GENERAL ELECTRIC REVIEW

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Detroit River Tunnel Electric Locomotive Hauling 1400 Ton Freight Train

GENERAL ELECTRIC REVIEW

ECONOMICS OF RAILWAY ELECTRIFICATION

It is generally recognized that the next distinct advance in the electric railway field will be the electrification of certain portions of our steam main lines. With increasing congestion of single track mountain divisions, still greater train weights and higher speeds must become operative. The limits of steam locomotive construction have been nearly reached, and while the introduction of refinements in construction and auxiliaries may offer a means of obtaining increased output and better economy over present practice, the steam locomotive as a type of motive power still falls far short of what the electric locomotive can accomplish in meeting the requirements of the operating department for main line service. The alternative is offered of double tracking or electrifying, and the paper presented by W. B. Potter before the joint meeting of British and American Mechanical Engineers and reprinted in this issue, treats in considerable detail with the general subject of the economies of railway electrification.

It is admitted that the cost of installing electric locomotives, motor cars and auxiliaries, on a steam line is an item for consideration. That an attractive return on the first cost of installation is effected, however, by the economies and flexibility of operation introduced by the adoption of the electric motor is the history of every installation where the apparatus has been properly selected to meet the service requirements.

Granting the benefits of electrification, the first question asked is, what is the cost? This leads immediately to a consideration of the type of apparatus best suited to meet the particular requirements. It is not surprising, therefore, that a large part of Mr. Potter's paper is devoted to giving, in commendable detail and clearness, a general comparison of installation and operating figures of the several systems of operation available for steam line electrification. In fact, the author starts out with the assumption that any reasonable service may be successfully operated with any of the several systems. By thus eliminating the question of purely electrical engineering, Mr. Potter is able to devote his attention to setting forth the economic comparison of the alternating current—direct current situation.

In consideration of trunk line electrification, it is evident that the source of power supply and its frequency will have much to do with the determination of the system of operation. Such large generating and distributing systems have been built up in the past few years that they will enter as a factor when considering the question of generating or purchasing power for a given installation. Large alternating current motors operate best at a frequency of 15 cycles. The alternating current system would, therefore, suffer a handicap in efficiency and first cost if considerations of frequency or balanced load on a polyphase supply system necessitated the use of frequency changers.

While 1200 volts offers many advantages as a standard trolley potential for interurban roads having city connections, it is not necessarily the economical limit of direct current apparatus design. We may expect, therefore, to see direct current potential of 1800 or 2400 volts proposed for trunk lines where the service conditions demand a large kilowatt train input.

While in Mr. Potter's paper no figures are given of operating results of any specific road, the data presented represents the experience accumulated from observing the operation of a majority of all the alternating current and 1200 volt direct current roads operating in this country. This data is presented in tables giving comparative first cost of installation and cost of operation obtained from interurban road records.

Though last in the field, the 1200 volt direct current system has made a most admirable showing. Costing but slightly more than 600 volt apparatus, the 1200 volt car and substation equipments have given equal satisfaction in operation and at practically the same cost of upkeep. Here then is a system admirably adapted to the needs of motor car operation over interurban lines. The question of feeder copper is largely eliminated with the possibility offered of locating substations 25 to 30 miles apart. No sacrifice in motors or equipment is necessary to permit of running over 600 volt city tracks. Substation equipment may comprise two 600 volt converters in series for 1200 volts, or a single rotary converter may be wound for the higher potential, both methods being proven entirely satisfactory.

The 1200 volt direct current system, therefore, receives the approval of Mr. Potter, to the extent that he expresses the opinion that it will entirely supersede the alternating current system, for interurban service, unless some marked advance in the art affords the means of considerably reducing the motor equipment cost of the latter.

Undoubtedly part of the favorable attitude toward electrification now displayed by railroad managements is due to the preparedness of the manufacturers to furnish reliable apparatus. Selection of a proper system of operation is therefore most likely to rest in individual cases upon questions of reliability and past performance, rather than adherence to any proposed arbitrary standards.

FIRE-DAMP PROOF APPARATUS

Throughout the coal mines of the United States the number of men killed each year has been steadily increasing. During the decade from 1895 to 1905, the number almost exactly doubled, while in 1907 the casualties reached a total of 6861 killed and injured. That the greater production of coal and the employment of a correspondingly larger number of miners does not account for the increase in these fatalities, is shown by the fact that for each 1000 men employed, the number killed was 2.67 in 1895, and in 1905 this ratio had increased to 3.53. In all the European coal producing countries, on the other hand, where the output of coal has likewise greatly increased, the number of deaths per 1000 miners has steadily diminished. In Belgium, for example, this number decreased from 1.40 in 1895 to 0.91 in 1905
In England from 1.49 in 1895 to 1.35 in 1905
In Prussia from 2.54 in 1895 to 1.80 in 1904
In France from 1.03 in 1901 to 0.84 in 1905

The advantages that these countries can claim over the United States in this respect are due to the exhaustive investigations that they have carried on regarding the causes and prevention of accidents, and the resulting stringent laws that have been enacted and are being enforced.

A large number of these fatalities are caused by explosions of gas or coal dust and very many more by falls of roofs and coal, which, in turn, are frequently due to past explosions that have weakened the walls or roofs.

In 1907 the importance of this subject as a whole was brought forcibly before the public by a series of disastrous explosions that occurred in the coal fields of Pennsylvania and West Virginia. The first of these took place on December 1st at the Naomi mine, 34 men being killed and injured. Less than a week later the most disastrous explosion in the history of American mining occurred at the well laid out and comparatively new mine at Monongah, West Virginia. In this explosion the fan was entirely wrecked, the engine house demolished, and, as nearly as is known, 361 men lost their lives. Within two weeks a third explosion wrecked the Darr mine at Jacobs Creek, Pa. In point of fatality, this explosion was second only to that at Monongah; of the 239 men in the mine, but one escaped with his life.

Since that time the United States Government has been carrying on extensive investigations as to the conditions existing in mines; e g. the origin of the gas, and the laws governing its outflow into the mines, the danger of explosions due to coal dust, etc., etc. To this end, the Mine Accident Division of the United States Geological Survey has opened an experimental laboratory in Pittsburg, where the actual mine gases are available for experiment.

As with the European countries, these investigations will eventuate in legislation looking to the prevention of explosions and similar accidents, and in supplying electrical machinery for mine use, it will be necessary to have it so designed as to preclude the possibility of its causing mine explosions.

In this issue of the Review, we print what we believe to be the first article that has been published in English on the subject of Fire-Damp Proof Apparatus The author gives the different methods of protection against fire-damp and discusses the results and conclusions arrived at through the various investigations.

ECONOMICS OF RAILWAY ELECTRIFICATION*

By Wm. Bancroft Potter

Engineer Railway Department, General Electric Company

1. National prosperity and importance are largely proportional to facilities for intercommunication, and since overland transportation is to so large an extent dependent on railways any development providing for better railway service is of paramount importance. Steam locomotives and electric motors are the two recognized means of applying power which are available for practical railway requirements. The fundamental principles which underlie the problem of train movement are the same in either instance, but a true comparison of their relative advantages can only be made by a study of each particular method.

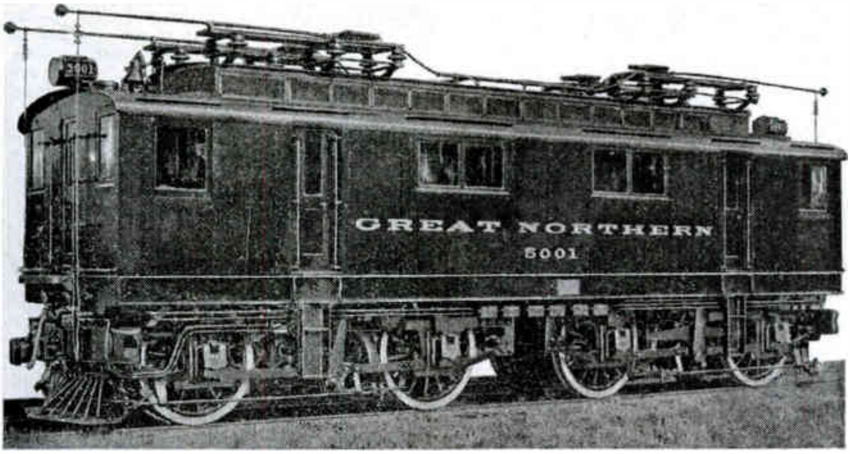

Fig. 1. Three-Phase Locomotive Used at the Cascade Tunnel of the Great Northern Railway

Trolley voltage	6600	Continuous rated draw bar pull	35,000
Frequency, cycles	25	Speed, mi. per hr.	15
Total weight, lb.	230,000	Duty—Three units to haul 1500 ton train up 2.2 per cent. grade.	
Weight on drivers, lb.	230,000		
Maximum rated draw-bar pull	77,000		

2. Much that has been written has treated the subject of electrification of steam railways from the general standpoint of averages, but unfortunately the economic application of electricity is not a subject for generalization—unfortunately, because averages are convenient and usually available, but often lead to erroneous conclusions, either for or against electrification. It is a mistake to assume that the average of the expenses for the entire railroad represents the actual expense for the particular conditions usually existing on the division under consideration.

3. On account of the investment already incurred, and because the question is usually one of determining comparative results, the electrification of an existing steam railway is a more complex problem than the electrical equipment of a new road.

4. Electrification, like any other engineering work, involves an investment against which there will be a fixed charge for interest and a liability of depreciation. The interest is a constant and permanent charge which must be met irrespective of any economy which may be secured by intelligent operation. The subject of depreciation is receiving more attention than formerly, the tendency having been to make the operating expenses

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* Paper presented before meeting of British and American Engineers, London.

cover this charge. However classified, the depreciation charge must be accounted for, and it is directly influenced by the character of the equipment with respect to reliability, durability, and capacity to provide for future requirements.

5. The utilization of higher trolley potentials, made possible with direct current by the development of the commutating pole motor and with alternating current by the development of the single-phase motor; the higher speeds of rotary apparatus in the sub-stations; and the development of the steam turbine, have effected a material reduction in the investment required and the cost of operation.

6. The different methods of electrification applicable in any instance should be carefully analyzed with regard to interest, depreciation and operating expense, and only the net result should be given consideration in determining the class of equipment. In this connection it is well to bear in mind that the expenditure is a lump sum which can be accurately determined, while depreciation and operating expense can only be approximated. Reference to the corresponding items of expense on railways operating under conditions comparable to those of the line to be electrified, will supply the most reliable figures. Future traffic developments must not be overlooked and the type of initial electrification should be selected with due regard to the ultimate requirements.

7. There would undoubtedly be an advantage in having the character of the energy supplied to the contact conductor uniform, but this is out of the question on account of the great difference in the requirements of specific conditions, such as congested urban or suburban service and comparatively infrequent trunk line train movements.

8. The sub-station and rolling stock may be equipped for operation with direct current or alternating current, single-phase or three-phase, and what is commonly spoken of as "the system" usually refers only to that part of the general scheme of electrification which comprises the sub-station and rolling stock equipment. There are exceptional cases where the power station and transmission lines have direct relation to the rolling stock equipments; but with the development of alternating current transmission, this is less frequently the case than it was a number of years ago when 600 volt power stations supplied power directly for the operation of 600 volt motors.

9. The development of apparatus for higher voltage direct current has so far increased its scope that direct current at either 600 volts or higher may be considered the most economical for city and interurban service, and for the electrification of steam railways where the density of traffic is sufficient to require a relatively large investment for rolling stock, as compared with that required for the secondary distribution system and the sub-station apparatus.

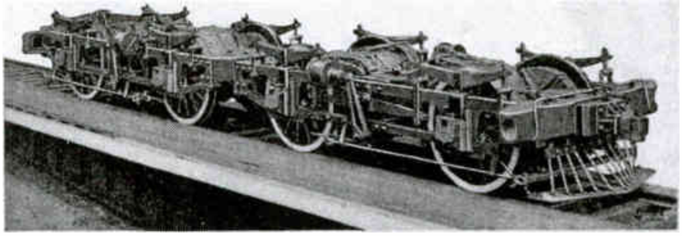

Fig. 2. Trucks for Three-Phase Locomotive, Great Northern Railway

10. Single-phase and three-phase rolling stock equipments are generally applicable only to exceptional conditions. The reason for this is the greater first cost of such equipments. This is especially true when comparing single-phase with direct current. The type of equipment used on the rolling stock may well be a more important factor in the economy of investment and operation than the scheme of power distribution.

11. Under the conditions which exist in America, direct current and single-phase are applicable to either level or grade work; while three-phase will probably be limited

to the latter where its regenerative feature of returning energy to the line may be of value. The relative economy of the different systems of electrification is dependent on the density of traffic and the character of power available, rather than on the length of the railway.

12. In cases where purchased power is used, or is depended on as a reserve, the frequency of the current supplied by the power company will have a bearing on the cost of sub-stations, and will thus affect the choice of the system. For direct current operation, rotary apparatus is used for converting the alternating into direct current, and the frequency of the supply is therefore relatively unimportant. For single-phase operation under the usual conditions, a frequency of not more than 15 cycles is desirable; and to provide this frequency, rotary frequency changers are as necessary as are rotary converters in the case of direct current, since the frequency of existing power companies ranges from 25 to 60 cycles.

13. With power supplied at the proper frequency for single-phase operation, permitting the use of static transformers and dispensing with frequency changers, the amount of energy required for a given trunk line service is in many cases nearly the same as for direct current, the greater weight of the equipped rolling stock, and the lower efficiency of the single-phase equipments, offsetting the rotary converters and trolley line or third rail losses of the direct current.

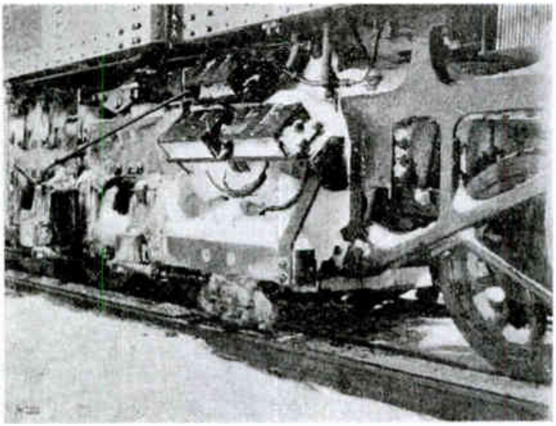

Fig. 4. Portion of a New York Central Locomotive After Running Through Snow

Fig. 3. Locomotive Used in the New York Central Electrification at New York

Voltage . . .	660 d c.	Maximum rated draw bar pull, lb.	47,000
Total Weight . . .	230,000	Continuous rated tractive effort, lb.	7,230
Weight on drivers, lb. .	141,000	Speed, mi. per hr.	60

14. The principal conditions which determine railway equipment are:

a Profile of road.
b Transportation required, *i.e.*, weight of trains or seating capacity of cars.
c Frequency of trains.
d Length of individual runs or distance between stops.
e Schedule required.
f Length of railway to be electrified.

15. In the selection of the electrical system best adapted to a particular set of conditions there are three items to be considered: (*a*) sub-stations, (*b*) contact conductors, (*c*) rolling stock. A comparison of these items determines the relative economic values of the systems. There are certain features under each of these items which may properly be examined. For trunk line service the values in Table 1 will be found within reasonable limits for the usual requirements.

16. We will consider briefly the effect of changes in the data sheet items (Par. 14):

a *Profile:* From a level country to a limiting grade of 1 or 1½ per cent. there will be little difference in the relative values of the systems. With steeper grades the conditions will be more favorable for alternating current.

b *Traffic Requirements:* Heavy individual train units favor the alternating current system with exception of the locomotives; light trains or multiple unit operation favor the direct current system.

c *Frequency of Trains:* Infrequent service with a relatively small number of locomotives favors the alternating current, frequent service the direct current. With increase in number of trains, the direct current systems gain relatively faster than the alternating current in economy of operation, due to relatively decreased sub-station operation, increased sub-station efficiency, and lower cost of equipment maintenance. It is therefore well to consider what the ultimate traffic density may be and select the system best suited to meet these requirementa.

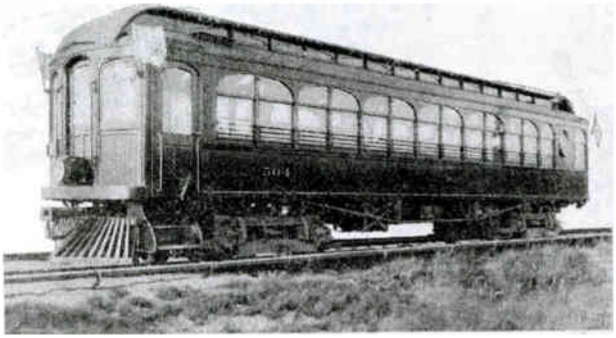

Fig. 5. Typical American Interurban Car, West Shore Railroad

d, e *Distance between Stops and Schedule Required:* Variations in these will not affect the relative value of systems unless extreme requirements, such as high schedule speed with short runs, make the use of direct current imperative.

f *Length of Road:* For a similar character of service throughout, the railroad may be of any length without affecting the relative desirability of the various systems. What is suitable for the first fifty miles will be equally suitable for any extension.

An examination of these variables will show that a change in the conditions to be met will radically change the relative economic value of the systems of electrification.

17. The single-phase system, by reason of the apparent simplicity of its elements and the utilization of higher potential for the contact conductor than is possible with direct current, is admittedly very attractive. There is the other side of the question, that the single-phase commutating motor is much higher in first cost and maintenance than the direct current motor. Over this subject of alternating current single-phase vs. direct current systems there has been a great deal of controversy. It is our opinion that comparative results obtained up to the present time are in favor of direct current.

18. Desirable as would be a standard system for all classes of service, we cannot hope to establish such a standard should it impose an additional expense without adequate return. A summing up of all the elements of each electrical system will generally lead to a definite showing of which system is most desirable to meet specific conditions. For trunk line service a higher potential than 600 volts will unquestionably be used; 1200 volts direct current will prove economical in some cases, but a still higher voltage is required to provide economically for the heavier intermittent service. Whether this potential will be 1800 or 2400 volts direct current or 11,000 volts alternating current cannot be settled arbitrarily.

Interurban Railways

19. Let us consider the interurban railway situation in the United States, particularly in regard to the various available schemes of electrification. These are, 600 volt direct current, 1200 volt direct current, and single-phase, the three-phase being objectionable on

account of the complications of the necessary double overhead distribution system.

20. The application of single-phase to new projects has been practically abandoned, there having been but one or two new installations in the last three years. This arrested development of a system which for a short time held forth considerable promise, has been brought about by a general recognition of its limitations. Experience has shown these to be:

- *a* Excessive weight of rolling stock.
- *b* Excessive cost of rolling stock.
- *c* High cost of equipment maintenance.
- *d* Increased power consumption.
- *e* Rapid depreciation of motor.
- *f* Rapid depreciation of car bodies and trucks.
- *g* Increased cost of maintaining track and roadway.

Moreover it is recognized that any interurban road in the United States must be capable of operating over existing city tracks from 600 volt direct current trolley, a condition which hampers the single-phase system on account of increased complications in the control system.

21. For interurban railways a potential of 1200 volts direct current has been selected, because with the motors wound for 600 volts the car may be operated at the same speed from either 600 or 1200 volt trolley, by connecting the motors all in parallel for 600 volt operation, and two in series with two groups in parallel on a 1200 volt section.

22. To show clearly the relative merits of the systems we have made an analysis of an interurban railroad 100 miles long with cars

TABLE I

Reasonable Values for Trunk Line Service

SUB-STATIONS

	600 V. D.C.	1200 V. D.C.	11,000 V. 1-Phase	11,000 V. 3-Phase
First cost per kw., complete	$26	$28	$11	$12
Comparison of installed kw., %	200–250	100–125	100	100–125
Load factor, machines in service, %	20–40	35–70	40–80	30–60
Average efficiency, %	78–88	87–92	97–98	97–98
Yearly operation and maintenance, each station	$5,000	$5,000	$2,500	$2,500

CONTACT CONDUCTORS*

	Third Rail		Overhead	
First cost, per mile	$5,000 to $7,000	$5,500 to $7,500	$3,500 to $7,000	$4,500 to $8,000
Efficiency, %	88–92	90–96	93–97	93–97
Maintenance per mile per year	$75–$125	$100–$150	$100–$200	$125–$250

ROLLING STOCK †

	600 V. D.C.	1200 V. D.C.	11,000 V. 1-Phase	11,000 V. 3-Phase
LOCOMOTIVES				
First cost, each	$44,000	$47,500	$64,000	$58,000
Weight, tons (2000 lb.)	125	125	160	160
Average efficiency, locomotive wheels to trolley, %	85	85	79	81
Maintenance per locomotive per mile, cents	4	4	8	5
MOTOR CARS (COMPLETE)				
First cost, each	$12,000	$13,500	$20,000	
Weight, tons (2000 lb.)	43	44	54	
Average efficiency, wheels to trolley	82	81	73	
Maintenance per car mile, cents	2	2.2	3.5	

* Variation in cost of third rail due to different weights of rail which may be required. Variation in cost of overhead due to variation in the class of construction, such as with wooden poles or with steel bridges.

† Other weights of locomotives will cost more or less about in proportion to their weights. With gearless direct current locomotives, the average efficiency of locomotive wheels to trolley is approximately 88 per cent.

in each direction every hour. This condition represents practically the minimum car requirements in the United States, and is therefore favorable to the single-phase. It is obvious that any increase in traffic density will be relatively more favorable to the direct current system on account of the lower first cost of cars, lower car maintenance and relatively lower cost of sub-station operation.

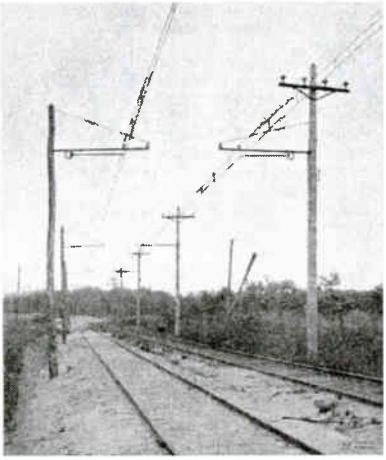

Fig. 6. Typical American Overhead 6600 Volt Single-phase Interurban Trolley Line, Baltimore and Annapolis Short Line, Annapolis, Md.

23. Assume a typical interurban condition.

a Profile: rolling country.
b Transportation required: passenger cars to seat 50 passengers and having baggage compartment, or the equivalent of 60 passengers without baggage compartment.
c Frequency of trains: one every hour in each direction.
d Average distance between stops: 3 miles.
e Schedule speed: 33 miles per hour.
f Length of road: 100 miles.
g To operate on existing 600 volt city tracks.

The general data required are approximated in Tables 2 to 7.

24. There will be an additional cost of operation and maintenance with the single-phase system for the items of track and roadway, due to additional weight of cars, car shop expenses in providing greater facilities for shop inspection and repairs, and greater skill in superintendence of equipment. In a number of instances this has been found to amount to several cents per car mile. A conservative estimate would require at least one cent per car mile to be added for these items.

25. The comparison in Table 7 brings out the fact that even for conditions selected as favorable to the single-phase system, the 600 volt direct current system is the more economical considering operation, maintenance and fixed charges. An examination of the elements which enter into the first cost and operation of a system will show at once that as the density of traffic increases there is a rapid gain in the relative advantage of the direct current over the single-phase system.

Conclusion

26. The saving effected by the 1200 volt direct current system is so marked that a great increase in the adoption of this potential for this class of interurban railroading may be anticipated, and on the other hand it will not be surprising if the single-phase interurban system is entirely discarded in America, unless some improvement is made in the art and a more economical equipment made available. There is no question regarding the mere movement of trains by any particular system—this may be taken for granted. The study of electrification is really a problem in economic engineering and not simply a technical problem.

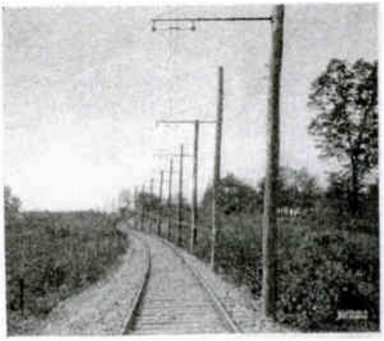

Fig. 7. 1200 Volt Direct Current Overhead Line Construction of the Pittsburg, Harmony, Butler and New Castle Railway, Pittsburg, Pa.

TABLES RELATING TO TYPICAL INTERURBAN ELECTRIC SERVICE

TABLE II

GENERAL DATA FOR CARS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Number of cars	15	15	18
Seating capacity, passengers	60	60	00
Distance between stops, miles	3	3	3
Schedule speed, miles per hour	33	33	33
Maximum speed, miles per hour	48	48	55
Weight each car, tons (2000 lb.)	35	36	43
Car miles per day	3000	3000	3000
Miles per car in service per day	300	300	300
Miles per car per day, average*	200	200	166
Estimated maintenance per car mile, cents			
a Electrical	0.70	0.77	1.50
b Mechanical	1.00	1.00	1.25
Total car barn expense	1.70	1.77	2.75
Amperes starting car	520	280	75
Amperes running car	174	94	24
Kilowatt hours per car mile at car	2.8	2.88	3.78
Cost each car complete	$10,000	$11,500	$17,000

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* On twelve American single-phase interurban roads the average miles per day called for on the published time tables, divided by the number of cars owned, is 138; on four 1200 volt roads which have been operating over a year this number is 237, the larger number of alternating current cars being required on account of the fact that a greater number are necessarily held in the barn for inspection and maintenance purposes. This explains why in the table above 18 alternating current cars are assumed and 15 direct current cars.

TABLE III

SUB-STATIONS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Number of sub-stations	9	4	2
Estimated momentary demand			
Cars starting	1	1	2
Cars running	1	1	0
Peak load, kilowatts	416	448	670
Average load, each sub-station, kilowatts	52	120	275
Size each unit, kilowatts	300	300	300
Number of units	2	2	3
Load factor (machines in service)	0.17	0.40	0.46
Average efficiency	0.76	0.87	0.96
Cost each sub-station complete	$24,000	$26,400	$10,000

TALE IV

FEEDER COPPER REQUIREMENTS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Maximum momentary demand midway between sub-stations			
Cars starting	1	1	2
Cars running	0	1	0
Amperes	520	374	150
Distance between sub-stations	11.8	28	66.6
Equivalent stub-end feed	2.9	7	16.6
Feeder required additional to 4/0 trolley	4/0	1/0	none
Cost overhead construction per mile, including both trolley and feeder	$2300	$2100	$1900

Bonding taken as $400 per mile of track

Transmission line taken in each case as $640 per mile of track and assumed to run entire length of right of way.

Power house: No power house is included, but it is assumed that power is purchased at the power station bus at one cent per kw-hr and fed at any convenient point into the transmission line.

TABLE V

POWER CONSUMPTION

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Total kilowatt hours per day at cars	8400	8650	11,400
Efficiency, secondary distribution	0.90	0.90	0.94
Sub-stations	0.76	0.87	0.96
Transmission line and power house step-up transformers	0.94	0.94	0.94
Combined efficiency	0.64	0.74	0.85
Kilowatt-hours per day at power house	13,100	11,700	13,400

TABLE VI

Summary of Costs

FIRST COSTS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Transmission	$84,000	$84,000	$84,000
Sub-stations	216,000	106,000	20,000
Secondary distribution	230,000	210,000	190,000
Bonding	40,000	40,000	40,000
Cars	150,000	172,500	360,000
Total	$720,000	$612,500	$694,000

ANNUAL FIXED CHARGES

DEPRECIATION	Life Years	Annuity 5%	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Transmission	20	30.34	$2,500	$2,500	$2,500
Sub-stations	20	30.34	6,500	3,200	600
Secondary distribution	15	46.34	10,600	9,700	8,800
Bonding	10	79.50	3,200	3,200	3,200
Cars (A.C.)	12	62.83			22,600
Cars (D.C.)	15	46.34	6,900	8,000	....
Total Depreciation			$29,700	$26,600	$37,700
INTEREST AND TAXES					
Interest 5%, taxes 1.5% of cost of electrical material			$40,000	$39,800	$45,000
INSURANCE					
1.5% of sub-station and car costs			$5,500	$4,200	$5,700
Total fixed charges			$81,200	$70,600	$88,400

ANNUAL OPERATION AND MAINTENANCE

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Transmission	$3,500	$3,500	$3,500
Sub-stations	17,000	7,600	500
Secondary distribution, including bonds	9,000	9,000	10,000
Cars	18,500	19,300	30,100
Power at one cent per kw-hr.	47,800	42,700	49,000
Additional cost maintenance of track and roadway, shops and supervision, due to heavier cars and more expert supervision required for the single-phase	....	....	10,900
Total	$95,800	$82,300	$104,000

ERRATA SHEET for pages 396 and 397, September 1910 Review

(Corrections are indicated by heavy faced type)

TABLE VI

Summary of Costs

FIRST COSTS

	600 V. D.C.	1200 V. D.C.	6600 V A.C.
Transmission	**$84,000**	$84,000	$84 000
Sub-stations	**210,000**	106,000	20,000
Secondary distribution	**230,000**	210,000	100,000
Bonding	**40,000**	40,000	40,000
Cars	**150,000**	172,500	**30 600**
Total	**$720,000**	$612,500	**$640.000**

ANNUAL FIXED CHARGES

Depreciation	Life Years	Annuity 5%	600 V D.C	1200 V D.C	6600 V. A C.
Transmission	20	30.34	$2,500	$2,500	$2,500
Sub-stations	20	30.34	6,500	3,200	600
Secondary distribution	15	46.34	10,600	9,700	8,800
Bonding	10	79.50	3,200	3,200	3,200
Cars (A.C.)	12	62.83			**19,200**
Cars (D.C.)	15	46.34	6,900	8,000	
Total Depreciation			$29,700	$26,600	**$34,300**
Interest and Taxes					
Interest 5%, taxes 1.5% of cost of electrical material			$46,000	$39,800	**$41,600**
Insurance					
1.5% of sub-station and car costs			$5,500	$4,200	**$4,900**
Total fixed charges			$81,200	$70,600	**$80.800**

ANNUAL OPERATION AND MAINTENANCE

	600 V. D.C.	1200 V D.C	6600 V A.C.
Transmission	$3,500	$3,500	$3,500
Sub-stations	17,000	7,600	500
Secondary distribution, including bonds	9,000	9,000	10,000
Cars	18,500	19,500	30,100
Power at one cent per kw-hr.	47,800	42,700	49,000
Additional cost maintenance of track and roadway, shops and supervision, due to heavier cars and more expert supervision required for the single-phase			10,900
Total	$95,800	$82,300	$104,000

TABLE VII

COMPARISON OF COST OF SYSTEMS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
1 First cost	**$720.000**	$612,500	**$640.000**
2 Fixed charges	**$81,200**	$70,600	**$80.800**
3 Operation and maintenance	95,800	82,300	104,000
4 Annual cost (Item 2 plus Item 3)	$170,000	$152,900	**$184.800**
Based on 1,003,000 car miles per year, additional annual charge per car mile above the cost for 1200 volts, in cents	2.1	0	**2.9**

TABLE VII

COMPARISON OF COST OF SYSTEMS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
1 First cost	$710,000	$612,500	$694,000
2 Fixed charges	$81,200	$70,600	$88,400
3 Operation and maintenance	95,800	82,300	104,000
4 Annual cost (Item 2 plus Item 3)	$176,000	$152,900	$192,400
Based on 1,095,000 car miles per year, additional annual charge per car mile above the cost for 1200 volts, in cents	2.1	0	3.6

27. Reliability of operation is of the greatest importance, not only to the public but to the operating company, and in this respect the electric motor with its simpler construction, even though the general service is supplied from a central power station, has proved its superiority over the steam locomotive. Except in the case of some extraordinary accident, the power station, substations and transmission line, in their entirety, are rarely rendered inoperative. The liability to interruption is principally centered in the equipment of the rolling stock, and for this reason the mechanical and electrical design of the motors, control and equipment devices, should receive careful consideration.

28. The electrical equipment of motor cars and locomotive is exposed to a large extent to dirt, water and snow; and not being particularly convenient for inspection, it usually receives less attention than the apparatus in the power station and substations. It is the custom on many roads to give the equipments a regular inspection once in a thousand or fifteen hundred miles, depending on experience, and to dismantle them for a thorough overhauling once a year. The character of the rolling stock equipment is a factor of far more importance to the reliability of the service than is often appreciated.

29. The steam locomotive has been brought to its present state of development through many years of experience. It is an exponent of the highest type of mechanical design, and notwithstanding its limitations, is remarkably efficient as a source of power. During the past twenty years the power of the steam locomotive has been practically doubled, but the demand today is for still greater power.

30. The multiple unit idea, to which electric service is so well adapted, was utilized in the design of the Mallet type of steam locomotive where the driving engines of two practically separate locomotives are supplied with steam from a single boiler. Mallet locomotives have been built having a weight of 441,000 lbs. on the drivers, the boiler having over 5800 sq. ft. of heating surface and a grate area of 100 sq. ft. To fire properly a locomotive of this capacity is difficult, and unlike the electric locomotive, its effectiveness depends on the steam from its own particular boiler.

31. With existing road clearances the steam locomotive unit, controlled by a single engineer, seems to have reached nearly the limit of power. The power of a steam locomotive being limited by the capacity of its boiler, an increase in speed can be secured only by a proportional reduction in tractive force. The electric locomotive, on the other hand, is supplied with practically unlimited power from an independent power station, and can maintain a speed and tractive force that would be impracticable with a steam locomotive. The application of electric locomotives to passenger and freight service will result in faster schedules with equal or even heavier trains than are at present handled by steam locomotives.

32. Since the electric locomotive is equipped with a number of independent motor units, controlled by one engineer from a single master controller, it makes no difference considering the complete locomotive as a machine, whether it be built as a single unit, or as two or three units having the same total weight on the drivers. For convenience in operation and repairs, it is probable that a single electric locomotive unit will be limited to a weight between 200,000 and 300,000 lbs. on the drivers, even when built for the heaviest service. There are electric locomotives now under consideration which as single units will exert a maximum tractive effort of 90,000

lbs., and which will be capable of maintaining a tractive effort of 35,000 lbs. at a speed of 30 miles per hour.

33. Many of the terminal and tunnel electrifications have been brought about from the desire to do away with the danger and nuisance caused by smoke and gas. The elimination of smoke has also an economic aspect in the electrification of terminal stations, in permitting material improvement in the character and value of railway buildings. The Quai d'Orsay terminal of the Paris-Orleans Railway in Paris, which has been in operation since May 1900, was the first instance where a steam railway profited by this feature of electrification.

34. The enhanced value of railway buildings is seen to a marked degree when terminals are electrified in large cities in which land values are high. The fact that electric operation will permit platforms on two or more levels adds greatly to the capacity of the station, or conversely, decreases the land area required for given traffic facilities. In the case of the New York Central terminal in New York City, there will be two levels of platforms, the entire suburban facilities being placed below those of the main line. The Pennsylvania terminal in New York is another instance of station design affording facilities for handling traffic that would be impossible under steam operation.

35. The electric locomotive is well adapted for the handling of trains where the character of the service will not permit the operation of individually equipped cars. Where the service is self-contained, individually equipped motor cars, operated in trains with multiple unit control, are recognized as providing for the most efficient handling of traffic.

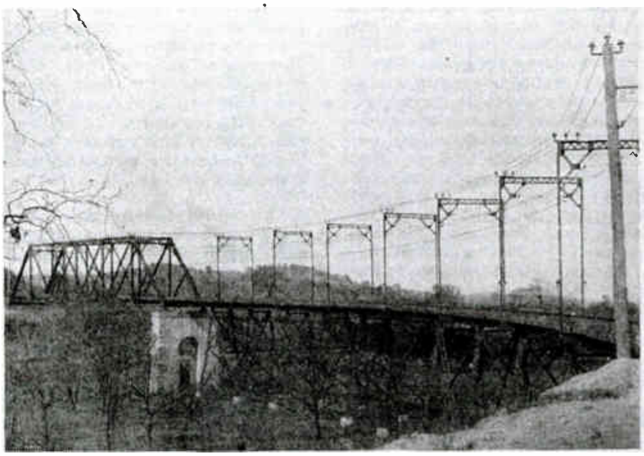

Fig. 8. 1200-Volt Overhead Line Construction on Steel Trestle, Pittsburg, Harmony, Butler and New Castle Railway, Pittsburg, Pa.

36. Economy in operation will be secured by proportioning the number of cars in a train to the traffic required during different hours of the day. The patronage on which the gross receipts depend will be much encouraged by providing a service with short intervals between trains. In the study of any scheme of transportation, due regard should be given not only to economical operation but also to the method of handling which will insure the maximum gross receipts.

37. The author desires to express his thanks to Mr. C. E. Eveleth for his assistance in the preparation of this paper.

THE STEAM TURBINE*

PART I

By Dr. Ernst J. Berg

The Condition of Steam in Turbines

The relation between the available energy and the pressures and conditions of steam was given in the first of these lectures. It has been shown how, when the steam is expanded, a certain amount of moisture is formed and how this moisture is partly re-evaporated by the internal losses. For instance, in the case discussed, where the final amount of moisture would have been 20 per cent., with 100 per cent. efficiency of the turbine, the actual moisture of the exhaust was only 11.4 per cent. on account of the losses. (See page 295 in July, 1910, Review.)

In a single stage turbine there would be no way to take advantage of this, since the steam is discharged directly into the condenser. In a multi-stage turbine there is, however, a gain (although slight) by the re-evaporation, and as a result we have the apparent paradox that the joint efficiency of all stages is greater than the efficiencies of the individual stages.

As an illustration, assume that a single stage turbine is operated with saturated steam at a pressure of 175 lbs. absolute and 28 in. vacuum; the available energy is then 253,000 ft. lbs. and the final moisture 23.4 per cent. At 70 per cent. efficiency of the turbine the energy available for re-evaporation (neglecting losses by radiation, which are small) is $0.30 \times 253{,}000 = 75{,}900$ ft. lbs. The latent heat at one pound absolute pressure is 1043.1 B.t.u.; therefore to evaporate one pound, $1043.1 \times 778 = 812{,}000$ ft. lbs. of energy are required. Therefore with 75,800 ft. lbs., 0.0935 lbs. of moisture are evaporated. The moisture is therefore:

$0.234 - .0935 = 0.1405$, or 14.05 per cent.

With a four stage machine operated with initially dry saturated steam at 175 lbs. absolute pressure and 28 in. vacuum, the following condition of moisture exists in the different stages when the efficiency of each stage is 70 per cent. and the work per stage is approximately the same.

First stage (63 lbs. pressure), 4 per cent. moisture;

Second stage (19.5 lbs. pressure), 7.8 per cent. moisture;

Third stage (5 lbs. pressure), 11.5 per cent. moisture;

Fourth stage (1 lb. pressure), 14.8 per cent. moisture.

Comparing this with the moisture given in the previous case, 14.1 per cent., we see that the four stage machine has converted more steam to water, or has abstracted more energy. The efficiency corresponding to this moisture is 72.4 per cent, as can readily be determined from the above method.

There is therefore an apparent gain in going to many stages. It might be well, however, to mention that the gain, although considerable between a one-stage and four-stage turbine, is proportionately very much less as the number of stages is increased. The gain is approximately 1.5 per cent. in going from four to twenty stages.

This gain, however, cannot be fully taken advantage of, since with an increased number of stages other difficulties appear, as, for instance, steam leaks around diaphragms, etc.

To illustrate the dependence of moisture on the efficiency, the following tables have been prepared for a single-stage and a four-stage turbine:

Single Stage Turbine

1st. Initial pressure, 175 lbs. absolute; initial condition, dry saturated steam; exhaust pressure, 1 lb. absolute (28 in. vacuum).

Per cent. efficiency of turbine	100	70	50	20
Per cent. moisture in exhaust	23.4%	14%	7.7%	1.4%

2nd. Initial pressure . . . 175 lbs. abs.
Condition of steam . . . 200° F. superheat
Exhaust pressure . . . . 1 lb. absolute

Per cent. efficiency of turbine	100	70	30	20
Per cent. moisture or superheat	17.6%	7.05%	0.05%	14° sup.

Four Stage Turbine

1st. Pressure, saturated steam . 175 lbs. abs.
Exhaust pressure . . . . . . 1 lb.

Per cent. efficiency of each stage	80	70	60	50	40	30
Per cent. moisture in 1st.	4.9	4	3	2	1.1	.01
Per cent. moisture in 2nd.	9.6	7.8	6.1	4.3	2.6	.08
Per cent. moisture in 3rd.	14	11.5	9	6.5	4.1	1.6
Per cent. moisture in 4th	18	14.8	11.8	8.6	5.5	2.4

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*The last of a series of three papers read before the employees of the Commonwealth Power Company, Chicago. The first and second papers were published in July and August issues of the *Review*.

2nd. Pressure	175 lbs. abs.
Superheat	200°
Exhaust pressure	1 lb.

Per cent. efficiency of each stage	80	70	60	50	40	30
Per cent. superheat in lb. of 1st stage	0.84%	106°	127°	148°	172°	192°
Per cent. moisture or superheat in lb. of 2nd stage	2%	0	44°	85°	126°	168°
Per cent. moisture or superheat in lb. of 3rd stage	7%	3%	.4%	20°	80°	136°
Per cent. moisture or superheat in lb. of 4th stage	12%	8.4%	5%	2%	35°	108°

It is interesting to note that with 200° superheat and dry exhaust the efficiency cannot be higher than about 45 per cent.

Unfortunately, it is very difficult to determine the true conditions of the steam in the exhaust. Practical experience has shown that it is next to impossible to get a true sample.

It is evident, however, that if there were any practical ways of obtaining the percentage moisture in the exhaust of a turbine, its efficiency could be directly told.

At first sight it might be thought that since there is substantially no radiation from the throttling valve, there should be practically no loss in available energy through its use. That it is inefficient, however, is found in practice and theory. We will assume that the boiler gives saturated dry steam at 175 lbs. absolute pressure, and that by throttling the pressure is reduced to 100 lbs. absolute.

The specific heat of superheated steam is not definitely known, but will be assumed as 0.5. We have, therefore, assuming no loss by radiation: total heat of saturated steam at 175 lbs. = total heat of saturated steam of 100 lbs. + $0.t_1$, where t_1 is the amount of superheat.

Total heat at 175 lbs. sat. steam is	1,194.9 B.t.u.
Total heat at 100 lbs. sat. steam is	1,181.9 B.t.u.

Thus $0.5t_1 = 13$, and $t_1 = 26°$ F.

From the equations previously given, it can be determined that the available energy of saturated steam between 175 lbs. and 1 lb. is 253,000 ft. lbs., and that the available energy of superheated steam at 100 lbs. and 26° superheat is 228,400 ft. lbs.

$$\text{Therefore } \frac{228,400}{253,000} = 0.902,$$

or 90.2 per cent. only is available at the lower pressure.

In this connection it may be of interest to discuss the use of the *throttling calorimeter*, and the bearing that the uncertainty of the specific heat of superheated steam has on the deductions.

It will be assumed that the calorimeter is connected to the atmosphere and that the initial pressure is 175 lbs. abs.; the condition of the steam is unknown and the temperature of the superheated steam at atmosphere pressure is 262° F., or 50° superheat.

Since the total heat is assumed to be the same at the two pressures, we get:

Total heat at 14.7 lbs. saturated steam $+ Cp \times 50 =$ (total heat of saturated steam at 175 lbs.) + (heat of the liquid).

Let x be the percentage steam, then $1 - x =$ percentage liquid.

The liquid heat at 175 lbs. pressure is 343.3; therefore we get:

$$1,146.9 + 50Cp = 1,194.9x + 343.3(1 - x).$$

or

$$x = \frac{803.6 + 50\,Cp}{851.6}$$

For $Cp = 0.5$ we conclude a moisture of 2.75 per cent.

For $Cp = 0.6$ we conclude a moisture of 2.1 per cent.

From the equation it is readily seen that with saturated exhaust steam the initial moisture may be 5.7 per cent. or more.

The calorimeter, therefore, cannot record more than 5.7 per cent. moisture under this pressure condition. In reality it is limited to a considerably smaller percentage, on account of the error in temperature deduction, difficulties of getting true samples of the steam when loaded with much moisture, etc.

The Reciprocating Engine

The reciprocating engine, especially when new and properly adjusted, converts the energy of steam into mechanical energy with high efficiency. This is particularly so when operating non-condensing, or with moderate vacuum only. It must be remembered that high efficiency does not mean low water rate in general, but low water rate when considering the energy delivered to the engine in the steam between any given pressure ranges. For instance, an engine operating non-condensing with initially dry steam of 175 lbs. abs. pressure and an efficiency, including generator, of 80 per cent., would have a water rate of 23.6 lbs. per kilowatt-hour. Another engine operating with the same initial pressure and 28 in. vacuum and taking 17.5 lbs. of water, would have an efficiency of 60 per cent.

Due to the number of large cylinders, cylinder condensation, etc., it is evident that the low pressure part of the steam engine is not as efficient as the high pressure part. In the steam turbine, due to the higher rotation losses in the part which has high pressure, the conditions are reversed, the low pressure stages working, as a rule, with higher efficiency than those of higher pressure.

The reciprocating engine can have higher efficiency than the turbine at high pressures, and the turbine higher efficiency at low pressures. An excellent combination is, therefore, a high pressure reciprocating engine in conjunction with a low pressure turbine. This combination is the more attractive from the central station point of view, since it does not mean discarding the available equipment, but only adding such new apparatus as the load requires. This combination is much cheaper than the addition of new high pressure turbines or reciprocating engines with their boilers; it also reduces very materially the coal consumption per kilowatt generated.

Mr. Barrus, in his book on engine tests, shows that ordinarily, condensing only effects a saving of 25 per cent. in water rate in compound engines, and 17 per cent. in single engines.

Based upon these figures and certain assumptions of efficiency it is possible to make a very instructive analysis of the gain that can be made by the installation of low pressure turbines.

As stated, the efficiency of a compound engine, when new and properly adjusted and operating at atmospheric exhaust, is very high; it may be 90 per cent. with ordinary care. However, the efficiency cannot be maintained at this value, but averages probably 80 per cent., which value represents about 75 per cent. efficiency when the losses of the electric generator are included.

The water rate of such a unit operating with initially saturated steam at a pressure of 175 lbs. absolute is $\frac{18.9}{0.75} = 25.2$ lbs. per kilowatt hour. (See table page 294, July, 1910, REVIEW). At 28.5 in. vacuum, according to Mr. Barnes, we may expect a water rate of $0.75 \times 25.2 = 18.9$ lbs., which corresponds to an efficiency of $\frac{10.12}{18.9} = 53$ per cent. (See table and interpolate between 28 in. and 29 in. vacuum.)

The available energy between 175 lbs. pressure and atmospheric exhaust is 139,500 ft. lbs.; thus energy converted per lbs. of steam in $0.75 \times 139{,}500 = 104{,}000$. The available energy between 175 lbs. pressure and 28.5 in. vacuum is 262,000 ft. lbs., thus the energy converted is $0.53 \times 262{,}000 = 139{,}000$. Therefore while operating condensing, the part of the steam engine unit which converts the low pressure steam to electrical energy supplies only $139{,}000 - 104{,}000 = 35{,}000$ ft. lbs. per lb. of steam.

Due to the internal losses and the reevaporation of part of the moisture incidental thereto, the steam contains practically 8.9 per cent. moisture at atmospheric pressure. The available energy of each pound of moisture of steam and water expanded to 28.5 in. vacuum is readily calculated at 130,900 ft. lbs. Thus the efficiency of the low pressure part of the steam engine cycle is only $\frac{25{,}000}{130{,}900} = 26.7$ per cent.

Depending upon the size, of course, the efficiency of a low pressure turbine set might be from 60 to 70 per cent. Assuming 65 per cent., as a mean value, it is evident that, for the same amount of steam, we can convert 130,900 foot lbs. to 38,000 foot lbs. useful work in one case, and in the other to 91,700 foot lbs. useful work. The total amount of useful energy in the former case is,

$$0.75 \times 139{,}500 + 0.267 \times 130{,}900 = 139{,}600$$

ft. lbs.

in the latter case:

$$0.75 \times 139{,}500 + 0.65 \times 130{,}900 = 189{,}800$$

ft. lbs.

Thus the low pressure turbine enables us to increase the output 36 per cent. when using the same flow of steam and the same amount of coal in both cases.

At overloads, the efficiency of the steam engine is usually considerably lower than at full load, so that it is undesirable to operate them at such loads. With the combination of a low pressure turbine, however, it is not the least objectionable to so operate them, since the turbine has a very uniform efficiency over a wide range of loads.

Therefore, not only is the joint efficiency high, but the output can be greatly increased with only moderate increase in steam flow. It is possible to more than double the output with 50 per cent. increase in flow.

(To be continued)

FIRE-DAMP PROOF APPARATUS

By William Baum

In the years 1903, 1904 and 1905 a great number of experiments on fire-damp protection were undertaken in Germany, in which all the prominent electrical manuacturers took part. These experiments had an important final result, their immediate value for the miner and the electrical engineer consisting in the fact that electrical drives have been introduced in fire-damp mines. The experiments acquire an additional value from the fact that they have enlarged our views concerning the phenomena of pressure and current as they are manifested in the ignition of gases.

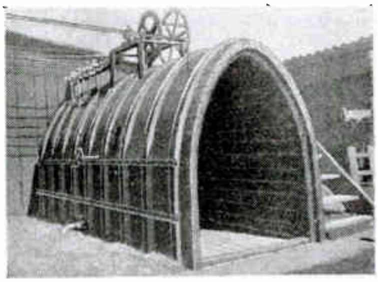


Fig. 1. Tank for Conducting Experiments with Fire-damp

Fire-damp is a mixture of air and mining gas, and enormous quantities of the latter gas (methan CH_4) are evolved in coal pits, due in all probability to a slow decomposition of coal. Some beds of coal are so saturated with gas that when they are cut it may be heard oozing from every pore of the rock, when the coal is called "singing coal;" and in other cases the gas escapes by what are termed "blowers," the mixture of gases frequently collecting in the old working or unventilated portions of the pit. Not infrequently fire-damp bursts forth in large quantities from the seams of coal, or from the strata of clay which divide them, and is the cause of terrible accidents.

Methan has a specific weight of 0.556 (air = 1), is readily inflammable, and burns with a slightly luminous flame, which in the upper part has a yellow and in the lower a blue color. Fire-damp with 5½ to 13½ per cent. methan must be considered dangerous; the highest explosion pressures and temperatures occuring if the gas contains 9½ per cent. methan. The lowest ignition point is given as 650 deg. C. It may be mentioned incidentally that for human beings, the inhalation of fire-damp is considered harmless.

A few remarks may be in place regarding the experimental laboratory and the manipulation of the experiments.

For reliable tests the substitution of other gases is not feasible, as fire-damp ignites in a manner peculiar to itself. The laboratory was so situated that methan could be received from a coal mine and the gases conducted to a storage tank. In order to obtain the temperature of a mine, steam heating was provided. Fig. 1 shows the experimental tank. The mixture with air took place by means of fans, the volume of the mixture being measured by a gas meter and the character of the gases determined by chemical analysis. For a rough determination a glass tube was filled with a sample which was ignited by an electric spark, a certain power of explosion being thus indicated.

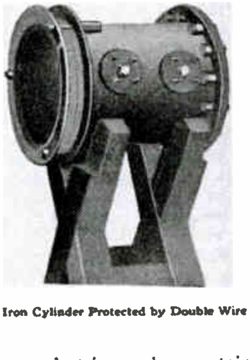


Fig. 2. Iron Cylinder Protected by Double Wire Gauze

The apparatus to be tested was placed inside the tank and the fire-damp ignited by an electric spark or a platinum spiral brought up to glowing heat by an electric current.

Fire-damp protection may be classified as follows:

(1) Net protection.
(2) Protection by means of solid cases.
(3) Opening protection.
(4) Protection by means of
  (a) Labyrinth.
  (b) Pipes.
  (c) Flanges.
  (d) Plates.
(5). Protection by submerging sparking parts in oil.
(6) Artificial ventilation.

(1) Net Protection.

The best known protection against fire-damp is the wire-basket of the safety lamp invented by Davy. The wire gauze is made of brass or steel wire of 0.0118 in. to 0.0138 in. dia. with 31 meshes per inch. The experiments showed that in selecting a certain wire net surface for a given unit volume of fire-damp the safety of protection was influenced by the location of the ignition point and the general character of the protected space.

Fig. 2 shows an iron cylinder which was sufficiently protected by a double wire gauze of 0.02 sq. inch per cu. in. fire-damp; *i.e.*, when an ignition took place in the center of the cylinder, the surrounding gases did not explode. With a single wire gauze, 0.025 sq. in. surface per cu. in. fire-damp was required. However, when the space in the cylinder was divided by a wooden disc with openings, as shown in the sketch (Fig. 3) and the ignition took place in the back part of the cylinder, the external gases were ignited. This process of igniting the surrounding gases, I shall term "puncture." In this case, two wire gauzes were provided having a distance between them of 0.78 in. and representing 0.125 sq. in. surface per cu. in. fire-damp. Reliable protection was secured with three nets.

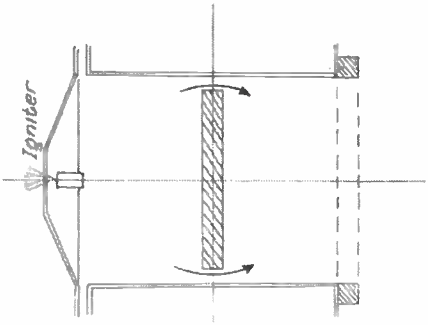


Fig. 3. Iron Cylinder of Fig. 2 Fitted with Wooden Partition

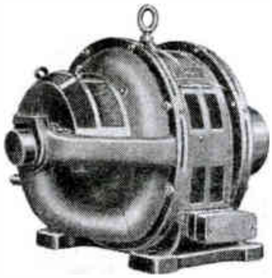


Fig. 4. 6 H.P. 500 Volt Slip Ring Induction Motor. This Motor Caused Ignition of Surrounding Gases, Owing to Large Openings Between the Feet and to Wire Gauze of too Large Mesh

These experiments showed that when the ignited fire-damp penetrated to confined spaces (as is the case with motors) the danger of puncture was increased. This is readily understood through the higher pressures which arise if the ignition takes place under these conditions. A wire gauze having a surface of 0.25 to 0.4 sq. in. per cu. in. fire-damp may be taken as a safe protection. In most cases, however, the phenomenon of "afterburning" was observed. After an ignition without puncture, fresh gases flew into the protected space and were ignited by the burning gases inside. This "afterburning," also known from the safety lamp, lasted often until all fire-damp in the experimental tank was consumed. It is seen, therefore, that electric apparatus with wire net protection would be destroyed by "afterburning."

Fig. 4 shows a 6 h.p., 500 volt slip-ring motor which punctured at once. There were large openings between the feet (Fig. 5) and the wire gauze was of too large mesh.

The collector of a 23 h.p., 500 volt direct current motor was protected by means of four double nets of 31 sq. in. surface enclosing 110 cu. in. fire-damp (0.282 sq. in. per cu. in.) and after an ignition inside the motor the surrounding gases exploded. This was also the case with a 6 h.p., 500 volt direct current series motor, "afterburning" occurring for a short period.

Poor results were experienced with a 30 h.p., 1000 r.p.m. induction motor with a short circuiting and brush lifting device, this motor puncturing, as the leads were not brought out tightly through the frame. After this trouble was remedied no puncture occurred, but "afterburning" took place, the solder melted, and the brush lifting device was destroyed.

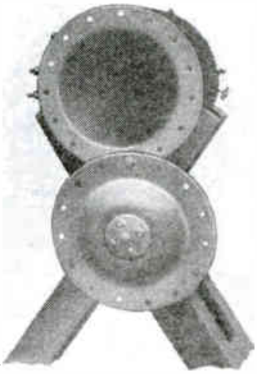


Fig. 5. Gas Tight Iron Cylinder for Determining Pressures Produced by Explosion of Different Mixtures of Methan and Air

(2) Protection by Means of Solid Cases.

Experiments have shown that totally enclosed motors "breathe" or absorb gases, especially if they are provided with doors or removable covers. Unless an enclosed motor has air-tight bearings, gases will pass into the interior of the machine. When put in operation, a motor "exhales," as the enclosed air heats up and expands. At standstill it "inhales," the enclosed air cooling down.

From the above it is seen that totally enclosed motors should be so designed that the frame and end shields will offer sufficient resistance to the explosion pressure should an ignition take place, since the interior of the motor will, in most cases, be filled with fire-damp.

In order to determine the explosion pressures, a gas-tight iron cylinder (Fig. 5) was filled with different grades of mixtures and ignited, the pressures being read by means of an indicator which registered on a rotating drum. Fig. 6 shows the pressures in atmospheres against per cent. fire-damp. How the burning process took place appears from the curves Figs. 7, 8 and 9, in which the explosion pressures are plotted against time in seconds. Quick combustion is characteristic of a medium mixture, slow combustion of poor and rich mixtures. The highest measured pressure was 6.5 atmosphere, and the highest calculated combustion temperature, 2000 deg. C.

Actual conditions in the depths of a mine are somewhat different from those that prevailed during the experiments, which were made on the ground with the gases under 1 atmosphere pressure. For example, at a depth of 2620 feet, the gases are under a pressure of 1.1 atmospheres, for which the explosion pressure would be 7 instead of 6.5 atmospheres. The designer should keep this point in mind.

In one experiment a casting enclosing the slip-rings of an induction motor was destroyed, although the dimensions were properly calculated to withstand the expected pressure. This led to the conclusion that higher pressures are likely to arise if the conditions are different from those of the original experiments.

As a matter of fact, if the ignition is allowed to pass from one space to another, the explosion pressures become dangerous. This was shown by the following experiment: With reference to Fig. 10, the iron cylinder was divided into the spaces A and B by means of a partition provided with an opening. At a certain distance from this opening the ignition was produced and a pressure of 1.7 atmosphere was observed at B before the gases had passed from A to B. When the ignition passed over to B, an enormous pressure arose in B and the partition was destroyed. The pressures in A and B then equalized.

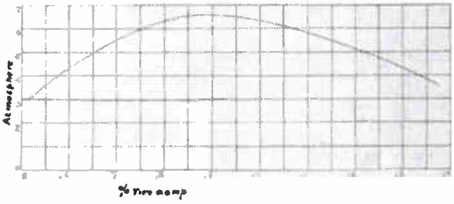
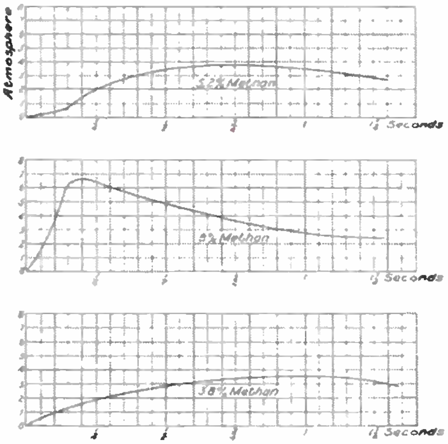


Fig. 6. Curve Obtained from Experiments with Iron Cylinder of Fig. 5

A considerable number of motors with enclosed frames failed in the tests on account of insufficient rigidity or because of large openings in the frame. In a 30 h.p. motor, the cast iron cover for the slip-rings was completely destroyed, owing to the fact that the shaft did not fit tightly to the bore of the bearing bracket. The clearance was then reduced to a minimum and a heavier cover and rubber gaskets provided. No puncture occurred this time, but the gaskets were pushed out sideways. Without the gasket puncture occurred, a considerable slit appeared, and the cover became deformed. In this case the gases had a second outlet through the oil chamber of the adjacent bearing.



Figs. 7, 8 and 9. Curves Showing Process of Burning of Different Mixtures of Coal Gas and Air in the Iron Cylinder of Fig. 5

The doors of a 7.5 h.p., 500 volt induction motor were torn off and puncture occurred, an inspection showing that there was a 1.2 in. opening at the bottom of the frame.

Enclosed controllers and fuse boxes have proven safe. Rough surfaces should be provided with gaskets. The fuses should be so designed that they will not burn with an external flame.

Notwithstanding the fact that the protection by means of solid cases has frequently failed, its application to small apparatus may be recommended; also, slip-rings or collectors may be safely protected by rigid covers. Attention is called to the danger which may arise if machined surfaces are used with gaskets, as these may be blown out by the explosion pressure.

(3) Opening Protection.

While with net protection the ignited fire-damp escapes under small pressures, high pressures arise with "opening protection." The surprising phenomenon that the high pressure fire-stream does not ignite the surrounding gases is explained by the considerable reduction of temperature corresponding to the degree of expansion. Furthermore, the gases assume an enormous velocity, which prevents ignition. This peculiarity is practically identical with that manifested when one passes the hand rapidly through a flame without getting burned.

The application of "opening protection" appears to be very limited, since it depends to a large degree upon the location of the ignition point and the character of the mixture. For instance, if the ignition takes place near the opening, the gases escape under small pressure and cause ignition. The experiments also showed that poor and rich mixtures are more dangerous than medium mixtures. This is due to the fact that poor and rich mixtures burn slower, as was shown in Figs. 7 and 8, and have more time to escape. They assume lower pressures and weaken the effect of expansion. Fig. 11, a and b, shows how, with a rich mixture

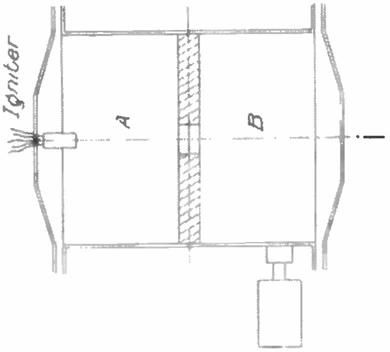


Fig. 10. Iron Cylinder of Fig. 5 Divided into Two Parts by Wooden Disc with Opening in Center

and the same location of the ignition point (in the back part of the cylinder), the pressure increases with decreasing cross-section of the opening. With the same mixture and opening, the pressure increases with the distance of the ignition point from the opening, as illustrated by Fig. 11, c.

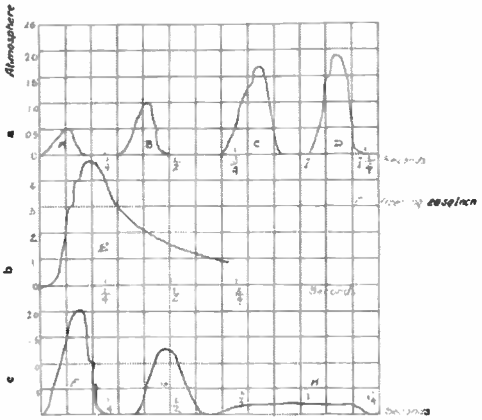


Fig. 11, a and b. Pressure Corresponding to Various Cross Sections of Openings for Rich Mixture and Same Position of the Ignition Point; c, Pressure Corresponding to Distance of Ignition Point from Opening for Same Mixture and Size of Opening

When the ignition was caused by a glowing platinum spiral instead of an electric spark, the cylinder "inhaled" fresh fire-damp from the outside (the ignition occurred without puncture) and these gases were ignited by the spiral. This process occurred several times until puncture finally resulted.

Fig. 12 shows the pressures for different cross-sections of openings and is of fundamental importance.

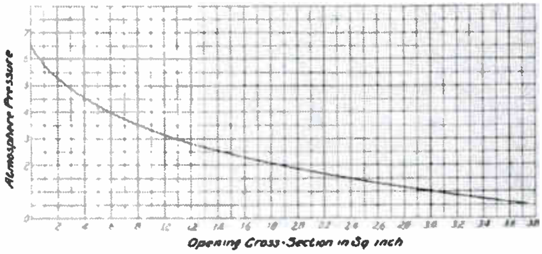


Fig. 12. Pressures Corresponding to Different Cross Sections of Opening

The small profit resulting from the experiments with "opening protection" is compensated for by the fact that they have given us an understanding of very important phenomena. It now appears that cracks, joints, openings, etc., in enclosed frames may not be dangerous in many cases, as the effect of expansion prevents ignition of the surrounding gases. It is important that these openings do not exceed a certain size. Referring back to the net protection, which is based on cooling effect and the breaking up of the escaping gases into fine currents, any opening greater than 0.0197 in. to 0.0295 in. will allow the escaping gas stream to remain hot and cause ignition.

The two important principles of fire-damp protection are based on the cooling and the expansion effect.

(4a) Labyrinth Protection.

In a labyrinth several openings are so arranged as to allow the gases to escape in zigzag. To obtain high pressure it is essential that the fire-damp be ignited in the rear. The labyrinth also offers a cooling effect, but has proven of little practical value.

(4b) Tube Protection.

The idea is obviously to conduct the escaping gases through pipes. Fig. 13 shows an iron cylinder with 12 tubes, each 0.515 in. inside diameter and 20 in. long. No puncture occurred with the ignition point in the center of the cylinder. When the tubes were arranged on both sides of the cylinder, the ignition of the surrounding gases occurred.

Wrought iron tubes of different inside diameters and lengths were filled with fire-damp, closed at one end and ignited at the other. Puncture took place with a tube of 1 in. inside diameter and 73 in. length; no puncture occurring with a 0.51 in. diameter tube of the same length. It seems that good protection would be obtained with tubes of smaller diameters.

(4c) Flange Protection.

The cylinder was provided with a flange in such a manner that a clearance remained between the two bodies. With an opening of 0.094 in. puncture could frequently be prevented. Flange protection is a modification of the "opening protection," with an additional cooling effect. It has not found practical application.

(4d) Plate Protection.

With reference to Fig. 14, thin discs are arranged above each other in such a manner as to allow the escaping gases to pass through parallel ring-slits, in which the fire-damp is broken up into small streams and efficiently cooled. When the distance between plates was 0.0196 in. and the thickness of the plates 0.0196 in. (½ mm.), the experiments were most gratifying. Tests were made with a large and a small percentage of mixture, the point of ignition being placed near and at a distance from the plates, and in no case did puncture occur.

When the clearance between the plates was enlarged from 0.0196 in. to 0.039 in., puncture occurred in several cases. This would indicate that a clearance of 0.0196 in. should not be exceeded. The rings should be 0.0196 in. thick, and the width of the path of passage 1.96 in.

"Plate protection" with a large number of slits represents a large cross-section and acts in a manner similar to the net protection; *i.e.*, the fire-damp is broken up into small streams and abundant cooling is secured. In this case the degree of protection increases with the number of slits. With a small number of plates, the principle of protection is similar to that of the "opening protection," which is based on the expansion effect. Here the safety of protection increases with a reduction of plates.

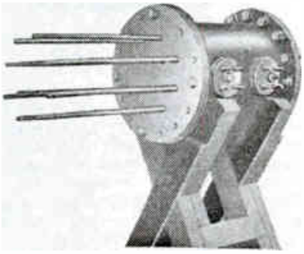


Fig. 13. Iron Cylinder Fitted with Twelve Tubes 0.515 Inside Diameter, 20 Inches Long

The interesting curve of Fig. 15 illustrates the "degree of safety," or the distance from the puncture limit depending on the number of slits.

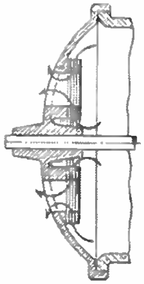


Fig. 14. Protection by Means of Thin Discs or Plates

A combination of plate and net protection proved to be absolutely safe. Afterburning was rarely observed and always ceased in a short time.

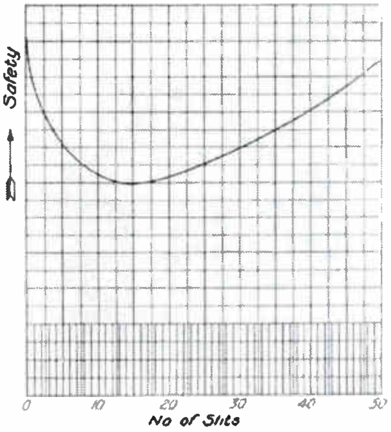


Fig. 15. Degree of Safety Secured by Plate Protection Depending Upon Number of Plates

Fig. 16 shows the design for a 30 h.p., 500 volt enclosed motor with plate protection, the discs of which have an outside diameter of 30 in. and correspond in every respect to those of Fig. 14. The armature has fans for self ventilation, and as an open motor the frame is good for 35 h.p. The motor was tested with poor, medium and rich mixtures when in operation at normal load, overload, and standstill, both when hot and when cold, and in no case did puncture occur.

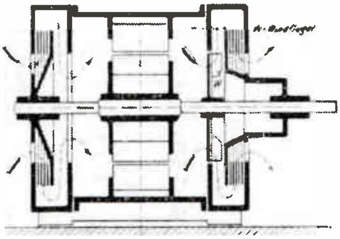


Fig. 16. Design for 30 H.P. 500 Volt Motor with Plate Protection

Another 30 h.p. motor with plates of proper dimensions gave interesting results. In this case the motor failed. Instead of using distance pieces between the discs, the plates had grooves 0.0106 in. in depth which on the other side appeared as ribs. Where these grooves occurred, the total distance between plates was 0.0302 in.

One of the later designs of plate protection is shown in Fig. 17. The motor is good for 15 h.p. One part of the plates is arranged in a cast iron frame at the top of the motor, the other plates being located within the two end shields. The motor is provided with fans and the air enters through the end shield slits, strikes along punchings and windings, and is blown out through the top slits, the action corresponding to that of a chimney. By this arrangement the output of the motor is reduced to 75 per cent. of that of an open motor with the same mechanical dimensions. The frames containing the plates can be taken out conveniently and cleaned from coal dust, etc.

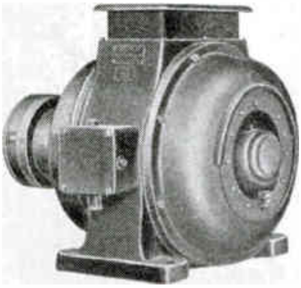


Fig. 17. 15 H.P. Induction Motor with Plate Protection

A 50 h.p., 1000 volt induction motor with this protection has been successfully tested by Belgium mine authorities.

Plate protection, of course, does not embody the only solution of the problem. Principally, any efficient protection will always be based on the cooling and expansion effect.

(5) Protection by Submerging Sparking Parts in Oil.

Fig. 18 shows a 10 h.p., 500 volt induction motor, the slip-rings of which operate in oil covering the brushes. The motor ran safely with long overloads, frequent starting, and reduced number of brushes. Artificial sparks were produced without giving any trouble. Whether the motor operated satisfactorily under actual working conditions is not known. The General Electric Company has built an induction motor with slip-rings under oil and, as far as is known to the writer, it has given no trouble. Attention is called to the danger which may arise if the brushes are not covered by the oil; in several experiments this was the cause of explosion, as the oil could not suppress the sparks.

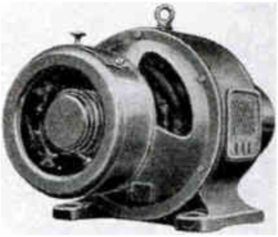


Fig. 18. 10 H.P. 500 Volt Slip Ring Induction Motor, the Rings of which Operate in Oil

Oil switches may be considered fire-damp proof if the oil completely covers the contacts. Resistance grids are often protected by a double net.

(6) Artificial Ventilation.

Where fresh air is available in mines, the installation of even the largest types of totally enclosed motors does not offer difficulties. The frame must be provided with gas-tight openings for the pipes which supply the fresh air in such quantities as to keep the motor cool. This artificial ventilation has the advantage of reducing the weight of the frame to a minimum, practically allowing the same dimensions which would be required for an open frame.

In concluding this article the writer wishes to emphasize the statement that it is not possible to say with certainty that plate protection is the best safeguard that it is possible to devise; it is, however, the best at present known. The intention of the article is to show the direction along which the design of fire-damp proof apparatus should be taken up.

Incidentally, it may be mentioned that the experimenters and designers have not taken out patents covering the various schemes.

The available literature has been freely used, especially the *Elektrotechnische Leitschrift* and the *Zeitschrift des Vereins Deutscher Ingenieure.*

COMMERCIAL ELECTRICAL TESTING

Part XI

By E. F. Collins

TRANSFORMERS

Special Tests

The following order of tests on transformers has been found to be most convenient:—Cold resistance; polarity; ratio and checking of taps; impedance; core loss and exciting current; parallel run; insulation tests; double potential for one minute; one and one-half potential for five minutes; and high potential test.

Transformers built for potentials above 50,000 volts should have the double potential test taken after the high potential test.

Since many of the tests on the different types are almost identical, a complete discussion on the air blast type will first be given, and then shorter discussions on the others.

Single-Phase Air Blast, Type AB Transformers

The transformer should be properly placed over the pit and the supporting boards must be sufficiently strong, otherwise the transformer may fall into the pit and injure anyone who may be stationed under it. No opening should be left through which air can escape and influence the reading of the thermometer on the transformer iron. When the transformer is in place, a careful inspection should be made, making note of any defect, no matter how slight, and if found, it should be repaired immediately.

The order of tests may be varied if found necessary; *i.e.*, if a resistance measuring set is not available, then ratio and taps may be taken; or, if the core loss alternator is in use, some other test should be made to prevent loss of time. Usually two or more transformers of the same rating are tested at once. In the following discussion, two or three transformers are considered.

Cold Resistance

As the temperature guarantee of the windings specifies that the increase-in-resistance method be used, considerable care must be taken in measuring resistances. This measurement is usually made as follows:—Place a thermometer on the coils of each transformer and send from 10 to 15 per cent. full load current through the transformer coils; this being generally the proper amount for two or four transformers. The ammeter should not read below the center of the scale, nor should the current be sufficient to appreciably heat the windings while taking resistance. For very low voltage secondary windings, use about 40 amperes, as this current usually gives sufficient drop to be read on the voltmeter. The drop lines must not include the resistance of any temporary connections. Adjust the resistance in the box until the reading comes to about the middle of the scale of the voltmeter. Considerable time will be saved by short circuiting the secondary while the primary is being measured, and by short circuiting the primary while the secondary is being measured. In measuring secondary resistances, especially when low, the contacts for the voltmeter leads should be carefully cleaned with sandpaper.

Take three readings on each coil, holding about the same current. It is far better to allow the ammeter to vary slightly, than to try to hold exactly the same reading, as the observer is likely to be prejudiced. In entering readings, always record the constants of the meters, the voltmeter resistance, the resistance of the drop lines, the resistance in the box and the temperatures of the coils. If the transformers have more than one primary and one secondary coil, a clear sketch should be made and the coils so marked as to prevent confusion. In recording results, the value of the unit deflection should be noted and readings pointed off accordingly. Readings should be taken as rapidly as is consistent with accuracy. The method of calculating rise in temperature by increase of resistance is explained under heat runs.

Polarity

The polarity test is taken, since it affords the only means of readily determining the connections required for transformers in banks; for instance, several transformers in parallel. When transformers are connected for measurement of resistance, the polarity test can readily be made with a special voltmeter. Select one transformer as a standard; when several are in test at once, one near the middle of the group should be chosen as it will be safer and more convenient when the transformers are run in parallel. With direct current flowing through one winding of the transformer, connect the special voltmeter across the terminals so as to get a positive deflection; then transfer the drop lines to the corresponding terminals of the other winding and break the current in the first winding. If the polarity is correct, a positive kick will be obtained. When making this test, have sufficient resistance in series with the voltmeter to protect it from damage.

It is not necessary to take polarity on more than one transformer of a group, as the parallel run will show whether or not they all have the same polarity. In taking polarity on special transformers, a clear sketch should be made showing the polarity. For tap polarity, see headings "ratio" and "checking taps."

Ratio

The ratio of a transformer is the ratio of primary voltage to secondary voltage, and should be equal to the ratio of primary turns to secondary turns. The usual method of determining this value is to apply about one hundred volts to the secondary winding and read the primary voltage, stepping it down with a suitable potential transformer. The ratio of the potential transformer should be as nearly that of the transformer in test as possible. The potential transformer must be operated at normal frequency and voltage, otherwise the ratio will be unsatisfactory. In very small transformers, the voltage should be applied to the primary windings.

When the ratio of the potential transformer is very nearly that of the transformer in test, the voltmeters should be interchanged after five readings have been taken. When this is done it is not necessary to correct voltmeter readings from curves, as the meter errors will appear in both columns and be eliminated. In determining any ratio at least five readings should be taken, and the result carefully calculated. If the ratio by test varies more than *one* per cent. from the rated ratio of voltage, check the ratio of turns; if the ratios of voltage and turns agree, repeat the ratio with the same meters; and if still out, repeat with an entirely different set of meters and potential transformer. If the ratio is still out, the transformer is wrong. Try the ratio of another transformer. If, however, the ratio should be correct when the second set of meters is used, a third set should be used and the ratio checked again. If the second and third sets of meters give a correct ratio, record both sets of readings.

In taking ratio on transformers with taps or dial switch, note whether or not full windings are used. If the transformer has more than one primary or secondary coil, note whether the coils are in series or multiple. The ratio must check within one per cent. of the ratio of turns. It is not necessary to take ratio on more than one transformer of a group, as the parallel run will determine whether they all have the same ratio.

Checking Taps

Nearly all transformers are provided with taps in one or both windings, so that a slight change in ratio or a low voltage for starting may be obtained. Before checking taps, procure the proper winding specification and sketch. Taps are easily checked by applying a certain voltage per turn to the low tension winding and reading the voltage between the terminals of the winding and the first tap; then between successive taps on the same coil. In some cases it is equally satisfactory to apply full potential to one winding and read the voltage between adjacent taps. This is done on dial switch transformers.

The method can best be explained by an example. Take an AB-25-400-6300/6195/6048/5985/5835/5600-170. The primary winding has six coils connected in series, of 43 turns each, with inside and outside ends.

This is called a single section coil. The secondary winding consists of six coils connected in multiple of 7 turns each. Taps are brought out of the primary coils P–1 and P–6 at the ending of the 29th, 34th, 38th and 41st turns from the inside end. This gives tap turns of 43 − 41 = 2, 41 − 38 = 3, 38 − 37 = 1, 37 − 34 = 3, 34 − 29 = 5 turns. Since the secondary winding has four coil terminal blocks, these coils can be connected in series, giving 14 turns. Applying 5 volts per turn = 70 volts to the secondary (Fig. 44), we read volts across terminals (1–2) = 10, (2–3) = 15, (3–4) = 5, (4–5) = 15, (5–6) = 25. The same readings will be obtained on the other end of the primary winding. These readings must be checked with the voltages required by the sketch. The volts per turn at normal potential $= \frac{170}{7} = 24.2$ volts. In changing from (1–7) to (2–8), four turns are cut out of the primary winding, and the primary voltage is decreased by 6300 − 6195 = 105 volts. Multiplying 24.2 by 4, 96.8 is obtained, which is as near 105 as possible, unless a tap be brought out at a half turn, which is seldom done.

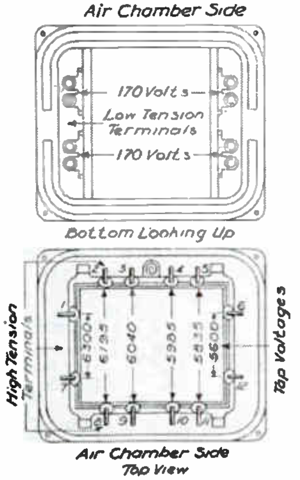


Fig. 44. Taps

Changing to (3–9), six turns are cut out and the primary voltage is decreased by 6195 − 6040 = 155 volts. Now 6×24.2 = 149.2, which is near enough to 155. The remainder of the taps should be checked in the same manner.

Great care should be taken in handling the voltmeter connected to the taps, for while the voltmeter reading is low, the circuit to which it is connected may be several thousand volts above ground. If the opposite end of the circuit be grounded, a severe shock may be obtained from the meter.

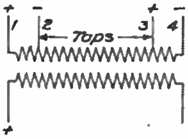


Fig. 45. Taps

In checking 50 per cent. taps, one meter should be used as a check and another to read the voltage across each half of the winding, the readings being taken first on one side and then on the other, holding the same reading on the check meter. A neat sketch showing the position of the taps should always be made. On transformers with only one tap on each end, it is often necessary to check its location by polarity. (See Fig. 45.) This is done as follows: with direct current flowing through the secondary, take polarity of (1–4), (1–2) and (3–4); if all the deflections are in the same direction, the taps are properly brought out; if some are reversed, the tap and line lead are interchanged.

Impedance

The expression $C = \frac{E}{R}$ for continuous current circuits is replaced in alternating current circuits by the equivalent expression $C = \frac{E}{\sqrt{R^2 + (2\pi f L)^2}}$, where C is the current, E the impressed e.m.f., f the frequency, L the coefficient of self-induction, and R the ohmic resistance. The expression $\sqrt{R^2 + (2\pi f L)^2}$ is known as the impedance of the circuit and is defined as the apparent resistance of a circuit containing ohmic resistance and self-induction. The term $2\pi f L$ is called the reactance of the circuit.

The impedance of a transformer is measured by short circuiting one of the windings and impressing an alternating e.m.f. on the other winding, taking simultaneous readings of amperes, volts, watts and frequency. The impedance of transformers should be carefully measured for the following reasons: Transformers operating in multiple divide the load inversely as their impedance voltage; *i.e.*, the transformer having the higher impedance will take the smaller part of the load and *vice versa*. When transformers of different types are operated in multiple, the impedance of one transformer must sometimes be increased by putting a reactive coil in the secondary circuit and adjusting until the desired impedance is obtained.

Impedance tests show whether a given arrangement of coils is satisfactory or not. If the arrangement is not satisfactory, excessive magnetic leakage will take place and a high impedance voltage result. The impedance watts will also be high, due to excessive eddy currents in the copper. Since regulation depends upon impedance to a great extent, a low impedance is very necessary for close regulation.

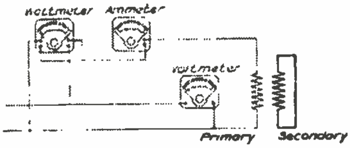


Fig. 46. Connections for Impedance Test

The impedance voltage of transformers usually varies from 1 to 4 per cent., although it may be as high as 6 to 7 per cent. The impedance watts usually do not exceed 1 to 1½ per cent. of the total capacity of the transformer and will be more than the calculated C^2R on account of eddy current losses in the copper. In transformers wound with large conductors the impedance watts will differ from the calculated C^2R of a transformer wound with small wire.

The following method should be followed in making an impedance test: Place a thermometer on the coils to obtain the temperatures; make a good short circuit on one winding, using as short a cable as possible and one of ample cross section, so that no appreciable losses will occur. Calculate the full load current by dividing the watts capacity by the maximum voltage of the winding in which the meters are placed, unless the engineering notices call for tests under different conditions. Select suitable meters and make connections as shown in Fig. 46, wiring to the alternator through a suitable transformer. The alternator must be operated at as near normal voltage as possible when the normal impedance reading is taken.

Take ten readings, starting at 50 per cent. and raising to 125 per cent. full load. Hold the speed constant and take simultaneous readings of amperes, volts and watts. It is essential that the speed be exactly right, since the reactance varies directly with the frequency. This curve should be plotted after the readings are taken (not as they are taken) to see if the curve is smooth; if the curve is not smooth, check it at once. Plot volts as ordinates and watts and amperes as abscissæ. The volt-ampere curve should be a straight line; the volt-watt curve should be a parabola. (Fig. 47). In taking the readings, results will be more satisfactory if meters are selected so that no change in them is necessary throughout the curve. On the record sheet, note the temperature of transformer coils and constants of all meters used. If a potential transformer is used, record its number and ratio. Also, state plainly the hour at which the test is taken.

The connections shown in Fig. 46 are used in preference to those in which the losses of the voltmeter and of the potential coil of the wattmeter are included in the reading of the wattmeter. In Fig. 46 the only extra loss is that in the current coils of the ammeter and wattmeter, and this is negligible.

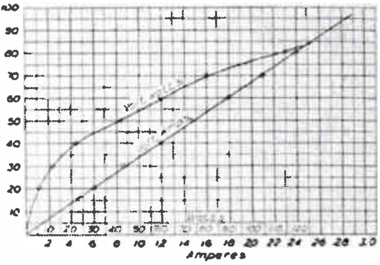


Fig. 47. Impedance Curve

A potential transformer or multiplier should be use with a wattmeter when the voltage exceeds 150 volts. It will be noted that the lower binding posts on Thomson wattmeters must be connected together when neither a potential nor a current transformer is used; and when the voltage of the circuit is above 2000 volts, they should be connected by a small fuse wire. The secondary of the potential transformer should not be grounded, however, unless a current transformer is used. The adjacent ends of the current and potential coils are connected to these binding posts and, unless they are connected to the same side of the line, there is danger of breaking down the insulation between the coils and burning out the wattmeter. Above 2000 volts the fuse wire is used to avoid electrostatic effects.

(To be Continued)

APPLIANCES FOR ELECTRICAL MEASUREMENTS

PART II

By C. D. Haskins
MANAGER LIGHTING DEPARTMENT, GENERAL ELECTRIC COMPANY

Portable Instruments

It seems superfluous to deal at any considerable length with portable instruments. They involve all of the primary characteristics of the switchboard instrument, combined in such physical form as to permit of portability without damage.

For direct current purposes the preferred instruments today are of the permanent magnet type, and are generally constructed on the D'Arsonval principle, with spring restraining forces and Foucault current damping. They are commonly non-astatic, and for this reason care must be exercised in their use to insure freedom from stray fields. Where any doubt exists as to this it is well to take reverse readings, by moving the instrument through 180 degrees and repeating the observation; if there is a difference between the two observations the mean is used as the true value.

The manufacturer usually strives to provide a somewhat higher degree of precision in the better class of portable instruments than in switchboard instruments.

To insure long continued good service it is essential that portable instruments be so constructed as to have a very light moving element and thus obviate the likelihood of damage to the bearings or pivots in transportation and use.

The voltmeter and the ammeter are the only two direct current portable instruments commonly used. Ohmmeters are manufactured and used to some extent, but are far less common than the portable Wheatstone bridge, within which, in fact, the former instrument is embodied, and can be cut in or out by a key button. It is not unusual to find voltmeters which are also so constructed as to permit of cutting out the resistance for the purpose of using the instrument for the measurement of very small current values, in which case the instrument becomes a milli-amperemeter.

Portable ammeters in capacities up to about 30 amperes generally have a self contained shunt; above this size they are generally accompanied by separate portable shunts, several shunts frequently being provided for use with a single instrument.

In the alternating current field portable instruments closely parallel the more important switchboard instruments, and their mechanisms are essentially the same, modified only as the conditions of use demand.

In most modern structures the portable alternating current voltmeter or ammeter or indicating wattmeter may be used also upon direct current, but subject to certain errors.

Many of the portable ammeters and voltmeters are provided with a moving iron vane armature, which, when the instrument is used on direct current, becomes polarized, and consequently introduces hysterisis errors, due to residual magnetism, so that the instrument when used on direct current will not give the same values at the points going up across and coming down the scale, a phenomena which disappears when these structures are used on alternating current. (This statement is not literally, though practically, correct, there being certain trifling variations at different frequencies.)

Moving coil instruments of the portable alternating current class may also be utilized on occasion for purposes of direct current measurement. Being so constructed as to be devoid of a dense magnetic field, they are more susceptible to deviation due to stray field or earth's field than instruments of the direct current D'Arsonval type.

Portable alternating current voltmeters are often and portable indicating wattmeters substantially always of the moving coil type, and practically all portable indicating wattmeters as commonly used in the art are primarily and essentially of the type preferred for alternating current; they are sensitive to stray fields, and are to be safeguarded in observation accordingly when used, as they often must be, on direct current.

Portable instruments have been particularly subject to specialization of construction for various purposes.

No better example of such specialization is to be found than that of the recently introduced watt indicator for lamp consumption measurements, an instrument which is so constructed as to screw into a lamp socket at one end whilst the lamp itself is screwed into a socket in the instrument, thus making it possible to get quick lamp values.

For the purpose of those who desire to make a further study of the physical principles which have been resorted to in devising indicating instruments, an appendix has been added to this lecture, classifying the structures into physical groups and summarizing their essential characteristics. For our immediate purpose we may run over these principles in the briefest possible way at this point.

Recording Instruments and Integrating Meters

It is well to say at this point that early practice seems to have been definitely formative in determining the nomenclature of the art in connection with the various classes of mechanisms used in applied electricity.

The terms which are current, and so well established that perhaps they must always remain permanent, are not always techincally correct; but they are established, and it is probably well to recognize them and use them.

Measuring devices which have a needle moving over a scale giving a fixed indication at a fixed value are classed broadly as "instruments." Structures which draw a line upon moving paper, showing the fluctuations in values of magnitude and of time, are known as "graphic recording meters" or "curve drawing instruments;" whilst those devices to which I have referred up to this point as "integrating meters," and which give electrical units × time are known broadly as "meters," or "recording meters," this latter being a misnomer now established and to be recognized by reason of usage.

Graphic recording instruments are useful in many connections since they provide a fixed physical record over a considerable period of all the fluctuations upon the system to which they are attached.

A paper ribbon or disk is moved at a fixed rate of speed, bringing a certain portion of the accurately divided paper under the needle at each hour of the day.

The needle in such instruments is armed with a pen or with other means for permanently marking the paper, and the result is a crooked line which may be read against the scale marked upon the paper itself; thus the "load" at any hour of the day or night is a matter of record.

Coming almost within the class of graphic recording instruments is the oscillograph, an instrument by which current fluctuations of minute value and of excessively brief period, are recorded on a rapidly moving sensitized ribbon, sheet or plate by means of refracted light

In the modern oscillograph records of current fluctuations in a telephone circuit are easily obtained, and movement periods as low as one-twentieth of a second are readily recordable in large amplitude.

Thus an oscillograph excited in a telephone circuit makes upon the moving film a linear record of a word, dependent upon the volume of vibration and consequent current fluctuation in the circuit, which is readily recognizable. It seems entirely feasible, and indeed probable, that at some early day actual language can thus be reduced to a linear equivalent which the trained eye may be capable of reading. I have myself in a very brief time become able to read numerous words thus inscribed by the current fluctuation incident to the brief vibration with little or no difficulty. In short, the eye may thus be trained to read the sound wave, and, whilst radically different voices may speak the same word and transmit it with varying vibrations through the same circuit, the characteristic form of vibration remains. The amplitude may vary with the tone and the wave period may vary with the rapidity of enunciation, but the characteristic shape remains readily recognizable.

It will be seen that where it is advisable to have a record day by day, or month by month, of the voltage of the system at a given point, recording instruments are almost invaluable; they are, for example, frequently used to determine the voltage fluctuations at the ends of feeders, etc.

Graphic recording ammeters are useful in determining the load characteristics at given points. It may be important, for example, to determine whether at some time during the day the energy delivered at a given portion of the circuit is extremely high in relation to the average, and if so at what time this occurs.

When alternating current service is involved a wattmeter of the curve drawing type is even more valuable and important.

For purposes of general rough measurement, structures involving the use of the paper disk for record are common and generally satisfactory; but where greater precision is required, and especially when it may at times be desirable to integrate the result of a day's performance by means of the planometer, the unidirectional paper ribbon is to be preferred since obviously the use of the planometer is not possible on a paper disk on which the lower values of the scale are moving at a lower rate of speed than the highest values.

It seems necessary to devote but few words to the consideration of integrating meters, or, as they are known in the art, "recording meters." The purpose of the recording meter is naturally to record the power-time units delivered to a given point of consumption, generally to determine the charge basis, as in the case of the gas meter. Such structures are of course used for other purposes also, notably upon switchboards for the determination of the gross output from generators or over feeders. In the latter connection the record of such meters is frequently used for checking the efficiency of the generators against pounds of coal consumed, or the losses of the distribution system by checking against the sum of the consumers' meters.

In the early days of the art substantially all recording meters were ampere hour meters, and they were constructed in almost numberless physical forms.

During the days of the ampere hour meter (they are still in use in some parts of Europe), electrolytic meters of various types were exceedingly common, as, for example, the so-called Edison meter, which depended for its record of ampere hours used upon the electro-deposition of metal from one plate to another, the increase in the weight of one plate, or the decrease in the weight of the other being the measure of the number of ampere hours passed.

Clocks were used whose speed was varied by the amount of current passing, a differential gearing giving the record.

In alternating current primitive split-phase induction motors were resorted to, utilizing such a form of construction as to result in speed varying directly with the current, the propelling mechanism being retarded by an air vane load.

Such hundreds of mechanisms might be described thus briefly as having been in some measure current in some period in the art during the past twenty-five years.

The ampere hour as the unit of measurement could not endure and will probably never be introduced for general purposes, because the true measurement of output—that is, the value that measures the input into the plant—is power, horse powers or fractions of horse powers, and obviously, the ampere hour was not a measure of this, except when delivered at a fixed voltage. Even in direct current the voltage is literally never constant, and when alternating current became, as it has become, practically universal, the question of power factor rendered resort to the "watthour" as the value unit quite unavoidable.

The established recording meters of 1910 are substantially without exception, recording watthour meters, and are, as the result of economic evolution, practically all constructed on the electro-dynamic principle. It is probable that there are in use in the United States today not less than two and a half million recording electricity meters of the electro-dynamic type, commonly referred to as "motor meters."

For direct current such meters generally have a wound field and a wound armature, the armature being in series with a high resistance and responding to fluctuations of potential, the fields being fixed and generally in direct series with the load and consequently responding to fluctuations of current.

The torque of such a meter is obviously dependent upon the product of the concurrent volts and amperes, or the true watts on the system.

The torque of such a mechanism is directly proportional to the watts imposed upon it, and therefore the restraining force must constitute a load increasing directly with the speed.

Good modern practice has demonstrated, by a process of engineering elimination, that in such structures, i.e., motor type meters for use on direct current, the speed through the range within which accuracy is to be expected should not be less than one and one-half or more than thirty revolutions per minute.

It is good practice to prescribe that recording meters for general use shall have no error in excess of five per cent. at any load between five per cent. and one hundred and twenty-five per cent. of the meters normal rating. The full load torque of such meters should be guaranteed to be not less than one hundred and fifty grammes, millimeters.

Since the moving elements of such structures rotate upon step bearings, and since the weight of these moving elements ranges from one hundred to three hundred grammes, it is obvious that the nature of the fixed bearings and the material from which these are made, plays an important part in the permanent good behavior of these devices.

At the present time but two good materials are known for this purpose, and it is usual to specify that the bearing jewel shall be either of sapphire or diamond.

It is interesting to note at this point and in this connection, that the contact area of the rotor of such motor meters is so inconsiderable that the actual pressure upon the step bearing is about two hundred tons per square inch. A noteworthy fact in view of the delicate nature of the machine.

Meters of this type may be readily calibrated by moving the damping magnets radially in relation to the damping disk, and calibration through a range of 10 per cent. can generally be thus accomplished.

In testing it is usual to connect a load to the meter in series with an ammeter, and place a voltmeter in multiple upon the system.

The volts multiplied by the amperes then give the true watts; by using the simple formula:

$$S = \frac{watts}{3600 \times constant}$$

the speed at which the disk should revolve in revolutions per second is obtained. The speed of the disk should now be obtained with a stop watch, and such corrections made as may be required.

It will be noted that a constant is introduced in this formula; it is so introduced because a very large number of the meters in common use utilize a dial constant. The constant is used for the purpose of keeping the speed range of the structure within the theoretical limits indicated by good mechanical practice. In some cases the constant is eliminated at the dial, this elimination being dependent upon the gear ratio. In other cases it is not so eliminated, and in such cases it is necessary to multiply the reading of the dial by the constant. In all cases the constant of the meter will be found marked upon some portion of the structure.

Alternate current meters differ radically in mechanical features from the direct current meters, but in essentially no electrical details.

The motor mechanism consists essentially of a split phase motor, having current and potential coils, both fixed, however. The actual rotor or armature consisting of a disk in which Foucault currents are induced, dependent upon the inductive coercion of the coils, responding to true watts.

The restraining mechanism, as in direct current watt hour meters, is a Foucault current disk or cup, and for mechanical convenience the motor armature and restraining armature are usually one, thus securing a lighter moving mechanism.

The weight of the moving element in alternating current meters being materially less than in direct current meters, it is unnecessary to provide so considerable a torque, and it is considered good modern practice to specify full load torque of 75 grammes milli-meters for single-phase, and 150 grammes milli-meters for polyphase inductive type alternating current meters.

The method of testing alternating current meters is essentially the same as for direct current meters, save that it is customary to use a portable indicating wattmeter instead of the voltmeter and ammeter; or in connection with either direct current or alternating current meters, a portable calibrated load, with a voltmeter, may frequently be resorted to as a convenient expedient.

It seems scarcely necessary to say that both direct and alternating current meters are used today in a very great number of modified forms, according to their application.

In the case of switchboard meters, especially where very large values have to be measured, alternating current meters are usually used with current coils in the secondary of current transformers, and potential coils in the secondary of potential transformers; frequently the transformers are the same as those used in exciting the switchboard instruments.

Direct current meters for the measurement of large values are almost without exception designed to be connected directly in series with the circuit to be measured; this fact, by reason of the large masses of copper involved, seriously modifies the physical design of the structure, but in no case is the inherent principle involved affected.

Sustained, rather than initial accuracy differentiates the good from the bad recording meter, and it is therefore peculiarly necessary in connection with recording meters to prescribe accurately the qualities which the meter shall embody, since no initial test can be relied upon to determine what the behavior of the structure will be at a relatively early subsequent time.

No other branch of the electrical art seems to have developed along two parallel lines more clearly divided than the instruments and meter art.

In all of this group of machines the moving forces are at best very small, the work done minute, and therefore friction, (a constant variable,) is the real enemy of accuracy. This is true of indicating instruments, but most noticeably true of recording meters.

One school of engineering has developed along the line of the creation of structures of the greatest refinement, in relation to the minimizing of friction and the reduction of weight of the moving parts. This school obviously drifted towards continually greater structural refinements of finish, and speedily brought itself into the field of mechanisms involving the jeweler's and the mathematical instrument maker's skill.

The other school, and the essentially American school, whilst it gave due importance to the minimizing of weight and initial friction, gave paramount importance to the securing of high torque, and *high load*. Its purpose can best be stated by a physical example. If the coercive mechanism of the meter be constructed to do, at a given point of its load, one thousand units of work, and if the restraining mechanism or load be accordingly made to dissipate (consistent with the same law) nine hundred and ninety units, the remaining ten units of work being expended in overcoming friction in the initial condition, then a doubling of the friction affects the total load but one per cent., and introduces but that error into the instrument.

Such a structure is therefore obviously better than one in which the work at the same load as above is one hundred units, (limited by the effort to secure light moving weight) the work done being distributed in the ratio of ninety-five units in the restraining element (load) and five units for initial friction. In such a structure the initial friction is but half that of the more rugged mechanism, but the doubling of this friction in service results in the introduction of a five per cent. increase in the load and a corresponding deviation from accuracy.

These two examples may be said to exemplify the character of the two schools under which development has taken place in the electrical measuring device industry, and it is unnecessary to say that the school which provides the robust, well constructed, high energy machine has prevailed over that which demands ultra-refinement of construction and of care.

Appendix.

1. Modifications of the marir r's compass, on simple galvanometers, consisting of a polarized movable element under the influence of a coil or coils, carrying the current to be measured. This is the earliest group.

2. Solenoids.—Dependent upon the pull of a coil or coils on an iron plug or armature acting against gravity, a spring or other restraining force.

3. Magnetic repulsion instruments having iron, consisting of a movable and a fixed piece of soft iron, both situated in the same field, consisting of a coil or coils carrying the current to be measured. Both pieces of iron being polarized in the same direction tend to repel each other, this force acting, as in all of the instruments of the mechanical group, against some restraining force.

4. Magnetic vane instruments.—Consisting of a vane or armature of soft iron, constituting the moving element, and placed within the influence of a coil or coils carrying the current to be measured. The normal position of the magnetic vane at no load is across the magnetic path created by the current in the coil or coils, the tendency being for the vane to place itself parallel with or in some cases to surround the field created by the passage of current through the coil.

5. A fixed and a movable coil or coils. sometimes with, but generally without iron—a development of the Siemens dynamometer. The movable coil tends to place itself either at right angles to, or in the same plane with the fixed coil, depending upon the relative direction of current in the two coils. This principle may obviously be modified to provide for one fixed coil repelling and another fixed coil attracting a movable coil.

6. A movable coil or conductor, with or without iron, situated in the field of a magnet, the movable coil tending to take a position at right angles to or parallel with the flux of the permanent magnet, depending upon the direction of current in the moving coil—a development of the D'Arsonval galvanometer.

7. A movable coil or conductor, commonly with a small number of turns and frequently consisting of a disk or sector instead of a coil, constituting a short circuited secondary in the field of a coil or coils carrying the current to be measured. This device is operative on alternating current only. The movable short circuited coil or sector tends to move in relation to the fixed coil or field, exerting force in opposition to the restraining force of a spring or gravity.

These classes, Groups 1 to 7, inclusive, constitute what might be termed the dynamic group.

It will be noted that of these four groups, 1 to 4, consist of instruments having a moving element carrying no current, and are therefore free from conductors. Groups 5, 6 and 7 have moving wire carrying current, necessitating the introduction of flexible conductors or collectors.

We now come to a series of somewhat indefinite groups, which may be broadly classed as temperature instruments, in which the position of the needle or indicator is governed by a change in temperature; in short, thermometers applied to electrical measurement by resorting to structures, the temperature of governing parts of which will vary with the current to be measured. There are in this general class the following groups, which unfortunately are less well defined than the genera of the dynamic group.

8. A thermometer surrounded by a conductor whose temperature varies with the current, the scale of the thermometer being graduated to indicate the current causing any given temperature. Such instruments, in common with most of this class, are dependent upon a fixed room temperature, unless a correcting constant or means for mechanical correction be provided.

9. Instruments in which the position of the needle is dependent upon the expansion or contraction of a conductor due to changes of temperature in that conductor, caused by the current passing through it. A well known type of this group is the Cardew voltmeter.

10. Thermostats provided with an indicating needle, and in which either the moving element consists of a metallic and a nonmetallic substance with differential co-efficients of expansion, the metallic elements carrying the current, or the moving element consists of two metals of different co-efficients of expansion connected in series, and carrying the current. A third form consists of a simple thermostat heated by radiation from a fixed coil, the moving element carrying no current.

There is one principle which has been used in electrical instruments which is more commonly seen in pure thermostats. It falls within the next group.

11. This principle is the development of pressure within a confined space, due either to the expansion of gas or fluids under temperature increases, or to the volatilization of a fluid having a low boiling point. The generated pressure may either expand a diaphragm forming a portion of the walls of the receptacle retaining the gas or fluid, or may cause the straightening of a bent tube containing a volatile fluid or gas, as in a common form of thermostat. In the first form motion is communicated to the needle as in a steam gauge or an enaroid barometer, in the second form by the direct attachment of the needle to the bent tube.

There are other instruments falling within the thermal class which hardly come within the scope of the definitions I have cited. They are unimportant and are intentionally omitted.

12. Electrostatic instruments.—These comprise a single family and genus. They consist of practical applications of the electrometer and several practical forms. Two or more plates are symmetrically arranged in two, or in some cases three, groups. One group is attached to one pole of the system under measurement, and the second to the other pole. The moving element consists of a light metallic vane having capacity large in relation to its mass. The tendency of the moving vane is to place itself with its greatest length parallel to the shortest path between the plus and minus fixed plates. Another form has one or more fixed plates attached to one pole of the system to be measured, and a movable vane attached to the other pole. The tendency in such a structure is for the movable vane to place itself parallel with the shortest path between the fixed plate or plates and the point of attachment of the movable plate or plates.

Instruments of this class are largely used for the measurement of very high potentials where the conducting of current through a coil, moving or otherwise, would be attended either with grave practical difficulties, or with material physical danger to the structure or human life, or with an unnecessary expenditure of energy.

We now come to a class of instruments in which the actuating force of the needle is derived from an independent source, and its application to the moving element is only governed, either in volume or in period, by the current to be measured. We have in this class two general groups:

13. The first being a source of air or fluid pressure, controlled in intensity by a valve; for example, a reducing valve electrically controlled, a source of air or fluid pressure and a pressure gauge.

14. The second group comprises a clock or its equivalent, directly connected to a

needle. In such a structure the clock is started by the current and drives the needle forward over the scale until the torque of a spring connected to the hand balances the coercive force of the measuring coil, at which point the relay contact is broken, causing the clock to stop with its needle upon the value reached. This device is a modification of the balance, and is practically a weighing machine. Unless still further modified the needle remains upon the highest reading reached during use.

We now come to a class of instruments rarely used as working instruments of position, but very generally used for secondary or bench standards. These are balances, structures incapable of indicating the desired measurement without manual manipulation. They are in two general classes:

15. Instruments in which a definite torque is produced by resorting to any of the structures heretofore described (but generally to a fixed and movable coil or coils). This torque is manually balanced by the winding up of a spring, as in the Siemens dynamometer, or by the manual adjustment of a counterweight, as in the Kelvin balance—the position of the needle attached to the spring manualy wound, or the position of the weight manually adjusted, being read. Such readings may be direct, but for convenience are more commonly arbitrary, and are multiplied by a known constant.

16. Finally we have instruments designed to be brought to zero, used in conjunction with a Wheatstone bridge.

A NEW METHOD OF COLOR TESTING

By R. B. Hussey

In connection with the general investigation of candle-power distribution and the efficiency of different luminous sources, the writer has been trying for some time to find a method of determining and expressing the color of any light. The result sought was not so much the physical composition of the light as it was the everyday effect or common usefulness of the given light.

As a physical problem, the color of a light source may in general be determined by the use of a spectrophotometer, where the spectrum of the light under test is compared section by section with the spectrum of any desired standard. This process, however, is long and tedious and requires somewhat elaborate and special apparatus; and the results, while of considerable interest as a physical determination, are of less value when the apparent and commercial values of lamps are sought. For practical purposes the value of a light source is determined not so much by the particular wave lengths present as by the apparent effect of the light on ordinary goods; not on white goods alone, since it is possible to have a lamp, for instance, such as the mercury vapor lamp, which will give good results where nothing but black and white is viewed, but which will badly distort nearly every separate color. As it seems to the writer, the practical criterion must be the effect on white and on colored material and in order to get some definite comparative figures, the following method has been tried and found to give good results.

In this method an ordinary Lummer Brodhun comparison photometer head is employed, and in place of the usual white screen a series of colored screens are used, each consisting of an opaque slide covered on both sides with colored paper. A set of sixteen colored papers was selected, of as near pure colors as it was possible to obtain, and extending through the range of the spectrum from the red to the violet. Particular care was taken to have both sides of each slide covered with paper of the same hue.

If the two lights under comparison are of the same color, the reading obtained will be the same whatever color of screen is employed, provided, of course, that the screen is of the same color on both sides; but if the lights are of different colors, a reading will be obtained which will represent the relative effect of the two lights on the particular color used. It is, of course, impossible to obtain colored paper or any colored material with pure spectral colors, and in the papers used in this test it is quite evident that the violet contains a considerable amount of red. But since this lack of purity is a general and, it may almost be said, an unavoidable condition, effort should not be made to entirely eliminate its effect, inasmuch as the end sought is, as noted above, the apparent effect produced on colors in common use.

After having obtained readings of the intensity of each of the colors of a luminous source as compared with that of a convenient working standard, it becomes an easy matter

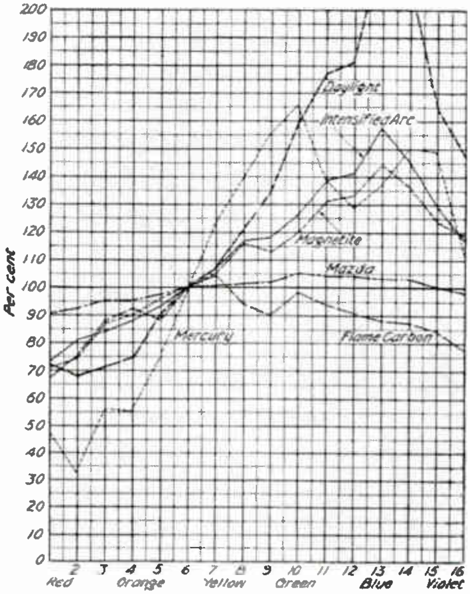


Fig. 1. Analysis of the Light Produced by Various Illuminants

to reduce these to terms of percentage values of the standard, taking any desired point as a basis (100 per cent.). In order to make the results more nearly comparative with ordinary spectrophotometric curves, the color (No. 6) that seemed to be nearest the color of the sodium flame (D line) was chosen as the basis and all the curves brought to 100 per cent. at this point. After a number of different lamps have been tested, any one may, of course, be chosen as the standard, and the others figured to that as a basis of reference.

The diagram of Fig. 1 shows the results obtained from tests on several common forms of lamps, as compared with a carbon incandescent lamp running at 4 watts per horizontal candle.

In the case of arc lamps, the test was repeated several times with different observers in order to get an average result that would be somewhat independent of the variations in the arc, and also to eliminate largely the differences in the eyes of different persons. It may be said, however, that among those who have taken these readings there have been only comparatively small differences. All the observers were men who had done considerable photometric work and were familiar with the apparatus. In order to reduce the chances of an error creeping in from the so-called "Purkinje effect," the intensity on the screen was kept at a reasonably high figure and not far from the same value for all lamps. The range of intensity was from 1 to 3 foot candles.

In addition to tests on a number of different commercial lamps, tests were also made to determine the comparative color value of daylight. The variation of intensity and color in ordinary daylight is so marked that it was necessary to take a large number of readings under as many conditions of sky and weather as possible. The curve for daylight as given represents an average of readings taken in summer and winter from clear and cloudy sky, with and without direct sunlight. From these daylight value the curves taken on commercial lamps have been reduced to the daylight basis, so that each represents the color value of the particular luminous source as compared with daylight, which is the normal standard.

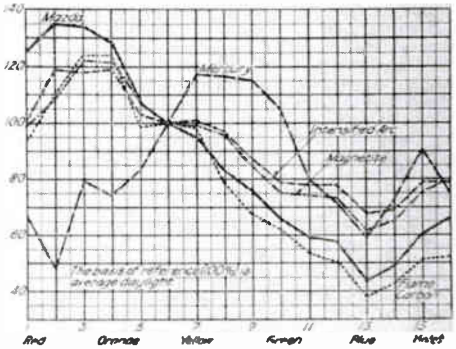


Fig. 2 Analysis of the Light Produced by Various Illuminants, as Compared with that of Daylight

MOTOR DRIVE IN A BOOK BINDERY

By F. J. Chisolm

The Williams Book Binding Company, of 40 Rose St., New York City, was organized in 1889 by George T. and W. J. Williams. At that time two machines were used to assist in the hand work and power for the plant was obtained from a vertical shaft driven by a Corliss engine located in the basement. This shaft passed through the various floors and to it was belted the horizontal shafting. The ceilings were obstructed with shafts and belts which became an increasing annoyance owing to loss of production from damage by oil and dirt. The breaking of belts and consequent delays, and the lack of flexibility in obtaining variable speeds resulted in the adoption, in 1898, of the electric drive.

At present a 40 kw., 250 volt, 650 r.p.m. generator supplies current to the various motors and to the lighting system of the plant. This generator, which is mounted on the ceiling as shown in Fig. 1, is belted to a horizontal shaft provided with a friction clutch, this shaft in turn being belted to the vertical shaft mentioned above. By means of the friction clutch the generator may be started or stopped from the floor below.

Fig. 2. General View of Fourth Floor

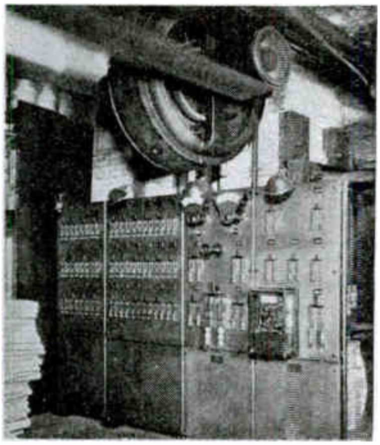


Fig. 1. 40 Kw. Generator and Main Switchboard

Fig. 1 also shows the main switchboard, which is located directly beneath the generator. The generator panel (second panel from right hand end as shown) is provided with a main line switch, a 300 scale voltmeter, a 200 scale ammeter, a field rheostat controlling handle, and several smaller switches for the 230 volt lighting circuit. The panel to the extreme right is a feeder panel for the 230 volt lighting circuit and also feeds the fourth floor distribution board (Fig. 2). A Thomson astatic totaling wattmeter is mounted on this panel and has been found to be a source of valuable information as regards the power requirements of the plant. The two remaining panels serve as distribution boards for the lights and motors of the fifth, or generating floor.

A battery of six Dexter folders with mechanical feeders is shown in Fig. 3. The motors for these folders are started and stopped by means of two-button push buttons, six of which are located at different points about each machine, so that the attendant may stop or start the machine from any position. These push buttons control an automatic starter for the motor. A field rheostat is also installed, and by setting this the foreman in charge can arrange for any given speed, so that the attendant need only operate the controlling buttons. The automatic starter, field rheostat, main line switch and fuses are mounted on a slate panel set up within the framework of the folder, but not visible in the cut.

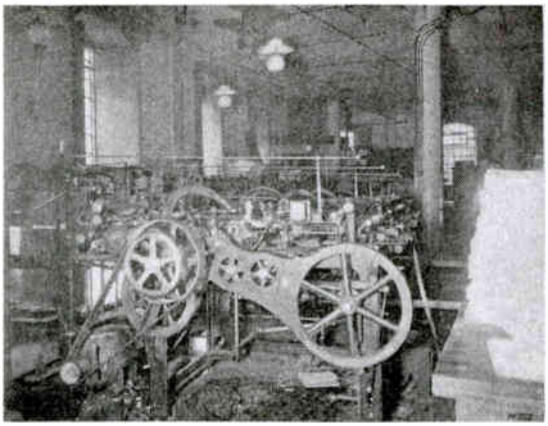


Fig. 3. A Group of Six Dexter Folders Fitted With Mechanical Feeders

Fig. 4 shows a cutter, the attendant of which is working busily. The motor for this machine is started and stopped about once in every ten minutes. The apparatus is self-explanatory.

The makers of the pasting machine shown in Fig. 5 did not believe that this piece of apparatus could be operated by a motor because of the fact that it had to be stopped quickly and would require an unusually strong man on the brake. A motor, an automatic starter, and a dynamic brake made this machine manageable by a girl attendant, who needs only to push the control button.

A rounder and backer is a slow moving machine used for rounding the back of a book. As ordinarily equipped, the electrical application consists of a hand operated rheostat, a motor, and a foot switch to open the holding coil of the rheostat when the brake is worked. When it is desired to reverse the machine, the flywheel is pulled back by hand. Fig. 6 shows an arrangement by means of which considerable time is saved both in the frequent use of the hand starting rheostat and in the cumbersome method of pulling back the flywheel by hand. The reversing switch, when moved from the vertical, will cause the automatic starters to operate, thereby energizing the motor. The foot brake is made in the form of a lever and is so connected to a contactor that when the lever is pressed down, the circuit will open at the time that attendant's weight comes on the flywheel; the operation being the same when the machine is reversed. The attendant

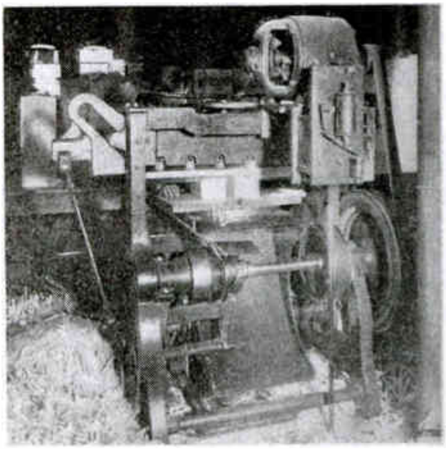


Fig. 4. Paper Cutter

keeps his foot on the brake most of the time. A field rheostat enables the foreman to set the speed for the output desired; this may vary from 30 to 90 books an hour according to size, shape and weight of material.

A very interesting machine is that which, from its function, is known as the gatherer. A book is usually made up of sections which will ordinarily vary in number from 25 to 60. It is the purpose of this machine to gather these sections in proper order so that when delivered the pages read consecutively. The starter for this gatherer is mounted on the far wall, as shown in Fig. 7, the operating buttons being located on the machine at the receiving end. The motor is mounted on pipe supports, out of the way, as shown.

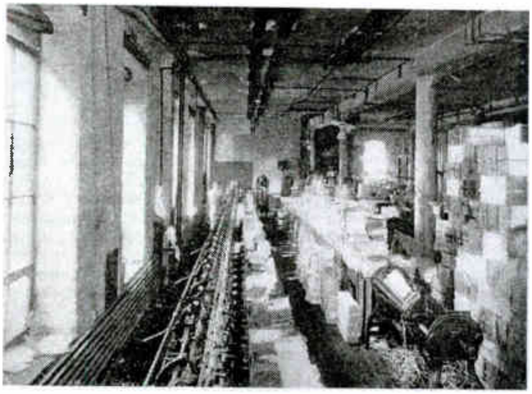


Fig. 7. Gatherer

About 35 motors varying in size from ¼ h.p. to 5 h.p. are now installed in this plant. Small motors of one horse-power or less, operating machines which require practically no starting torque, are compounded and thrown across the line. These motors are started by 3-way snap switches which give full field before the armature is switched onto the line; this arrangement obviating considerable trouble from the blowing of fuses.

Nearly all motors larger than one horse-power are provided with automatic starting devices, the result of which is an increase of 15 per cent. in the output for a given number of men and machines. This increase in production has not been due alone to the speeding up of various machines, but to the time saved through not having the employees concerned with starting the motors.

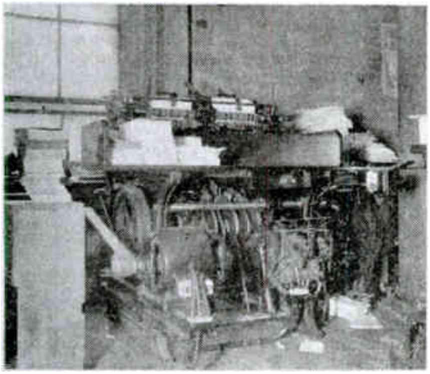


Fig. 5. Posting Machine

At first, when hand operated rheostats were used, the girl attendants would pull away from a rheostat handle when a spark occurred; several attempts usually being made before the lever was finally set on the holding coil. The male attendants, on the other hand, would hold the handle on a point until smoke came from the rheostat, when they would let the handle go and wait for the rheostat to cool. It was to eliminate these losses that the company installed automatic starting devices and the results have more than justified the expenditure.

Before the addition to the switchboard equipment of the totaling wattmeter mentioned previously, it had been the custom of the company and the owners of the building to arrive at an agreement as to the probable power requirements and to draw up a contract accordingly. The wattmeter showed a 25 per cent. smaller average load than that agreed upon and a corresponding reduction was made in the price for power.

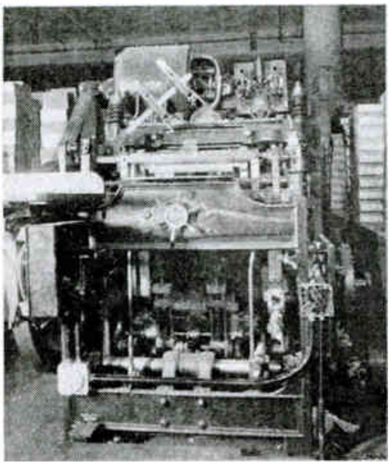


Fig. 6. Rounder and Backer

For service of this kind, motors of at least 25 per cent. greater capacity than ordinarily required for driving the machines must be used, in order to provide a reserve when starting on weak field. The variation of field strength in this installation was between normal and 60 per cent. As stated before, many of these motors were compounded to obviate the bad effects of starting on weak field, and with this precaution no trouble has been experienced in operating the motors.

The electrical equipment of this plant is of General Electric manufacture throughout.

THE VOLTAGE CONTROL OF GENERATORS AND FEEDER SYSTEMS*

By F. W. Shackelford

In our consideration of this subject, we will discuss only alternating current system, as this system is the one most commonly in use.

The study of central station conditions may be classified under three heads:

1st.—The source of energy.
2nd.—Its generation.
3rd.—Its distribution.

The first of these has no part in this paper, but in the construction of a station it bears a most important relation to the second. The selection of the kind of energy; that is, whether coal, gas or water power, will, of course, depend upon the existing conditions; but I wish to point out that this selection is made only after a most careful consideration as to economical operation. The generation of electrical energy comes most vitally into our consideration, and to a large extent the form of generating units will be dependent upon the system decided upon in the first case.

Assuming that the speed and regulation characteristics of the generating units have been most carefully selected, we are still confronted by the fact that the station may be required to deliver current not only for lighting but also for power and electric railways. The power and railway loads can, in general, be readily handled during the day hours, but will always conflict with the lighting peak, and during the winter months considerably overlap it. Many plants are required to furnish lighting during the entire day and are consequently more difficult to handle. Without some form of automatic voltage regulator it is impossible to take care of the heavy swings in voltage caused by fluctuating power and railway loads. Even in the case of purely lighting loads it is an exceedingly hard matter to take care of the voltage properly by hand regulation, and especially so at peak load. It is essential, therefore, for good service and economical operation of the generators to automatically control their voltage.

Accurate generator voltage regulation means that the exciters and generators shall deliver energy in exact proportion to the demands made upon them. A slight increase in voltage of a large station means increased

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* Paper read before the National Electric Light Association, St. Louis, Mo.

losses in transformer cores; likewise a decrease in voltage at maximum station load means actual losses in revenue.

Many forms of generator voltage regulators have been developed, but on account of the many variable elements entering into the problem, few have met with any great success.

Regulators have been designed which operate directly on the alternating current generator field rheostat by varying the resistance. Such a scheme may be made to give fairly good results where only one generator is concerned, but at best it is sluggish and not anti-hunting. With any such scheme it is impracticable to operate two or more such devices in parallel where more than one generator is operated on the same 'bus, on account of hunting and cross currents.

It is always best from the standpoint of regulation to operate both the generators and the exciters in parallel, or groups in parallel, by which arrangement it is possible to regulate all of the machines from a single regulator.

The most successful and best known devices for this purpose are the General Electric Type TA generator voltage regulators.*

These regulators are now designed with from one to twenty-four relays, and I believe it would be safe to say that with a properly designed station equipment the largest regulator would take care of an output of from 50,000 to 60,000 kilowatts.

Before leaving this subject it might be well to mention that, by installing one regulator on each side of the system, this type of regulator has been adapted to the control of direct current stations and has also proven most successful in the control of three-wire direct current systems where the neutral is derived by using two 125 volt generators.

These regulators have also been adapted to the control of power factor and have been used successfully on long transmission lines in connection with synchronous condensers for boosting the power factor and the voltage.

We now come to the third consideration, namely, that of the feeder systems of distribution.

It would seem as though in some instances, after the power and generating plant had been constructed and the lowest cost per kilowatt obtained at the switchboard, the feeder systems had been laid out indiscriminately. It should, however, be borne in mind that a station may lose in the feeding system that which has been saved by carefully designing and selecting the prime movers and generators. It is in the feeding system and the distributing network that we suffer the greatest losses, having to consider both transformer losses and the loss in the lines. Without regulators it becomes a question of putting up not the most economical copper but copper of such section as will take care of the drop within at least 2 per cent.

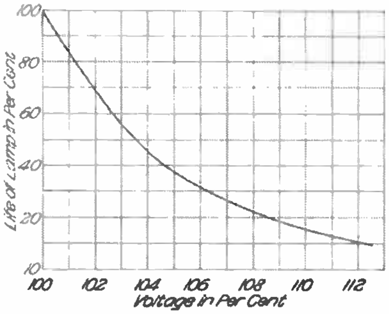

Fig. 1

Such a large section of copper could in a great number of cases be avoided by the use of regulators, and it is therefore a question of the cost of copper required to keep the drop within limits, as against the cost of the most economical copper plus the cost of regulators.

Considering that a station has designed its feeders for a 2 per cent. drop to the centres of distribution, we also find it necessary to deal with the fluctuations on each individual feeder, which cannot be compensated for even by increasing the copper.

In any city of average size, we have three distinct groups of lighting consumers:

1st. —Business.
2nd.—Manufacturing.
3rd. —Residence.

It is practically impossible to regulate the voltage of the generators at the station so that the voltages at the centres of distribution in each of these three divisions are approximately normal. The lighting of the business section in nearly every case demands first attention, and as its load is generally at peak in advance of that of the others, its voltage could be maintained fairly well, while that of the other sections would, with few exceptions, be above normal.

The curves will serve to give you a clear idea of the performance of incandescent lamps.

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*A description of these regulators will be found in the Review for June, 1909.

Fig. 1 shows the life of the lamp in percentage, the normal life being taken at 100 per cent., at 100 per cent voltage. Fig. 2 shows the power consumed by a lamp in percentage, corresponding to the voltage in percentage. Fig. 3 shows the candle-power of a lamp corresponding to the percentage of voltage applied to its terminals.

It will be noted that the life of a lamp is affected most seriously by increases of voltage. This becomes a source of much expense to a station giving free lamp renewals and much trouble to those that do not supply lamps free, as it then becomes a burden on the consumer, which in turn reacts on the station.

The useful life of a lamp at 4 per cent. excess voltage is only 45 per cent. of the life at normal voltage.

On the assumption that the average lamp is operated at 4 per cent. excess voltage for one-half the time, and at normal voltage the remaining time, this condition would decrease the life of the lamp by one-third. On the further supposition that each connected lamp is used two hours per day, 300 days per year, and that the average useful life of a lamp is 800 hours, the excess cost of lamp renewals is shown in the following tabulation:

Total Number of Lamps Connected	Total Lamp Renewals at Normal Voltage (800 Hours)	Total Lamp Renewals Under Conditions Given (532 Hours)	Cost of Excess Renewals Taking Cost at 10 cents per Lamp
10,000	7,500	11,200	$370
20,000	15,000	22,400	740
30,000	22,500	33,600	1,110
40,000	30,000	44,800	1,480
50,000	37,500	56,000	1,850
100,000	75,000	112,000	3,700
500,000	375,000	560,000	18,500
1,000,000	750,000	1,120,000	37,000

By reference to Fig. 2, it will be noted that the decrease in power consumed by a lamp at reduced voltage is in the ratio of 2 to 1, that is, a 2 per cent. drop from normal voltage results in a 4 per cent. loss in power.

This fact may be insignificant when considering a single unit, but its importance will be appreciated by the tabulation given below, which shows a direct loss to a station without beneficial or compensating features.

Assuming, as in the previous case, that each lamp is used two hours per day, 300 days per year, and that the voltage is maintained at normal one-half the time and 4 per cent. below normal the remainder (which latter condition would necessarily occur at peak load), the average loss in power for the total time is 4 per cent. On the basis of using 50 watt lamps, and taking the average selling price per kilowatt hour at nine cents, the loss per year is as follows:

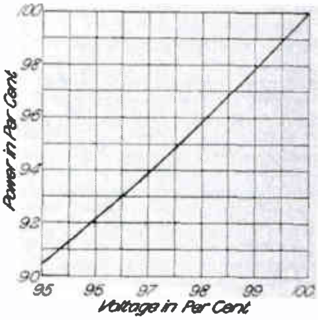

Fig. 2

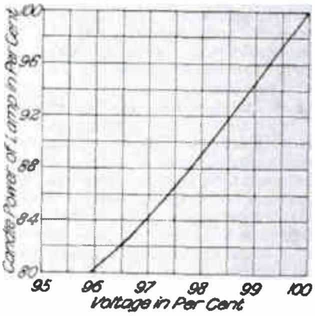

Fig. 3

Total Number of Lamps Connected	Anticipated Revenue per Year	Loss in Revenue per Year Resulting from Above Conditions
10,000	$30,240	$1,209
20,000	60,480	2,418
30,000	90,720	3,627
40,000	120,960	4,836
50,000	151,200	6,045
100,000	302,400	12,090
500,000	1,512,000	60,450
1,000,000	3,024,000	120,900

The candle-power of a lamp is affected most seriously by a decrease in voltage, and because of the poor and variable illumination is often the cause of righteous indignation on the part of the consumer. The watchword of any station should be "good service," whereby is gained satisfied customers and increased business.

Feeder circuits, like individuals, have their own characteristics, and when the load on a feeder becomes of importance it is necessary to regulate it individually.

It is apparent from the foregoing that the need of regulation would develop many schemes for correcting voltage troubles. Some of the schemes proposed embody the use of a permanent boosting transformer to take care of peak conditions, or the use of two transformers, one with saturated and the other with unsaturated cores, the primaries opposing and the secondaries in series, thus boosting the voltage as the load increases. Each of these schemes present several objections, which I believe are so well understood that it is unnecessary for me to take up your time in explanation of them.

Of all the methods tried, that of a variable ratio transformer is the only one which has given satisfaction. This may be a standard transformer with primary in shunt and secondary in series with the circuit to be controlled, the secondary being provided with a number of taps which are connected to a dial switch or controller, so that the line voltage may be raised or lowered as required. The induction type of regulator is essentially a variable ratio transformer but, instead of the voltage being raised or lowered in a few steps, the voltage is adjusted by almost infinite steps.

Such devices may be hand, motor, or automatically operated. The hand and motor operated regulators, however, are necessarily dependent upon the station operator for service, while the automatic regulator, when once adjusted for line conditions, is always on the job.*

Now, as to the method of applying such regulators to different systems, it will be necessary to discuss briefly the following systems of distribution.

1st. —Single-phase.
2nd.—Two-phase, three-wire and four-wire.
3rd. —Three-phase, three-wire and four-wire.

Single-Phase System of Distribution

The single-phase system of distribution is very simple and has been widely used in the past for lighting circuits. In such a system it is only necessary to supply one single-phase regulator to each feeder.

Two-Phase System of Distribution

The two-phase system of distribution may be divided into two classes; *i.e.*, two-phase three-wire, and two-phase four-wire. The two-phase three-wire system possesses an advantage over the single-phase in that it can take care of a power load as well as a lighting load. In applying regulators to such a system it is necessary to use two single-phase regulators, since under certain conditions the load on one phase tends to unbalance the voltage of the other phase.

The two-phase four-wire system, which is established by inter-connecting the phases at the middle point or by maintaining the phases entirely separate, is an improvement over the two-phase three-wire system. It is preferable to operate the phases entirely separated, and the application of regulators is made by installing a single-phase regulator on each phase in cases where the phases are not balanced, and by using a quarter-phase regulator where the phases are practically in balance. In some stations it is advantageous to use both methods of regulating, though this is an exception to general practice.

Three-Phase System of Distribution

The three-phase system of distribution can be either three-wire or four-wire. In applying regulators to a three-phase three-wire system it becomes necessary, in case the three phases are unbalanced, to employ three single-phase regulators, one in each phase. Wherever practicable, however, it is advisable to use only one phase of a three-phase feeder to handle the lighting load, installing a regulator in this phase and letting the other two phases shift for themselves. Where a three-phase power load is regulated it is desirable to distribute the load so as to maintain as nearly as possible a balanced system, and therefore to use a three-phase regulator for controlling it.

Where the three-phase four-wire system is used, it is generally necessary to employ single-phase regulators, one in each leg, operating between this leg and the neutral wire. However, by properly balancing, it is possible to employ a single three-phase regulator on each feeder.

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*Descriptions of these regulators will be found in the issues of the Review for July, 1908 and June, 1909.

THE ELECTRIC LIGHT PLANT AT MUKDEN, MANCHURIA*

In 1908, the Manchurian Government was largely controlled by a coterie of foreign educated, progressive and competent officials, of which H. E. Tang Shaoiji, Governor of the province, was the leader. Many improvements were inaugurated during their brief tenure of office, not the least of which was the appropriation of funds for the installation of an electric light system for the capital, it being proposed to furnish light principally for the many Government Yamens, and streets.

The first plans, therefore, called for a rather limited plant, as commercial lighting seemed rather hopeless at first, owing to the cost, and the fact that all shops close at sundown and the inhabitants as a rule retire very early.

Data of Present Plant

Normal capacity of present plant	5000	lights—16 c.p.
Lights in operation	5000	" carbon.
Street lights 60 c.p.	300	series tungsten.
Miles of streets lighted	10	
Miles of pole line constructed	23	
Miles of wire on poles	70	
Capacity of line wires	20000	lights.
Transformers installed	62	
Capacity of transformers	8000	lights.

Due to the number of poorly constructed telephone lines and the inflammable interior walls and ceilings of houses, special attention and extra precautions have been taken to protect all circuits with enclosed safety fuses. Double the number of fuses that are used in American or European practice have been placed in the circuits. Wires of ample size have been used and special efforts have been made to securely fasten wires to insulators. The poles are set deep and are well guyed, and strong cross-arms with iron insulator-pins support insulators designed for a much higher voltage than that in use.

The entire work of installation was completed with remarkable celerity. The engineer of the General Electric Company, who had the matter in charge, arrived in Mukden the first of July, 1909, and began the organization of several gangs of workmen and drew plans for power station and pole line arrangements. House wiring was started in the Government Yamens about August 1st, and the erecting of power-station machinery August 15th. The plant was given a twelve hours test run on September 30th, and put in operation with about one thousand lights, October 3rd. The lighting service has been supplied for seven months to date without accident or interruption, except for one period of twenty nimutes, due to a misunderstanding of orders. The G.E. series tungsten street lighting system which was put in operation in November, shortly after the arrival of the final shipment of equipment, has been generally approved by the officials and public, and is giving every satisfaction, as it is peculiarly adapted for the streets of a Chinese city.

Contrary to expectations, since the date of starting the plant, orders for the installation of lights have been received more rapidly than they can be filled. Practically all of the new buildings, public and private, have been equipped with ample illumination. Yamens, schools, shops, theatres, hotels and residences have electric lights, and the people evince rapidly increasing knowledge of their advantages and a desire for sufficient lights of the latest type. A good market for heating and cooking apparatus, as well as small power motors, is being developed.

Plant Extension

Shortly after putting the plant in operation the management was convinced that the plant would be loaded to its capacity before the following spring, and arrangements were made for its extension. Owing to the high cost of fuel, the most efficient machinery would be most economical and it was decided to install a 600 h.p. Curtis steam turbine driving General Electric dynamos of 400 kilowatts capacity. To add to the reliability of the plant, a separate small turbine-driven dynamo of 20 kilowatts capacity will be installed. The steam from the turbines will be condensed in Wheeler surface condensers and a high vacuum held with electric motor-driven pumps. The condensed steam will be pumped direct to the boilers and used continuously. Babcock & Wilcox boilers of the latest design will be installed and equipped with automatic mechanical stokers. A super-heater will be integral with the boilers to eliminate the danger of water in the steam. The boiler capacity will be sufficient for the two turbines.

The General Electric Company has received orders for transformers, wire, meters, lamps and wiring supplies of the most approved design, which will be delivered this

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* Abstracted from the *Far Eastern Review* for May, 1910.

spring. The quantities will be sufficient to bring the system to twelve thousand lights. The equipment for four hundred more G.E. series street lights of the same type as adopted by the Shanghai municipal council, will also be delivered this spring, with a number of flame arc-lights and miniature lights for advertising signs.

Although power for lighting is sold by meter cheaper than in other cities in China, the receipts for lighting service have considerably exceeded expenses from the start, and with the plant completed as now designed, the receipts will cover operating expenses and cost of extensions, and leave a reasonable profit on the invested capital.

By next summer all of the mint machinery will be driven with 25 h.p. and 50 h.p. General Electric three-phase induction motors, supplied from the lighting dynamos. This will make it profitable to run the electric plant all day and supply motors installed in any part of Mukden, as well as fans and other electrical conveniences.

The credit for the success of this plant must be given to Taotai T. Y. Key through whose foresight, ability to appreciate new conditions, and knowledge of engineering problems, it was made possible to complete the installation of the plant in a space of time hitherto considered impossible in China. All the installation work (except some trivial pole setting done previous to the arrival of the General Electric Company's engineer from New York and which it was necessary to do over again) was done between the dates of July 2nd, and September 30th, when lights were turned on—a period slightly under three months. The Chinese and foreign inhabitants of Mukden have repeatedly given testimony to the extreme quickness with which the engineer in charge successfully completed the work, after a proper beginning was made on his arrival.

LIFE OF DIAMOND JEWELS

By F. G. Vaughen

What is the life of a cupped diamond jewel? This question is often asked by prospective users who are weighing the first cost of the diamond against that of the sapphire. To answer is impossible, for some of the cupped diamond jewels first manufactured are still in service; and although in some cases they show signs of wear, have an unbroken, perfectly polished bearing surface and are apparently good for millions of revolutions to come. During the past six years one of the larger lighting companies has purchased for use in direct current meters, a total of 17,000 diamond jewels, of which 13,000 were placed in service in 1906-7 or earlier, and have been in continuous use ever since. Three of these jewels have been lost by fire or have been crushed, and 57 have been worn to a point where it seemed desirable to reject them. This means that in three years' continuous service, less than one-half of one per cent. have had to be replaced for any cause.

The following tabulation, taken at random from this company's records, shows the remarkable life of cupped diamond jewels. It will be noted from column 2 that a majority of these jewels have been installed *prior* to a certain date, thus showing that the actual number of revolutions is more than the tabulation gives—how much more it is impossible to say, as no record of installation date was made. All of these jewels are still in service, so the tabulation gives no indication of what the ultimate life may be.

Ampere capacity of meter	Jewel installed prior to	Jewel installed	Life up to present date in millions of revolutions
75	8-06		17.8
7½	7-06		5.5
25	3-07		6.3
15		11- 2-06	9.
25	9-06		8.7
200	9-06		14.7
50		1-29-07	25.
50	12-06		6.2
7½	7-06		12.8
150	7-06		14.3
150	8-06		12.8
50	7-06		11.3
150	8-06		46.
150		1-16-07	25.6
50		10-15-07	11.5
150	4-07		15.0
100		10-16-07	19.5
100	8-06		10.1
50		1-15-07	45.9

THE VERTICAL CARBON FLAME ARC LAMP

By G. N. Chamberlin

Engineer Arc Lamp Department, General Electric Co.

The 6.6 ampere luminous lamp is acknowledged to be the most modern and efficient means for general street illumination. This fact has become so well recognized that, after thorough investigation of other illuminants, particularly other forms of arc lamps, its conspicuous merits have led to its being adopted for the lighting of many of the large cities, among others Boston, St. Louis, Pittsburg and Minneapolis.

Fig. 1. Vertical Carbon Flame Arc Lamp

In many cases, however, there are certain squares, parks or sections of streets where lamps of greater power are desired. In any city using the 6.6 ampere luminous lamp (or even the enclosed 6.6 ampere direct current system) for its general lighting, these areas can be illuminated to advantage by the General Electric vertical carbon flame lamp, on account of its high candle-power, exceptional efficiency, attractive appearance and the character of its light, which through its penetrating quality furnishes excellent illumination even in foggy weather. The lamps are so designed that, without other change in lamps or system, they may be used to replace lamps of either of the above systems by simply being connected in their stead.

Fig. 3 shows the light distribution from the 6.6 d.c. enclosed; the 6.6 d.c. luminous, and the 6.6 d.c. flame lamps, the latter lamp being equipped with a 26 in. diffuser and a light opal globe.

Figs. 1 and 2 show respectively the external and the internal appearance of the vertical carbon flame lamp. It has been designed along the lines of modern commercial arc lamp practice; it consists essentially of a simple focusing frame operated by a design of magnets, armatures, clutches, cutouts, etc., that has been tried out for years in the standard General Electric direct constant current enclosed lamp.

Fig. 2. Mechanism of Vertical Carbon Flame Arc Lamp

Lamp casing is of heavy copper and is made in two sections so arranged that they may be telescoped on each other, thus rendering any section of the mechanism easily accessible.

The upper electrode consists of an ordinary ½ in. by 12 in. cored enclosed arc carbon, while the lower electrode is a carbon tube $\frac{11}{16}$ in. by 11 in. having a specially prepared core, manufactured and sold only by the General Electric Company. A pair of carbons will burn about 20 hours. It is interesting to note that lamps must be connected so that the lower carbon will be positive. To insure perfect alignment, the lower carbon holder has a ball and socket joint.

Aside from smaller installations, about 50 of these lamps have been in continuous operation in the streets of Boston for over a year.

Fig. 4 shows one of these lamps with pole as used in Copley Square, Boston; the lamps are hung so that the arcs are 50 feet from the curb.

Multiple Flame Lamps

By removing the cutout contacts and replacing the starting resistance with a series resistance, the lamp is suitable for constant potential 110 volts, d.c. operation, giving practically the same light distribution and carbon life as is obtained with the series lamp.

For multiple work the lamp is adjusted for 6.5 amperes, 70 to 75 volts at the arc. The advantage of operating lamps singly on 110 volt circuits instead of two in series at the higher current is obvious.

For multiple series operation, two lamps are used in series on 220 volts, or 5 in series on 500 volts, this being one-half the number of lamps that are required in the case of either potential if the higher current, converging carbon types of lamps are used.

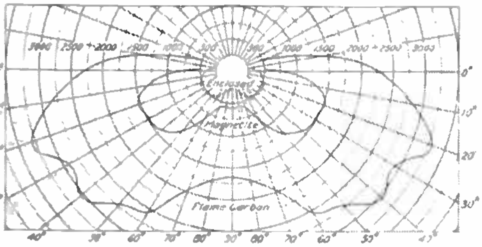

Fig. 3. Distribution of Light from Enclosed, Magnetite and Vertical Carbon Arc Lamps

For multiple series connection the series lamp with the magnetic cutout removed or disconnected, is used. This gives to each lamp a self-contained cutout and cutout resistance, insuring the operation of the remaining lamps in circuit in case one arc for any reason becomes extinguished. An external series of steadying resistance is used with each set of lamps in series.

Fig. 4. Vertical Carbon Flame Arc Lamp, Copley Square, Boston

For the present the lamp is available for d.c. circuits only.

Summarizing, the lamp has the following advantages over all types of converging carbon flame lamps:

Simple mechanical construction.

Higher efficiency.

Efficiency obtained at low current (6.6 amperes) making lamp available for existing series circuits.

Lamps may be connected singly on 110 volt circuits and thus operate with less complication in line wiring and lamp design.

Longer carbon life.

NOTES

During the month of June the following student engineers entered the Testing Department of the General Electric Company.

Georgia School of Technology

Fosterling, C. W.

Iowa State College

Corlette, L. H.
Mercer, J. M.
Noble, J. A.

Lehigh University

Foust, C. A.
Swope, R. B.

Leland Stanford University

Binns, C. A.
Cramer, H. P.
Parker, F. T.
Wall, R.

North Dakota Agricultural College

Moore, D. H.

Ohio State University

Taylor, B. W.

Pennsylvania State College

Beebe, L. H.
Bower, G. W.
Graeff, W. K.

Purdue University

Dull, A. W.
Harrison, E. M.
Knapp, L. H.
Proctor, W. R.
Sage, W. C.
Snyder, T. I.
Thomas, E. E.
Whicker, M. N.

Rose Polytechnic Institute

Henry, H. W.
Madison, H. J.
Poindexter, P. W.

Stevens Institute of Technology

Whyte, A. C.

Tuffts College

Taylow, C. W.

Tulane University

Wolf, A. F.

Union College

Becker, W. J.
Charest, J. G.
Dennis, A. R.
Dillinger, G. A.
Grover, H. H.
Kelley, S. D.
Kriegsman, A. E.
Paul, W. E.
Sears, R. P.
Sherman, A. H.
Slutter, N. W.
Whitmore, P. J.

University of California

Cumming, G. B.

University of Colorado

Allen, H. E.

University of Illinois

Bailey, E. H.
Pierce, L. G.
Wheatlake, B. C. J.

University of Kansas

Card, B. A.
Farber, E.
Morris, G. S.
Ponsler, R. L.

University of Kentucky

Bennett, C. S.
Mills, G. P.
Shanklin, S.
Shelby, J. B.

University of Maine

Chadbourne, V. R.
Hall, C. A.

University of Nebraska

Hepperlen, J. A.
Huston, C. B.
Smith, D. F.
Thornberg, C. E.

University of Wisconsin

Stilwell, E. D.

Virginia Polytechnic Institute

Paine, R. A.

It is expected that the present G.E. Investment Club will be gradually liquidated after the August assessment is paid. There seems to be a general desire among the present members that a new club should be formed along substantially the same lines, but not requiring compulsory liquidation at any specific time. It is proposed to start a new club early in September, 1910, and preparations are already under way to that end.