on the variations of the permeability of the steel.

May I be allowed in conclusion to express my gratification that so much utility has been found by Mr. Frank in the employment of my arithmetical method of harmonic analysis, itself derived from that of Professor Runge of Hanover. I desire to thank him for the exposition of it which he has given.

Edmund C. Stone (by letter): I have made a number of oscillograms on a three-phase core type transformer with star-connected primary, which check those given in the paper. The wave form impressed was somewhat flatter than a sine wave and the effect of this in peaking the phase voltage was very marked.

If three single-phase transformers in star are connected to a three-phase generator and the neutral of the transformer is connected to that of the generator, the conditions in the transformers are the same as if each was alone on a single-phase circuit; the magnetizing current having its characteristic shape in each transformer. The neutral is the return circuit for all the transformers, so that the instantaneous values of its current are the sum of the instantaneous values of all the magnetizing currents. It carries all of the third harmonic components of the single-phase currents, which add to each other numerically, since in a symmetrical three-phase system the third harmonics all have the same phase. Now imagine for a moment that an e.m.f. could be impressed on the neutral which would cause a current to flow exactly equal and opposite to the current already in the neutral. Such a current would divide and flow in the same direction through the transformers thus cancelling out the third harmonic component of the single-phase magnetizing currents. The current in the neutral would then be equal to zero and the neutral could be opened without changing the conditions in any way. Hence it will be seen that when the transformers are star connected with the neutral open, a current of triple frequency is present in each one which is of the same phase in all three transformers and is *subtracted* from the single-phase magnetizing current, thereby eliminating from the latter its third harmonic. This current, of course, sets up a flux of triple frequency and same phase in all the cores, which subtracts from the single-phase flux and introduces a third harmonic into the counter e.m.f. wave accordingly. Such a third harmonic increases the maximum value of the phase e.m.f. but does not appear at the terminals of the star-connected windings. When the secondaries are connected in series or delta, however, the triple frequency components of voltage are in phase and add to one another, thus producing an unbalanced e.m.f. around the delta. When the delta is closed this voltage becomes practically zero and a current flows which is equal to that producing it; that is the third harmonic of the single-phase magnetizing current has been transferred from the primary where it cannot flow, to the secondary where it can flow through the closed delta.

In the case of three single-phase transformers, the flux set up by the triple frequency component of magnetizing current has the same circuit as the main flux, that is, the core of the transformer, which being of exceedingly low reluctance, permits considerable flux to be set up, thus causing great distortion to the wave form of the phase e.m.f. (as shown by sheet No. 13). In the case of the three-phase core type transformer, however, this triple frequency flux cannot pass around the main circuit, since it would then be opposed by the flux of another phase. The result is that it must find a return path through air or the case and end frames. This local circuit has necessarily a high reluctance so that only a small flux is set up by the third harmonic current and the wave form of the phase e.m.f. is only slightly distorted.

C. Fortescue (by letter): This paper shows very clearly the necessity of considering the wave forms of generator e.m.fs. of transformer exciting currents, etc., with reference to their effect in polyphase circuits.

The writer, during the past few years, has been frequently called upon to explain phenomena due to such causes and many of his conclusions are corroborated by the data given in Mr. Frank's paper and his explanation of them.

Referring to Mr. Frank's discussion of interconnected transformers: it is shown that if the third harmonic component of the exciting current is prevented from flowing by the method of connecting the transformers a third harmonic component of e.m.f. will appear in the transformer windings, which will increase the insulation stress throughout the transformer. It may be well to remark that the effect would not be so marked in ordinary commercial transformers as for the case given, since the iron is not usually run at so high a density as 90 kilo-lines per square inch.

In star-delta connected transformers, a third harmonic component flows in the delta windings, which is the exact equivalent of the missing third harmonic component of the exciting currents in the star connected primary. If the primary line to line e.m.f. is not a sine wave, it may contain any odd harmonic but the third and its multiples, provided that all three waves of e.m.f. from line to line are similar in form. Each of the harmonics in the three phases are in proper three-phase relation and will also appear in the neutral to line e.m.f. across the transformers. But where the effect of these harmonics may have been to peak the wave form from line to line, their effect will be to flatten the wave form across the transformers, that is, from neutral to line, the converse of this also being true. We should therefore expect to find that with star-delta connected single-phase transformers, a peaked e.m.f. wave form from line to line would result in a higher iron loss in the transformers than that obtained with a corresponding single-phase sine wave measurement. And similarly, if the line to line e.m.f. wave form is flattened, the observed iron loss should be less. Perhaps this may be the explanation of the difference in iron loss observed by Mr. Frank, when measured single-phase and three-phase with neutral disconnected and delta closed.

In sheet No. 10 of Mr. Frank's paper, we have a triple harmonic 0.63 amperes occurring in the secondary delta connection. Multiplying this by the ratio of transformation, we have for the corresponding primary single-phase, third-harmonic component, 3.15 amperes, and the equivalent single-phase exciting current is, therefore, $\sqrt{5.81^2+3.15^2} = 6.6$ amperes. This is 10 per cent higher than the value found for single-phase, namely 6.05 amperes. The cause of this apparent discrepancy is probably due to the wave form of the line to line e.m.f., which may be somewhat peaked, thereby resulting in a flattened e.m.f. wave form from transformer neutral to line, and therefore a higher exciting current and iron loss.

The third harmonic is not present in the line to line e.m.f. of symmetrically wound three-phase generators, but it occurs in the e.m.f. of two-phase generators and, therefore, it will appear also in three-phase e.m.fs. obtained by transformation from two-phase. The wave forms of line to line e.m.f. in such cases are not similar. Such a system may be considered as made up of a symmetrical system on which is superimposed a third harmonic three-phase system. If such a system is connected with a true three-phase system, this three-phase third harmonic component may be the cause of grave trouble.

In conclusion, the writer would like to see more data as to the effect of different polyphase connections on the iron loss of the transformers, to supplement Mr. Frank's valuable contributions.

C. A. Adams (by letter): The immense amount of data gathered by Mr. Frank on this important and interesting subject, is almost staggering, and it is quite impossible to do justice to it in a limited discussion. A somewhat careful reading developed the necessity for some additional explanations and amplifications which are here presented with the hope that they may help others similarly interested.

The area of the loop L_c, of Fig. 9, respresents the eddy current loss as well as the hysteresis loss and the loop is broader abeam than the true hysteresis loop. The eddy current energy is supplied by a current component in phase with and of the same shape as the impressed e.m.f., and the real hysteretic energy current is equal to F_E less this eddy current component, with which it is in phase.

The relative values of the maximum inductions of the various harmonics are not the same as the relative values of the corresponding e.m.fs. since the induction is the integral of the e.m.f. and therefore involves its frequency as well as its amplitude; *e.g.*, if the third harmonic e.m.f. is 52 per cent of the fundamental e.m.f., the third harmonic flux is only 17⅓ per cent of the fundamental flux.

For the purpose of explaining several points in connection with the oscillograms, it will be desirable to review briefly the various transformer connections.

In every case it is assumed that the impressed e.m.f. is balanced, symmetrical, sinusoidal and 3 phase; also that a third and a fifth harmonic exciting current are necessary for a sinusoidal flux.

THREE SEPARATE TRANSFORMERS, PRIMARIES STAR, SECONDARIES DELTA

1. *Isolated Neutral—Open Secondary Delta.*

The third harmonic exciting current cannot be supplied, therefore,

The flux must contain a third harmonic, such that it would require for its m.m.f. a third harmonic current equal and opposite to the third harmonic current that would be required by the otherwise sinusoidal flux.

The star e.m.f. will then contain a corresponding third harmonic and the voltage across the open neutral will be three times the third harmonic phase e.m.f., since the three are all in phase.

The fifth harmonic exciting current will appear in the primary since the three fifth harmonic currents neutralize each other just as do the fundamentals.

The three third harmonic e.m.fs. in the secondaries will add together and appear across the open delta, thus the open delta voltage should differ from the open neutral voltage only by the ratio of transformation.

2. *Isolated Neutral—Closed Secondary Delta.*

As soon as the delta is closed the third harmonic e.m.f. in the delta will produce a third harmonic current which will supply the previously missing third harmonic exciting current and restore the flux to the sinusoidal form; but this flux cannot be quite sinusoidal since there must be a small third harmonic e.m.f. in the secondary to produce the third harmonic exciting current.

The phase e.m.fs. are therefore sinusoidal barring this very slight third harmonic, and the voltage across the neutral is practically zero.

The fifth harmonic exciting current will appear in the primary as in (1).

3. *Connected Neutral—Closed Delta.*

If the slight third harmonic in the phase e.m.fs. were to retain the same value as in (2) there would now result third harmonic currents in the primaries of approximately the same m.m.fs. as those of the third harmonic current in the secondary delta; but this would reverse the third harmonic flux and is obviously impossible. *I.e.*, the total third harmonic exciting current in primary and secondary cannot appreciably exceed its previous value in (2). Therefore, since the third harmonic e.m.f's in primary and secondary are equal, as well as the local impedances of the circuits in which the e.m.fs. act the third harmonic current will be divided evenly between primary and secondary, thus requiring only one half of the third harmonic flux and phase e.m.f. of (2).

However, if there be ever so small a third harmonic in the impressed phase e.m.f., it may (if in the proper phase) *just* supply the impedance drop of the necessary third harmonic exciting current, and entirely eliminate any need of even the slightest third harmonic flux and secondary phase e.m.f.

Then no third harmonic exciting current would appear in the secondary delta, as it would all appear in the primary.

If however the slight third harmonic in the impressed primary phase e.m.f. be of the opposite phase, it will drive the exciting current to the secondary delta by causing an increased third harmonic flux and secondary phase e.m.f.

This last is the reason why in some of the oscillograms (taken with connected neutral and closed delta) the third harmonic exciting current appears in the secondary delta, and sometimes in the primary and neutral, and sometimes in both.

Curves 69 and 70, sheet 11, analyzed in Figs. 24 and 25, show a small third harmonic exciting current in the primary lines and neutral, but as the third is less than the fifth it is reasonably certain that the larger part of the third is to be found in the closed delta, although no oscillogram thereof is given. The fundamental, fifth, seventh, and eleventh harmonics in curve 70, Fig. 25, are due to an unsymmetrical system, as they would otherwise cancel out.

The curves of sheet 2 also show the harmonic exciting current divided between the primary and secondary for the same case of connected neutral and closed delta, the larger part being in the primary, while for the case of sheet 11 the larger part was in the secondary.

4. *Connected Neutral—Open Secondary Delta.*

In this case each transformer is entirely independent and the exciting current will flow in the primary as in the case of a single transformer with sinusoidal impressed e.m.f. and open secondary.

The three third harmonic exciting currents will add together in phase in the neutral while the fundamentals and fifth harmonics cancel out.

If the impressed e.m.f. on each transformer is absolutely sinusoidal, the induced e.m.f. and flux will be distorted an imperceptible amount by the internal impedance drop due to the third and fifth harmonic currents, and there would be a very slight third harmonic e.m.f. across the open delta, the fifth cancelling out with the fundamental. These are, however, too small to be of any practical importance.

The considerable third harmonic e.m.f. across the open delta in curve 15, sheet 3, must be due to a third harmonic in the impressed e.m.f.; a careful inspection of curve 12 will show this to be the case.

Curve 75 of sheet 12 also shows a third harmonic e.m.f. in the secondary for this same connection, but in this case it is only ½ per cent whereas in curve 15 it is 5 per cent. In this case (curve 75) it may therefore be partly if not largely due to the e.m.f. distortion produced by the large third harmonic current in the primary.

ONE THREE PHASE TRANSFORMER

If the three cores are *absolutely symmetrical* and the impressed e.m.fs. balanced, there can be no third harmonic flux in the main magnetic circuit. Any such flux in the core legs must return *via* the surrounding non-magnetic material; *i.e.*, the reluctance of the third harmonic flux path is many times that of the fundamental flux path.

1. *Isolated Neutral—Open Delta.*

In this case there can be no third harmonic exciting current, therefore there must be a third harmonic flux of sufficient magnitude to eliminate the need of a third harmonic exciting current; *i.e.*, a flux which would require for its m.m.f. a current equal and opposite to the third harmonic current that would otherwise be present. But the reluctance of the third harmonic flux path is so large (as explained above) that a negligibly small third harmonic flux is sufficient to neutralize the third harmonic current. Thus it is that the leg e.m.f. is practically sinusoidal and the voltages across the open neutral and open delta are zero, in spite of the fact that there is no third harmonic exciting current, see Sheet 21.

It is obvious that closing the neutral or the delta or both would have no appreciable effect upon the curves, as is shown on sheets 18, 19 and 20.

In a similar manner numerous other interesting points can be explained.

J. J. Frank: The paper was prepared primarily for the benefit of operating engineers to emphasize the great practical value of an investigation of the distortion of current and potential wave shapes found in the common banking of transformers. The absence of any discussion by operating engineers is somewhat of a disappointment.

The confirmation by Silvanus P. Thompson of my conclusion that the current wave distortion depends only on the variations in the permeability of the steel is very gratifying.

The discussion by C. A. Adams, calling attention to the possible amplification of the data submitted in my paper, is also very gratifying.

A paper presented at the 248th meeting of the American Institute of Electrical Engineers, San Francisco, May 6, 1910.

TRANSMISSION LINE CROSSINGS OF RAILROAD RIGHTS-OF-WAY

BY ALLEN H. BABCOCK

It is necessary to protect:

1. The railroad communication circuits (telegraph, telephone and signal) from mechanical injury and from contact with high tension wires.
2. The train crews from personal injuries due to sagging or fallen wires.
3. The trains themselves from mechanical damage and from the liability of fire should a wreck occur at the crossing point.
4. The railroad structures from damage by fire due either to crosses between communication circuits and fallen or sagging transmission circuits, or to high potential electromotive forces induced therein by excessive unbalancing of the transmission circuits.

Having in mind the fact that contact with transmission circuits is dangerous to both life and property, it was natural that the early attempts at protection were of the nature of guard wires, in some form or other.

Many of us have had experience with some such device. Nearly all of us who have had sufficient experience have found unsatisfactory all forms of guards as yet devised. Even those of the deep basket type have failed at times to give complete protection. Furthermore, any pole line is worked at about minimum factor of safety; hence, to increase the load on it at the very point where maximum security is demanded is an engineering anomaly. Prophecy after the fact is easy.

The next step is obvious; to construct the transmission line with maximum factor of safety both in the crossing span and also in each of the adjacent spans, so that nothing short of a general catastrophe shall bring the line into dangerous proximity to the railroad right of way. So well recognized is this principle that the power and the railroad interests are now working in harmonious conjunction to devise an economical mechanical and electrical construction for these crossing spans, so much more secure than that of the transmission line elsewhere, that if ever failure occurs it must be at some other point.

In general, it is advisable, wherever possible, to place underground all low potential power circuits, and communication circuits. The following general specifications cover the points that are now under discussion between the power and railroad companies.

GENERAL SPECIFICATIONS FOR THE CONSTRUCTION OF OVERHEAD ELECTRIC LIGHT OR POWER LINE CROSSINGS—

GENERAL

1. All crossings carrying current at more than nominal 2,300 volts to ground shall come under the provisions of these specifications, unless special conditions in large cities or otherwise shall make a modification thereof necessary or desirable.

2. Complete drawings shall be furnished in duplicate for approval before construction is commenced.

3. The power company shall give the railroad company one week's notice prior to the commencement of work.

4. All work, including the materials entering into the work, shall be subject to the inspection and approval of the railroad company.

5. The power company shall protect the railroad company against any suits for damages arising by reason of any patented devices being used in the work under these specifications.

CLEARANCES

6. Vertical clearance, under the most favorable conditions of temperature or sag, shall be as specified by the railroad company, but shall not be less than 35 ft. above the top of rail and not less than 10 ft. above any existing wires on the right of way.

7. Side clearance for structures that it may be necessary to locate on the railroad company's right of way shall not be less than 10 feet from the center of the nearest present or proposed track.

CROSSING SPAN

8. The crossing span shall be carried on towers or poles which shall be self-supporting under the most unfavorable conditions of loading, or of broken conductors.

9. Supports for the crossing span, and for the adjacent spans on each side, are to be generally in a straight line and preferably at right angles to the railroad.

10. Conductor supports shall be guyed away from the tracks in such manner as to make it impossible for the supporting structures to fall toward them.

11. In general, steel towers shall be used, although under certain conditions wooden structures, with concrete or other approved foundations, may be permitted.

12. Foundations shall be designed to resist double the greatest tendency to overturn under the most unfavorable conditions, due to breakage in the line or otherwise.

13. In designing tower foundations, the weight of earth shall be taken at 90 lb. per cu. ft. and the weight of concrete at 140 lb. per cu. ft.

14. When towers are used, they shall be constructed of soft or medium soft steel, thoroughly painted or galvanized.

15. Tower construction shall be shown or specified in detail on plans submitted for approval by the railroad company. They shall give sufficient data so that stress diagrams may be constructed for the given loads.

16. All steel structures on the railroad company's right-of-way shall be grounded in an approved manner and shall be provided with approved danger signs.

17. Steel structures supporting the crossing span shall have a factor of safety of not less than three, based on the ultimate strength of the material and considered under the most unfavorable conditions of loading, wind and broken conductors.

18. Wooden structures supporting the crossing span, and also wooden crossarms, shall have a factor of safety of not less than five, based upon the ultimate strength of the material and considered under the most unfavorable conditions of loading, wind and broken conductors.

All the following sections shall apply to the crossing span and to each span adjacent thereto:

PINS

19. Material: cast steel, iron pipe, malleable iron or other crude metal, galvanized.

20. Where wooden crossarms are used, a grounded metal strip must connect all pins electrically.

21. Pins shall be designed for factor of safety of three, under most unfavorable conditions.

INSULATORS

22. Material: porcelain only above 7,000 volts, and porcelain or glass below 7,000 volts.

23. Insulators shall be designed for voltages 25 per cent in excess of the rated working voltage of the other insulators on the line.

24. Pin type insulators shall have metal bridge caps, or the equivalent.

25. If suspended type of insulator is used, all connections between the parts of the insulator shall be of the interconnected link type, or its equivalent. Whatever type of insulator and attachment is used, the conductor must hold to the supporting structure even if the insulator is mechanically or electrically shattered.

26. Clearance: Insulators shall clear all parts of the supporting structure (except pins and crossarms), not less than 12 in. up to 24,000 volts, plus one inch per 10,000 volts additional.

CONDUCTORS

27. Material: copper, aluminum or other non-corrosive metal. For spans carrying current up to 5,000 volts, minimum size No. 6 B. & S. copper, or aluminum, or other material or alloy of equivalent strength. Above 5,000 volts, minimum size No. 0 B. & S. copper, not less than seven strands (or six strands around a non-conducting center), or aluminum, or other metal or alloy of equivalent strength.

28. Tension shall be adjusted to be equal on each side of the supports of the crossing span.

29. Clearance between conductors and tower structure (except pins and crossarms) shall be not less than 12 in. up to 24,000 volts, plus one-half inch for each additional 1,000 volts.

30. Minimum clearance between conductors shall be not less than 24 in. up to 24,000 volts, plus one inch per 1,000 volts additional.

31. The conductors shall be clamped mechanically to the insulator.

32. The conductors shall be connected to the supporting structure at an auxiliary connection that will insure positive grounding of the conductor in case of failure of the primary insulation.

33. All crossing conductors shall be wrapped or shielded against arcing where they pass over the insulators or through clamps.

34. No splicing will be allowed in any of the three spans named.

35. Crossings shall be designed for one-quarter inch ice radially of weight 60 lb. per cu. ft., plus the weight of the conctduor, plus a horizontal wind pressure of 20 lb. per sq. ft. on a projected area of the ice covered cable. (Obviously where ice is never formed, that element of the calculation can be omitted.)

36. Maximum of allowable stress shall be not more than three-tenths of ultimate strength.

37. All calculations shall be based upon a temperature range of 130 deg. fahr.

The foregoing specifications are tentative in the sense that while they represent the present mutual understanding of the interested parties, they have been adopted merely as a provisional basis for discussion. As such they are submitted for the consideration of the members. It is hoped that your criticism will be construction as well as destructive.

The following table will serve to show that the subject is one not to be disposed of lightly. With 482 crossings to be legislated for on a single trunk line, it is easy to see that the agreement reached must be reasonable and equitable, or it will not stand.

CLASSIFICATION OF POWER CROSSINGS. SOUTHERN PACIFIC COMPANY

Division	Under 2500 volts	2500 to 5000 volts	5000 to 10000 volts	10000 to 15000 volts	15000 to 25000 volts	25000 to 35000 volts	35000 to 65000 volts	Over 65000	Not listed	Total
Coast...........	119	3	30	13	8	0	5	0	1	179
Western........	47	3	9	7	3	3	42	3	3	120
Sacramento.....	42	6	6	0	14	0	12	5	—	85
Shasta..........	11	0	0	0	8	0	3	0	5	27
S. Joaquin......	6	0	0	3	2	18	0	5	2	36
L. Angeles......	1	0	0	0	18	6	0	0	2	27
Tucson.........	1	0	0	0	0	0	0	0	0	1
Salt Lake.......	1	0	1	2	0	0	2	0	1	7
Total..........	228	12	46	25	53	27	64	13	14	482

DISCUSSION ON "TRANSMISSION LINE CROSSINGS OF RAILROAD RIGHTS-OF-WAY" SAN FRANCISCO, CAL., MAY 6, 1910.

John Harisberger: I would ask Mr. Babcock if he has any suggestions for a satisfactory crossing for the right of way by transmission lines?

A. H. Babcock: The only suggestions are those embodied in these specifications. The first and second paragraphs cover the point, that up to the present no basket or guard, or similar construction has been found satisfactory. The power companies themselves have attempted to develop that sort of thing and have found that after it was put in service there were so many disadvantages, that the device had ultimately to be abandoned. It is thought now that the only satisfactory way of handling the subject is to make the crossing so strong mechanically and electrically that it cannot come down at that point.

John Harisberger: The requirements of the Northern Pacific have been to place poles on either side of the track so high that even if a wire broke it would not reach at most the top of a box car. It seems to me that that would be the requirement if the right of way were not of such width that it would be impractical.

A. M. Hunt: In paragraph 27, "Conductors," Mr. Babcock has stated that "material: copper, aluminum, or other non-corrosive metal," should be used. It would appear to me that the element of strength in the conductor over the track is the main essential, and that perhaps could be better attained by the use of heavy galvanized steel conductors, such as cross the Straits of Carquinez, used by the Bay Counties Power Company. They are steel cables and are always kept painted and in first class condition. The possibility of rupture is very much less than if they were of copper or aluminum, or material of equal conductivity. That one point of exception can well be taken to the specifications.

C. F. Adams: In clause No. 19; "Material: cast steel, malleable iron, or other crude metal, galvanized." Under that specification a cast iron pin could be used. In paragraph 23 it states: "Insulators shall be designed for voltages 25 per cent in excess of the rated working voltage of the other insulators on the line." I believe that if a step of that kind were taken, it would result simply in the taking of a succession of steps. In other words, the general public would call for as good an insulation as the railroad company did, and then the railroad company could call for 25 per cent in excess of what the public were then getting. It seems to me that what is proper for the entire system should be sufficient for the railroad company.

There is one other point that I note here, which does not seem to have been embodied in the presentation of this paper. It states: "In general, it is advisable wherever possible to place underground all low potential power circuits, and communication circuits." I believe that clause is correct, and I think also that it should be applied to communication circuits of telephone signal and telegraph lines by the railroad companies. I know of nothing better than a few feet of earth and a little lead to protect from a high-tension circuit falling to the ground.

Lewis B. Stillwell: I agree fully with Mr. Babcock that special and adequate protection should be provided in all cases where high-potential transmission circuits cross railway lines. I do not think, however, that the problem is one of any great difficulty. It is to be noted that the accidents mentioned by Mr. Babcock, with one exception, were not occasioned by reason of the fact that the circuits were not properly protected. They were purely mechanical accidents and due to gross carelessness. In Italy, notably on the Valtellina, a wire net is suspended beneath the transmission circuits where highways are crossed. These are somewhat awkward in appearance, but properly erected and maintained, they appear to afford adequate protection. Crossings of this character should be built upon the same principles upon which bridges are constructed, that is to say, they should be built so that the line will not fall down. As a bridge problem, railroad crossing by a transmission circuit is very simple. Ample factors of safety are practicable and a little care will provide against failure. If a circuit breaks between two poles or towers on opposite sides of a railway crossing, provision should be made for grounding that circuit before it can touch the locomotive or car passing beneath it. This can be accomplished by placing a grounded conductor in a horizontal position, where the falling conductor must touch it before reaching the top of the car.

As regards the specifications suggested by Mr. Babcock relative to conductors, it would seem that while this is unobjectionable in general from the standpoint of the power company and should be satisfactory to the railway company, specification No. 27 could be made more definite by requiring in general terms a mechanical factor of safety rather than prescribing arbitrarily the size of the wire with reference to the voltage. It would be reasonable to require that the span crossing the track be constructed with a very high factor of safety. In conjunction with this, some plan of grounding the circuit and cutting it out automatically in case the wire breaks, would be unobjectionable.

I understand that in the judgment of the engineers of the Pacific Gas & Electric Co., automatic circuit breakers are not yet developed to a point where they can be relied upon for very high potentials. This being the case, if the two towers supporting the wires which span the railroad be connected electrically by adequate earthing or by conductors and provision made for effectively grounding the conductor in case it breaks, I do not see how any material damage to a car is liable to occur.

P. M. Downing: There are a few points in the paper which I think might be improved upon slightly, but in general, I think the specifications as proposed, come nearer meeting the approval of the power companies than anything that has yet been submitted. Our experience here on the Coast in the matter of protective devices where power lines cross railroad rights of way, is a rather long one. We started in with the idea of using some sort of a basket device to catch the wires in case they should break at these crossings. These basket devices consisted of wires carrying a sort of lattice work in order to catch the broken circuits, but we found that these baskets were more of a menace than protection, for the reason that they were very hard to maintain on a long span, and where the railroad right of way was wide, the strains thrown on the supporting structure was very great, and we had so much trouble with those that they were finally abandoned.

The specifications, as I understand them after going over them very hurriedly, provide for good mechanical construction. To my mind, this comes nearer meeting all requirements than anything else which could be submitted. However, as I say, there are a few points which, to my mind, might be improved upon, but I have not gone into the specifications fully enough as yet to be entirely familiar with them.

Markham Cheever: To one who has been interested in this subject for a considerable time, the prefatory remarks in the paper appear as a most excellent statement of the present status of the problem. The old basket type construction as pointed out by the author is obviously inadequate and introduces an element of hazard greater than the danger it prevents. Numerous other designs have been proposed, many of them involving a tension in the crossing span less than the tensions either side, and this again introduces additional risk by reason of the many dead-end connections. It is now being widely recognized that a more reliable construction is produced by running each line conductor straight through, avoiding any splices or dead-end connections in the crossing or adjacent spans, and maintaining uniform tensions. A design based upon this principle has been largely used for the crossings of high tension lines over the tracks of the New York Central Railroad. Two towers are placed close to the railroad right of way, one on either side. The precautionary feature consists of auxiliary ties to each line conductor from insulators supported on the track sides of the structures and at lower elevations than the main insulators. Should the conductor break on the supports adjacent to the track or at any point behind, allowing the conductor to slacken, the auxiliary ties hold the crossing span suspended, at the same time efficiently grounding it.

Sidney Sprout: Some gentleman made the remark a few moments ago that a few feet of earth between the transmission line and the telegraph line was probably the safest insulator that could be had. I have noticed that the telephone company, the Pacific States, at its crossing with street railways is making a general practice of putting a cable underneath the streets. I will offer just a few suggestions, as I have not read the specifications through since I came in. I did not expect to take any part in the discussion, but I think if we would reverse the specifications somewhat, where there is a trolley crossing or a high tension transmission crossing of the railroad, considerable difficulty or danger can be eliminated by the railroad companies putting every 200 feet their telegraph and signal lines underneath the ground in a cable. I believe they do that at present at a number of places along the lines where they enter the depots. This seems to me to be a way to avoid the difficulty that came up in one of the cases mentioned at Antioch, where the towers were built carelessly, or otherwise, and dropped across the line, and that would make, of course, considerable confusion. I think that the transmission companies or the power companies would be perfectly willing to pay for any expense of running underground at such places as they cross. Of course, the other dangers of lines coming down on the track, and the trouble, the mechanical trouble, of engineers, and so forth, would not be avoided by this; but it seems to me that the greater part of the danger of which Mr. Babcock speaks, would be avoided by a very slight expense of running the wires underground. I think that the transmission people have racked their brains and spent considerable money for suitable means of crossing railroad lines, as well as telephone and telegraph lines, by which they might be saved from annoyance or the liability of danger that they are causing by running overhead. As some gentleman has said here, the very means that they expected the most of, seemed to fail; and I believe that if we look on the other side of it, that the telephone people have done it probably unintentionally, or possibly because electric people have delayed in putting in proper protection—and of course they have protected themselves—but it seems to me that they have solved one of the great troubles and annoyances by putting all of their lines underneath the track where they cross street railways or steam railroad lines. I know they still call on transmission people to protect their lines, but I believe they would rather put their lines underground than to run the risk and danger of the wires breaking and coming down on to a trunk line service. A great many of our lines cross the telephone and telegraph lines between the main stations, Los Angeles, San Francisco, and Portland, and it means considerable to them if it does break down. I appreciate the necessity of something being done, and I think that Mr. Babcock's paper is one that we should consider very seriously, and I think that the Institute should take some steps regarding the matter, instead of letting it drop without more serious thought than what has been already brought out.

J. P. Jollyman: Mr. President, I believe that it is possible for the power companies and the railroad companies to reduce their troubles to a minimum. It is undoubtedly possible to construct a protection that would be absolute, but the question of cost would be prohibitive, except in very special cases. The power companies are interested in the matter nearly as much as the railroad companies, and anything that will be to the advantage of the one, would be of advantage to the other. The matter of underground crossings is something that would have to be studied very carefully, for an underground crossing in connection with a telephone, telegraph or signal service line may add to the difficulty, of satisfactory operation. In some cases the companies operating these lines might even prefer to go overhead and take their chances. I think, on the whole, that the specifications as read by Mr. Babcock, if faithfully carried out would lead to as safe a crossing as can be reasonably expected under present conditions.

R. W. Van Norden: I have not read this paper as carefully as I would like, but, from the discussion which has been given so far, I cannot see but that the necessary points are covered as well as they can be, as Mr. Jollyman says, without too much cost. On the section that Mr. Babcock spoke of, on the Southern Pacific, we have built a good many crossings, and while we have used small wire, I do not remember that we have had an accident where it affected a telegraph system, but possibly once, and that was not at a crossing, but was in the case of a blast at Rocklin that threw the transmission line down, and the blast affected the telegraph signal system. I do not recollect that there has ever been any serious break at any crossing. The only system we used was the basket system, which I do not particularly believe in. There have been some experiments made along the lines suggested, of grounding, so that in breaking it grounds before striking earth. Those have not been carried out very carefully, so I cannot tell you what the experiments resulted in. .

President Stillwell: I do not fully agree with Mr. Cheever in regard to the basket suspension plan. Its effectiveness is purely a matter of construction and maintenance. In Italy, apparently they maintain it properly—that is what we do not always do very well in this country. We put up devices of this character and then fail to maintain them. In my opinion, the basket construction, while not the best, can be made effective in the case of comparatively short spans, if properly maintained.

R. W. Van Norden: There is another point that I think of. Mr. Hunt spoke of putting up steel in place of copper or aluminum. I know of one case where we used steel in spans, and one of them was across a railroad track. Some of the wire was copper, very small No. 6, I think, the span was between 800 and 1000 feet long. We used also No. 6 steel telephone wire. The telephone wire broke in the winter a number of times, apparently due to snow loads on the line, but the copper wire would not break at the same time. The steel would pull out; it would not make a quick break, it would pull out to about one-half of its diameter, and then it would break, but the copper would not break at all.

C. F. Adams: I would like to reply to the suggestion of the President concerning the matter of grounding. That would be operative on lines of limited length and low frequency. On lines approximating the length that you will find here in California, with a frequency of 60 cycles, if it is grounded 100 miles from the station, it does not give you enough short circuit current at the station to overload the generator and carry it beyond normal. That has been tried out, and it has been thoroughly demonstrated that a short circuit may occur on any one of the three phases and yet the operating station may not have sufficient indication of a short circuit to really warrant them in pulling their current off the line.

President Stillwell: This sort of a paper is an admirable one in my opinion; it is not overloaded with unnecessary explanations; it is precise and explicit, and is a very essential start toward standardizing a very important matter, and I think that at the proper time, the standardizing committee of the Institute operating, for example, in conjunction with the proper committee representing the railways, might agree once and for all upon specifications which would be adhered to. That would save a great deal of trouble to all concerned, and I see no reason why a question of that kind cannot be taken up in that manner.

A. H. Babcock: Mr. Harrisberger suggests that adequate protection can be secured by using high poles set so close to the right of way that a broken wire will not be able to strike the tracks. Doubtless he has in mind narrow rights of way. The Western Railroads often have 400 foot rights of way so that it is difficult to see how poles can be erected high enough to prevent a broken wire striking the signal and telegraph circuits.

As a rule the wires break near the support, either by vibration or by burning.

Mr. Hunt mentions the possible use of iron wire or steel wire under section 27 of specifications, and cites the case of the Carquinez Straits span where the cable has been operating for a great many years with great success. I think he overlooks the point that the Carquinez cable is so heavy that a man can be sent out on the cable to inspect it and to maintain it. In certain sections of this country the salt fog will eat up an iron wire in a very short time. Experiments made along the east side of San Francisco bay show that the ordinary galvanizing of overhead trolley line parts is by no means an adequate protection, and that the metal rusts very quickly. For these reasons it is doubtful that any small iron wire, say No. 4 or

No. 6, can be used to make a thoroughly safe construction, without a great deal of maintenance cost in the way of replacements. Usually a transmission line wire is put up and forgotten as long as possible, so that the railroad company has reason to be suspicious of iron wire crossings.

If I understand Mr. Adams correctly he feels that the iron pipe pin would be barred out by section 19. Possibly it might be well to make an amendment there and mention specifically iron pipe.

The President has referred to the protection used on one of the Italian lines with which I am not familiar. Some of the French lines use a through span bridge over the tracks, through which both the telephone and transmission wires are carried. It is difficult to imagine a more complete protection than is afforded by such construction, but it is very expensive. It is neither equitable nor possible to attempt to shift the total burden of the expense of such crossings entirely from one party to the other. It is properly a matter of joint responsibility and interest. The broad principle involved in this matter is met by the railroad man every day in the crossings of his rights of way with other railroad rights of way. The senior road at the crossing does not stand much of the cost, while the junior road bears the greater part of it. A road that is senior in one place may be the junior road in some other locality because lines are being extended all over the country. We have a number of such cases—for instance, in connection with the power transmission lines now operating in this part of the country. In these cases undoubtedly the railroad company will be obliged to stand the greater part of the expense.

The foregoing remarks will refer also to Mr. Sprout's and Mr. Jollyman's discussions.

The suggestions made by the president that the railroad companies and the Institute shall join in a general discussion of this subject seems to me to be one that may have a very far-reaching consequence. I, for one, would be very glad to see such an arrangement brought about.

Ralph D. Mershon (by letter) Mr. Babcock's paper deals with a subject to which I have given considerable attention. Some time ago I wrote an article dealing with the subject.* It embodied my ideas as finally crystallized after various discussions and investigations relating to the subject. The endeavor was made to lay down the conditions which should be met in transmission line crossings in order to ensure safety. I quote these conditions, from the article, as follows:

(*a*) It should be so constructed that the line conductors (line wires or cables) and the supporting structures at each side of the track would be of proper strength to withstand the

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*" Transmission Line Crossings over Railroads ", ***Railroad Gazette***, February 7, 1908.

ice and wind loads which might come upon them. It should be self-sustaining; that is, should be capable of standing up under the action of wind and ice without reference to the remainder of the line, so that the line on one or both sides of the crossing, might break without interfering with the crossing itself.

(*b*) There should be sufficient overhead clearance between the line and the track, so that there would be no possibility of contact except by deliberate intent.

(*c*) The line conductors should be far enough apart so that they could not swing together.

(*d*) The line conductors should be sufficiently massive so that an arc might exist between them for several seconds, without danger of burning or melting them off.

(*e*) If the supporting structures are of steel, or the insulator pins are of metal and the pins connected to each other, or to ground, the insulators should have cast metal caps cemented upon them. These caps, or extensions of them, should extend out on each side of the insulator for some distance along and underneath the conductor, in order to further protect the conductor, or else the conductors should have, in addition to the caps, a protection from arcs in the form of a serving of wire upon them for some distance on each side of the insulator. The result of such protection will be that an arc formed near the insulator will expend itself upon the serving wire, or metal casting, instead of upon the conductor itself.

Mr. Babcock has gone into this matter in greater detail than was attempted in the article above referred to. In general, his specifications appear to me to conform with the ideas as laid down therein, though they do not seem to me as clear as they might be in regard to the matter covered by the latter part of (*a*). Apparently his specifications are intended to cover the construction of the supports and cables not only of the crossing span but of the adjacent spans on each side of the crossing span, and they contemplate the construction of these three spans of equal strength. Yet in item 17 he specifies the strength of the steel structures for the crossing span only, and says nothing about the supports for the two adjacent spans. It seems to me that, in general, it were better to so design the three spans that those adjacent to the crossing span could go down without injuring the crossing span. I will deal with this matter further in my remarks under ¶ 27.

There are a number of additional minor points in Mr. Babcock's specifications with which I do not quite agree. These differences will appear from what follows, in which I shall refer to such of the items of the paper as seem to me should be modified, designating them by the figures used in the paper.

¶6. This item contemplates that the power wires shall necessarily pass *over* the wires already on the right-of-way. It seems to me that there might often be cases where it would be safer and better to have the power wires pass ***under*** the existing wires, the latter crossing the power wires with a span so short on structures so high that, even though the existing wires should break near one structure, they could not reach the power wires.

¶20. It seems to me that not only should the pins be electrically connected to each other, but that this connection should be effectively grounded, especially if the wooden cross-arm is carried by a wooden structure. In the case of a metal cross-arm carried by a wooden structure, the metal crossarm should be grounded.

¶25. In the present state of the art of making the inter-connective link type of insulator, it may be working a considerable hardship upon the power transmission companies to require their use. And, so far as my experience goes, the cemented form of suspension insulator can be safely depended upon.

¶26. I am not quite sure that I understand this item, but if I do it seems to me the clearance provided is rather small. For 100,000 volts, for instance, it would be only 19.6 in.

¶27. I do not quite see the reason for making the minimum size of conductor less with lower voltages than with higher ones. Other things being equal, the danger of burning a conductor is greater with a lower voltage than with a higher one. Because with the same power capacity in each case the arc with the lower voltage would be heavier than with the higher. Inasmuch as the power capacity of the circuit as well as the voltage has to do with the amount of damage that might be done by an arc, it would seem to me better to either specify the size of the conductor with reference to both the power and voltage, or else to specify for all cases a conductor so heavy as to take care of any condition which might be met with in ordinary practice. It seems evident from this item and the next one that Mr. Babcock contemplates that the same size of conductor shall be used upon the crossing span, and the two spans on each side thereof. I should suggest the consideration of a great deal smaller and weaker conductor on each of the adjacent spans, so that if the transmission line itself should go down the conductors of these spans might break before injuring the crossing span.

¶32. I am not sure what this paragraph means. If it refers to the use of the device consisting of an auxiliary insulator and a connection from it to the line cable, together with a grounded guard against which the line cable is supposed to land in case it is burned off, the advisability of such provision seems to me questionable. I should prefer to make the cables heavy enough, and so protect them near the insulators, that they would be capable of successfully withstanding a power arc until the circuit breakers controlling the power line opened, or until the arc ruptured itself, in case the circuit breakers failed.

¶35. I do not see why the horizontal wind pressure should be added to the weight of the conductor and its covering of ice, instead of taking the resultant of the weight and wind pressure. I presume, that this wording of this item is an inadvertence.

Frank F. Fowle (by letter): The paper by Mr. Babcock agrees very well in its general recommendations with the conclusions presented by the writer two years ago in a paper prepared for the Association of Railway Telegraph Superintendents, and since published. The writer also attacked the fallacy of screen and basketwork protection some four years ago, which Mr. Babcock aptly characterizes as an engineering anomaly.

In general the problem presented is that of designing a transmission line crossing so that it shall be stronger electrically and mechanically than the balance of the line, and so that the probability of failure shall be practically extinguished. The crossing should compare with the balance of the line as follows:

1. The mechanical and electrical factors of safety should be greater.
2. The conductors should have greater conductivity per unit of length.
3. The conductor separations should be greater.
4. The entire structure should be absolutely fire proof for voltages above 10,000.
5. The protection against arcing should be greater, and against the effects of arcing.

A factor of safety in mechanical stresses of 3 is often recommended for dead loads, but in view of the possibly great damage that would result from failure, a factor of 4 seems to me no more than adequate. In choosing a factor of safety, the elastic limit as well as the ultimate strength should be considered.

For voltages below 10,000 where steel structures are for any reason not possible, the cross-arms and pins should be of steel in any case. Single wooden poles are not desirable, and some form of fixture made of two or more poles, such as an " *A* " fixture, or an " *H* " fixture, seems very essential. Wooden poles should be fire-proofed for several feet above the ground, and the butts should be creosoted. A factor of safety of 6 is recommended for all timber. Steel cross-arms and pins on timber structures should be thoroughly grounded.

Insulators designed for electrical stresses 25 per cent in excess of the main line would seem to be no more than adequate, especially in view of the fact that the damage done by lightning, and the maximum stresses caused by it, are largely local. A larger margin of safety in the insulators appears to be desirable in districts where lightning is severe.

As regards conductors, the unreliability of single aluminum strands of small size prevents their use; and aluminum should always be stranded. No. 6 B. & S. copper has an ultimate strength of nearly 1,300 lb., and is hardly suitable for crossings of this character. A minimum size of No. 2 B. & S. or No. 0 B. & S., stranded, will be better practice. If this size of copper has more than the necessary conductivity, copper-clad steel of corresponding strength may be substituted. The conductivity and diameter of conductor at the crossing should exceed that in the main line by at least 25 per cent.

Low-tension circuits carried on the high-tension line should be treated at the crossing as though they were high-tension circuits, for a failure on the line at some distance from the crossing may impress a very high tension on these circuits for a short time, causing them to break down at numerous places. If this proves to be a more costly procedure than carrying them underground at the crossing, the latter course is the obvious one.

Sleet loads vary greatly in different parts of the country, according to climate. A radial thickness of ¼ inch may suffice in California or in the extreme South, but it is much too small in the Central and Eastern states. The writer has seen accumulations on small wires in Illinois of about 1 inch radius, in severe storms. The records of the Weather Bureau will frequently furnish the necessary data upon which to base safe practice in this respect.

A wind pressure of 20 lb. per sq. in. on flat surfaces normal to the wind, computed from the formula,

$$p = 0.004\ V^2 \qquad (1)$$

corresponds to a velocity of 70.7 miles per hour. The writer found that for a period of ten years, at Chicago, the highest recorded velocity during a severe sleet storm was 50 miles per hour. The Weather Bureau maxima are based on observations at 5-minute intervals with a cup anemometer. Observations made with the Dynes pressure anemometer show instantaneous velocities, as much as one-third in excess of the 5-minute maxima of the cup anemometer, uncorrected. This indicates instantaneous true maxima as high as 67 miles per hour.

The Chicago observatory is 310 ft. above the street level, and it is reasonable to expect that the corresponding maxima at heights of 50 to 60 feet are considerably less, but how much less it is not possible to say with great accuracy. The contour of the ground, the presence of sheltering trees and buildings, and the general topography of the surrounding country, all have a vital bearing upon the wind pressures that may be expected at any given place.

The matter of maintenance is as important as that of design or construction, in providing safety for all time. Non-corrosive conductors, such as copper and aluminum, will give no trouble unless there are certain gases present in considerable quantities, such as occur where there is a profusion of smoke from soft coal or fumes from chemical works. The corrosion of steel, however, is another matter and a serious one. Galvanizing is an initial protection, but not permanent; and it cannot be renewed. It has a life of perhaps 15 years. Painted steel structures, periodically inspected and repainted, should have a much longer life, probably three times as great for permanent structures. The initial factor of safety cannot be maintained unless corrosion is prevented. The same is true with respect to the decay of timber. Therefore it appears to be an essential part of a crossing contract between a power company and a railroad company to provide for periodical inspections, and to place a limit upon the safe dimensions of structural members, so that the processes of corrosion or decay shall not defeat the original purpose.

Another phase of this problem is a legal one, which assumes considerable importance from the railroad point of view. Crossings on private right of way are under the control of the railroad company, but this is not true as regards crossings upon highways or public roads. The latter in most cases are subject to no further regulations than the state laws impose upon all wire crossings, which commonly specify a minimum clearance and sometimes minimum spans, steel pins and double cross-arms. It becomes the duty of electrical engineers to rectify this defect and point out the dangers. Legislation is much needed to place in the hands of the state railroad commissions the necessary authority to deal with such crossings and properly safeguard them.

Percy H. Thomas (by letter): *General.* The crossing of railroad rights of way by power lines represents much the same problem as the crossing of public telephone lines, the latter perhaps offering the widest exposure of the public to danger. Therefore it would perhaps be well to consider the two cases together.

In general the plan outlined in the paper is sound. It will probably however be found, as in the past, impracticable to provide a single set of hard and fast specifications to cover all cases. Crossings vary greatly, not only in importance and exposure but as well in physical characteristics; from the crossing of a main line railroad by a minimum length span of a power line to the very long span, possibly crossing a river with a little used branch railway line along one bank. Flexibility in the specifications could be obtained presumably by the relaxing of specific requirements where there appeared occasion for such a course, and where local conditions furnish justification therefor. The mutual sense of fairness between the engineers of the power and the railroad or telephone company must be relied upon to arrive at an equitable result in each case, the general specification giving a starting point and expressing the best practice for the average condition.

As an example of varying conditions to be determined on by mutual agreement in any particular case I may mention the thickness of ice to be assumed in calculating break down strength.

While it may be well as a matter of principle to provide for the furnishing of full drawings to both parties, and serving long notice of construction with the idea that the company being crossed will check up all details of the design, experience will undoubtedly show the precaution to be omitted in a majority of cases.

Specific Points in the Specifications.—As one of the most dangerous possibilities is the burning off and dropping of a conductor, as by the puncture of an insulator, it may in some cases be well to support the span by a second auxiliary insulator which may furnish mechanical support even if the line conductor be elsewhere grounded.

In cases of wooden cross arms where the nearby spans utilize ungrounded pins it would be well to ground the pins for several poles on each side of the crossing as otherwise lightning reaching the line near the crossing might find an easier ground path at the crossings insulator which must have a grounded pin.

¶8. Guys properly installed should be considered as forming part of the strength of the structures. This applies as well to ¶12.

¶23. The requirement of a special insulator at the crossing while entirely reasonable in one sense will cause a great deal of labor in many cases and perhaps disproportionate expense. if for example a special structure for the tower were thereby required.

It is an open question whether the interlinked type of suspension insulator or the concentric type is really safer in preventing the dropping of the line in case of trouble. The weakness of the interlinked type is the ease with which the link may be burned off if the insulator is punctured.

¶26. This clearance around the insulator seems a little excessive and hardly necessary in all cases.

¶27. This section should be so worded as to clearly permit well galvanized steel.

¶28. It will not always be feasible and it will often be trivial to equalize the strain in the span conductors at the cross over.

¶32. This section is not very clear.

¶33. The serving should extend to some distance on each side of the insulator.

¶35. This maximum wind stress seems too high for cylindrical surfaces; the value 12 has often been used. Of course in special localities the higher value may be warranted.

¶36. Taken in connection with all the other allowances made for safety it would seem safe to use a higher portion of the ultimate conductor strength, especially with a stranded conductor, than 0.3. For instance, 0.4 or even more has frequently been used. In taking extreme precautions in so many features an excessive total may be reached.

Nothing is here specified about the simultaneous conditions that shall be taken to represent the most severe conductor strain.

A. H. Babcock (by letter): Mr. Mershon considers that the two spans adjacent to the crossing span should be constructed under the same specifications as the crossing span. Usually these two spans are on private rights-of-way with which the railroad company is not concerned, unless a mechanical weakness in these spans shall be the cause of a failure in the crossing span, a contingency paragraph 10 is expected to cover. In some cases where the power company plans have been submitted, a head guy towards the tracks has been requested on the two outer poles of the adjacent spans. These combined with the guys mentioned in Section 10 effectually guard against mechanical troubles in the spans adjacent to the crossing span. His suggestion that there may be cases where it would be safer and better to have the power wires pass under the existing wire does not seem practical. Usually power companies object strongly to having any kind of a wire suspended over their circuits; and certainly were I in charge of the construction force of the railroad company I would not care to have my men stringing telephone or signal wires over a live high tension transmission line any more than I think the power company's engineers would like to have railroad line crews so engaged.

His objection to paragraph 20 probably comes from a hasty reading of the said paragraph.

The objection to paragraph 25 does not seem to be well taken since the paragraph states distinctly "of the interconnected link type or its equivalent." It is doubtful that any cemented type of insulator will stand a rifle ball and not drop the line, whereas an interconnected insulator, especially if located a considerable distance from the power house, can be completely shattered and not drop the line; furthermore since these insulators are specified for only a very few spans of the whole transmission line, their unit cost may be many times that of the other insulators used and not increase the total line cost materially.

His objection to paragraph 26 possibly will disappear if the provisions of this paragraph are taken into account in connection with paragraph 29. The size of the conductor specified for the lower voltages in paragraph 27 was intended to cover distribution circuits such as are commonly used in this section of the country where No. 6 copper has been found satisfactory. It is not usual to use wire of this size in long distance transmission line work except for unimportant branches. In these cases it is hardly likely that sufficient current to burn off a No. 6 copper wire could be forced through it.

He states that he is not quite sure what paragraph 32 means. Perhaps its meaning will be made clear by a statement of the fact that in the operation of the large net-work in Central California no form of automatic circuit breaker as yet developed has given satisfaction, and it is the custom to operate these circuits tied in solid to the power house without any automatic devices intervening. Under these conditions it is evident that a grounding of the conductor when it comes down will be of considerable value, though it has not been found in practice that any grounding device installed at a distance from the power house will burn off the conductor.

I am glad to have my attention called to the possible ambiguity in paragraph 35. Up to this time it never had occurred to me that anyone would think of adding the horizontal wind and the gravity forces in any other fashion than as a geometric resultant.

Mr. Fowles' suggestion that the railroad company shall hold periodical inspections of the power company's structures in the crossing span strikes me as being a good arrangement provided the railroad company does not thereby assume any legal responsibility whatever for the safe operating condition of the power company's structures.

His suggestion that the conductivity and diameter of the conductor at the crossing shall exceed that in the main line by at least 25 per cent does not seem to me necessary for such transmission circuits as are operated in this part of the country, for the reason that it is practically impossible for any generating system to force into a net-work enough current to fuse any wire that is used. If any strengthening of the conductor at the crossings is needed, therefore, the reasons are purely mechanical, in which case it is proper to increase the ultimate strength of the section by a certain per cent, (say 25 in order to be consistent), rather than to increase by a stated amount, the diameter of the conductor, the material of which is not specified.

For many years I have agreed with Mr. Thomas that it is impracticable to provide a single set of hard and fast specifications to cover all cases and have consistently endeavored to have every crossing contract brought up as a separate matter. The table which forms the last paragraph of the original paper will show how difficult and how cumbersome this procedure can become, and after a number of years experience it was found desirable to draw up a general set of specifications, such as are here presented, for the guidance of the power companies in submitting their plans; and to require of them the submission of the detailed plans and specifications called for in paragraph 2, and the notice specified in paragraph 3, so that the railroad company may have an opportunity to check the details. Should Mr. Thomas ever appear before the Southern Pacific Company as engineer for a transmission company about to install a crossing with the railroad company's right-of-way he will find that detailed plans and specifications will be required by the railroad company and that his designs will be most carefully checked before the crossing contract is signed. In an organization less complete and less comprehensive than that of the railroad company this precaution might be neglected; but the Harriman lines organization is more military in form than is usually found in commercial enterprises. The division superintendents are held personally responsible for all such matters and they would no more dare permit an unauthorized crossing to be installed and maintained over their lines than would a subaltern manoeuver his command independent of the orders of his superior officer.

Mr. Thomas considers that the guys installed should be included in the calculations of the strength of the structures. Doubtless this is necessarily so in the case of the wooden pole construction, otherwise the structure becomes bulky beyond all reason; but in the case of steel structures it would seem desirable not to include the guys in the structure calculations but to have them as an additional safeguard.

Mr. Thomas' objection to the requirements of paragraph 23 does not seem to me to be well taken because the cost of a large insulator on possibly two or three spans of a long line is certainly out of all proportion to the cost of possible damage of a single failure of the transmission line at this point. In the East it may be an open question whether the interconnected link type of suspended insulator or the concentric type is really safer in preventing the dropping of the line in case of trouble, but experience in the West has shown distinctly that inter-link connection of this kind will not burn off in case of line trouble, unless such connections are very near the power station.

It is rather curious that Mr. Thomas should find in paragraph 26 an excessive requirement while Mr. Mershon finds the same paragraph to be too lenient.

I cannot agree that paragraph 27 should be re-worded to permit of well galvanized steel. Under no conditions, especially around sea-fog belts, should galvanized steel conductors of any kind be permitted to cross the railroad company's right-of-way.

Mr. Thomas is the only engineer so far who has objected to the provisions of paragraph 36. A conductor strung with a factor of safety of 2½ will be found to lie in a very flat curve, much flatter than is usually met with in practice. A safety factor of even 3½, such as is called for in the specifications, gives a reasonably flat curve, and in many cases the ordinary line construction as installed at ordinary temperatures, shows much higher factors of safety than are herein required. The requirement of paragraph 36 is intended to cover excessive strains produced by low temperatures or high winds.

I regret that Mr. Mershon's paper "Transmisison Line Crossings over Railroads"—*Railroad Gazette*, Feb. 7, 1908, and Mr. Fowles' paper presented two years ago before the Association of Railway Telegraph Superintendents, were unknown to me before these specifications were written—first, that I might have had the advantage of their experience, and second, that I might publicly have given them credit for such information from these papers as may be found in the specifications.

In conclusion I have to express my obligations for assistance to Mr. E. B. Katte, chief engineer, Electric Traction, New York Central Lines, and also to Mr. Joseph T. Richards, chief engineer of Maintenance of Way of the Pennsylvania Lines, both of whom have favored me with copies of their standard specifications.

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