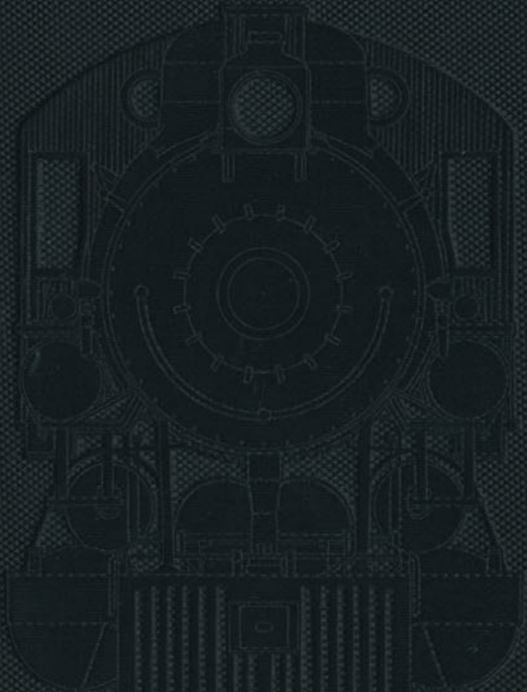

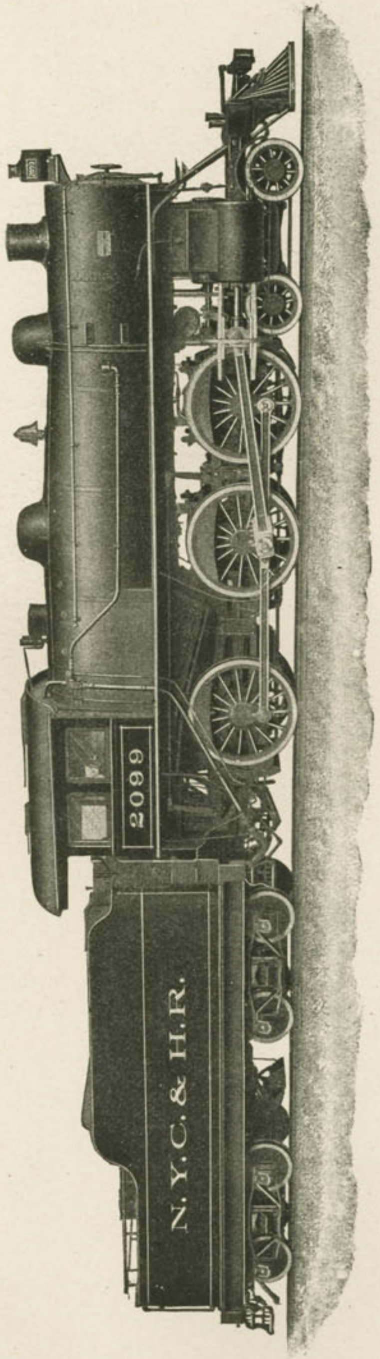

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PROFUSELY ILLUSTRATED WITH HALF-TONES, DIAGRAMS AND LINE CUTS

1913 EDITION

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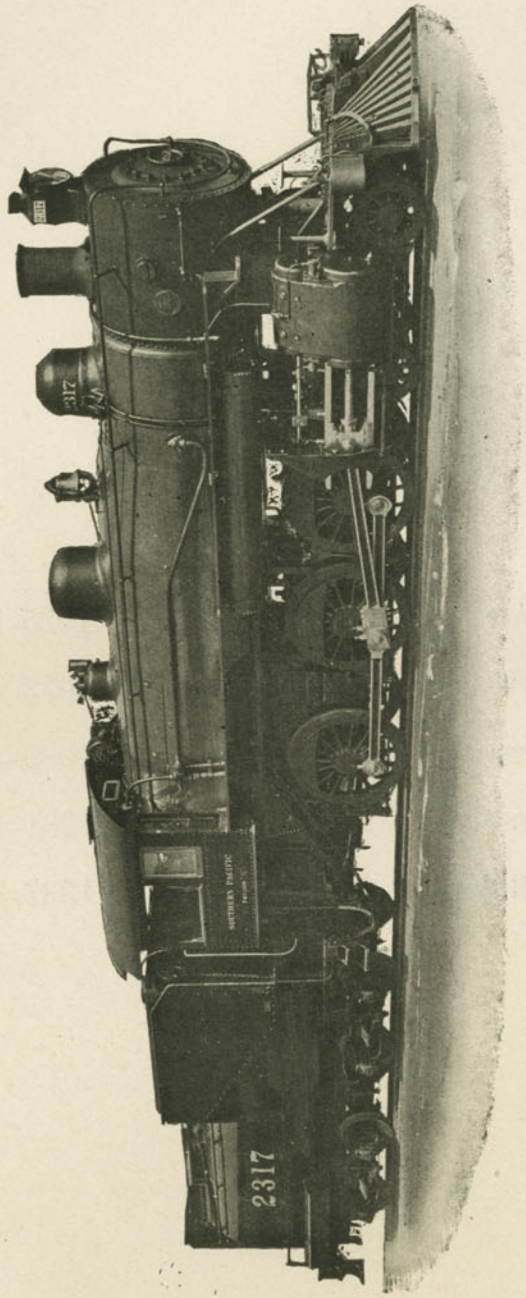


TEN-WHEEL OIL-BURNING PASSENGER LOCOMOTIVE USED ON THE SOUTHERN PACIFIC R. R.
(Baldwin Locomotive Works)

Compressed Air.

Compressed Air is usually conceded to mean air under a gage pressure of from 30 pounds per square inch up; 3,000 pounds per square inch being the usual limit, and pressures of from 60 to 100 pounds being the usual practice. Before going into the subject of Air Compression, however, it might be advisable to state briefly the chief characteristics of free air in order that its actions under pressure may be the more easily understood.

The most important characteristic of free air and the one which bears most directly upon its efficiency when compressed is the fact that it expands when heated and absorbs moisture. The following table (Table 1) shows the effect of heat upon a given

TABLE 1.

Of the volume and weight of dry air at different temperatures under a constant atmospheric pressure of 29.92 inches of mercury in the barometer (one atmosphere), the volume at 32° Fahrenheit being 1.

Temperature in degrees.	Volume in cubic feet.	Weight of a cubic foot in lb.	Temperature in degrees.	Volume in cubic feet.	Weight of a cubic foot in lb.	Temperature in degrees.	Volume in cubic feet.	Weight of a cubic foot in lb.
32	1·000	0·0807	275	1·495	0·0540	1,300	3·585	0·0225
42	1·020	0·0791	300	1·546	0·0522	1,400	3·789	0·0213
52	1·041	0·0776	325	1·597	0·0506	1,500	3·993	0·0202
62	1·031	0·0761	350	1·648	0·0490	1,600	4·197	0·0192
72	1·083	0·0747	375	1·689	0·0477	1,700	4·401	0·0183
82	1·102	0·0733	400	1·750	0·0461	1,800	4·605	0·0175
92	1·122	0·0720	450	1·852	0·0436	1,900	4·809	0·0168
102	1·143	0·0707	500	1·954	0·0413	2,000	5·012	0·0161
112	1·163	0·0694	550	2·056	0·0384	2,100	5·216	0·0155
122	1·184	0·0682	600	2·158	0·0376	2,200	5·420	0·0149
132	1·204	0·0671	650	2·260	0·0357	2,300	5·624	0·0142
142	1·224	0·0660	700	2·362	0·0338	2,400	5·828	0·0138
152	1·245	0·0649	750	2·464	0·0328	2,500	6·032	0·0133
162	1·265	0·0638	800	2·566	0·0315	2,600	6·236	0·0130
172	1·285	0·0628	850	2·668	0·0303	2,700	6·440	0·0125
182	1·306	0·0618	900	2·770	0·0292	2,800	6·644	0·0121
192	1·326	0·0609	950	2·872	0·0281	2,900	6·847	0·0118
202	1·347	0·0600	1,000	2·974	0·0268	3,000	7·051	0·0114
212	1·367	0·0591	1,100	3·177	0·0254	3,100	7·255	0·0111
230	1·404	0·0575	1,200	3·381	0·0239	3,200	7·459	0·0108
250	1·444	0·0559						

volume of air, and it will be seen that if this air is not allowed to expand and is confined in a given space the effect of heating is to raise the pressure. Conversely, therefore, when air is compressed, its temperature is raised as shown in Table 2.

TABLE 2.

Heat Produced by Compression of Air.

Atmospheres.	Pressure.		Volume in Cubic Feet.	Temperature of the Air throughout the Process. Degrees.	Total Increase of Temperature. Degrees.
	Pounds per Sq. Inch above a Vacuum.	Pounds per Sq. Inch above the Atm'sph're (Gauge Pressure).			
1·00	14·70	0·00	1 0000	60 0	00·0
1·10	16·17	1.47	0 9346	74·6	14·6
1·25	18·37	3·67	0·8536	94·8	34·8
1·50	22·05	7·35	0·7501	124·9	64·9
1·75	25·81	11·11	0·6724	151·6	91·6
2·00	29·40	14·70	0 6117	175·8	115·8
2 50	36·70	22·00	0·5221	218·3	158·3
3·00	44·10	29·40	0·4588	255·1	195 1
3·50	51·40	36·70	0·4113	287·8	227 8
4·00	58·80	44·10	0 3741	317·4	257·4
5·00	73·50	58·80	0·3194	369·4	309·4
6·00	88·20	73·50	0·2806	414·5	354·5
7·00	102·90	88·20	0·2516	454·5	394·5
8·00	117·60	102 90	0 2288	490·6	430·6
9·00	132·30	117 60	0·2105	523·7	463·4
10·00	147·00	132 30	0·1953	554·0	494·0
15·00	220·50	205·80	0·1465	681 0	621·0
20·00	294·00	279·30	0·1195	781·0	721·0
25·00	367·50	352·80	0·1020	864·0	804·0

These tables apply to dry air only. The effect of moisture will vary the figures of temperature and to some extent will effect the pressures, but many useful deductions may be drawn from the tables. It is seen, for instance, by studying Table 1, that a volume of dry air will be doubled if its temperature is increased about 500 degrees, and conversely, of course, if the volume remains constant an increase of about 500 degrees in temperature will double the pressure. The addition of moisture serves to increase these figures, because moisture increases both the specific heat and the heat-conducting capacity of the air.

The thermal results of air compression and expansion are shown by the accompanying diagram (Fig. 1). Both the temperature of the air and its volume are shown at different stages of compression. The simplest application of this diagram is that which gives the gage pressure represented at different points of the

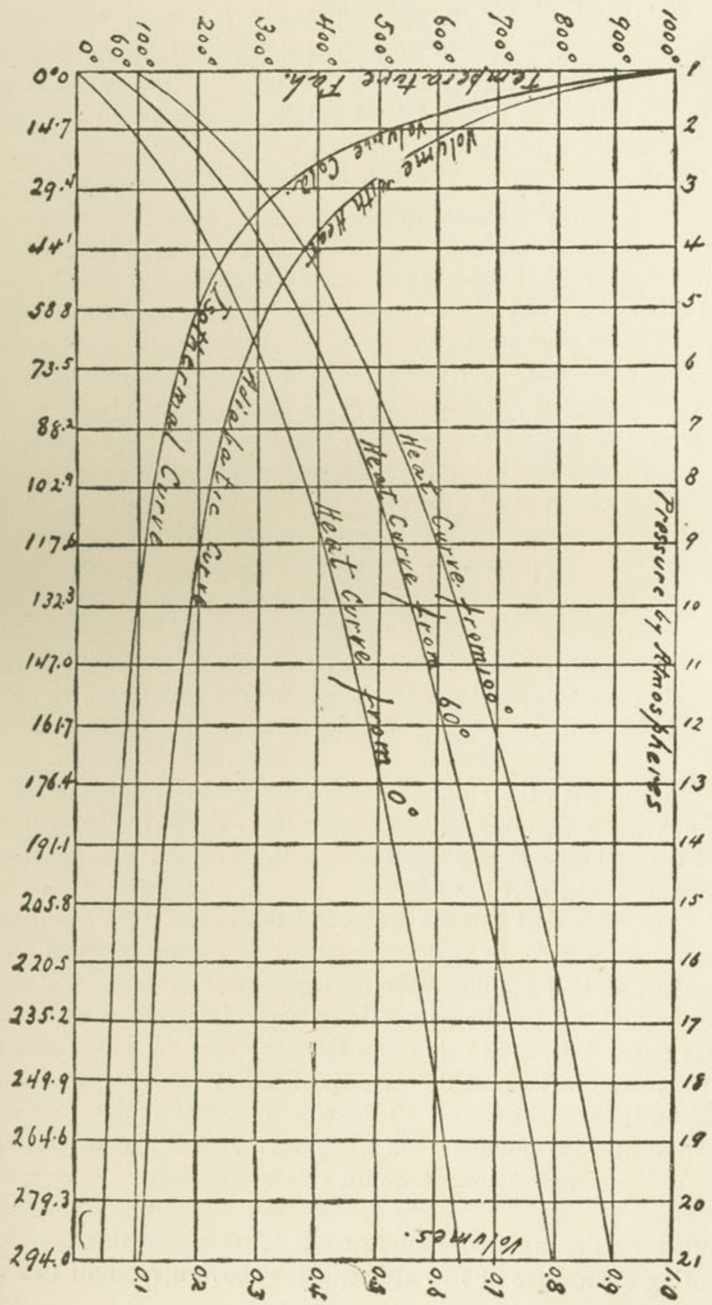


Fig. 1

stroke. This is shown in the vertical lines. But in compressing air we produce heat, and it is important to know the temperature at any given pressure, also the relative volume. All of these are shown in the diagram. The initial volume of air equal to 1 is taken and divided into ten equal parts, each division between two horizontal lines, shown by the figures at the right, representing one-tenth of the original volume.

The vertical and horizontal lines are the measures of volumes, pressures and temperatures. The figures at the top indicate pressures in atmosphere above a vacuum; the corresponding figures at the bottom denote pressures by the gage. At the right are volumes from one-tenth to one. At the left are degrees of temperatures from zero to 1000° F. The two curves which begin at the left-hand corner and extend to the lower right are the lines of compression; the upper one being the "Adiabatic" curve, or that which represents the pressure at any point on the stroke with the heat developed by compression remaining in the air. The lower is the "Isothermal," or the pressure curve at constant temperature. The three curves, which begin at the lower left-hand corner and rise to the right, are heat curves, and represent the increase in temperature corresponding with different pressures and volumes, assuming in one case that the temperature of the air before admission to the compressor is zero, in another 60 degrees, and in another 100 degrees.

Beginning with the adiabatic curve, we find that for one volume of air, when compressed without cooling, the curve intersects the first vertical line at a point between 0.6 and 0.7 volume, the gage pressure being 14.7 pounds.

If we assume that this air was admitted to the compressor at a temperature of zero, it will reach about 100 degrees when the gage pressure is 14.7 pounds. We find this by following down the first line intersected by the adiabatic curve to the point where the zero heat curve intersects this same line, the reading being given in figures to the left immediately opposite. If the air had been admitted to the compressor at 60 degrees, it would register about 176 degrees at 14.7 pounds gage pressure. If the air were 100 degrees before compression, it would rise to about 130 degrees at this pressure.

Following this adiabatic curve until it intersects line No. 5, representing a pressure of five atmospheres above a vacuum (58.8 pounds gage pressure), we see that the total increase of temperature on the zero heat curve is about 270 degrees; for the 60 degree curve it is about 370 degrees, and for the 100 degree curve it is about 435 degrees. The diagram shows that when a volume of air is compressed adiabatically to 21 atmospheres (294 pounds gage pressure) it will occupy a volume a little more than one-tenth; the total increase of temperature with an initial temperature of zero is about 650 degrees; with 60 degrees initial temperature it is 800 degrees, and with 100 degrees initial it is 900 degrees.

It will be observed that the zero heat curve is flatter than the others, indicating that when free air is admitted to a compressor cold the relative increase of temperature is less than when the air is hot. This points to the importance of low initial temperature. It is plain that a high initial temperature means a higher temperature throughout the stroke. The diagram gives the rise of temperature during compresssion from initial temperatures of 0, 60 and 100 degrees. If we compare the compression line from zero with the compression line from 100 degrees we observe that in compressing the air from, say, 1 atmosphere to 10 atmospheres, the original difference, which at the start was only 100 degrees, has now been about doubled; that is, it has reached 200 degrees, and in carrying the compression to 20 atmospheres the difference becomes about 250 degrees. Each horizontal division represented by the figures at the left is equal to 100 degrees, and the space between any two adjacent horizontal lines may be subdivided into 100 equal parts representing 1 degree each.

Where there is a system of cooling the air during compression, the lines on the indicator cards can be traced between the adiabatic and isothermal curves on the diagram. In practice the best compressors show a line about midway between these two curves. Compressors using a spray of water for cooling show a pressure line a little nearer the isothermal.

For all practical purposes in using this diagram it is best to follow the adiabatic curve in all determinations, except where the exact pressure line is known. This diagram will be found convenient for those who are called upon to figure the pressures at different points in the stroke of an air compressor, and it points out the common error of neglecting to take into consideration in one's figures the fact that, at the beginning of the stroke, one atmosphere in volume already exists. Beginning at the upper left-hand corner, the adiabatic pressure curve intersects the first vertical line at that point in the stroke when the pressure on the gage will register 14.7 pounds.

The next vertical line shows where the gage reaches 29.4 pounds, and it is evident here that the piston of an air compressor travels much farther in reaching 14.7 pounds than in doubling that pressure or in reaching 29.4 pounds; thus an air compressor is an engine of unevenly distributed resistance. During the early stages of the stroke it has a slowly accumulating load to carry, while later on this load is increased very rapidly. This is one of the reasons for heavy fly wheels on air compressors.

The loss due to the heat of compression is the greatest loss in the production of compressed air, and to prevent this a cooling medium is supplied that will abstract the heat of compression. Water is usually employed, and it has been used in various ways, calling into existence two distinct classes of compressors:—

1. Wet Compressors.
2. Dry Compressors.

WET COMPRESSION.

In the first class, water is introduced directly into the cylinder during the compression process, and in the second case no water is admitted to the air during compression.

Wet compressors may be subdivided into two classes:—

(a.) Compressors in which water is sprayed into the cylinder during compression, and

(b.) Those which use a water piston for compressing. The first class of wet compressors has shown the highest degree of efficiency for single-stage (or simple) compressors, because the water is thoroughly mixed with the heated air and takes up the heat readily (due to the difference in the specific heats of water and air). The injected water must not be excessive, or damage will result to the compressor. An increased capacity also results from using water in the cylinder to fill the clearance spaces.

The spray-injection compressor has been used mostly in France. It will show a higher thermodynamic efficiency than the dry or jacketed compressor; its commercial efficiency, however, is not so high, owing to the fact that it must operate at a very low speed, the water preventing proper cylinder lubrication and impurities in the water attacking the walls of the cylinder. On this account, at the present time, there is probably not a single compressor builder who follows the wet process.

DRY COMPRESSORS.

In the dry compressor the external walls of the cylinder are flooded with water. This has scarcely any cooling effect upon the air being compressed, however, as only a thin film of air is in contact with the cylinder walls, and that for a very short time. Jacketing is therefore effective only for cooling the cylinder walls sufficiently to prevent the lubricant from carbonizing. Efficient

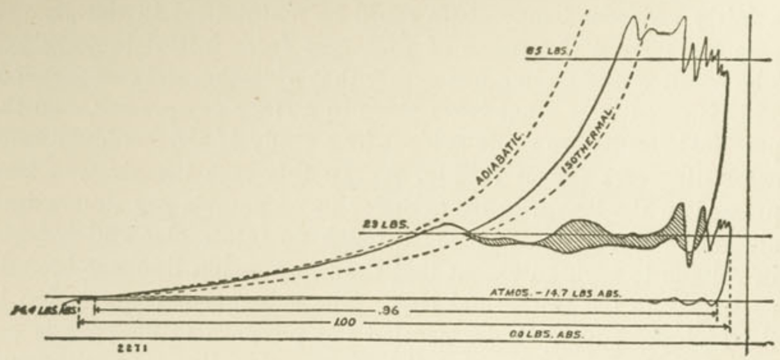


Fig. 2

cooling can only be effected in compressors of the dry type by what is known as "stage compression," that is, compressing in two or more cylinders connected in series and passing the air through an intercooler, or nest of pipes through which cold water is circulated, between each two stages.

It should be stated here that when air is compressed in a cylinder without the removal or escape of any of the heat produced, the compression is known as "adiabatic." When compression is carried on in such a way that heat is removed as fast as it is produced, the compression is "isothermal." In the first case the air delivered under pressure will be at the high terminal temperature corresponding to that pressure. In the second, the compressed air will have the same temperature at which it entered the cylinder. Adiabatic compression is the kind which all pneumatic engineers seek to avoid, while isothermal compression is the impossible ideal. The actual results secured in the best compressors are intermediate between these, but nearer to the adiabatic. With intercooling the compression obtained is nearer the isothermal than is possible with any other form of dry compressor.

The process is the same as though, supposing the compression to be carried on in a single cylinder, the piston were stopped for a moment at different points in the stroke, and the air, already partially compressed and heated, withdrawn long enough to be cooled by some external means to its initial temperature and then returned to the cylinder to be further compressed. It is evident that a fairly uniform temperature could be maintained in the air volume throughout the range of pressures from initial to terminal. The result would be in effect nearly that of isothermal compression. This is essentially what takes place in a stage compressor, and the practical results are made evident by a study of the combined indicator diagrams shown in Fig. 2. In this case the air was compressed in the low-pressure cylinder to 23 pounds per square inch absolute. Here it was passed through an intercooler and reduced in volume to such an extent that the compression line was brought very near to the isothermal line. The subsequent compression in the high-pressure cylinder carried the pressure to 85 pounds per square inch, at which point the compression line was still much nearer the isothermal line than the adiabatic, although the compression in this cylinder was practically adiabatic.

After much experimenting the manufacturers of air compressors have fixed upon 80 pounds gage pressure as the maximum terminal pressure which can be most economically obtained in a single cylinder, and for pressures from 85 pounds up they have adopted compound compression in two, three and four stages, the number of stages increasing with the pressure, as follows:—

Either single or two stage for pressures of 80 to 100 pounds.

Two stage for pressures of 100 to 600 pounds. Either three or four stage for pressures above 600 pounds.

The accompanying table (Table 3) shows the loss due to heat by adiabatic compression as compared with isothermal compression, or compression without gain or loss of heat. Any beneficial effect due to jacket cooling is not considered, but in the figures for stage compression the air is supposed to be cooled to atmospheric temperature (60° F.) by the intercoolers.

Tables 4 and 5 show respectively the horse power developed in compressing a cubic foot of free air from atmospheric pressure (14.7 lbs.) to various gage pressures, and the per cent of work saved by compound compression compared with simple compression.

TABLE 3.

Showing the Maximum Loss of Work Due to Heat in Compressing Air from Atmospheric Pressure (14.7 Pounds) to Various Gage Pressures by Simple and Compound Compression.—"*Copyrighted by F. M. Hitchcock.*"

Initial Temperature of the Air in Each Cylinder Taken as 60° F (Jacket Cooling Not Considered)					
Gage Pressure	Number of Atmospheres of Compression	Maximum or Theoretical Per Cent. of Work Lost by Adiabatic Compression Compared With Isothermal Compression			
		One Stage	Two Stage	Three Stage	Four Stage
70	5.76	30.5	13.9	8.8	6.06
80	6.44	32.7	14.8	9.4	6.36
90	7.12	34.7	15.6	10.1	7.31
100	7.80	36.6	16.5	10.5	7.82
125	9.50	41.1	18.3	11.7	8.8
200	14.61	51.2	22.2	14.2	10.5
300	21.41	61.1	25.8	16.3	12.0
400	28.21	68.7	28.6	18.0	13.0
500	35.01	75.0	30.9	19.3	14.0
600	41.82	80.4	32.7	20.3	14.9
800	55.42	89.4	35.7	22.2	16.2
1,000	69.03	96.2	37.8	23.2	16.9
1,200	82.63	102.9	40.3	24.7	17.7
1,400	96.24	108.6	41.6	25.8	18.5
1,600	109.84	113.4	43.4	26.4	19.2
1,800	123.45	117.8	44.8	27.2	19.8
2,000	137.05	122.0	45.8	27.8	20.2

TABLE 4.

Horse Power Developed in Compressing a Cubic Foot of Free Air from Atmospheric Pressure (14.7 Pounds) to Various Gage Pressures.—"*Copyrighted by F. M. Hitchcock.*"

Initial Temperature of the Air in Each Cylinder Taken as 60° F (Jacket Cooling Not Considered)					
Gage Pressure	Isothermal Compression	Adiabatic Compression			
		One Stage	Two Stage	Three Stage	Four Stage
10	.0332	.0358			
20	.0551	.0623			
30	.0713	.0842			
40	.0842	.1026			
50	.0950	.1187			
60	.1042	.1331			
70	.1122	.1465	.128	.122	.119
80	.1194	.1585	.137	.131	.127
90	.1258	.1695	.146	.139	.135
100	.1317	.1800	.154	.146	.142
125	.1443	.2036	.171	.161	.157
150	.1549	.2244	.186	.174	.169
200	.1719	.2600	.210	.196	.190
300	.1964	.3164	.247	.229	.220
400	.2141	.3613	.276	.253	.242
500	.2279	.3889	.299	.272	.260
600	.2393	.4318	.318	.288	.275
700	.2489	.4608	.335	.302	.289
800	.2573	.4873	.349	.314	.299
900	.2649	.5114	.363	.325	.310
1,000	.2720	.5337	.375	.335	.318
1,200	.2829	.5742	.397	.353	.333
1,400	.2924	.6102	.414	.368	.347
1,600	.3012	.6427	.432	.381	.359
1,800	.3087	.6724	.447	.393	.369
2,000	.3154	.7003	.460	.403	.379

INTERCOOLERS.

Intercoolers are of various designs, some being constructed to cool the air by passing it through coils of pipe, or nests of tubes, contained in tanks kept filled with cool running water, and in others the water is passed through the coils or tubes, and the air made to circulate about them, being split into thin streams and forced back and forth over the pipes by means of baffle plates, Fig. 3. In any design, however, the object is to remove all the heat produced by one compression before the next is begun. The

TABLE 5.

Showing the Per Cent of Work Saved in Compressing Air from Atmospheric Pressure (14.7) to Various Gage Pressures by Compound Compression Compared with Simple Compression." *Copyrighted by F. M. Hitchcock.*"

Initial Temperature of the Air in Each Cylinder Taken as 60° F. (Jacket Cooling Not Considered)			
Gage Pressure	Two Stage	Three Stage	Four Stage
70	12.7	16.5	18.8
80	13.5	17.4	19.8
90	14.2	18.2	20.4
100	14.7	19.1	21.1
125	16.1	20.8	22.9
200	19.2	24.5	26.9
300	21.9	27.7	30.4
400	23.7	30.0	33.0
500	25.2	31.8	34.8
600	26.5	33.3	36.3
700	27.3	34.5	37.3
800	28.3	35.5	38.6
900	29.0	36.4	39.4
1,000	29.7	37.2	40.4
1,200	30.9	38.5	42.0
1,400	32.1	39.7	43.1
1,600	32.8	40.8	44.1
1,800	33.5	41.6	45.0
2.000	34.3	42.4	45.8

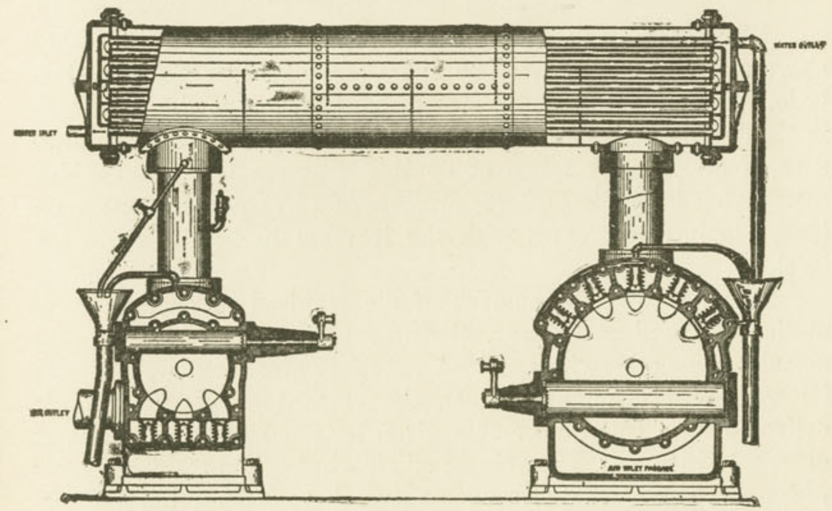


Fig. 3

best intercoolers are provided with a sufficient amount of cooling surface to accomplish this, so that the air is taken into each compression cylinder at practically initial temperature.

The amount of cooling surface that intercoolers should have depends upon the capacity of the compressor and the number of compressions in each cylinder, together with the initial temperature of the air and of the cooling water; but in ordinary two-stage compressors, working under average conditions, about one square foot of cooling surface should be provided for every 10 cubic feet of free air per minute. If the intercooler has an exceptionally generous allowance of cooling surface, and the cooling water is sufficiently cold, it is quite possible to cool the air passed through it to a temperature considerably lower than it had as free air when taken into the low-pressure cylinder. It is usual to figure on supplying a compressor with about one gallon of cooling water for every 50 cubic feet of free air it compresses.

Receiver intercoolers should always be used, as they are much more efficient than intercoolers of small capacity, because they allow the air more time for cooling between stages, and also decrease the losses due to wire-drawing. If the intercoolers do not have good efficiency, there is no economy derived from using stage compressors.

ALTITUDE COMPRESSION.

When compressors are operated at altitudes considerably above sea level it is necessary to make radically different calculations as to the volume of air required, owing to the difference in the density of the atmosphere or free air. The barometric pressure of air, usually taken at 30 inches at sea level, and which corresponds to an atmospheric pressure of 14.75 pounds per square inch, absolute, decreases with the increase in height above sea level.

When stating the amount of air required to operate pneumatic tools and machinery, the amount at sea level is always meant, unless otherwise specified. As free air, however, varies in its weight at different heights, the amount of compressed air delivered by a compressor at a given terminal pressure varies at different altitudes. The volume of air displaced by the compressor piston is, of course, the same under all conditions, but the efficiency of an air compressor of a given capacity, measured in

TABLE 6.

Showing the Effect of Altitude Upon Volume of Air When Compressed to Various Pressures.

"Copyrighted by F. M. Hitchcock."

Altitude in Feet	Barometric Pressure		Percentage of Efficiency of Air at Altitudes Considering Its Volume 10 Per Cent. at Sea Level					Percentage Increase in Volume Necessary to Give at Altitudes Efficiency Equivalent to Sea Level				
	Inches of Mercury	Pounds Per Square Inch	Gage Pressure (Pounds)					Gage Pressure (Pounds)				
			60	80	100	125	150	60	80	100	125	150
0	30.00	14.75	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0
1,000	28.88	14.20	96.9	96.8	96.7	96.6	96.5	3.2	3.3	3.4	3.5	3.6
2,000	27.80	13.67	94.0	93.8	93.6	93.4	93.3	6.4	6.6	6.8	7.1	7.2
3,000	26.76	13.16	91.1	90.7	90.5	90.3	90.1	9.7	10.2	10.5	10.7	10.9
4,000	25.76	12.67	88.3	87.8	87.5	87.2	87.0	13.2	13.9	14.2	14.7	14.9
5,000	24.79	12.20	85.6	84.9	84.0	84.2	84.0	16.8	17.8	18.2	18.7	19.0
6,000	23.86	11.73	82.9	82.1	81.7	81.2	81.0	20.6	21.8	22.4	23.1	23.4
7,000	22.97	11.30	80.3	79.5	78.9	78.5	78.2	24.5	25.8	26.7	27.4	27.8
8,000	22.11	10.87	77.7	76.9	76.3	75.8	75.4	28.7	30.0	31.0	31.9	32.6
9,000	21.29	10.46	75.2	74.3	73.7	73.2	72.8	32.9	34.6	35.6	36.6	37.4
10,000	20.49	10.07	72.8	71.8	71.2	70.6	70.2	37.3	39.4	40.4	41.6	42.4

delivered compressed air, decreases rapidly with the increase in altitude.

As a matter of fact, however, this difference is partially compensated for by the fact that the compressed air motor discharges against a lower pressure, thus securing practically the same ratio of expansion in both cases, provided the air could be used expansively. Usually it is not advisable to permit of much expansion, owing to the freezing at the exhaust. If reheaters are used, however, considerable expansion may be effected.

Mr. F. M. Hitchcock has written authoritatively upon air compression at altitudes, and the tables shown herewith were calculated by him and are reproduced by his permission. The first table (Table 6) is derived from the following formula, which represents the relation of the volume of air at an altitude to that at sea level when compressed to a given pressure.

$$v_1 : v_2 : : 1+\frac{P}{P_2} : 1+\frac{P}{P_1}$$

in which

v_1=volume of free air at sea level.
v_2= " " " altitude.
P_1=atmospheric pressure at sea level.
P_2= " " altitude.
P =gage pressure at which air is delivered.

Table 7 gives the horse power required to compress one cubic foot of free air at various altitudes from atmospheric pressures to gage pressures in one and two stages. At sea level it is advantageous to compress air to 85 pounds or over in two or more stages. Owing to the fact, however, that air is of less density at high altitudes, the number of compressions that are necessary for the required gage pressure are increased, and there is, therefore, far more economy in compounding at high altitudes than at sea level. For the same reason it pays to compound at altitudes for lower pressures than at sea level.

As an illustration of the use of the tables, consider that 1000 cubic feet of free air is compressed to 80 pounds at sea level by

TABLE 7.

Horse Power Developed in Compressing a Cubic Foot of Free Air at Various Altitudes from Atmospheric Pressure to Various Gage Pressures.—"*Copyrighted by F. M. Hitchcock.*"

Initial Temperature of the Air in Each Cylinder Taken as 60° F. (Jacket Cooling Not Considered)										
Altitude in Feet	Barometric Pressure		Horsepower Developed							
			Simple Compression			Two-Stage Compression				
	Inches of Mercury	Pounds Per Square Inch	Gage Pressure (Pounds)			Gage Pressure (Pounds)				
			60	80	100	60	80	100	125	150
0	30.00	14.75	.1333	.1586	.1804	.1177	.1374	.1535	.1708	.1859
1,000	28.88	14.20	.1314	.1561	.1774	.1158	.1350	.1508	.1675	.1820
2,000	27.80	13.67	.1295	.1536	.1744	.1139	.1324	.1478	.1641	.1781
3,000	26.76	13.16	.1277	.1512	.1714	.1118	.1298	.1449	.1607	.1742
4,000	25.76	12.67	.1259	.1489	.1686	.1098	.1273	.1422	.1574	.1707
5,000	24.79	12.20	.1239	.1465	.1657	.1079	.1250	.1391	.1541	.1670
6,000	23.86	11.73	.1219	.1440	.1628	.1059	.1225	.1362	.1510	.1634
7,000	22.97	11.30	.1199	.1416	.1599	.1041	.1203	.1336	.1478	.1598
8,000	22.11	10.87	.1181	.1391	.1571	.1020	.1181	.1308	.1445	.1563
9,000	21.29	10.46	.1163	.1367	.1543	.1001	.1156	.1281	.1415	.1529
10,000	20.49	10.07	.1144	.1345	.1516	.0984	.1133	.1254	.1384	.1493

TABLE 8.

Showing the Effect of Altitude Upon the Horse Power Developed in Compressing Air to Various Pressures.

(Simple Compression).

Copyrighted by F. M. Hitchcock.

Altitude in Feet	Barometric Pressure		Per Cent. of Horsepower Required to Compress Same Piston Displacement Compared with Sea Level			Per Cent. Decrease in Horsepower Required to Compress Same Piston Displacement Compared with Sea Level			Per Cent. Increase in Horsepower Required to Compress Volume of Air Equivalent in Effect to a Given Volume at Sea Level
	Inches of Mercury	Pounds Per Square Inch	Gage Pressure (Pounds)			Gage Pressure (Pounds)			
			60	80	100	60	80	100	
0	30.00	14.75	100.0	100.0	100.0	0.0	0.0	0.0	0.0
1,000	28.88	14.20	98.6	98.4	98.3	1.4	1.6	1.7	1.7
2,000	27.80	13.67	97.2	96.9	96.7	2.8	3.1	3.3	3.3
3,000	26.76	13.16	95.8	95.3	95.0	4.2	4.7	5.0	5.1
4,000	25.76	12.67	94.5	93.9	93.5	5.5	6.1	6.5	6.8
5,000	24.79	12.20	93.0	92.4	91.9	7.0	7.6	8.1	8.6
6,000	23.86	11.73	91.5	90.8	90.2	8.5	9.2	9.8	10.5
7,000	22.97	11.30	90.0	89.3	88.6	10.0	10.7	11.4	12.2
8,000	22.11	10.87	88.6	87.7	87.1	11.4	12.3	12.9	14.1
9,000	21.29	10.46	87.2	86.2	85.5	12.8	13.8	14.5	16.0
10,000	20.49	10.07	85.8	84.8	84.0	14.2	15.2	16.0	18.0

simple compression. The horse power developed is 1000x.158 (Table 7)=158. Considering the compression to be at an altitude of 10,000 feet, from Table 6 it is seen that the volume must be increased 39.4 per cent in order that the compressed air at the altitude may be equivalent in effect to that at sea level. In other words, a volume of 1394 cubic feet of free air is required. The horse power factor for simple compression to 80 pounds at 10,000 feet altitude is seen to be 0.134 (Table 7), so that 1394 feet x 0.134=186 horse power is required for the same effect. This may also be obtained by multiplying the horse power required at sea level (158) by the percentage of increase given in the right-hand column of Table 8 (0.18).

The figures for horse power given in Table 7 do not include friction losses, for which 10 to 15 per cent should be added, depending upon the efficiency of the compressor used. In connection with the air end, it should be borne in mind that steam-actuated compressors exhaust into lower atmospheric pressure at altitudes, so that the back pressure is less; therefore, for the same steam pressure as at sea level there is a gain in the net mean effective pressure obtainable from the steam, which should be considered in designing steam-actuated compressors for use in high altitudes.

THE COMPRESSED AIR POWER PLANT.

Concentration and centralization in the generation of power are now the standard practice in all industries, and the central compressed air power plant is, therefore, of considerable interest, as it is a comparatively recent departure in compressed air work, and is receiving widespread attention. For, while compressed air as a means for transmission of power is by no means new, it is only within the last few years that the central air compressing plant for general power purposes has become a recognized feature of industrial economy.

Central compressed air power plants may be classed under two headings:—

Temporary Plants.
Permanent Plants.

The former are made up largely of compressed air installations for contractors, and comprise only such apparatus as may be easily transported and erected. In selecting a compressor for such a plant it is first necessary to know the number of cubic feet of free air per minute required.

The reader has probably noticed the extensive number of tables contained in this article, and in the section devoted to formulas and tables he will find a great many more. The authors believe that too much emphasis cannot be laid upon the value of tabulated data in connection with compressed air work, and it has been their desire to present a sufficient array of tables to enable anyone to figure out his own requirements.

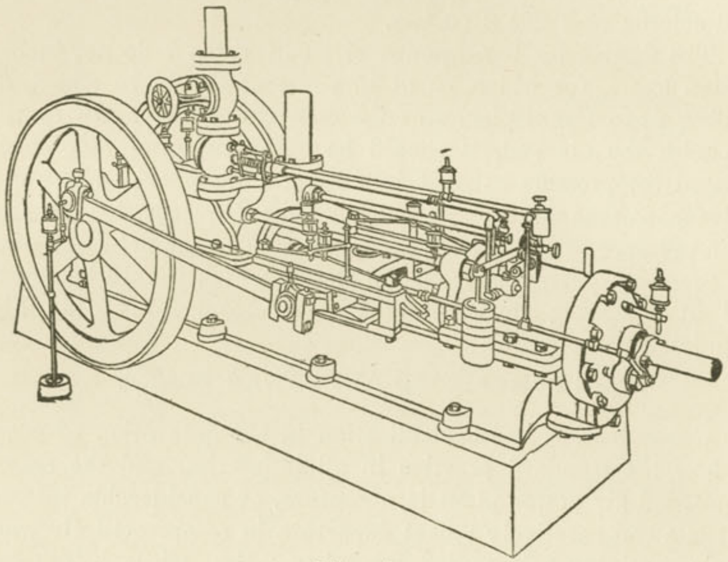


Fig. 4

After ascertaining from tables, therefore, the amount of air required, it is advisable to select a compressor of considerably larger capacity; first, because practically all air compressors are rated at higher speeds than it is advisable to operate them; and, secondly, because all builders of air compressors rate their machines by "piston displacement." In other words, if a machine is rated to deliver 300 cubic feet of free air per minute, it means that this is the volume which the piston displaces per minute at rated speed and *not* the actual quantity of air delivered. An allowance of at least 10 per cent should be made for the volumetric inefficiency of the compressor, and it is usually advisable to purchase a machine of 50 per cent greater capacity than the work in hand requires in order that proper provision may be made for future growth in the plant.

Practically the only type of air compressors adapted for use in temporary plants is the straight-line type. This class of compressor, as may be seen from the illustration, is self-contained, supported on a single frame, easily transportable, does not require a special foundation, and may be quickly lined up and erected. Furthermore, machines of this class are strong, durable and simple in construction, are adapted to rough usage, and do not require the services of a skilled mechanic in the engine room.

In installing a temporary plant care should be taken to obtain cool air for the compressor, for every five degrees' reduction in temperature of the intake air means a gain of about 1 per cent in the volumetric efficiency of the compressor. Circulating water should be provided for the cylinder jackets, and, if it is desired to economize in the use of water, water heated in the compressor may be used to feed the boiler after leaving the compressor jacket.

Before leaving the subject of the straight-line air compressor, it might be well to say a few words regarding the valve gears in use on these machines. As a general rule the steam cylinders, especially on the larger machines, are fitted with Meyer cut-off valves, smaller machines being fitted with plain slide valves. The air end of the compressor, however, presents a variety of valve types, a common one being horizontal poppet valves for both inlet and outlet. Some makes of straight-line compressors are fitted with Corliss air inlet valves and poppet outlet valves.

Straight-line air compressors are sometimes constructed with two-stage air cylinders, arranged in tandem and with Corliss steam valve gear. There is but little demand for such machines, however, and they are not to be commended, for, if the requirements of the plant point to the installation of a two-stage machine, the duplex type is much more efficient than the straight-line, owing to the fact that the load is more evenly distributed, thereby giving higher economy in compression, better equalizing of the strains in the machine and better regulation. Furthermore, if one is to pay the higher price for a two-stage straight-line machine fitted with

Corliss valves, it would be as well to spend a little more and obtain a duplex compressor..

PERMANENT PLANTS.

Permanent compressed air power plants should represent all that is best in compressed air practice. As a matter of fact, very few of them do, especially the plants in coal mines, where fuel is

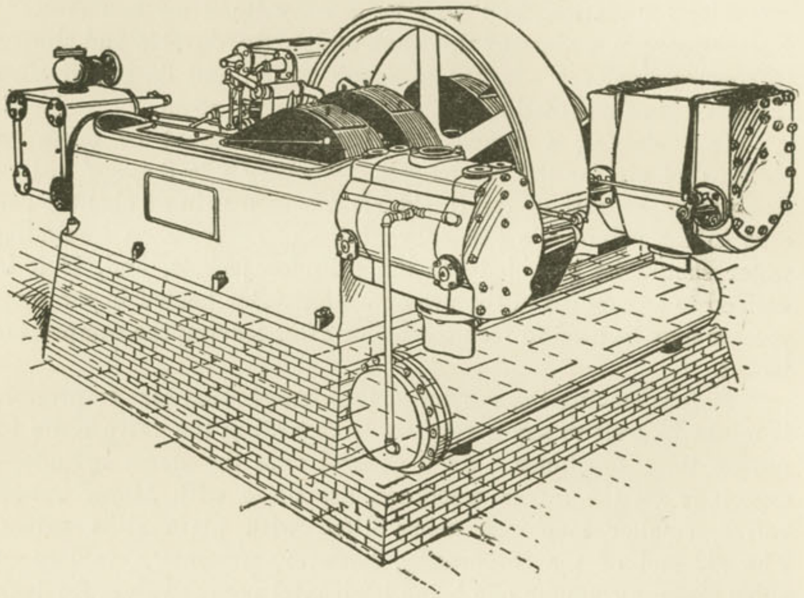


Fig. 5

cheap. This condition is to be regretted, as it acts as a handicap to compressed air and creates a false impression of its economy and efficiency. The permanent compressed air power plant should be fitted with only the latest and most economical compressors and operated condensing. The two-stage compressor is, therefore, the best machine for this service and should be fitted with compound steam cylinders, if the steam pressure is high enough to warrant it. Such a machine will be very economical of steam and will require but slight attention, the air regulator governing the speed to conform to variations in load.

Compressors for use in permanent plants are constructed in a variety of styles and types and may be classed as follows:—

CORLISS VALVE GEAR ON STEAM CYLINDERS.

Style of Compressor	Approximate Water Rate per I. H. P. Per Hour Condensing	Approximate Water Rate per I. H. P. Per Hour Non-Condensing
Two-Stage Air with Compound Steam Cylinders	13—18	22—25
" " " " Duplex " "	22—25	25—30
Duplex " " Compound " "	13—18	22—25
" " " Duplex " "	22—25	25—30

MEYER CUT-OFF VALVE GEAR ON STEAM CYLINDERS.

Style of Compressor	Approximate Water Rate per I. H. P. Per Hour Condensing	Approximate Water Rate per I. H. P. Per Hour Non-Condensing
Two-Stage Air with Compound Steam Cylinders	22—25	25—28
" " " " Duplex " "	26—30	32—35
Duplex " " Compound " "	22—25	25—28
" " " Duplex " "	26—30	32—35

Small machine shops are generally fitted with belt-driven compressors, or either electric-motor or gas engine-driven machines. The water rates given above are approximate only, and are the average of a great many tests. In some individual cases differences of from two to four pounds occurred, but the authors believe that they are close enough for all practical purposes and that they represent performances under ordinary conditions. It will be noted that the Corliss compressors are rated at a lower steam consumption than the Meyer valve machines.

CARE OF COMPRESSORS.

Lubrication. The proper lubrication of air compressors is most important, as air cylinders do not require oil either in quality or quantity as do steam cylinders. What is good for one is bad for the other. A steam cylinder needs oil of low flash point and in large quantities, as the tendency of wet steam is to wash the oil out of the cylinder. Not so with air; there is no washing tendency and very little oil will last a long time. This oil should be of the best quality obtainable and of a high flash point. It should be a non-coking oil, that is, when evaporated on a piece of hot metal it should not leave a deposit of carbon. This is a point which has been very much neglected, and this neglect is responsible for much waste of money and, what is worse, for explosions, which destroy property and threaten lives.

The actual amount of oil which should be used in an air cylinder is one-quarter of that which should be used in a steam cylinder of the same size. This might be considered a maximum, as very much less will often suffice, especially where the oil is of the best quality. Too much oil, where there is a coking tendency, results in the choking and gumming of valves and ports. A discharge valve may stick through coking, in which case it will admit some of the hot compressed air into the cylinder against the receding piston, which upon the return stroke is compressed and carried to a temperature beyond the flashing point.

Cleaning Valves. Sometimes when discharge valves give trouble they are cleaned by injecting kerosene; this is a fatal error. Kerosene should never be used in the air cylinder, but, instead, the oil-cups should be filled with soap-suds, made preferably of soft soap, which should be fed into the cylinder; the compressor should be run on soap-suds instead of oil for a day each week, care being taken to feed oil for a half hour before shutting down, so that the parts may not be subject to rust, which is the only danger from soap-suds.

It is very good practice to keep an extra set of discharge valves on hand, as this enables the engineer at any time to replace those on the compressor with clean ones. The change may be accomplished in a very few minutes and the dirty valves may be thoroughly cleaned by the engineer at his leisure.

RECEIVERS.

Every compressed air power plant should be fitted with an adequate receiver, or, sometimes, several receivers, to take care of

the fluctuations in the air line and of the pulsations of the compressor. A receiver also gives the air a chance to deposit part of the moisture expelled through compression and prevents this water from being carried over into the air mains.

The proper size of receiver to handle a given quantity of compressed air may be ascertained by consulting the trade catalogs. In case, however, it is desired to determine this factor theoretically, it may be easily accomplished by the following method:—

1st. Determine the maximum capacity of the compressor per minute in free air (piston displacement per minute will do).

2d. Calculate what volume this air will occupy at the working pressure, and this will be the required volume of the receiver.

This is a very easy calculation to make, as the following example will illustrate:

Suppose the maximum piston displacement of compressor per minute is 65 cubic feet.

Working pressure=80 pounds (gage).

To determine the volume of 65 cubic feet of free air when compressed to 80 pounds' pressure, the following formula may be used:

$$V_2=\frac{14.7\ V_1}{P_2+14.7}$$

In which V_1=maximum piston displacement in cubic feet per minute=65.

P_2=working pressure (gage)=80 pounds.

V_2=volume of the air at the higher pressure.

Substituting in this formula we have:

$$V_2=\frac{14.7x65}{80+14.7}=10 \text{ cubic feet.}$$

This would be the volume of a receiver 18 inches in diameter and 6 feet long. It is therefore possible, by using the above formula, to determine approximately the minimum sized receiver necessary, but in making selection a larger one is preferable. There is no drawback in having the receiver too large; in fact, most troubles are caused by the receiver being too small to overcome fluctuations in pressure and by not allowing the air to remain stationary long enough to cool and to deposit part of its moisture.

AFTERCOOLERS.

It is often necessary to obtain "dry" air from the compressor plant. This is notably the case in railway yards where compressed air is used for operating switches and signals. In this work the pipes are laid horizontally under the ground, and there is usually no point at which entrained moisture may be allowed to accumulate and be drained off. Furthermore, the pipes are small and the switch mechanisms so delicate that any water carried into them would be liable to cause trouble. "Dry" air is secured by means of an aftercooler, or a receiver fitted with pipes through which cold water is circulated in the same manner as in an intercooler. Sometimes, however, aftercoolers consist simply of a nest of pipes exposed to the atmosphere, and the compressed air is led through them on its way to the receiver.

Aftercoolers may be installed at slight expense and form a very valuable addition to a compressed air plant where the air is used in operating pneumatic tools and other delicate appliances.

REHEATERS.

It has already been shown that air when heated expands. It is, therefore, evident that if compressed air be heated just before it enters a motor cylinder its volume will be increased and more work may be obtained from it. By reheating air, therefore, some of the work which was lost in compression, due to inefficient cooling, may be regained and the efficiency of the cycle increased. It pays then to use a reheater. Just how much it pays is still a matter open to discussion; it depends, for one thing, on the cost of fuel. It is certain, however, that theoretically the cost in heat units of the volume of air produced by reheating is less than one-eighth of the cost of the same volume produced by compression. As a general rule, a gain in efficiency of from 15 to 20 per cent may be counted upon as a result of reheating. In order, however, that reheating may be effective, the reheater should be placed very close to the motor cylinder, as air cools very rapidly when transmitted through pipes exposed to the atmosphere.

TRANSMISSION.

There are numerous formulas for the flow of compressed air in pipes, of which D'Arcy's is the most generally used. In this

formula D=cubic feet of compressed air discharged per minute under the terminal pressure from a pipe of any diameter and length; d=inside diameter of pipe in inches; p=allowable drop in pressure during transmission; w=density of the compressed air at the initial pressure; l=length of pipe in feet; c=a coefficient found by experiment; then

$$D=c\sqrt{\frac{d^5 \times p}{w\,l}}$$

The following tables give values for $w, \sqrt{w}$, and for $c\sqrt{d^5}$, which will greatly facilitate the making of calculations with D'Arcy's formula:

TABLE 9.

Nominal Diameter Pipe Inches	Actual Diameter Inches	Actual Area	D'Aarcy's Coefficient C	$C\sqrt{d^5}$	Nominal Diameter Inches	Actual Diameter Inches	Actual Area	D'Arcy's Coefficient C	$C\sqrt{d^5}$
1	2	3	4	5	1	2	3	4	5
1	1.048	0.8626	45.3	45.3	5	5.025	19.99	58.4	3298
1¼	1.38	1.49	47.8	86.0	6	6.065	28.888	59.5	5273
1½	1.61	2.03	50.3	138.3	7	7.023	38.738	60.1	7817
2	2.067	3.356	52.7	297	8	7.98	50.04	60.7	10988
2½	2.46	4.78	54.4	537	9	8.937	62.73	61.2	14872
3	3.026	7.388	56.1	876	10	10.019	78.839	61.8	19480
3½	3.56	9.83	56.9	1,304	12	12.00	113.098	62.1	30926
4	4.026	12.73	57.8	1,856	14	14.25	159.485	62.3	45699
4½	4.5	15.93	58.1	2,492	16	16.4	211.24	62.6	64102

TABLE 10.

Gage Pressure	Ratio of Pressures $\frac{P2}{P1}$	W Weight of One Cubic Foot at Pressure Column 1.	$\sqrt{W}$	Gage Pressure	Ratio of Pressure $\frac{P2}{P1}$	W Weight of One Cubic Foot at Pressure Column 1.	$\sqrt{W}$
1	2	3	4	1	2	3	4
0	1.00	0.0761	0.276	55	4.74	0.3607	0.600
5	1.34	.1020	.319	60	5.08	.3866	.622
10	1.68	.1278	.358	65	5.42	.4125	.642
15	2.02	.1537	.392	70	5.76	.4383	.662
20	2.36	.1796	.424	75	6.10	.4642	.681
25	2.70	.2055	.453	80	6.44	.4901	.700
30	3.04	.2313	.481	85	6.78	.5160	.718
35	3.38	.2572	.507	90	7.12	.5418	.736
40	3.72	.2831	.532	95	7.46	.5677	.753
45	4.06	.3090	.556	100	7.80	.5936	.770
50	4.40	.3348	.578				

Mr. Lucius I. Wightman has calculated a set of tables for the transmission of compressed air at different pressures. Two of these tables are given herewith and are sufficient for most cases, compressed air being generally used at pressures of from 80 to 100 pounds.

Valves and bends should be considered as adding to the length of the pipe line and should be taken into account in making calculations. The following tables may be used to advantage for this purpose:

TABLE 11.

LOSS OF PRESSURE IN POUNDS BY FRICTION IN TRANSMISSION OF AIR THROUGH PIPES 1000 FEET LONG

INITIAL AIR PRESSURE 80 POUNDS GAGE

By L. I. Wightman

DELIVERY IN CUBIC FEET OF COMPRESSED AIR PER MINUTE (first header row) / EQUIVALENT DELIVERY IN CUBIC FEET OF FREE AIR PER MINUTE (second header row)

Size of Pipe Inches	7.74	11.3	15.2	19.4	23.2	27.2	31.0	38.7	46.5	54.2	62.0	69.7	77.4	92.9	108.2
	50	75	100	125	150	175	200	250	300	350	400	450	500	600	700
1	14.31	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1¼	3.96	8.46	15.31	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1½	1.53	3.26	5.92	9.64	13.79	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2	.33	.71	1.28	2.09	2.99	4.09	5.34	8.32	12.01	. .	. .	. .	. .	. .	. .
2½	.10	.21	.39	.64	.91	1.25	1.63	2.54	3.67	4.99	6.53	8.25	10.81	. .	. .
3	.03	.08	.14	.24	.34	.47	.61	.96	1.38	1.88	2.45	3.13	3.83	5.61	7.46
3½	.01	.03	.06	.11	.15	.21	.27	.43	.62	.84	1.11	1.40	1.73	2.46	3.37
4	. .	.01	.03	.05	.07	.10	.13	.21	.30	.41	.54	.69	.85	1.22	1.66
4½	. .	. .	.02	.03	.04	.06	.07	.12	.17	.23	.30	.38	.47	.68	.92
5	. .	. .	.01	.01	.02	.03	.04	.07	.09	.13	.17	.22	.27	.39	.53
6	. .	. .	. .	. .	.01	.01	.01	.02	.03	.05	.06	.08	.10	.15	.20
7	. .	. .	. .	. .	. .	. .	. .	.01	.01	.02	.03	.04	.05	.06	.09
8	. .	. .	. .	. .	. .	. .	. .	. .	. .	.01	.01	.01	.02	.03	.04
9	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	.01	.02	.02
10	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	.01	.01
12	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
14	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
16	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .

Size of Pipe Inches	124.0	139.5	152	232	310	387	465	542	620	697	774
	800	900	1000	1500	2000	2500	3000	3500	4000	4500	5000
1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1¼	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1½	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2½	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
3	9.86	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
3½	4.42	5.61	6.64	15.41	. .	. .	. .	. .	. .	. .	. .
4	2.18	2.77	3.29	7.62	13.62	. .	. .	. .	. .	. .	. .
4½	1.19	1.54	1.82	4.24	7.58	11.79	. .	. .	. .	. .	. .
5	.69	.88	1.04	2.43	4.32	6.88	9.72	13.25	. .	. .	. .
6	.27	.34	.40	.95	1.69	2.64	3.79	5.27	6.78	8.54	10.55
7	.12	.15	.18	.43	.77	1.19	1.73	2.35	3.07	3.89	4.79
8	.06	.08	.09	.22	.39	.60	.87	1.19	1.55	1.97	2.46
9	.03	.04	.05	.12	.21	.33	.48	.65	.85	1.08	1.33
10	.02	.02	.03	.06	.12	.19	.28	.37	.49	.66	.77
12	.01	.01	.01	.02	.04	.07	.11	.15	.19	.25	.30
14	. .	. .	. .	.01	.02	.03	.05	.06	.09	.11	.14
16	. .	. .	. .	. .	.01	.01	.02	.03	.04	.05	.07

TABLE 12.

LOSS OF PRESSURE IN POUNDS BY FRICTION IN TRANSMISSION OF AIR THROUGH PIPES 1000 FEET LONG

INITIAL AIR PRESSURE 100 POUNDS GAGE

By L. I. Wightman

Size of Pipe Inches	DELIVERY IN CUBIC FEET OF COMPRESSED AIR PER MINUTE: 6.41	9.61	12.81	15.81	19.22	22.39	25.62	31.62	38.44	44.78	51.24	57.65	63.24	76.88
	EQUIVALENT DELIVERY IN CUBIC FEET OF FREE AIR PER MINUTE: 50	75	100	125	150	175	200	250	300	350	400	450	500	600
1	11.89	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1¼	3.29	7.42	13.20	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1½	1.28	2.87	5.11	7.75	11.42	. .	. .	. .	. .	. .	. .	. .	. .	. .
2	.27	.62	1.15	1.68	2.48	3.36	4.43	6.72	9.95	13.41	. .	. .	. .	. .
2½	.08	.19	.34	.52	.76	1.03	1.36	2.06	3.04	4.11	5.40	6.85	8.21	12.21
3	.03	.07	.12	.19	.29	.39	.51	.77	1.14	1.54	2.06	2.57	3.08	4.58
3½	.01	.03	.05	.08	.13	.17	.23	.35	.51	.69	.92	1.16	1.39	2.14
4	. .	.01	.02	.04	.06	.09	.12	.17	.25	.34	.45	.57	.68	1.03
4½	. .	. .	.01	.02	.03	.04	.06	.09	.14	.19	.25	.32	.38	.57
5	. .	. .	. .	.01	.02	.03	.04	.05	.08	.11	.15	.18	.22	.33
6	. .	. .	. .	. .	.01	.01	.02	.02	.03	.04	.05	.07	.08	.12
7	. .	. .	. .	. .	. .	. .	.01	.01	.01	.02	.03	.03	.04	.05
8	. .	. .	. .	. .	. .	. .	. .	. .	. .	.01	.01	.02	.02	.03
9	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	.01	.01	.02
10	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	.01
12	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
14	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
16	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .

Size of Pipe Inches	DELIVERY IN CUBIC FEET OF COMPRESSED AIR PER MINUTE: 89.56	102.5	115.3	126.5	192.2	256.2	316.2	384.4	447.8	512.4	576.5	632.4
	EQUIVALENT DELIVERY IN CUBIC FEET OF FREE AIR PER MINUTE: 700	800	900	1000	1500	2000	2500	3000	3500	4000	4500	5000
1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1¼	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1½	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2½	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
3	6.19	8.13	10.23	12.39	. .	. .	. .	. .	. .	. .	. .	. .
3½	2.79	3.67	4.64	5.60	12.81	. .	. .	. .	. .	. .	. .	. .
4	1.38	1.81	2.29	2.76	6.68	11.35	. .	. .	. .	. .	. .	. .
4½	.77	1.00	1.27	1.23	3.51	6.61	9.56	14.04	. .	. .	. .	. .
5	.44	.57	.76	.88	2.03	3.62	5.51	8.11	10.95	14.48	. .	. .
6	.17	.22	.28	.34	.78	1.41	2.14	3.16	4.26	5.59	7.04	8.51
7	.07	.10	.13	.16	.36	.67	.97	1.44	1.93	2.55	3.22	3.88
8	.04	.05	.06	.08	.18	.33	.49	.76	.98	1.30	1.64	1.98
9	.02	.03	.04	.04	.09	.18	.27	.39	.53	.72	.89	1.07
10	.01	.02	.02	.03	.05	.10	.16	.23	.31	.41	.52	.63
12	. .	.01	.01	.01	.02	.04	.06	.09	.12	.16	.21	.25
14	. .	. .	. .	. .	.01	.02	.03	.04	.05	.07	.09	.11
16	. .	. .	. .	. .	. .	.01	.01	.02	.03	.04	.05	.06

Globe Valves, Tees and Elbows.

The reduction of pressure produced by globe valves is the same as that caused by the following additional lengths of straight pipe, as calculated by the formula:

$$\text{Additional length of pipe} = \frac{114 \times \text{diameter of pipe}}{1 + (36 \div \text{diameter})}$$

Diameter of pipe	1	1½	2	2½	3	3½	4	5	6 inches
Additional length	2	4	7	10	13	16	20	28	36 feet
	7	8	10	12	15	18	20	22	24 inches
	44	53	70	88	115	143	162	181	200 feet

The reduction of pressure produced by elbows and tees is equal to two-thirds of that caused by globe valves. The following are the additional lengths of straight pipe to be taken into account for elbows and tees. For globe valves multiply by $\frac{3}{2}$:

Diameter of pipe	1	1½	2	2½	3	3½	4	5	6 inches
Additional length	2	3	5	7	9	11	13	19	24 feet
	7	8	10	12	15	18	20	22	24 inches
	30	35	47	59	77	96	108	120	134 feet

These additional lengths of pipe for globe valves, elbows and tees must be added in each case to the actual lengths of straight pipe. Thus a 6-inch pipe, 500 feet long, with 1 globe valve, 2 elbows and 3 tees, would be equivalent to a straight pipe 500+36 +(2×24+(3×24)=656 feet long.

Compressed air transmission lines should preferably be laid above the ground, as in this way leaks are more easily located and corrected. Great care should be taken to insure *absolutely tight* joints, as more money can be lost through a few seemingly insignificant leaks in the line than can be saved by the utmost refinement of compound steam and air cylinders. Long turn elbows should always be used and proper expansion joints inserted at frequent intervals. Every low point in the line should contain a trap for the drainage of entrained moisture and all valves should be of the gate pattern, as these offer less resistance to flow.

COMPRESSED AIR FORMULAS AND TABLES.

Pi=absolute intake pressure in pounds per square inch.

Pt=absolute discharge pressure in pounds per square inch.

N=number of stages in which compression is to be accomplished.

M. E. $P._t$=theoretical mean effective pressure.

H. $P._f$=theoretical horse power.

H. $P._f$=horse power including 15 per cent friction.

E=altitude in feet.

TABLE 13.

Horse-Power and Mean Effective Pressure Developed in Compressing One Cubic Foot of Free Air From Atmospheric Pressure to Various Gage Pressures. Initial Temperature of Air in Each Cylinder 60° F. Jacket Cooling Not Considered.

Gage Pressure	Atmospheres Compressed	Isothermal Compression		Adiabatic Compression								Percent. of Power Saved by Two-Stage over Single-Stage Compression
				Single-Stage				Two-Stage				
		M. E. P.	Horse-Power	M. E. P. Theoretical	M. E. P. 15% Friction Included	H. P. Theoretical	H. P. 15% Friction Included	M. E. P. Theoretical	M. E. P. 15% Friction Included	H. P. Theoretical	H. P. 15% Friction Included	
5	1.34	4.13	.018	4.46	5.12	.019	.022	......	......	....	...	....
10	1.68	7.57	.033	8.21	9.44	.036	.041	......	......	....	....	....
15	2.02	11.02	.048	11.46	13.17	.050	.057	......	......	....	....	....
20	2.36	12.62	.055	14.30	16.44	.062	.071	......	......	....	....	....
25	2.70	14.68	.064	16.94	19.47	.074	.085	......	......	....	....	....
30	3.04	16.30	.071	19.32	22.21	.084	.096	......	......	....	....	....
35	3.38	17.90	.078	21.50	24.72	.094	.108	......	......	....	....	....
40	3.72	19.28	.084	23.53	27.05	.103	.118	......	......	....	....	....
45	4.06	20.65	.090	25.40	29.21	.111	.127	......	......	....	....	....
50	4.40	21.80	.095	27.23	31.31	.119	.136	......	......	....	....	....
55	4.74	22.95	.100	28.90	33.23	.126	.145	......	......	....	....	....
60	5.08	23.90	.104	30.58	35.10	.133	.153	......	......	....	...	....
65	5.42	24.80	.108	32.10	36.91	.140	.161	......	......	...	....	....
70	5.76	25.70	.112	33.57	38.59	.146	.168	29.81	33.71	.128	.147	12.3
75	6.10	26.62	.116	35.00	40.25	.153	.175	30.43	34.99	.133	.153	13.1
80	6.44	27.52	.120	36.36	41.80	.159	.182	31.44	36.15	.137	.158	13.6
85	6.78	28.21	.123	37.63	43.27	.164	.189	32.46	37.22	.142	.163	13.7
90	7.12	28.93	.126	38.89	44.71	.169	.195	33.37	38.36	.145	.167	14.2
95	7.46	29.60	.129	40.11	46.12	.175	.201	34.28	39.41	.149	.172	14.8
100	7.80	30.30	.132	41.28	47.46	.180	.207	35.20	40.48	.153	.176	15.0
110	8.48	31.42	.137	43.56	50.09	.190	.218	36.82	42.34	.161	.185	15.2
120	9.16	32.69	.142	45.69	52.53	.199	.229	38.44	44.20	.168	.193	15.5
130	9.84	33.75	.147	47.72	54.87	.208	.239	39.86	45.83	.174	.200	16.3
140	10.52	34.67	.151	49.64	57.08	.216	.249	41.28	47.46	.180	.207	16.6
150	11.20	35.59	.155	51.47	59.18	.224	.258	42.60	48.99	.186	.214	16.9
160	11.88	36.30	.158	53.70	61.80	.234	.269	43.82	50.39	.191	.219	18.4
170	12.56	37.20	.162	55.60	64.00	.242	.278	44.93	51.66	.196	.225	19.1
180	13.24	38.10	.166	57.20	65.80	.249	.286	46.05	52.95	.201	.231	19.3
190	13.92	38.80	.169	58.80	67.70	.256	.294	47.16	54.22	.206	.236	19.5
200	14.60	39.50	.172	60.40	69.50	.263	.303	48.18	55.39	.210	.241	20.1
250	18.00	42.70	.186	67.00	77.10	.292	.336	52.84	60.76	.230	.264	21.2
300	21.40	45.30	.197	72.80	83.80	.317	.365	56.70	65.20	.247	.283	22.1
350	24.80	47.30	.206	78.50	90.40	.342	.394	60.15	69.16	.262	.301	23.4
400	27.20	49.20	.214	83.50	96.20	.364	.418	63.19	72.65	.276	.317	24.2
450	31.70	51.20	.223	87.50	100.80	.381	.438	65.93	75.81	.287	.329	24.7
500	35.00	52.70	.229	91.40	105.20	.398	.458	68.46	78.72	.298	.342	25.1
1000	69.04	62.40	.272	122.90	141.50	.535	.615	86.80	100.00	.378	.435	29.4
1200	82.65	65.00	.283	132.00	151.80	.574	.661	91.30	105.00	.397	.456	30.8
1400	96.25	67.00	.292	140.00	161.00	.610	.702	95.50	109.90	.416	.478	31.8
1600	109.80	69.10	.301	147.50	169.00	.648	.740	98.80	113.80	.430	.495	33.1
1800	123.40	71.00	.309	154.00	177.00	.672	.773	102.20	117.70	.445	.512	33.9
2000	137.10	72.30	.315	160.50	185.00	.700	.805	104.50	120.20	.455	.524	35.0

For Isothermal or Adiabatic Compression.

Horse power=0.00436 M. E. $P._t$ **(A)**

Isothermal Compression for any number of stages.

$$\text{M. E. P.}_t = 2.3\ Pi\ log\left(\frac{Pt}{Pi}\right) \quad \textbf{(B)}$$

Adiabatic Compression.

For one stage

$$\text{M. E. P.}_t = 3.45\ Pi\left[\left(\frac{Pt}{Pi}\right)^{0.29} - 1\right] \quad \textbf{(C)}$$

For two stages

$$\text{M. E. P.}_t = 6.90\ Pi\left[\left(\frac{Pt}{Pi}\right)^{0.145} - 1\right] \quad \textbf{(D)}$$

For three stages

$$\text{M. E. P.}_t = 10.35\ Pi\left[\left(\frac{Pt}{Pi}\right)^{0.097} - 1\right] \quad \textbf{(E)}$$

For four stages

$$\text{M. E. P.}_t = 13.80\ Pi\left[\left(\frac{Pt}{Pi}\right)^{0.0725} - 1\right] \quad \textbf{(F)}$$

For five stages

$$\text{M. E. P.}_t = 17.25\ Pi\left[\left(\frac{Pt}{Pi}\right)^{0.058} - 1\right] \quad \textbf{(G)}$$

In general

$$\text{M. E. P.}_t = 3.45\ \text{N}\ Pi\left[\left(\frac{Pt}{Pi}\right)^{\frac{0.29}{\text{N}}} - 1\right] \quad \textbf{(H)}$$

The following formulas were deduced by E. F. Schaefer, M. M. E., and published in *Compressed Air*, March, 1906:

Adiabatic Compression for Sea Level Conditions.

For one stage

$$H.\ P._t = 0.10163\ (Pt^{0.29} - 2.183) \qquad \textbf{(I)}$$

For two stages

$$H.\ P._t = 0.30043\ (Pt^{0.145} - 1.477) \qquad \textbf{(J)}$$

For three stages

$$H.\ P._t = 0.51319\ (Pt^{0.097} - 1.297) \qquad \textbf{(K)}$$

For four stages

$$H.\ P._t = 0.72983\ (Pt^{0.0725} - 1.216) \qquad \textbf{(L)}$$

In general

$$H.\ P._t = \frac{0.2218695\ N}{(14.75^{\frac{0.29}{N}})}\left[Pt^{\frac{0.29}{N}} - (14.75)^{\frac{0.29}{N}}\right] \qquad \textbf{(M)}$$

Adiabatic Compression for Altitude Conditions.

Single Stage.

For 60-pound Gage Pressure.

$$H.\ P._t = 0.1333 - 0.0000019E \qquad \textbf{(N)}$$

$$H.\ P._f = 0.1533 - 0.00000215E \qquad \textbf{(O)}$$

For 80-pound Gage Pressure.

$$H.\ P._t = 0.1586 - 0.0000024E \qquad \textbf{(P)}$$

$$H.\ P._f = 0.1824 - 0.00000275E \qquad \textbf{(Q)}$$

For 100-pound Gage Pressure.

$$H.\ P._t = 0.1804 - 0.0000029E \qquad \textbf{(R)}$$

$$H.\ P._f = 0.2075 - 0.00000325E \qquad \textbf{(S)}$$

Two Stages.

For 60-pound Gage Pressure.

$$H.\ P._t = 0.1177 - 0.0000038E \qquad \textbf{(T)}$$

$$H.\ P._f = 0.1354 - 0.0000022E \qquad \textbf{(U)}$$

For 80-pound Gage Pressure.

$$H.\ P._t = 0.1374 - 0.0000024E \qquad \textbf{(V)}$$

$$H.P._f = 0.1580 - 0.00000275E \qquad \textbf{(W)}$$

For 100-pound Gage Pressure.

$$H.P._t = 0.1535 - 0.0000028E \qquad \textbf{(X)}$$

$$H.P._f = 0.1765 - 0.0000032E \qquad \textbf{(Y)}$$

For 125-pound Gage Pressure.

$$H.P._t = 0.1708 - 0.00000325E \qquad \textbf{(AA)}$$

$$H.\ P._f = 0.1964 - 0.0000037E \qquad \textbf{(BB)}$$

For 150-pound Gage Pressure.

$$H.P._t = 0.1859 - 0.0000036E \qquad \textbf{(CC)}$$

$$H.\ P._f = 0.2138 - 0.0000042E \qquad \textbf{(DD)}$$

Stage Compression.

Condition for best proportion.

$$r_1 = r_2 = r_3 = rN\sqrt[N]{R.} \qquad \textbf{(EE)}$$

TABLE 14.

TABLE OF THE VOLUME OF FREE AIR REQUIRED FOR OPERATING HOISTING ENGINES

THE AIR COMPRESSED TO 60 POUNDS GAGE PRESSURE

Diameter of Cylinder Inches	Stroke Inches	Revolutions per Minute	Normal Horse-power	Actual Horse-power	Weight Lifted Single Rope	Cubic Feet of Free Air Required
Single Cylinder Hoisting Engine						
5	6	200	3	5.9	600	75
5	8	160	4	6.3	1000	80
6¼	8	160	6	9.9	1500	125
7	10	125	10	12.1	2000	151
8¼	10	125	15	16.8	3000	170
8½	12	110	20	18.9	5000	238
10	12	110	25	26.2	6000	330
Double Cylinder Hoisting Engine						
5	6	200	6	11.8	1000	150
5	8	160	8	12.6	1650	160
6¼	8	160	12	19.8	2500	250
7	10	125	20	24.2	3500	302
8¼	10	125	30	33.6	6000	340
8½	12	110	40	37.8	8000	476
10	12	110	50	52.4	10000	660
12¼	15	100	75	89.2		1125
14	18	90	100	125.		1587

TABLE 15.

Diameter of Cylinder, in Inches	1⅞	2¼	2¾	3⅛	3¼	3⅝	4⅛	5½
No. of Drills								
1	44	67	81	120	130	141	166	194
2	77	117	142	211	228	247	292	340
3	114	173	210	310	336	364	428	503
4	150	228	275	408	442	478	564	659
5	183	279	337	500	542	587	692	810
6	216	329	397	588	638	692	814	952
7	246	375	454	673	728	790	928	1,085
8	275	418	507	750	813	882	1,040	1 212
9	301	458	554	820	890	964	1,135	1,327
10	324	494	597	884	957	1,040	1,222	1,430
12	376	573	692	1,025	1,110	1,205	1,418	1,658
15	452	688	830	1,230	1,334	1,446	1,705	1,990
20	602	915	1,105	1,640	1,775	1,925	2,263	2,650
25	748	1,140	1,378	2,043	2,218	2,400	2,820	3,300
30	898	1,368	1,655	2,455	2,658	2,890	3,380	3,960
40	1,195	1,820	2,220	3,260	3,535	3,830	4,520	5,270
50	1,495	2,275	2,750	4,060	4,420	4,790	5,640	6,600

TABLE 16.

FACTORS FOR ALTITUDES.

Altitude in Feet Above Sea Level	Atmospheric Pressure Pounds Per Square Inch	Factors — Air Pressure at Drill: 60 Lbs.	70 Lbs.	80 Lbs.	90 Lbs.	100 Lbs.
Sea Level	14.75	.789	.894	1.000	1.105	1.211
1,000	14.20	.814	.923	1.033	1.142	1.252
2,000	13.67	.839	.952	1.066	1.179	1.296
3,000	13.16	.865	.983	1.102	1.220	1.338
4,000	12.67	.893	1.016	1.139	1.261	1.383
5,000	12.20	.922	1.049	1.176	1.303	1.431
6,000	11.73	.952	1.085	1.218	1.350	1.482
7,000	11.30	.982	1.119	1.257	1.395	1.534
8,000	10.87	1.015	1.157	1.300	1.443	1.586
9,000	10.46	1.049	1.198	1.347	1.491	1.642
10,000	10.07	1.083	1.236	1.390	1.542	1.695
11,000	9.70	1.119	1.279	1.439	1.599	1.760
12,000	9.34	1.157	1.322	1.488	1.656	1.824
13,000	8.98	1.197	1.370	1.543	1.716	1.889
14,000	8.65	1.236	1.415	1.594	1.775	1.956
15,000	8.32	1.279	1.465	1.652	1.840	2.028

TABLE 17.

FLOW OF AIR THROUGH AN ORIFICE IN CUBIC FEET OF FREE AIR PER MINUTE FLOWING FROM A ROUND HOLE IN RECEIVER INTO THE ATMOSPHERE

Diameter of Orifice Inches	Receiver Gage Pressure: 2 lbs.	5 lbs.	10 lbs.	15 lbs.	20 lbs.	25 lbs.	30 lbs.	35 lbs.	40 lbs.
1/64	.038	.0597	.0842	.103	.119	.133	.1[illegible]	.173	.19
1/32	.153	.242	.342	.418	.485	.54	.632	.71	.77
1/16	.647	.965	1.36	1.67	1.93	2.16	2.52	2.80	3.07
⅛	2.435	3.86	5.45	6.65	7.7	8.6	10.	11.2	12.27
¼	9.74	15.40	21.8	26.70	30.8	34.5	40.	44.7	49.09
⅜	21.95	34.60	49.	60.	69.	77.	90.	100.	110.45
½	39.00	61.60	87.	107.	123.	138.	161.	179.	196.35
⅝	61.00	96.50	136.	167.	193.	216.	252.	280.	306.80
¾	87.60	133.	196.	240.	277.	310.	362.	400.	441.79
⅞	119.50	189.	267.	326.	378.	422.	493.	550.	601.32
1	156.	247.	350.	427.	494.	550.	645.	715.	785.40
1¼	242.	384.	543.	665.	770.	860.	1000.		
1½	350.	550.	780.	960.					
2	625.	985.							

Diameter of Orifice Inches	45 lbs.	50 lbs.	60 lbs.	70 lbs.	80 lbs.	90 lbs.	100 lbs.	125 lbs.
1/64	.208	.225	.26	.295	.33	.364	.40	.486
1/32	.843	.914	1.05	1.19	1.33	1.47	1.61	1.97
1/16	3.36	3.64	4.2	4.76	5.32	5.87	6.45	7.85
⅛	13.4	14.50	16.8	19.0	21.2	23.50	25.8	31.4
¼	53.8	58.2	67.	76.	85.	94.	103.	125.
⅜	121.	130.	151.	171.	191.	211.	231.	282.
½	215.	232.	268.	304.	340.	376.	412.	502.
⅝	336.	364.	420.	476.	532.	587.	645.	785.
¾	482.	522.	604.	685.	765.	843.	925.	
⅞	658.	710.	622.	930.	1004.			
1	860.	930.						

TABLE 18.

Air Consumption of Pneumatic Tools.

CHIPPING HAMMERS Size Cylinder X Stroke	Cu. ft. of Free Air per Minute.
1 1/16 x 1 1/2	13
1 1/16 x 2	15
1 1/16 x 3	16
1 1/16 x 4	17
RIVETERS	
1 1/16 x 4	17
1 1/16 x 5	19
1 1/16 x 6	22
1 3/8 x 6	26
1 3/8 x 8	28
1 1/16 x 9	24

TABLE 19.

Dimensions and Air Consumption of Valveless Stone-working Tools.

Weight, pounds and ounces....................	1—3	1—14	3—12	5—4
Length over all, inches........................	5 1/2	6 1/2	7 3/4	8 1/4
Outside diameter, inches......................	1 1/8	1 5/16	1 11/16	1 15/16
Diameter of piston, inches....................	5/8	3/4	1	1 1/4
Total length of stroke..........................	7/16	1/2	5/8	3/4
Length of stroke to working point, inches.....	5/16	3/8	1/2	9/16
Air consumption, cubic feet per min..........	5.5	6.5	7.5	8.5

TABLE 20.

Air Required for the Operation of Piston Air Drills.

Style	Size	Wgt. Pounds	Length, inches	Length of feed, inches	Diam. from side to center of spindle, inches	Morse taper socket, inches	Square top socket, inches	Size twist drill will drive, inches	Size wood drill will drive, inches	Reaming, inches	Tapping, inches	Flue rolling, inches	R. P. M. at 80 pounds	Cu. ft. free air per min. at 80 pounds	Hose connection, inches
Reversible	1	27	19 5/8	3	3 5/8	3	—	1	—	3/4	3/4	—	220	20	1/2
Non-Reversible	2	48	20 5/8	4	4 3/8	3	9/16	1 1/4	—	1	1	—	290	25	3/4
" "	3	52	22 3/4	4	4 3/8	4	9/16	2 1/4	—	2	2	—	290	35	3/4
Reversible	4	70	23 1/4	4	5 1/4	4	9/16	3	—	2 1/2	2 1/2	4	170	45	3/4
"	11	27	14 1/8	—	3 5/8	—	—	—	2 1/2	-	-	—	350	20	1/2
"	12	48	20 5/8	4	4 3/8	3	9/16	1 1/4	4	1	1	2 1/2	275	25	3/4
"	13	52	22 3/4	4	4 3/8	4	9/16	2 1/2	—	2	2	3	235	35	3/4
"	21	27	19 5/8	3	3 5/8	2	—	7/8	—	1/2	1/2	—	350	20	1/2

PUMPING BY COMPRESSED AIR.

Compressed air, for a number of years, has been used for pumping water, usually in direct-acting pumps in mines. It is not economical, however, to use compressed air in pumps of this class, and one of the three systems described later can be used to much greater advantage.

To find the amount of air and pressure required to pump a given quantity of water a given height in a direct-acting pump, find the ratio of diameters between the water and air cylinders and multiply the number of gallons of water per minute to be lifted by the figure given in the table below for the required lift. The result will be the number of cubic feet of free air per minute required.

For example: Suppose the ratio between cylinders to be 2 to 1. Required to pump 100 gallons per minute to a height of 250 feet. Find under 250 feet at ratio 2 to 1, the figures 2.06. Multiplying 2.06 by 100 gives 206 cubic feet of free air per minute

TABLE 21.

Volume of Air and Pressure Required to Drive Direct-Acting Steam Pumps.

Head of water in feet	Gage Pressure in Pounds Per Square Inch							Cubic Feet of Free Air per Minute to Lift One Gallon of Water						
	Ratio of Cylinder Diameters							Ratio of Cylinder Diameters						
	1 to 1	1¼ to 1	1½ to 1	1¾ to 1	2 to 1	2½ to 1	3 to 1	1 to 1	1¼ to 1	1½ to 1	1¾ to 1	2 to 1	2½ to 1	3 to 1
10	6							.22						
20	11	7						.28	.37					
30	16	10	7	7				.33	.42	.53				
40	21	13	9	9	7			.38	.47	.58	.72			
50	26	17	12	10	8			.44	.53	.65	.79	.94		
60	31	20	14	12	9			.49	.58	.70	.82	.99		
70	36	23	16	14	11			.54	.63	.75	.88	1.03		
80	42	26	18	15	12			.61	.68	.79	.95	1.11		
90	47	30	21	17	13			.66	.75	.87	.98	1.15		
100	52	34	23	21	16			.72	.82	.91	1.05	1.20		
125	65	42	29	25	20	10		.86	.95	1.06	1.18	1.33	1.67	
150	78	50	35	30	23	13	9	1.00	1.08	1.20	1.31	1.50	1.88	2.31
175	90	58	40	34	26	15	10	1.12	1.23	1.32	1.47	1.63	2.00	2.40
200	105	67	46	42	33	17	12	1.28	1.37	1.47	1.60	1.75	2.14	2.60
250		83	58	50	39	21	15		1.64	1.75	1.86	2.06	2.41	2.89
300		100	68	58	45	25	17		1.92	2.00	2.12	2.31	2.68	3.08
350			80	67	52	29	20			2.28	2.39	2.57	2.95	3.37
400			92	75	58	33	23			2.57	2.68	2.87	3.22	3.66
450			105	85	65	37	26			2.88	2.94	3.13	3.48	3.95
500				100	78	42	29				3.27	3.42	3.82	4.24
600					92	50	35				3.76	4.00	4.35	4.80
700					105	60	42					4.58	5.00	5.50
800						67	47					5.15	5.50	5.96
900						75	52						6.00	6.45
1000						85	58						6.70	7.00

as being required to handle the water. By inspecting the left-hand section of the table in column headed "2 to 1" it will be seen that the gage pressure required is 33 pounds per square inch. In using this table, however, an allowance of from 30 to 50 per cent should be made for friction in the machine, in order that accurate results may be obtained.

The most economical system of displacement pumping is the Return-Air System, invented by Prof. Elmo G. Harris, which has the great advantage of using the compressed air expansively. The illustration (Fig. 6) shows diagrammatically how this result is attained. Suppose the compressor to be in operation with switch set, as in the figure; the air will be drawn out of the right-hand tank and forced into the left-hand tank; and, in so doing, will draw water into the former and force it out of the latter. The charge of air in the system is so adjusted that when one tank is emptied

TABLE 22.

Lifting Capacities of DIRECT-ACTING Air HOISTS, with Volume Free Air per Lift and Cost per Single Lift and per Hundred Lifts, with a Maximum Lift of 4 Ft. and a Maximum Air Pressure of 90 Lbs. Air Furnished at 5 cts. per 1,000 Ft.

Diameter Cylinder	Effective Area Piston Square Inches	Maximum Weight Lifted Pounds	Cu. Ft. Free Air per 4 Ft. Lift	Cost of Air Per Lift	Cost of Air Per 100 Lifts
2″	3.05	274	0.74	$0.000037	$0.0037
3″	6.87	618	1.67	0.000084	0.0084
4″	12.22	1,099	2.97	0.000149	0.0149
5″	19.09	1,718	4.64	0.000232	0.0232
6″	27.49	2,367	6.68	0.000334	0.0334
7″	37.42	2,474	9.09	0.000455	0.0455
8″	48.87	4,398	11.88	0.000594	0.0594
9″	61.85	5,566	15.03	0.000752	0.0752
10″	76.36	6,872	18.56	0.000928	0.0928
11″	92.39	8,315	22.46	0.001123	0·1123
12″	109.96	9,896	26.73	000.337	0·1337

the other is just filled. At that moment the switch will reverse the pipe conditions so that action in the tanks will be reversed.

Another system of pumping water by displacement is by means of the Halsey pump. This pump is very simple in construction and possesses the advantage of being entirely automatic in its operation. As may be seen from the diagram (Fig. 7), it consists of a cylindrical steel tank 5 feet 6 inches in height and 2 feet 9 inches in diameter, which is submerged in the liquid to

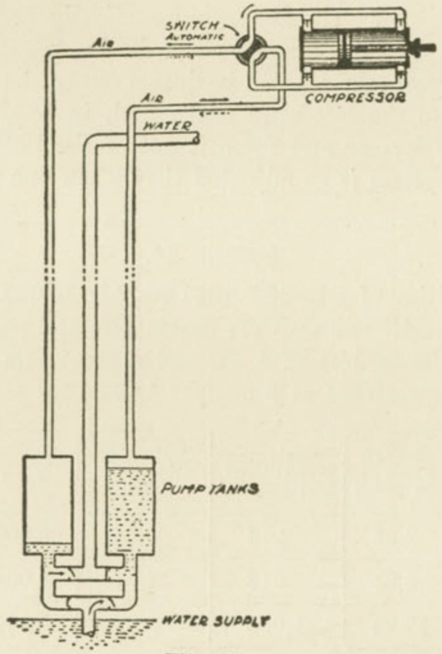


Fig. 6

be pumped. From the air valve contained in the top casting a rod descends into the tank. The water flows into the tank when the air exhaust is open, a float riding on top of the water. When the tank is full, the float engages with a collar on the rod, lifting the same, thus opening the air valve and closing the exhaust. The air is admitted directly to the surface of the water and forces it out. As the water level descends, the float follows. Its weight pulls down the rod and reverses the valve, thereby discharging the air, when the operation is repeated. The rod described operates a

supplementary valve, which turns the air into one or the other end of the main valve chest precisely like a common steam pump. It is plain that the machine is entirely automatic, extremely simple, and adapted to a very wide range of uses.

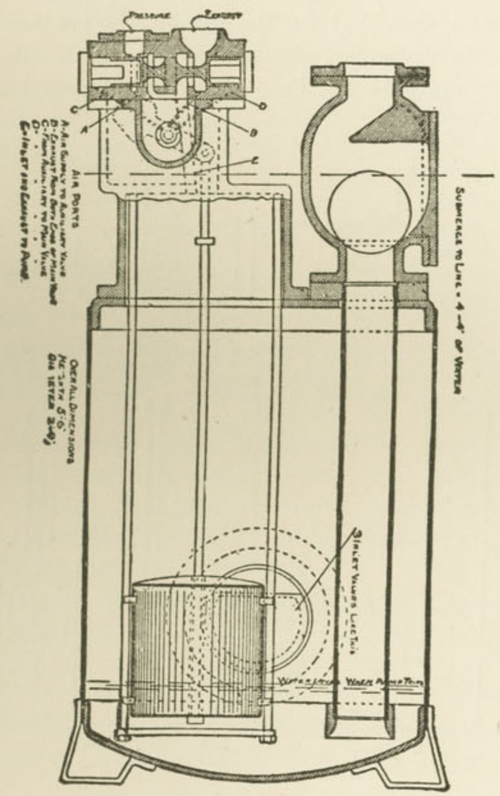


Fig. 7

THE LATTA-MARTIN PNEUMATIC DISPLACEMENT PUMP.

Still another system of displacement pumping is one perfected by the Latta & Martin Pump Company, and which embodies a number of improvements over the Halsey System. In general, the advantages possessed by the Latta-Martin pump are the same as those of the Halsey pump as regards application and operation. But the Latta-Martin pump has the distinction of possessing no floats or other attachments which might get out of order; furthermore, the water does not come in contact with the operating mechanism. This pump consists of two plain cylinders with a valve mechanism attached to their heads. This valve mechanism comprises a main valve and an auxiliary valve, each operated by air pistons, and an oscillating slide valve situated underneath the main valve, and operated in the following manner: In each cylinder there is situated a copper bucket which fills with water as soon as the pump is put in operation and remains full there-

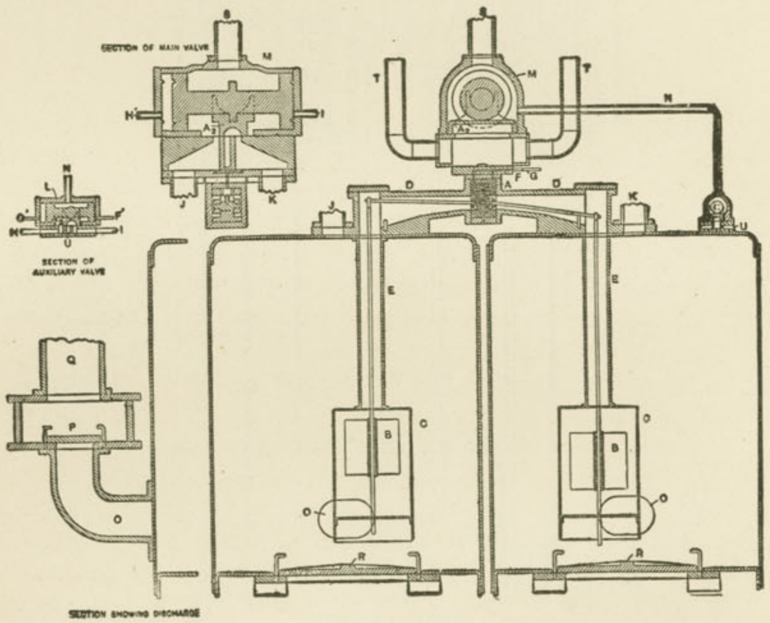


Fig. 8

after. These buckets are suspended from horizontal levers attached to the oscillating valve mentioned above. It will be seen that when one tank is filled with water (the other having had the water expelled by the action of compressed air) the bucket in that tank will be submerged in water, and will, therefore, be very much lighter than the bucket in the other tank which is suspended in air. The latter bucket, therefore, becomes a dead weight and pulls down on the rod and lever to which it is attached,

and operates the auxiliary valve which throws live air into the piston valve above, which in turn operates to admit compressed air into the tank filled with water and exhausts the air from the other tank. This operation being repeated alternately produces a continuous flow of water.

Installations of this system of pumping have been very successful, and it is used for the water works system of the city of Hickory, N. C., where water is pumped from the South Fork River at a distance of three miles from the compressed air power plant located within the city limits.

AIR LIFT SYSTEM.

This system is adapted only to the pumping of artesian wells, where considerable submergence of pipe may be obtained, and is not adapted to shallow wells. It is said to have been invented in the eighteenth century and to have been in use at Freiberg, Saxony. In this country the name of Dr. J. G. Pohlé is most intimately associated with the advancement of the system. The original Pohlé system has been modified and improved, however, so that to-day the system is in general use in breweries, manufacturing plants, power houses, and is being used extensively in connection with city and town water supply.

The advantages of the airlift system are numerous and important. The chief ones may be enumerated as follows:—

1. Involves the use of no submerged working parts to get out of order.
2. Will handle mud and gritty matter without injury to the apparatus.
3. Uses no pistons, plungers, suction or discharge valves to get out of order.
4. Absence of all obstructing mechanisms in well allows each well to be pumped to its *full* capacity.
5. The production, therefore, does not depend upon the pump, but rather upon the capacity of the well. Results reaching from two to five times the quantity possible with any system of mechanical pumping.
6. The action of the compressed air tends to clean the well and increase its capacity.
7. Provides *cool* water. This is most important where water is used for condensing purposes.
8. System is most flexible in its operation, and may be applied to any number of wells, no matter how scattered.

Method of Operation. In the air-lift system a pipe, known as the "discharge" or "eduction" pipe, is submerged in the water. This pipe does not touch the bottom of the well, but is elevated above it so as to freely admit water through its lower end, which is open. Alongside of this pipe, either on the outside or within, is a small pipe properly proportioned and intended to convey compressed air to a point near the bottom of the eduction pipe. It is usual to provide what is called a "foot-piece," which forms the nozzle connecting the air pipe with the water pipe, but in what is known as the "central-pipe system" this foot-piece is not needed, the air pipe being placed within the eduction pipe to a point near the bottom where it discharges the compressed air into the water column.

It is evident that as soon as the air is admitted to the eduction pipe it displaces a considerable percentage of the water being distributed through it in the form of bubbles. These bubbles of compressed air, therefore, have the effect of making the column of water in the eduction pipe lighter than the column of water outside, causing a constant flow and discharge of water and air at the surface. This is what takes place when lifts are moderate; when lifts are in excess of 25 feet, however, the increased weight of the water column produces a different effect. The compressed air bubbles cohere as they ascend, forming piston-like layers which expand as they near the surface and the pressure upon them decreases, causing the discharge to be alternately a mass of water and then a portion of air.

In order that an air-lift system may be operated to best advantage, the eduction pipe should be submerged not less than 50 per cent of its total length nor more than 60 per cent. The following table (Table 23) gives the approximate efficiencies which may be expected for various percentages of submergence:

TABLE 23.

Submerged Per Cent of Length of Water Pipe.	Efficiency Per cent.
60	50
50	40
40	30
33	25
30	22

It is evident that the greater the submergence the greater will be the air pressure required, it being necessary to use a pressure a little greater than is required to support a column of water of the given height. It is also evident that the starting pressure will be slightly greater than the working pressure, as all the water in the air and eduction pipes must be displaced before the system settles down to working conditions. As a general rule, ½ pound per foot of submergence may be allowed for the starting pressure and the working pressure is obtained by multiplying the number of feet submergence by 0.433.

Size of Pipes. The area of the eduction pipe should permit of discharging 15 gallons per minute to each square inch of area of the pipe. The accompanying table gives sizes of eduction and air pipes and the number of gallons of water per minute to which they are adapted.

TABLE 24.

Size of Well in Inches.	Water Pipe in Inches	Air Pipe in Inches.	Gals. Water per Minute.
4	1½	¾	25
4½	2	1	50
5	2½	1	75
6	3	1¼	100
7	3½	1½	150
8	4	1½	200
9	5	2	300
10	6	2	450

An approximate rule for estimating the amount of compressed air required to lift different quantities of water is known as the "Pohlé formula," and is as follows:—

$$\text{Cub. ft. free air per minute} = \frac{\text{Gals. water required per minute} \times \text{lift in ft.}}{125}$$

Individual conditions vary so in character, however, that it is always better to seek the advice of an expert before deciding upon the size of pipe to be used or the air compressor to be installed.

TABLE 25.

Lift, Submergence and Air Required for Air-lift Pumping.

Lift in Feet.	Volume of Air to 1 Cubic Foot of Water.	Submerg. (Equals 60 Per Cent. Total Water Pipe) Feet.	Submerg. for Special Lift. Feet.	Air Pressure Subm. 60 Per Cent. Pounds.	Air Pressure for Special Lift Submerg. 60 Per Cent Pounds.	Cub. Ft. Free Air per Gallon per Minute.	H. P. per Gallon per Minute.
25	2	38	50	17	20	0.3	0.0184
50	3	75	100	33	44	0.4	0.0426
75	4.5	113	150	49	65	0.6	0.0828
100	6	150	200	65	87	0.8	0.1320
125	7.5	188	250	82	109	1.0	0.1910
150	9	225	300	98	120	1.2	0.2544
195	10.5	263	350	115	152	1.4	0.3150
200	12	300	400	130	173	1.4	0.3808

CONCLUSION.

For the benefit of those who contemplate installing compressed air machinery the following remarks are given and we believe will be found of value:—

1. Remember that all air compressors are rated higher than their actual capacity, therefore always purchase one of larger capacity than your requirements demand.

2. Remember also that as soon as compressed air is introduced in your plant a thousand and one usages for it will occur to you which you never thought of before. It is better, then, to purchase a compressor at least 50 per cent larger than you think you require, to allow for this future "expansion."

3. It pays to buy a *high-grade* compressor. Such a machine will pay in the end many times the difference in cost.

4. Be sure that your intake air is secured from a cool, clean place.

5. Use only the best lubricating oil of high flash point and light body.

6. Never use kerosene to clean outlet valves; use soap and water.

7. It pays to install a two-stage compressor if air is used at 85 pounds or over and in quantities of 150 cubic feet per minute or over.

8. Volumetric efficiency in air compression is the ratio of the free air delivered in a compressed state to the piston displacement. It may be taken at from 80 to 90 per cent, depending upon the class of compressor. Some compressors have shown a volumetric efficiency as high as 94 per cent.

9. Roughly speaking, the volumetric efficiency of an air compressor is lowered 3 per cent for every 1000 feet of altitude above sea level.

10. An increase in economy of 10 per cent may be expected from the use of a two-stage air compressor for ordinary pressures.

11. A gain of 1 per cent in volumetric efficiency is to be expected for every 5° F. decrease in temperature of intake air.

12. A compressed air transmission line should be laid in such a way as to avoid pockets. In case it is impossible to lay the line without pockets, these should be drained with suitable traps or blow-off connections. Sharp bends should be avoided and the pipes should be of ample capacity.

13. It is important that the air receiver be of sufficient size. A correctly proportioned receiver obviates fluctuations of pressure due to pulsations of compressor, and acts as a drain on the air line.

14. The air connection to the pressure regulator should always be run from the receiver, as it is necessary to have a pressure free from pulsations. Furthermore, if connection was made to air discharge pipe, the pressure might be below normal due to rapidity of flow in that line.

15. Dry air may be obtained by the use of an aftercooler.

16. In cross-compound air compressors the ratio of low to high pressure cylinder areas=

$$\sqrt{\frac{\text{absolute pressure of compression}}{\text{atmospheric pressure}}}$$

17. The most effective factor operating to reduce the efficiency of a compressed air installation is leakage.

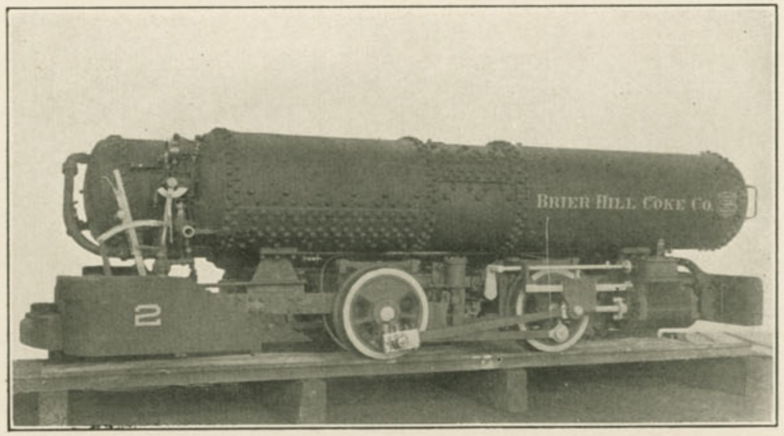
18. Percentage of clearance in air compressors runs from 1½ to 3. Some manufacturers have a fixed rule that the clearance between piston and cylinder head shall be $\frac{1}{16}$ inch.

19. A safety valve should be provided on intercooler or passage leading from low-pressure cylinder to high-pressure air cylinder.

20. In starting up a new compressor, one discharge valve should be left out at each end of the air cylinder. Steam should be allowed to blow through steam cylinder with drips wide open until cylinders are thoroughly warmed up. The drips should then be closed and machine run without raising any pressure in the air cylinders. The discharge valves may then be replaced and machine operated at full load.

21. An interesting point in air compressor operation is the fact that, although the steam and air cylinders may be of the same diameter, it is possible to compress air to a higher pressure than the steam pressure in the steam cylinder. This is because the M. E. P. in the steam cylinder may be made greater than the M. E. P. in the air cylinder, by causing the cut-off to occur late in the stroke. This extra energy is stored in the fly-wheel, which in turn carries the machine over the point where the pressure in the air cylinder is higher than the steam pressure.

12,500-POUND COMPRESSED AIR LOCOMOTIVE USED AT THE HOSMER MINES, HOSMER, B. C.



28,000-POUND COMPRESSED AIR LOCOMOTIVE USED BY THE BRIER HILL COKE CO.

(H. K. Porter Co.)

Compressed Air Locomotives.

Although the compressed air locomotive is now used for many purposes, it took nearly 25 years from the time that the first air locomotive was built before its advantages for special purposes were appreciated.

The first compressed air locomotives were built for the Plymouth Cortege Co. at North Plymouth, Mass., about 1873, and that company is still using some of the original locomotives. The next lot of compressed air locomotives were built in 1891, for W. H. Brown & Sons, Old Eagle Mines, for service at the coal mines at Elkhorn Station, Allegheny Co., Pa. The tanks in this machine were charged with air at a pressure of 400 pounds per square inch and contained 174 cubic feet. They had cylinders 8 inches in diameter by 14 inches stroke, and weighed about 16,700 pounds. They were capable of hauling a train from 1,000 to 2,000 feet on one charge of air.

The first compressed air locomotives to be operated in the anthracite region in Pennsylvania were built in 1895, and from then on a large number of compressed air locomotives have been used throughout this country for mine service.

Advantages of the Air Locomotive. The air locomotive has several distinct advantages over the steam or electric locomotive. With no boiler requiring renewal of tubes and staybolts, the cost of maintenance is less than that of the steam locomotive. While the cost of installation of compressed air haulage is approximately the same as that of electricity, the cost of operation is less. The compressed air locomotive is the best type of service where absolute safety from fire or explosion of gas is required. Simplicity, absence of fire or necessity for wires or other conductors in connection with the operation of the locomotives render them extremely desirable for a wide range of service in mines and industrial establishments.

Essential Features. Among the essential features which are required of a compressed air haulage plant are the following: One or more compressed air locomotives to suit the conditions; one or more air compressors of sufficient capacity; one or more charging stations depending on the length of the line; and a storage system to admit of placing charging stations at convenient points. The locomotives must be suited to the conditions, and heavy enough to secure sufficient adhesion. The adhesion is usually about one-fifth the weight on driving wheels, and ordinarily the tractive force developed by the cylinders should be equal to the adhesion, and both the adhesion and tractive force, due to the cylinders, must be fully up to the requirements imposed by the weight of train, grades, rolling friction and curves. Ordinarily, the gauge of track may be made to suit the convenience of the user.

Adaptability of Compressed Air Locomotives. The compressed air locomotive is especially adapted to certain classes of service requiring absolute security against fire or explosion of gas. With the use of compressed air as a motive power, there is absolutely no danger from fire. This feature gives the air motor a distinct advantage over steam and electric locomotives for underground haulage in dangerous coal mines, or in powder mills, cotton mills, lumber yards and other industrial plants engaged in the manufacture of explosive or inflammable materials. The air motor is also the most satisfactory type of locomotive for plantation service, where the dryness of the fields at certain seasons of the year requires some form of haulage positively safe from fire. But the field of the air motor is not limited to that class of service where freedom from danger of fire or explosion of gas is essential. Its simplicity, economy, and efficiency have led to the increasing use of the air motor in all kinds of mine and industrial service.

The machinery of the air locomotive is similar to that of the steam locomotive; but, instead of a boiler in which the power is generated, the air motor is equipped with one or more main storage tanks which are charged with air at a high pressure. The capacity of the tanks and the pressure of the air required are

governed by the conditions of the service for which the locomotive is intended. Where height and width are very limited, it is necessary to use tanks of small capacity and air at high pressure. From the main tanks, air is delivered through a regulating valve to an auxiliary low pressure reservoir, in which the air is carried at a uniform working pressure, and from which it is admitted to the cylinders by means of a suitable throttle. The locomotive storage tanks receive the air at the charging stations through a filling pipe fitted with suitable couplings and flexible joints. If the locomotive is equipped with one or more storage tanks, the filling pipe connects with each tank and check valves are provided, permitting any one of the tanks to be shut off if necessary.

Method of Charging Compressed Air Locomotives. Two methods may be used in charging the locomotive; it may be charged direct from the compressor or from a reservoir. Direct charging requires a larger compressor than if the reservoir system is used. Except where the intervals between trips are long, the latter method is the more economical. With the reservoir system, the reservoir is recharged with air at the required pressure while the locomotive is making its trip, and the compressor is thus kept running continuously at a fairly uniform speed. The reservoir may consist of a storage tank or a pipe line. In the majority of cases, the pipe line is used; because, with this system, the air may be carried to any part of the plant where it may be desired to operate the motor, and charging stations may be installed at the most convenient points. The choice between the pipe line and the tank storage system depends entirely upon the character of the service and local conditions. The compressor may be installed in connection with an existing steam plant, if there is one, under the care of the same engineer, thus involving no increase in the cost of the attendance of the plant.

Gauge of Air Locomotives. Thirty-six inch gauge is usually wide enough for the heaviest compressed air locomotive built. Gauges from 18 inches to 24 inches are used when the gangway in a mine is very narrow, or when unavoidable obstructions near the track render the use of a very narrow locomotive essential. In such cases the locomotives used are generally small, and the narrow gauge presents no serious difficulties. Locomotives of 6 tons weight are built for 18 inches gauge, and a 14-ton locomotive can be built to suit 24 inches gauge without departing to any great extent from standard designs.

Pressures Used. The present practice in regard to the pressure used in charging compressed air locomotives is 1,000 pounds per square inch in the pipe line, and 800 to 900 in the tanks on the locomotive. All the new plants being built to-day are using approximately these pressures. In order to use compressed air locomotives, it is, of course, necessary that a compressed air haulage plant be used for the purposes of charging the compressed air locomotive.

Design of Compressed Air Locomotives. After determining the gauge, weight, size of cylinders, width and height of the compressed air locomotives required, the next essential feature to be settled is the capacity of storage reservoirs on the locomotive, the required capacity depending upon the amount of work to be performed with one charge of air. This amount of work depends upon the weight of train, the grades, the distance, and the design and condition of track and rolling stock. This last determines the co-efficient of rolling friction. On standard railroads the co-efficient of rolling friction is frequently as low as 6½ pounds per ton of 2,000 pounds. In industrial or mining operations a co-efficient of 30 pounds per ton is by no means uncommon where favorable conditions exist, and poor design and neglect assist in making the cars run hard. The co-efficient of rolling friction as here used is the force measured in pounds that must be exerted in order to move one ton of 2,000 pounds at a uniform velocity of six miles per hour on straight and level track. If then the system of tracks operated over by a locomotive are nearly level, and if the cars and track are in such condition as to make a co-efficient of 30 pounds apply, about four and one-half times as much power will be required to do any given amount of work as would be required to do the same amount of work with a co-efficient of rolling friction of 6½ pounds per ton. With heavy grades the influence of the co-efficient of rolling friction is not so great, but it is always an important factor in determining the amount of work which must be performed.

Main Storage Tanks. The main storage tanks on the locomotives should be made of the best quality flange steel plates, of a tensile strength of 60,000 to 65,000 pounds per square inch.

The longitudinal seams should be sextuple or octuple riveted, with butt joints and welt strips inside and outside; the circumferential seams should be double riveted. All rivet holes should be reamed after the tanks are fitted up. The rivets should be of soft steel, and should be driven by a power riveter capable of exerting a pressure of 300,000 pounds. All caulking should be done with a round-nosed tool and pneumatic hammers on edges planed to a true bevel. The heads of the tanks should be spherical in shape, formed by hydraulic pressure from steel plates 35 to 50 per cent thicker than, and of the same quality as, the cylindrical sheets. After the heads leave the flanging press they should be turned in order to insure a perfect fit. The front head is generally fitted with a man-hole. The man-hole cover should be of cast steel, and the plate around the hole should be heavily reinforced by a steel casting. The man-hole is an essential feature of good construction, as it allows of riveting in the last head, and provides for inspection and a proper method of securing tanks to saddle. If there is no man-hole, the last head must be put in with patch bolts, or else must be flanged concave. The tanks, after they are completed, should be subjected to a test pressure of about 30 per cent greater than the working pressure, and should be made absolutely tight at this test pressure.

The exceptions to the above method of storage tank construction are: for very high pressure, seamless steel tubing tested to double the working pressure is sometimes used; and for tanks of small diameter, for ordinary pressures, welded wrought iron cylinders, tested to a pressure of 50 per cent in excess of the working pressure, are uesd.

The Automatic Reducing and Stop Valve. The duty of these parts of the compressed air locomotive is to maintain automatically a specified uniform pressure at the throttle valve (usually 140 to 150 pounds per square inch), the pressure in the main storage tanks meantime fluctuating between the limits of 800 or 900 pounds just after charging, and 140 or 150 pounds just before charging. The valves should be absolutely tight when the locomotive is at rest, or drifting down grade, and also be capable of maintaining the specified pressure at the throttle valve when the locomotive is working at its maximum power, and when the pressure in the main storage tank is reduced to approximately the same pressure that is required at the throttle valve.

Porter Reducing and Stop Valve. The valve used on compressed air locomotives built by the H. K. Porter Company consists of one automatic reducing valve and one automatic stop valve. The reducing valve consists of a double-seated balanced valve and an actuating piston. The air pressure in the auxiliary reservoir acts on one side of this piston, tending to close the valve. This action is opposed by a spring properly adjusted to hold the valve off its seat until the maximum allowable pressure is reached in the auxiliary reservoir, when the pressure of the air overcomes the resistance of the spring, and the valve closes. The pressure in the auxiliary reservoir is adjustable, as the pressure varies with the tension of the spring, which can be altered by turning two nuts. This valve alone would be sufficient, if the locomotive was always using air. The necessity for a supplementary valve is only apparent when the locomotive is not using air. To meet this condition, a second valve is placed between the above described valve and the main storage tanks on the locomotive. This valve is single-seated and closes with the pressure. The motion of this valve is controlled by the throttle lever and the high pressure air. When the throttle valve is open the valve is entirely open, and when the throttle valve is closed this valve is closed with sufficient pressure to insure tightness. Thus, by the use of two valves, close regulation at all times and tightness when no air is being used are attained.

The Auxiliary Reservoir. The auxiliary reservoir simply serves to equalize the fluctuating demands of the cylinders. It is usually a piece of pipe from 4 to 9 inches in diameter, and from 6 to 15 feet long.

The Throttle Valve. The throttle valve is generally of special design. Difficulty in the use of the ordinary double-seated locomotive type of throttle valve is sometimes encountered, so that a single-seated balanced valve of special design is often used. It is a compound valve in which a small valve first opens to equalize the pressure on the two sides of the larger valve, which is then readily opened.

The Cylinders. The cylinders of compressed air locomotives are ribbed for the absorption of heat from the atmosphere, instead of being lagged to retain the heat, as in steam locomotive practice.

Valves, Links, Frames and Running Gear. The valves, links, frames and running gear are in all respects the same as in steam locomotive practice.

Sand Boxes. Sand is always needed (more especially in mines) to prevent slipping of the driving wheels. Dry sand must be used, and all compressed air locomotives are equipped with sanding apparatus operated by compressed air.

Oiling Devices. The crank pins are generally supplied with compression grease cups, the cylinders and slide valves with automatic lubricators. The driving boxes are provided with cellars packed with woolen waste, the eccentrics and guides with oil cups. These are the most important bearings and wearing faces. All other bearings have oil holes.

The other details of compressed air locomotives are in all respects similar to the steam locomotive, except that the exhaust is taken as directly as possible to the atmosphere, as it is not needed to create a draught.

Reheating. Reheaters are used on compressed air locomotives, and the increased efficiency attained makes the subject a most attractive one, more especially for surface work; but it is doubtful if the increased efficiency justifies the additional complication, except in special cases where the locomotives are making an unusually large mileage and the cost of fuel is extremely high. Compressed air locomotives are equipped with reheaters whenever the circumstances justify it.

Charging Stations. The charging stations consist of a flange-tee, or elbow, a stop valve, and flexible metallic coupling and bleeder valve. The valves used for this purpose should have the valve seat of case-hardened mild steel and a hard bronze valve. The valve and seat should both be easily renewable. The flexible metallic coupling generally consists of three ball joints and three pieces of extra heavy $1\frac{1}{4}$-inch wrought iron pipe, and a screw coupling. The thread is coarse, so that only a few turns are required to couple the locomotive to the charging station. Without this flexible coupling it would be necessary to stop the locomotive exactly at the same point every time a charge of air was taken. With it a range of several inches each way is permissible.

This feature saves much time in charging. A bleeder valve is used for exhausting the air between the charging station stop valve and the check valve on the locomotive, after the operation of charging is completed.

Pipe Lines. When pipe is used for stationary storage two forms of pipe couplings are used; one the usual sleeve coupling, and the other a flange coupling. With the sleeve coupling, if a leak should occur, a strip of soft metal hammered into the recess will put a stop to the difficulty. The flange coupling is intended for use at intervals of 200 to 400 feet, in order that any joint in the pipe line may be easily accessible, in case a length of pipe should for any cause require renewal, or in case a change of location should become necessary. The flange couplings are also to be used when the location requires the introduction of bent lengths of pipe into the pipe line, it being generally impossible to use sleeve couplings with bent pipe on account of the great radius through which the bent end swings.

In installing pipe lines, care must be exercised to relieve the line of all initial strains. If a bend is required, heat the pipe to a red heat and bend it to the required shape. Do not attempt to spring it into position after screwing it into the preceding length.

The Compressor. For charging air locomotives the pipe line pressure to be maintained by the compressor is seldom less than 700 or more than 1,200 pounds per square inch. For these pressures the three or four-stage compressor is required. The three-stage straight-line machine is the most economical construction, and the four-stage duplex the most expensive. Massive construction, properly proportioned water-jacketed cylinders, good casting, intercoolers of ample capacity and valves and pistons of proper design, and the best of material and workmanship throughout, are the essential features of the successful high-pressure compressor. The compressors are furnished with speed and pressure governors, and gauges to show the pressure after each stage of compression.

The design of the compressor may be modified to meet special conditions. The operating power may be water power or electricity, if preferred to steam. If driven by steam the engine may be the simple slide valve, or the highest type of compound

condensing engine, or any type of engine between the two which may be called for by the cost of fuel and the character of the installation. An auxiliary two-stage locomotive compressor with intake of air at 80 to 100 pounds pressure may be used where there is a surplus of low pressure air, but this plan is not recommended, because in practical working it is impossible to avoid objectionable fluctuations in the supply of low pressure air.

How the Plant is Designed. The work to be performed may be calculated as follows:

Let C=Co-efficient of rolling friction in pounds per ton.
G=Grade resistance in pounds per ton.
R=Resistance due to curves in pounds per ton.
W=Weight of train and locomotive in tons.
D=Distance in feet.

Then the work to be performed, expressed in foot pounds, will be equal to DW (C+R+G), or DW (C+R—G). G is plus when the train is going up grade, and minus when the train is going down grade. When G is minus, and greater than CR, the train will roll down grade without using power. The grade resistance is equal to 20 pounds per ton for each one per cent of grade. The ton used in these calculations is a net ton of 2000 pounds. If down grades do not require the brake in order to control the speed within safe limits, the grade resistance G may be averaged without causing an error. After determining the total amount of work to be performed between charges, provision must be made for storing sufficient compressed air on the locomotive to do the required amount of work. It may be found that the tanks required to contain the air are too heavy or too bulky, in which case arrangements for charging more frequently must be made.

The calculations indicated above must be gone through with for each installation, and if there are several trips in different directions, with differing grades, curves, and loads to be hauled, calculations must be made for each run, and the locomotive tanks proportioned and charging stations located to secure the best results at minimum cost.

Storage Requirements. There are two requirements of the stationary storage—first, it must be capable of containing a supply of compressed air immediately available for charging the tanks on the locomotive to the full specified pressure. To secure this result the conditions represented by the following equation must be fulfilled:

Let V=volume of the stationary storage in cubic feet.
v=volume of tanks on the locomotive in cubic feet.
P=pressure in stationary storage in pounds per square inch.
p=desired pressure in tanks on locomotive in pounds per square inch.
p′=residual pressure in pounds per square inch in the tanks on the locomotive just before charging.

Then $V(P-p)=v(p-p')$.

To illustrate the use of the above equation, suppose the tanks on a locomotive contain 100 cubic feet, and that it is desired to charge them to 800 pounds, the residual pressure before charging being 100 pounds, and the pressure in the stationary storage is not to exceed 950 pounds. What must the volume of the stationary storage be in order to instantly charge the tanks on the locomotives to 800 pounds?

Then V is unknown.
P=950 pounds.
p=800 pounds.
p′=100 pounds.
v=100 cubic feet.

Transposing the above equation $V=v\frac{(p-p')}{(P-p)}$. Substituting the above values $V=100\frac{(800-100)}{(950-800)}=466\frac{2}{3}$ cubic feet.

When two or more locomotives are to draw on the same stationary storage system, the capacity of the stationary storage should be somewhat increased, so that if two or more locomotives should be charging at about the same time each may receive approximately a full charge.

The second requirement is that it must consist of such pipe, or combination of pipe and tanks, as will best serve to connect the compressor with the charging station, or charging stations. The charging stations must be located to suit the locomotives and the work. The compressor must be located as near the boilers as possible in order to get dry steam. Other things being equal, the shortest and most direct connection which can be made between the compressor and charging stations will be the best, but attention must be paid to convenience in laying, and accessibility for inspecting and repairing the pipe. The pipe should be kept in plain sight as far as possible; its condition will then be known, and leaks, if they occur, may be found and remedied. The pipe line should be made as straight as possible; though a few bends are a good thing as they serve to take up expansion. If the line is of considerable length, the pipe should be of sufficient size to give the required volume. This plan cannot be improved on, and in the majority of cases is the one that has been used. There are exceptions to this rule, as follows: If the required volume necessitates the use of pipe larger than can be economically handled and laid; if the surrounding conditions are such as to make the preservation of the pipe in good condition difficult and expensive; in either case a smaller pipe should be used to convey the air, and one or more storage tanks used to make up the required volume. In the use of compressed air at lower pressure for pumps, coal cutters, rock drills, etc., lines of pipe convey the compressed air from the compressor to the drills, cutters and pumps. In this case it is primarily a passageway; the air is in almost constant motion, and the size of the pipe depends upon the quantity of air needed, the pressure required at the machines, the pressure at the compressor, and the length of the line. The pipe is then made sufficiently large to convey the required quantity of air at a velocity which the pre-determined difference in pressure is capable of imparting to the air contained in the pipe. The difference in the function of a pipe line for compressed air locomotives is that the pipe line in this case is primarily a receiver. Air is pumped into it constantly, and drawn intermittently. When a locomotive charges, the air nearest the charging station flows into the tanks on the locomotive, the air farther away simply expanding to fill up the vacant space. The compressor running constantly is, however, only crowding air into the end of the line.

An example with figures and dimensions may serve to explain more clearly this meaning. Suppose the locomotive tanks to contain 100 cubic feet; the pressure just before charging, 100 pounds; the desired pressure after charging, 800 pounds; the pressure in the stationary storage, 950 pounds. By the previous calculation, the capacity of the stationary storage is to be $466\frac{2}{3}$ cubic feet. Suppose the compressor to be located 5600 feet from the charging station, then 4-inch pipe would give the required capacity, as 12 lineal feet of 4-inch pipe contain one cubic foot. The operation of charging consists of the air nearest the charging station flowing from the stationary storage into the tanks on the locomotive until the pressure in the tanks on the locomotive is equal to the pressure in the stationary storage, when the flow will stop. To increase the pressure in the tanks on the locomotive from 100 to 800 pounds will require $\frac{(800-100)\,100.}{14.7}=4672$ cubic feet of free air. One cubic foot of air at pressure of 950 pounds gauge is equivalent to $\frac{964.7}{14.7}=65.6$ cubic feet of free air. It will therefore require $\frac{4762}{65.6}=72\frac{1}{2}$ cubic feet of air at 950 pounds gauge pressure, to furnish the amount of air required to charge the locomotive tanks. It will require $72\frac{1}{2}\times12=870$ lineal feet of 4-inch pipe to contain this amount. The air contained in the 870 lineal feet of pipe nearest the charging station will, therefore, be pushed into the tanks on the locomotive by the expansion of the air contained in the remaining 4730 feet of pipe. The compressor is working during the time of charging, but the quantity compressed during so brief a period does not materially affect the above-described operation. When the charging station valve is first opened, the difference in pressure is 850 pounds per square inch, sufficient to give the air a very rapid motion. As the operation of charging nears completion, the difference in pressure decreases, but the quantity of air to be moved decreases as the difference in pressure decreases, so that unless the pipe is made small, no serious delay can occur. The entire operation of charging, including the time occupied in making the coupling and breaking it, seldom occupies more than one and a half minutes; and the charging station valve is never open more than 40 or 50 seconds for each charge. At the compressor end of the line, the

time occupied in replacing the air drawn off in charging is anywhere from ten to sixty times as great, depending upon the number of locomotives and the character of the work. It is plain, then, that if large pipe is to be used to reduce the friction, it should be put in near the charging station rather than near the compressor.

The Compressor. The capacity of the compressor is determined by the frequency with which the locomotives must be charged, and the quantity of air required for each charge. Having calculated by the method above indicated the amount of air required per trip, the number of trips per charge (or of charges per trip) will depend upon the capacity of the locomotive tanks. To compute the required compressor capacity in cubic feet of free air per minute:

Let C=the required capacity of the compressor expressed in cubic feet of free air per minute.
C'=the cubic feet of free air required to charge the locomotive.
N=the number of charges required to do the required amount of work in any specified time.
T=time in minutes.

Then $C=\frac{N\,C'}{T}$

If the locomotives are to be charged at approximately equal intervals of time throughout the day, one application of the above equation will be sufficient. In any other case several applications should be made to determine the maximum and minimum rates of consumption, and a compressor selected capable of supplying air in sufficient quantity for all conditions of service, and, at high altitudes, the rarified condition of the atmosphere must be taken into consideration.

Care of Compressed Air Plants. With a plant properly designed and installed, only ordinary care and mechanical ability are required to maintain it in serviceable condition. Use a low cold test oil in the cylinders of the locomotive. A pure, natural West Virginia well oil which shows about 29 gravity and a cold test of five degrees below zero Fahrenheit is one that is recommended. A small quantity of good air compressor oil is used in the cylinders of the compressor. See that all bearings are properly lubricated with good engine oil, and that all parts of both locomotive and compressor are kept reasonably clean, and the compressed air haulage will not ordinarily give much trouble.

Largest Installation of Compressed Air Locomotives. The largest installation of compressed air locomotives is at the Anaconda Copper Mining Company's Reduction Works at Anaconda, Montana. These reduction works operate twenty-four hours per day and seven days per week. When running full, twelve compressed air locomotives are used sixteen hours a day, and nine are used the remaining eight hours. Twelve of these locomotives weigh 26,000 pounds, having cylinders 9½ inches in diameter by 14 inches stroke; driving wheels, 28 inches in diameter; a rigid wheelbase of 60 inches; main storage tanks of 218 cubic feet capacity; tractive force 5700 pounds. The largest locomotive weighs 42,000 pounds, has cylinders 12 inches in diameter by 18 inches stroke; driving wheels 36 inches in diameter; a rigid wheelbase of 60 inches; main storage tanks of 218 cubic feet capacity, tractive force 9180 pounds.

The compressed air locomotives are operated over about 18 miles of standard gauge track laid with 60-pound rails, located inside of an irregular area about half a mile square.

The main storage tanks are charged, at intervals of from twenty minutes to one hour, with air at a pressure of from 700 to 800 pounds per square inch, which is then reduced to a pressure of about 150 pounds for use in the cylinders of the locomotives. When the pressure in the main storage tanks, as shown by a gauge facing the engineer, has dropped to a point near 150 pounds per square inch, the locomotive is stopped at the next charging station and recharged, this operation of recharging taking from one to two minutes.

The compressed air required by the locomotives is furnished by two compressors, having cross-compound steam cylinders equipped with Corliss valve-gear, and four-stage air cylinders. The compressors are duplicates. The high-pressure steam cylinder is 20 inches, and the low-pressure steam cylinder 40 inches in diameter; all air cylinders are single-acting; the intake air cylinder is 37¼ inches in diameter, first intermediate cylinder 20¼ inches, second intermediate cylinder 12½ inches, high-pressure cylinder 6 inches, and the common stroke is 48 inches. The

intake and first intermediate cylinders are placed behind one steam cylinder; the second intermediate and high-pressure cylinders behind the other. All the air cylinders are water-jacketed, and intercoolers are provided for cooling the air after each stage of compression.

The compressors are equipped with automatic speed and pressure governors. They are operated with steam at 150 pounds pressure and with a vacuum of 17 inches in the condenser, perfect vacuum at the elevation being 24 inches. The rated speed is 70 revolutions per minute; the horse-power developed per revolution, 8.7; the steam consumption per horse-power-hour when operating at a speed of 55 revolutions per minute, 18.67 pounds.

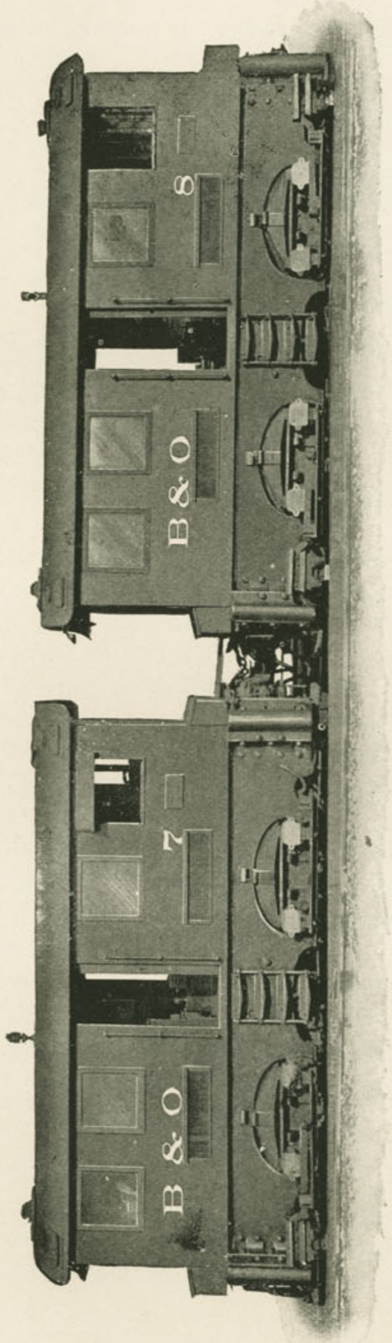
The remainder of the haulage equipment consists of a system of piping varying in size from 2 to 6 inches.

Small Air Locomotives. Small compressed air locomotives are used for various purposes, the smallest practical compressed air locomotives ever built being used by the Loretta Iron Co., Loretta, Michigan. The weight of the machine is 5500 pounds; gauge of track, 27 inches; rigid wheel base, 22 inches; extreme width, 36 inches; height, 4 feet 9 inches; length, 7 feet; cylinders, 4 inches diameter by 7 inches stroke, inside connected by a crank axle to the rear driving wheels.

REVIEW QUESTIONS.

COMPRESSED AIR LOCOMOTIVES.

1. What are the advantages of a compressed air locomotive over steam and electric locomotives?
2. What are the essential features required of a compressed air haulage plant?
3. When was the first compressed air locomotive built in this country?
4. For what purposes are compressed air locomotives best adapted?
5. In what way does the machinery of an air locomotive differ from that of a steam locomotive?
6. Give two principal methods of charging compressed air locomotives.
7. What is the gauge generally used on air locomotives?
8. What pressures are used for charging compressed air locomotives?
9. How should the main storage tanks which take the place of a boiler in a steam locomotive be made?
10. What is the duty of the automatic reducing and stopping valve?
11. Why are reheaters used on compressed air locomotives?
12. Of what value is the auxiliary reservoir?
13. Describe briefly a compressed air charging station and explain what features are essential for proper operation.
14. What type of air compressor is generally used for charging compressed air locomotives?
15. What are the two principal storage requirements of a compressed air haulage plant?
16. How is the capacity of the compressor determined?
17. What care should be given to compressed air plants?



ELECTRIC LOCOMOTIVES—BALTIMORE & OHIO RAILROAD
(The General Electric Company)

Electric Railroading.

The engineer of to-day, no matter in what kind of a plant he may work or in what branch of engineering he may be interested, must of necessity be acquainted with the laws of electricity and the application of the electric current to commercial uses.

Ohm's Law. The fundamental principle of all electric circuits depends upon three things: Electro-motive force, current and resistance—and the first law of electrical science that must be learned is Ohm's Law. This law states that the current strength in the circuit is equal to the electro-motive force divided by the resistance, or putting it in the form of a formula, it is written

$$\text{Current strength} = \frac{\text{Electro-motive force}}{\text{Resistance}}$$

Let the current strength equal C, the electro-motive force, E, and the resistance, R, and the formula becomes

$$C = \frac{E}{R}$$

In practice the unit of a current is called an ampere, the unit of electro-motive force is called a volt and the unit of resistance is called an Ohm.

Electro-motive Force. The electro-motive force, or E.M.F. as it is often written in abbreviated form, is produced in various ways. It may be converted from chemical energy, as in a battery, or it may be converted from mechanical energy by a dynamo or generator. The electric current is made to flow through a conductor by electro-motive force. As all conductors possess some resistance, and as the current moves through each part of the conductor with equal intensity, the electro-motive force is expended by driving the current through each part of the conductor. The unit of the electro-motive force is the volt, named after the Italian scientist, Volta, and is the electrical pressure furnished by a certain kind of battery whose poles are zinc and mercury, known as the standard cell.

Resistance. The resistance of a wire or conductor depends upon its length and area of cross-section. The resistance of a wire is directly proportional to the length and inversely proportional to its area; that is, a wire two feet long would offer twice the resistance of a wire one foot long, and a wire whose diameter is twice the diameter of another wire would have only one-fourth the resistance, providing the wires were made of the same material.

Conductivity, or conductance, is the reverse of resistance, and is used to designate the conducting power of any size wire of any material. The relative conductivity of different metals with copper as standard is shown in Table 1.

TABLE 1.

	Relative Conductivity.	Relative Resistance.
Silver	102	.98
Copper	100	1.00
Gold	77	1.3
Aluminum	64	1.5
Zinc	30	3.3
Brass	22	4.5
Iron	16	6.2
Platinum	11	9.9
Lead	9	11.1
Mercury	1.6	63.2
German Silver (18 per cent. Nickel)	5.5	18
German Silver (30 per cent. Nickel)	3.6	28

The unit of resistance is the Ohm, and is based upon the resistance of a column of mercury 41.85 inches long and weighing 223 grains at 32 degrees Fahrenheit.

Circular Mil System. Since the conductivity of a conductor varies with its cross-sectional area, the mil or circular mil furnishes a system of designating cross-sectional area of an electric conductor which has been universally adopted. The length of one-thousandth of an inch is a linear mil or simply a mil. The area of a circle one-thousandth inch in diameter is one circular mil.

A wire of copper of commercial purity one foot long and one circular mil in cross-sectional area has a resistance of 10.79 Ohms at a temperature of 75 degrees Fahrenheit, so that if a wire's cross-sectional area is known its resistance can be determined by simple division, as the resistance varies inversely as the cross-sectional area of a conductor; therefore, if the resistance of the wire of one circular mil is divided by the circular mils in the area of another wire of the same length, the result will be the resistance of the latter wire.

Wire Gauges. There are various wire gauges in use which are based upon the cross-sectional areas of the wires, each size being designated by a number. The numbers range from No. 0000 up to No. 36, and so on, the lower the number the larger the diameter of the wire and the lower the resistance. The wire gage generally used in the United States for copper wire is the Brown and Sharp gage, usually called "B & S wire gage," or "American wire gage." The Birmingham or Stub's gage is sometimes used, but is not so much heard of as formerly. A table of the resistance of bare copper wire with its different properties will be found in table No. 2.

In studying the table it will be noticed that the weight and area about double with every three numbers.

Rules for Resistance. If the wire table is not handy, the resistance of pure copper wire can be found by multiplying its length in feet by 10.5 and dividing the product by the cross-section in circular mils.

Current. The intensity of the current flowing through any circuit is measured in amperes, and is the direct result of the electro-motive force and resistance of the circuit. The existence for any length of time of a current of electricity always implies the existence of a circuit. When a current is passing through an electric circuit, electro-motive force must be expended to drive it through, as the resistance of the circuit opposes the transmission of the current, and the current driven by electro-motive force through a resistance indicates electric energy.

Heat Developed by a Current. When a current does work in overcoming a resistance, the work performed is converted into

TABLE 2.

PROPERTIES OF BARE COPPER WIRE.

Brown & Sharpe Gage.						Birmingham or Stubs Gage.
Number.	Diameter in parts of an inch.	Diameter in mils.	Area in circular mils.	Weight in pounds per 1000 feet.	Resistance in ohms per 1000 ft. at 60° F.	Diameter in mils.
0000	.46	460.	211 600	624.	.048	454
000	.4096	409.6	167 800	546.	.061	425
00	.3648	364.8	133 100	437.	.076	380
0	.3249	324.9	105 500	350.	.096	340
1	.2893	289.3	83 690	272.	.122	300
2	.2576	257.6	66 370	244.	.153	284
3	.2294	229.4	52 630	203.	.194	259
4	.2043	204.3	41 740	172.	.245	238
5	.1819	181.9	33 100	146.	.307	220
6	.1620	162.	26 250	124.	.388	203
7	.1443	144.3	20 820	98.	.491	180
8	.1285	128.5	16 510	82.	.621	165
9	.1144	114.4	13 090	66.	.783	148
10	.1019	101.9	10 380	54.	.979	134
11	.0907	90.74	8 243	43.	1.229	120
12	.0808	80.81	6 530	35.	1.552	109
13	.072	71.96	5 178	27.	1.964	95
14	.0641	64.08	4 107	21.	2.485	83
15	.0571	57.07	3 257	15.	3.133	72
16	.0508	50.82	2 583	12.	3.914	65
17	.0453	45.26	2 048	10.	5.028	58
18	.0403	40.3	1 624	7.3	6.363	49
19	.0359	35.89	1 288	5.3	7.855	42
20	.032	31.96	1 022	3.7	9.942	35
21	.0285	28.46	810.1	3.1	12.53	32
22	.0253	25.35	642.4	2.4	15.9	28
23	.0225	22.57	509.5	1.9	19.93	25
24	.0201	20.1	404.	1.5	25.2	22
25	.0179	17.9	320.4	1.2	31.77	20
26	.0159	15.94	259.8	1.0	40.27	18
27	.0142	14.2	201.5	0.7	50.49	16
28	.0126	12.64	159.8	0.6	64.13	14
29	.0113	11.26	126.7	0.51	79.73	13
30	.01	10.03	100.5	0.43	101.8	12
31	.0089	8.93	79.7	0.30	128.5	10
32	.0079	7.95	63.21	0.24	159.1	9

heat. This production of heat causes a rise of temperature in the conductor, and the temperature will continue to rise until the heat generated is exactly balanced by the rate of dissipation of the heat by conduction, convection and radiation. The necessary resistances of electrical machines involve the production of heat in their operation, which causes a rise of temperature; but as insulating materials can only stand moderately high temperatures,

such machines must be designed without becoming too hot, which is accomplished by increasing the radiating surface and by supplying radiation.

The utilization of this heating effect is illustrated in the incandescent lamp, electric stoves, cooking utensils, car heaters, soldering irons, etc. Wires carrying current may become heated so as to become dangerous, so that the wires are limited as to their safe carrying capacity, as shown in Table 3. Wires smaller than No. 14 are never used in wiring except for special purposes.

TABLE 3.

TABLE OF SAFE CARRYING CAPACITY OF INTERIOR WIRES.

Size of Wire, B. & S. Gage.	Circular Mils.	Current in Amperes.	
		Rubber Insulation.	Other Insulations.
14	4,107	12	16
12	6,530	17	23
10	10,380	24	32
8	16,510	33	46
6	26,250	46	65
5	33,100	54	77
4	41,740	65	92
3	52,630	76	110
2	66,370	90	131
1	83,690	107	156
0	105,500	127	185
00	133,100	150	220
000	167,800	177	262
0000	211,600	210	312
300,000 CM.	300,000	270	400
500,000 CM.	500,000	390	590
1,000,000 CM.	1,000,000	650	1,000
2,000,000 CM.	2,000,000	1,050	1,670

Power. The unit of electrical energy is called the watt and is the amount of power expended when one ampere is flowing in a circuit at a pressure of one volt. It is equivalent to $\frac{1}{746}$ of one horse power. The number of watts utilized in any circuit can be found by multiplying the drop of voltage by the current passing through it, or by squaring the current and multiplying by the resistance, or,

$$\text{Watts} = EC = C^2R.$$

For commercial currents and voltages the watt is a very small unit, so that a kilowatt (=1,000 watts) is generally used as the unit of electrical power. It is represented by the abbreviation K. W. A horse power is equal to 746 watts, or approximately three-fourths of a K. W.

Electric Circuits. Ohm's law, E=CR, states that with a constant current the electro-motive force varies directly with the resistance, so that whenever the resistance in the circuit is changed, the electro-motive force will change. This is known as a constant current circuit, a typical illustration of which is an arc lamp series system, and the more lamps there are in series the more energy must be expended.

The constant potential circuit maintains a fixed difference of

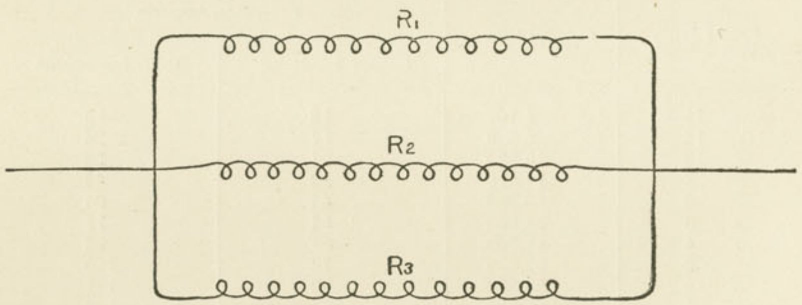


Fig. 1

potential at the terminals of any apparatus, and is illustrated by the ordinary incandescent lamp system.

Resistance of Circuits. When a circuit consists of various parts, all of different resistances, but connected in series forming a single path, the total resistance of the circuit is the sum of all the resistances. When a circuit is in branches, that is, connected in parallel, each of the parallel paths must be calculated separately.

The resistance of any number of wires in parallel is equal to the product of the resistance of each circuit divided by the sum of those same resistances. For instance, suppose in Fig. 1 the resistance of the three parallel circuits, R_1, R_2, R_3, is to be obtained; then the resistance which, when substituted for the three resistances, will give the same value of current flowing through it as is represented by the formula

$$\frac{R_1\ R_2\ R_3}{R_1\ R_2+R_1\ R_3+R_2\ R_3}$$

In the case of two similar wires connected in parallel the resistance is reduced one-half.

MAGNETISM AND THE ELECTRO-MAGNET.

Uses of the Electro-Magnet. While the scientific world in general is acquainted with all the laws of the magnet and electro-magnet and its apparent peculiarities, the average person, however much he might be familiar with machinery and devices which contain this interesting piece of mechanism, has usually not given much thought to its fundamental laws of action. That it is an important device in the generation and utilization of the electric current need scarcely be mentioned. All one has to do is to look around and see what an important part it plays in the life of the world. It is the so-called "lines of induction," generated by the electro-magnets of a dynamo, that makes the electric current possible, and it is this same principle which causes the motor to revolve with such power, the telephone to reproduce the voice, the telegraph to respond to the touch, the arc lamp to burn all night, the transformer to become almost a magician by changing volts and amperes into each other, and many other applications which can be thought of.

What is this device which plays such an important role in all electric apparatus? It is a very simple arrangement of three things: an iron core, a coil of copper wire and an electric current. When the current is turned on it flows around the iron core and magnetizes it, and it is usually a magnet only so long as the current is turned on.

Magnets in general are known as permanent magnets and electro-magnets. The use of the former is practically limited, but there are many important features of the electro-magnet that can be best explained by the permanent magnet, as they both come under the same laws of magnetism.

Every magnet has two poles or ends, called the north pole and the south pole, named after the poles of the earth, because from the earliest days it has been known that the earth is a magnet, and that a magnetic needle, if mounted on a pivot so that it can swing freely, will point north and south. The north seeking point has therefore been called the north pole of the magnet and the other end the south pole. By means of a magnetic needle many laws of the magnet have been found. If a bar of iron that contains magnetism, and all iron does contain magnetism to a greater or less extent, is held near the magnetic needle, it is observed that one end is attracted by one end of the bar while the other end is repelled. If two magnetic needles are used, it is found that two of the ends will attract each other, while the other ends will repel each other. From this is derived the first laws of magnetism, that "Like magnetic poles repel one another; unlike poles attract one another."

Among the peculiarities of magnetism is that a magnet must have two poles; it cannot have one. If a magnetic bar be broken into two pieces, each piece will have two poles, and possess the same properties as the larger piece, and if the pieces are broken again and again, each piece must have a north and a south pole.

It is found that, by placing two magnets near each other, some will attract or repel each other with greater force than others. This is called magnetic force, and it gives the second law of magnetism: "The force exerted between two magnetic poles is proportional to the product of their strength, and is inversely proportional to the square of the distance between them." In other words, the stronger two magnets are, the greater is the magnetic force exerted, and this force diminishes very rapidly as the distance between them is lengthened, and increases very fast as the magnets approach each other. This can easily be illustrated by taking a magnet and placing it near a nail; at a certain distance the nail will not be in the least attracted by the magnet, but as the magnet is moved closer the force becomes so great that the nail will suddenly move to the magnet and cling to it.

In speaking of magnets in general, it is assumed that they are made out of iron or steel. The only other metals of importance that possess the power of magnetism are nickel and cobalt, but they are rarely if ever used.

Magnetic Induction. Magnetism may be communicated from one piece of iron to another in two ways: by actual contact or by induction. It is this latter method of inducing magnetism that is the most important. A magnet is supposed to throw out around it a number of magnetic lines, and when a piece of iron comes

within the range of those lines it becomes a magnet by induction. The lines are called lines of induction, and the stronger the magnet the more lines of force per square inch it throws out. The strength of a magnet depends upon the kind of iron from which it is made. When a body possesses a high degree of magnetism it is said to possess a high degree of permeability; that is, some irons are better conductors of lines of induction than others, and the more permeable the iron the higher it can be magnetized, and hence the greater the magnetic force it is capable of exerting.

Not all magnetic substances retain their magnetism permanently. Hard steel retains some of the magnetism imparted to it, but cast iron and many impure qualities of wrought iron retain

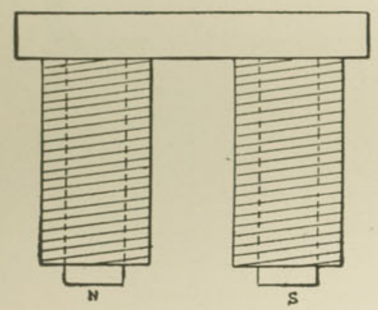


Fig. 2
Horseshoe Magnet.

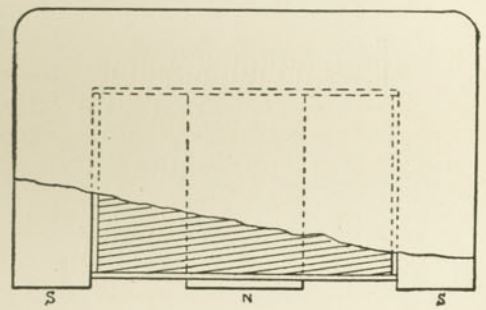


Fig. 3
Iron-Clad Magnet.

their magnetism imperfectly. This property of retaining its magnetism is called residual magnetism, so that steel would be said to contain considerable residual magnetism, while very soft iron possesses very little residual magnetism.

Another method, and by far the one most widely used to produce magnetism, is the electric current, and magnets produced by the electric current are therefore called electro-magnets. They are made in numerous forms, depending on the purpose to which they are to be put, the bar electro-magnet, the horse-shoe electro-magnet, the ironclad electro-magnet and the solenoid and plunger, as shown in Figs. 2, 3, and 4, being familiar types. The polarity of an electro-magnet depends upon the direction in which the current is flowing around it. Various rules for remembering the relation of the electric current and the magnetic force have been given. One of the best rules is that the direction of the current and the flow of the magnetic flux are related in the same way as the rotation and travel of a right-hand screw; that is, when the current travels around the bar in the direction a right-handed thread turns, the north pole would be represented by the point of the screw, and the south pole by the head, as shown in Fig. 5.

Permeability. In any electro-magnet the degree of magnetism depends upon the number of turns of wire, the strength of the current, and the permeability of the iron. As a product of the number of turns and the amount of current is called ampere-turns, this can

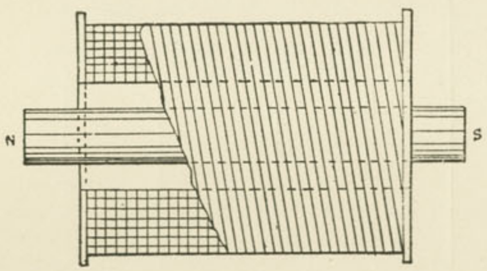


Fig. 4
COIL AND PLUNGER.

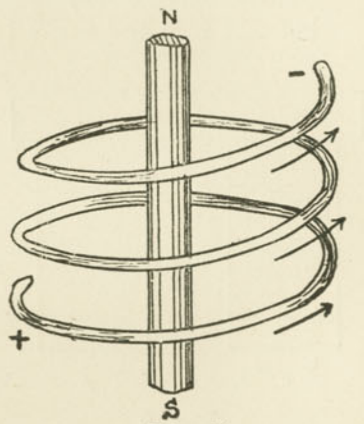


Fig. 5
RELATION OF ELECTRIC CURRENT AND POLARITY.

be simplified by saying that the magnetization depends upon the number of ampere-turns and the reluctance of the circuit, the term reluctance being used the same in a magnetic circuit as the term resistance is used in an electric circuit and the term permeability being very similar to conductivity. Certain kinds of iron have a certain permeability, so that if the number of ampere-turns on the magnet are known, the degree of magnetization is known. These are not proportional in the least, but vary as follows: When there is no current passing around the core of an electro-magnet it has very little magnetism, and what it has is called residual magnetism. When the current is turned on the degree of magnetization jumps very rapidly, and as the current is increased the magnetic field

becomes stronger, but nowhere in proportion to the first amount. As the current continues to be increased, this portion grows less and less until the amount of magnetism gained by increasing the current is very small. The iron is then said to be saturated; that is, no more lines of force can be crowded into a square inch economically. When the magnetizing current is removed the iron loses its magnetism and becomes as before. Fig. 6 shows three curves for wrought iron, steel and cast iron, illustrating the above principle.

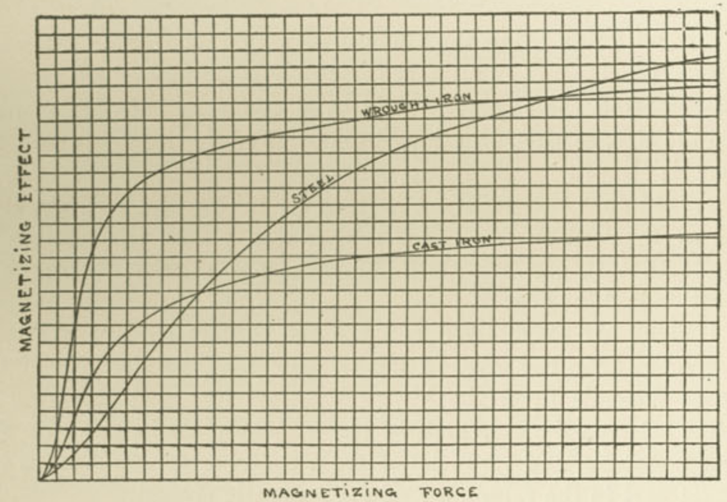


Fig. 6
RELATION OF MAGNETIZING FORCE AND MAGNETIZING EFFECT.

Ampere-turns. As the amount of magnetizing force depends upon the number of ampere-turns, it does not make any difference whether the small current with a large number of turns or a large current with a small number of turns be used; that is, 2000 turns of wire with 10 amperes passing through it will give the same degree of saturation to an iron core as 200 turns with 100 amperes, the product in each case being 20,000 ampere-turns.

Magnetic Laws. In general, it can be stated that the laws of the magnetic circuit follow very closely the laws of the electric circuit, and while Ohm's law is given as

$$\text{CURRENT}=\frac{\text{electro-motive force}}{\text{resistance}}$$

for the electric circuit, the law of the magnet circuit is

$$\text{MAGNETIC FLUX}=\frac{\text{magneto-motive force}}{\text{reluctance}}$$

the magnetic flux being the amount of magnetization or magnetic current, the magneto-motive force being the number of ampere-turns creating the magnetic field, and the reluctance depending upon the size, section, length and material of the iron core and the magnetic circuit.

When an electro-magnet is used for lifting and pulling, such kind as is used on cranes for lifting iron plates, the number of pounds that it can lift depends upon the square of magnetic induction and the area of poles. It is therefore of necessity to have the iron highly magnetized and a large contact surface available in order to have the greatest lifting power. The strength of the magnet depends upon the kind of plate lifted and the kind of contact between the pole and the plate. The plate in this case acts as an armature, and its distance from the pole faces plays an important part in the reluctance of the magnetic circuit.

Action of Dynamo Magnets. In a dynamo the armature or field must revolve, so that there must necessarily be some air space between the poles and the armature. This air space adds materially to the size that the electro-magnets must be in order to drive the required magnetic flux through it. In the case of a dynamo the lines of magnetic force are not used for attracting the armature, the function of the poles being merely to provide a great number of these magnetic lines, as the electro-motive force of a dynamo is proportional to strength of the field, the number of conductors on the armature, and the speed of rotation. In a shunt dynamo the voltage drops as the load goes on, unless the current is increased to make the field stronger. In a series machine the voltage increases as the load increases; so this principle is taken advantage

of in a compound machine for strengthening the electro-magnets, and hence the fields.

In the motor the electro-magnets are used for creating a magnetic field, which acts upon the currents flowing through the armature conductor so as to drag the armature around. Therefore, very powerful magnets are used, so that a great torque can be produced without requiring much current in the armature.

Other Uses of Electro-magnets. When used with the electric telegraph, the electro-magnets attract an armature which emits audible sounds. When first used with the telephone, the speaker talked to an elastic plate of thin sheet iron, which vibrated and transmitted its every move to a similar plate in a similar telephone by electro-magnetic induction. As now used in the carbon transmitters, the vibrations of the voice change the resistance of the granulated coke placed behind the metal disc, so that currents are set up in the circuit receiver, which is composed of a magnet and a magnet coil. When the current is strong, due to the voice, it increases the magnetic field and draws the elastic plate toward it and when it is weak it causes it to recede, the electric coil on the permanent magnet tending to increase or decrease the magnetism. This sets in vibration the disc, which throws the air into similar vibrations at the transmitting end, thus reproducing the sound. The mechanism of an arc lamp is adjusted by electro-magnets, so that the carbons are kept always a certain distance apart as the carbon is consumed. In a transformer the alternations of the current in the primary coil magnetize and demagnetize the iron core, which in turn sets up currents in the secondary coil in whatever ratio in respect to the voltage and current that is desired. A transformer is a closed electro-magnet with two coils upon it. Usually the primary coil consists of many turns of fine wire to receive small currents at high pressure and the secondary, of a few turns of large wire at a low pressure. This combination can be reversed, in which case it is called a step-up transformer.

Design for Different Purposes. These are only a few of the many applications of the electro-magnet. Their design in each case depends upon the particular purpose for which it is to be used. In general, it may be said that when a very powerful attraction at very short distances is required, a short cylindrical magnet of the ironclad type is found to be the best. To attract iron across a wide bar gap which offers much reluctance, a horseshoe shape with long cores is used, as it requires a great number of ampere-turns to generate the necessary force to drive the magnetic flux across the gap. To give a gentle pull over a long range a solenoid, or coil and plunger device, is used. For giving a very quick-acting magnet, the coils are not wound all along the iron, but only at the poles. As the tendency of a magnetic circuit is always to make itself shorter, the yoke and armature should form as nearly as possible a closed magnetic circuit.

The kind of pole tips, or pole shoe, used on an electro-magnet also depends upon the purpose for which the magnet is to be used. On a dynamo the pole shoes are put on the ends of the pole pieces to distribute the magnetic flux over a large area in order that the lines of force between the poles and the armature will not be so concentrated, thus reducing the resistance of the magnetic circuit.

Value of Laminated Cores. When used with alternating currents, the cores of the electro-magnets should be made of very thin plates or of very small iron wires. The alternate rapid reversals of the magnetism in the magnetic field of an electro-magnet, when excited by alternating currents, set up so called "eddy currents" in every piece of metal. The effect of these "eddy currents" in the iron is to heat it, which means loss of power. By subdividing the core into layers or laminations, the effect of the eddy current is minimized, as the strength of this lost and useless current depends upon the thickness of the plates.

Principles of Dynamos. The generation of electro-motive force, and the various manifestations of electric energy met with in engineering practice, depend upon the principle of electro-magnetic induction. If an electric conductor lies in a field of force, near some magnetic pole, it will not be affected by this field so far as the electro-motive force in it is concerned. If, however, either the wire is moved so as to cut these lines, or the magnet is moved while the conductor is stationary, electro-motive force will be formed in the conductor. If the ends of the conductor were connected to a proper instrument, such as a voltmetre, it would be evident that the electro-motive force existed. The cutting of these lines of force by an electric conductor represents the impressing of force upon the conductor, and if the proper conditions are established the electro-motive force impressed on the conductor by the field of force will produce a current.

There are two conditions necessary for producing a current,

namely, the conductor must form part of a closed circuit and the number of lines of force through the conductor must vary in number, or only a portion of the circuit must cut lines of force. In the case of dynamos both of these conditions exist at once. As the

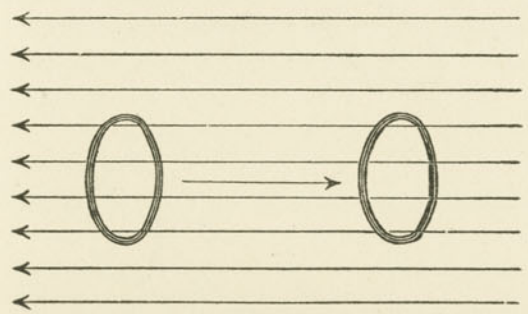


Fig. 7

armature conductors cut lines of force they vary the number of lines of force. Figs. 7 and 8 represent two movements of a conductor in a uniform field of force in which no electro-motive force is produced in the conductor, as the number of lines of force

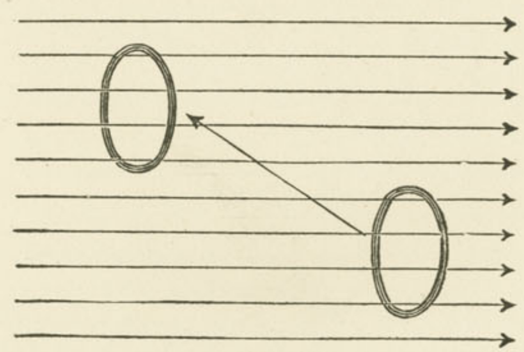


Fig. 8

cut by the conductor in its movement does not vary. Figs. 9 and 10, however, represent conditions such that the number of lines of force is varying, and hence electro-motive force and current will both result. In the case of Figs. 7 and 8 no power is expended in moving the ring through the field; in Figs. 9 and 10 power must be expended.

Field of Force in Practice. Magnetic fields of force in practice are generally produced by electro-magnets. The number of

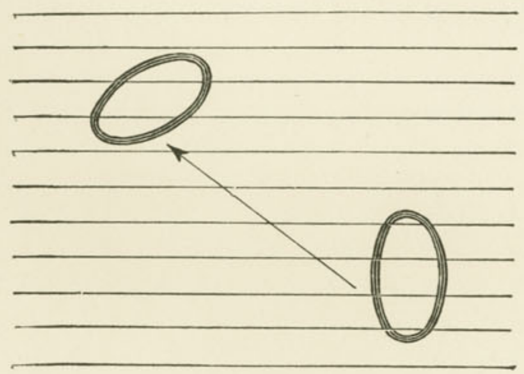


Fig. 9

poles used vary in practice, but the same general plan for varying the north and south poles alternately is followed. Fields of force

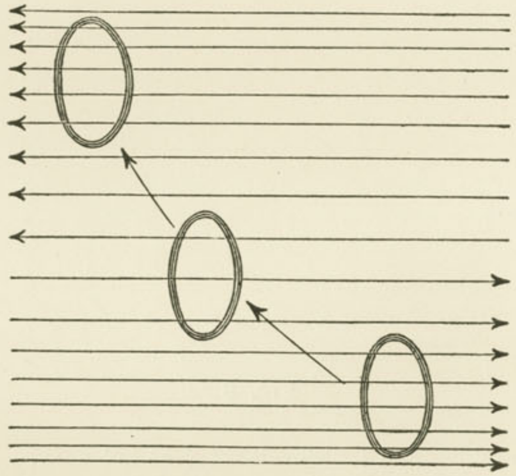


Fig. 10

may be moved past conductors or past coils forming parts of circuits; or the conductors and coils may be moved past them; or the relations of field to conductors or coils may be kept changing

as in inductor generators. In all cases electro-motive force is impressed on the circuit.

Dynamos. Dynamos may be defined as machines used to convert mechanical energy into electrical energy by means of the principle of electro-magnetic induction. In all commercial machines the mechanical energy is supplied in the form of rotation, and the electrical energy is delivered either as direct current or as alternate current.

PRINCIPLE OF DYNAMOS.

If a loop of wire be revolved in a magnetic field about an axis

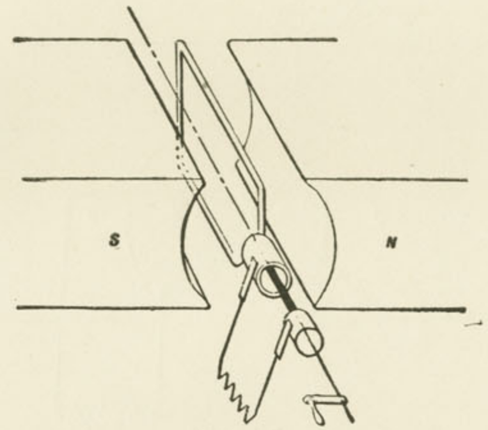


Fig. 11

perpendicular to the lines of force, as in Fig. 11, then each side of the loop is a conductor moving across the lines of a magnetic field, and as such will have an electro-motive force induced in it. The directions of the induced electro-motive forces in the two sides will be opposite to each other, and since they are on opposite sides of the loop, the pressures, instead of opposing each other, will be added together. If the two ends of the wire from which the loop is made be connected to slip rings and a circuit be completed through contacts sliding on them, a current will flow. For each complete revolution the current changes its direction twice, and the arrangement shown in Fig. 11 is an elementary alternating current dynamo or alternator.

The Commutator. A commutator is used on a shaft of a machine when it is desired to get a direct current. In the case of Fig. 12 a commutator having two similar cylindrical parts of metal, insulated from each other and affording sliding contact for two brushes, would be sufficient. One end of the wire would be attached to one part of the commutator and the other end to the other part. The brushes are so placed that at the instant that the electro-motive force in the loops changes its direction the brushes slide across from one segment of the commutator to the other, and thus the current, while reversed in the loop, is left following in the same direction in the outside circuit. In practice, however, a

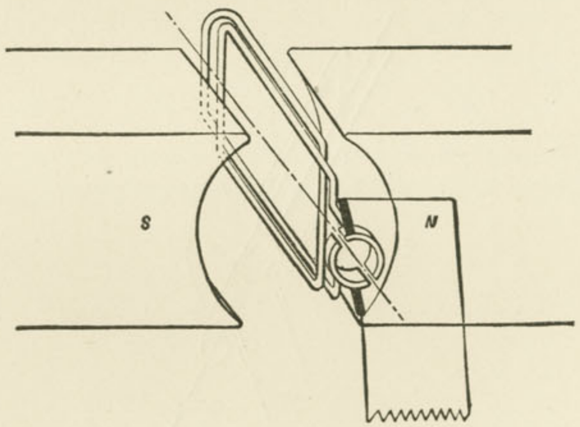


Fig. 12

great number of conductors and commutator bars are required, as the electro-motive force would fluctuate, which is not permissible in ordinary direct-current generators.

The Armature. The general arrangement of the loops of wire in which the electro-motive force is induced, the iron core which sustains them, and the necessary insulation constitute what is known as the armature of a dynamo. They are made in various forms, which will be described later.

Field Magnets. All commercial dynamos at the present day have their magnetic field produced by electro-magnets, called field magnets. In small machines there are usually two poles, but in large machines it is usual to use multipolar field magnets in which

any even number of poles, alternately north and south, are arranged concentric to the armature. Almost all modern machines belong to the multipolar type.

The magnetic circuit of a dynamo is shown in Fig. 13. The field coils are wound on the poles, and the current required to set up the magnetic field is furnished by the dynamo itself, even at starting, when the residual magnetism in the magnets is utilized. The portion connecting the poles is called the yoke, and the space between the magnet poles and the iron core of the armature is

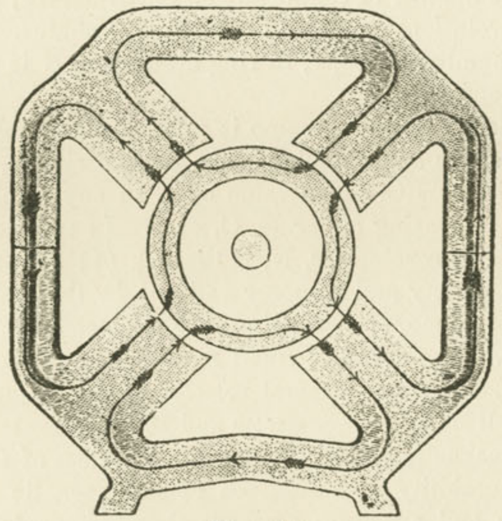


Fig. 13

called the air space, or air gap. This air space must be made as small as possible in order to prevent excessive leaking of the magnetic flux, and also to reduce the reluctance of the magnetic circuit, as the air space possesses a very high reluctance. The smaller the air space, the smaller the magnetic force required, and the smaller, consequently, the number of ampere turns needed on the field coils of the electro-magnet. To reduce the air space as much as possible, the armature's disks are often toothed so that the wires may set down in the grooves and the teeth may come as close to the pole pieces as practice will permit.

The total reluctance of the magnetic circuit is the sum of all the reluctances of the yoke, field cores, pole pieces, air gaps and armatures.

Calculation of Electro-motive Force in Dynamos. The fundamental formula upon which all dynamos are designed is as follows:

$$E=\frac{N\,C\,n}{10^8}$$

in which E=electro-motive force in volts; N is the strength of the field; C is the number of conductors on the armature; and n is the number of revolutions per second. In drum armatures, N is equal to twice the number of loops; in ring armatures, N is equal to the number of loops.

The capacity of any dynamo is equal to the number of watts which it generates and supplies to the outside circuit, so that the capacity varies as EC. The value of E in any machine can be increased by increasing either N, C, or n. In practice the value of the number of revolutions, N, is limited, (1) by considerations of mechanical safety and economy and (2) by the desirability, in the case of a dynamo, of connecting it to the steam engine or other prime mover. The speed of small machines is greater than that of large ones, but the peripheral velocity of the circumference of armature of all sizes lies between 25 and 100 feet per second. The value of the magnetic flux N, depends upon the size of the machine, and the permeability or reluctance of its magnetic field. The field magnets and armature core are therefore made of low reluctance, and the air gap between the pole pieces and armature is made small. The number of conductors, C, on the armature can be increased by decreasing the size of the wire, but sufficient cross-section must be left in the conductors to carry the maximum current of the machine without causing excessive heating. Good practice demands from 400 to 800 circular mils cross-section of armature conductor per ampere, the larger values being for machines that run continuously.

Laminated Armature Cores. Since the iron core of the armature is practically a conductor moving in a magnetic field, it has induced in it an electro-motive force, which should be kept as small as possible, as the energy thus generated appears in the form of heat, and will produce an excessive temperature of the armature

if not prevented. This is done by making the iron core of the armature of thin iron disks insulated from one another.

These currents produced in the core are called Foucault or eddy currents, and they are proportional to the square of the thickness of the disks or laminae. In practice the thickness of the armature disks will be found to vary from .01″ to .06″. For insulation between the disks, reliance is usually placed on the iron oxide that forms on them during their manufacture. Generally every six disks or so, insulation is made perfect by interposing shellac, japan or paper. For small armatures, the disks are punched whole from sheet iron. These punchings are assembled on the shaft, and are held in place by brass collars at each end of the disks and are tightened by means of nuts on the shaft or similar device.

In large machines the armature disks are punched in parts and these are assembled with their joints staggered. With large machines the disks are not directly attached to the shaft, but they are mounted on a spider, which in turn is connected with the shaft.

Rating of Dynamos. The American Institute of Electrical Engineers recommends that all electrical and mechanical power be expressed, unless otherwise specified in kilowatts; that the full load current be that current which with the full load voltage gives the rated kilowatts; that all guarantees on heating, regulation, and sparking should apply to the rated load, except where expressly specified otherwise; that direct current generators should be able to stand an overload of 25 per cent for one-half hour without an increase of temperature elevation exceeding 15 degrees centigrade above that specified for full load; and that direct current motors should, in addition, be able to stand an overload of 50 per cent for one minute.

Temperature of Electrical Machinery. The rise of temperature of the parts of a dynamo or motor should be referred to the standard conditions of a room temperature of 25 degrees centigrade, and the apparatus should neither be exposed to draft or inclosed, except when otherwise specified. If the room temperature differs from 25 degrees centigrade, the observed rise of temperature should be corrected ½ degree for each degree difference. The temperature should be measured after a run of sufficient duration to reach practical constancy. This is usually from 6 to 18 hours, according to the size and construction of the apparatus. It is recommended that the following maximum values of temperature should not be exceeded:

Field and Armature........	50°C.
Commutator and Brushes....	55°C.
Bearings and other parts....	40°C.

In using a thermometer care should be taken to so protect the bulb as to prevent radiation from it and at the same time not to interfere seriously with the normal radiation from the part to which it is applied. Cotton waste around the bulb of the thermometer will usually answer the purpose.

Armature Windings. The electro-motive force of a dynamo, or the voltage which it gives out, depends upon three factors: the strength of the field, the number of conductors on the armature and the speed of the armature. It is a well-known fact that strengthening the field of a dynamo increases its voltage, and increasing the speed also increases the voltage; but for any constant potential machine the number of conductors on the armature which are active in producing electro-motive force always remain constant.

The designer of a machine, in taking these things into consideration, fixes upon the strength of the field and the speed of the machine, from which he derives the number of conductors on the armature required; or, he assumes the number of armature conductors, and calculates the field and speed to produce a certain voltage; but, whatever the method, the result is, that a large number of conductors must be placed upon the armature in such a way that the proper electro-motive force is generated, the size of the wire must permit sufficient current to pass through it without overheating, and proper connections must be made to the commutator, etc.

The principle difficulty experienced by the early student of electricity was in understanding the armature winding, and a man who, in those days, could perform the task of successfully winding an armature so that it was in balance and did not short circuit or overheat, or who could finish the maze of wires bristling from the armature in a neat series of connections to the proper commutator bars and get a desired voltage, was looked upon as a wizard. A careful study of the subject reveals that certain objects must be

attained in any winding, and a systematic method must be adopted before even the simplest can be understood.

Types of Armatures. It is usual in the discussion of this subject to divide the different types of armature windings into the "closed-coil" and "open-coil" types, ring and drum types and the kind of windings into lap and wave windings. When the inductors and commutator segments are not all electrically connected with each other, the winding is called an open-coil winding. Open-coil windings are used chiefly on arc lighting dynamos. Closed-coil windings are more generally used for incandescent lighting and power purposes. In the case of the closed-coil wind-

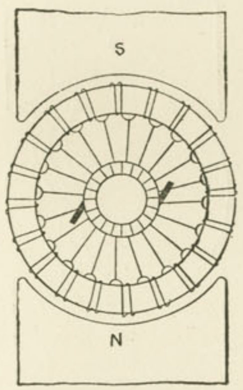


Fig. 14

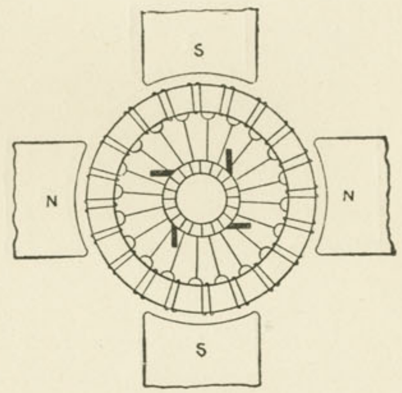


Fig. 15

ings all the inductors on the armature are engaged all the time in adding electro-motive force to the circuit, except when short circuited by the brushes at commutation, and while there are many forms of closed-coil windings the inductors in all of them form one or more endless circuits around the armature core. The two principal types of closed-coil armatures are the ring armature and the drum armature.

The ring armature consists of an annular ring around which the armature conductors are wound in a continuous spiral or number of spirals which are tapped off at equal intervals to the commutator bars. Fig. 14 shows a simple, bipolar, two-circuit ring winding. The magnetic lines of the field pass from the north pole to the south pole. As the armature rotates, the conductors on the exterior surface cut across the magnetic lines twice in each revolution, and since there is no flux on the inside of the ring, the conductors on the inside serve merely to connect the outside conductors in series.

A four-pole ring winding is shown in Fig. 15. The winding is similar to that shown in Fig. 14, but the number of brushes is doubled, and the number of coils should be a multiple of the number of poles. There are two negative and two positive brushes, the brushes of the same polarity being connected together. There are other types of ring windings which are arranged to give different results. For instance, if in Fig. 15 two brushes were to be used instead of four brushes, the end connections would be con-

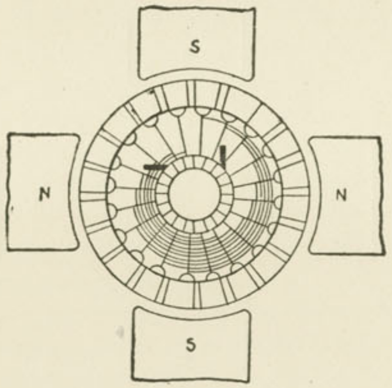


Fig. 16

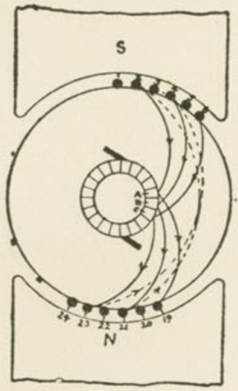


Fig. 17

nected together as shown in Fig. 16. For machines with a larger number of poles there would be a corresponding increase in the number of circuits in the armature.

Drum Armatures. Windings for drum armatures are very complicated, and an attempt to show by a diagram a complex winding would only result in confusion. They differ from ring windings, inasmuch as the conductors lie on the outside surface of the core, and hence all the wire is active in producing electro-motive force except the end connections, while in the ring armature a large amount of wire is utilized in merely serving as conductors on the inside of the ring. In a ring armature the adjacent coils are in series with each other, while in a drum armature the connections must be so made that each conductor must join another

conductor in such a manner that the electro-motive force is cumulative. The return coil always lies under a pole of opposite polarity, so that it involves a series of end connections, which entirely cover the end of the armature core.

The end view of a drum winding is shown in Fig. 17. The coils are so connected that the current passes from bar to bar. In the figure but two complete turns are shown, but all the other coils are connected similarly. Coil No. 2, after traversing longitudinally along the south pole, is brought across the end to commutator bar marked A, from whence it goes to coil No. 19 on the other side of the armature, which traverses longitudinally along the north pole and across the back of the armature indicated

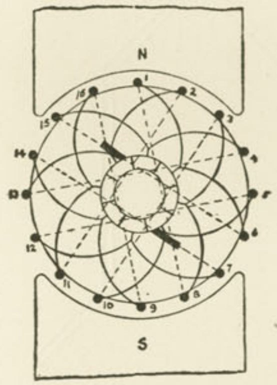


Fig. 18

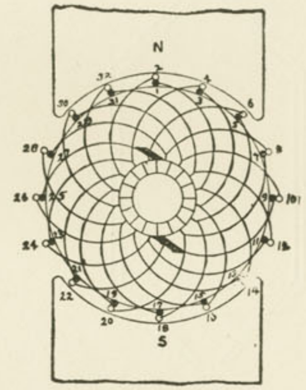


Fig. 19

by the dotted line, and back along wire marked No. 4 to commutator bar marked B, to which wire No. 21 is also attached, and so on all around the armature. Fig. 18 represents a completed winding of a simple drum armature where there are as many bars as there are coils. Fig. 19 represents a winding two layers deep for a two-pole machine. As the number of poles increase and the number of conductors on the armature multiply, the winding becomes still more intricate, but still the same law applies of joining a conductor under one pole to a conductor under another pole of reversed polarity.

The open-coil winding is similar to the closed-coil, with the exception that each coil is alternately cut in and out of circuit and is not connected to any other coil by end connections. The opposite coils are connected in series. This style of armature winding is used chiefly for arc light machines. The electro-motive force is varied by shifting the brushes, which cut coils in and out of circuit, so as to maintain an even current on the line.

The coils are wound on drum armatures in one of two ways, known as lap winding or wave winding. The winding of an armature is very much simplified these days by the formation of coils, shown in Figs. 20 and 21. Fig. 20 represents a coil for a lap winding, and Fig. 21 a coil for a wave winding. For small machines wire is used in their construction, but for large size

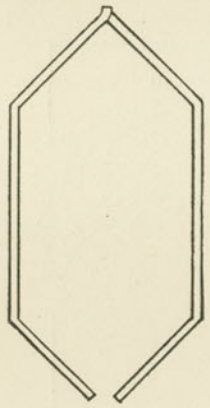


Fig. 20

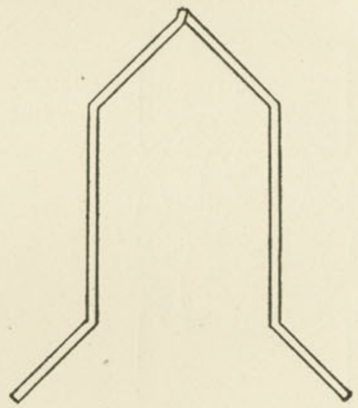


Fig. 21

machines they are formed of flat rods. They are insulated carefully and are formed by machinery so that they will exactly fall in place when placed on the armature. The different forms of windings can be shown in a different manner from those shown in Figs. 16, 17, 18, and 19. In those figures the windings are shown as they would appear on the armature looking on them at the end. A far easier way is to look at them at right angles to the plane of the coils and assume the circumference of the armature to be one flat plane. In this manner the conductors on the armature and the connections to the commutator can be shown more clearly. Fig. 22 represents a developed wave winding, the coil goes across the armature and back without crossing itself, while in the lap

winding the wire doubles back on itself at every turn. Fig. 23 represents a developed lap winding.

Whatever the style of drum winding, great care must be

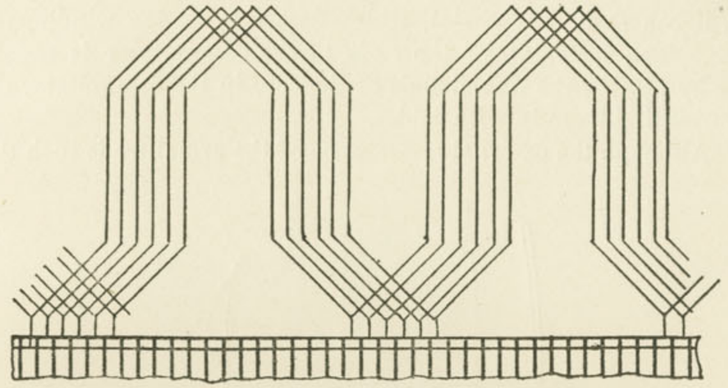


Fig. 22

exercised both in regard to insulating and fastening the coils, especially the end connections. They are usually insulated with

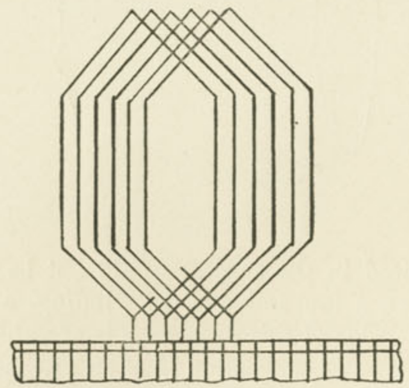


Fig. 23

mica, where the best of insulation is needed, but on account of its cost and the difficulty of manipulating the mica, canvas, oiled paper and vulcanized fibre are among the insulations used. Japan and shellac are used liberally, especially when canvas is used. All armature conductors must be banded to prevent their dislodgment under the centrifugal action at high speeds. The wire used for this purpose is generally composed of hard drawn brass, phosphor-bronze or steel. It is wound over insulating strips, forming a band of several turns, which are sweated together with solder. With toothed cores, a strip of maplewood is fitted into the recesses, and acts like a cover to the slot, which firmly holds the windings in place. The fastening of the ends to the commutator is usually done by placing the tinned ends of the core in the commutator slot and sweating them in with solder.

Although the external appearance of the armature is such that

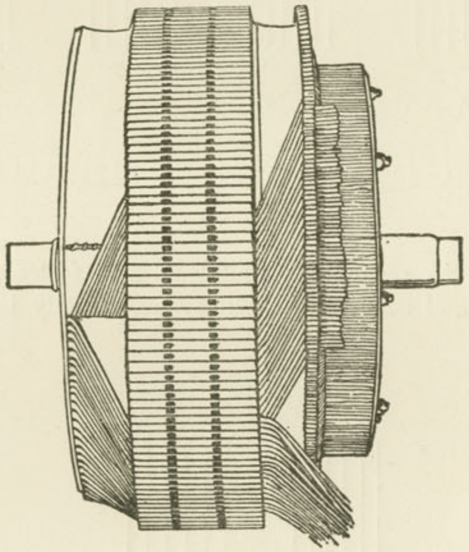


Fig. 24

one not experienced in the subject would not be able to see any difference between a lap and a wave winding, a difference does exist, and a knowledge of this difference is of value, as it can then be told what the type of connection is in an armature that requires repairs, and knowing this much, the cause of the trouble can more readily be found, and the proper remedy provided. In Figs. 22 and 23 it will be seen that in the first figure the ends of either side of the coil do not run in the same direction. In Fig. 23 both ends of the same side of the coils turn in the same direction. From this it can be seen that if an armature is wound with single turn coils it can at once be determined whether the connections are of the lap or of the wave type. This fact can be made clear by means

of Figs. 24 and 25, which are reproductions of armatures of large generators in which each coil consists of but a single turn. Fig. 24 is a wave winding in process of construction, and, as is clearly shown, the ends to the commutator run in the opposite direction from those at the back of the armature. Fig. 25 is a lap wound armature in the finished state, and, as will be noticed, the coil ends bend down at both sides. From this it can be found that with a large armature, so large so that each coil consists of but one turn, all that is necessary is to look at the coil ends, and if these turn in the same direction at both ends, as in Fig. 25, the connection is of

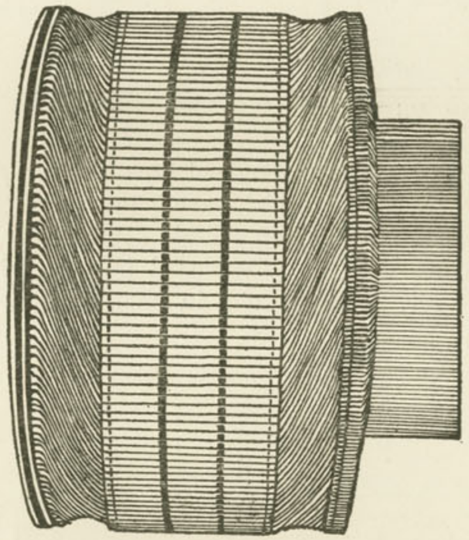


Fig. 25

the lap-type, and if they turn in the opposite direction, as shown in Fig. 24, the connection is of the wave type. If the armature is small and the coil consists of more than one turn, it is not so easy to determine the nature of the connection, as then the coils will have the same form for both types of winding; but if it is examined more closely, the direction in which the wires run from the coils to the commutator segments can be determined as well as the character of the connection; for if it is a lap winding, the connections with the commutator segments will be found to run to two adjoining coils, while if the connection is of the wave type the wires from the commutator segments will spread out and run to coils separated from each other by a considerable distance.

Types of Dynamo Field Magnets. While the horseshoe shape of magnet is as simple as a magnet can be made, this form is not commonly used in the construction of modern dynamos. For a

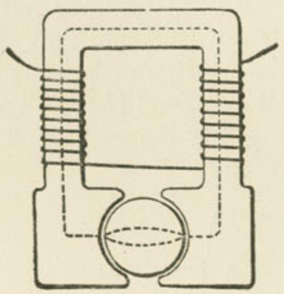


Fig. 26

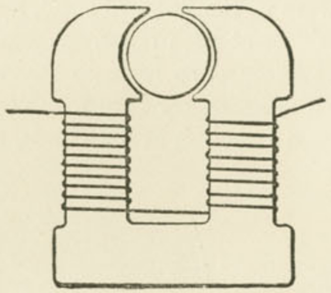


Fig. 27

number of years it was the standard type, but has gradually been superseded by other forms which have magnetic and constructional advantages that more than compensate for the loss of simplicity. The horseshoe type, which is repeated in Fig. 26, herewith, is still used, however, to some extent in small machines, but even in

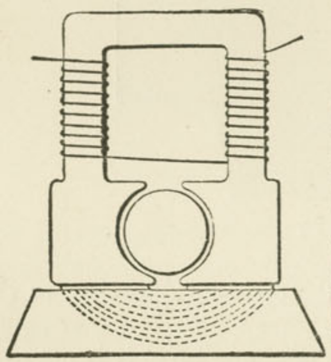


Fig. 28

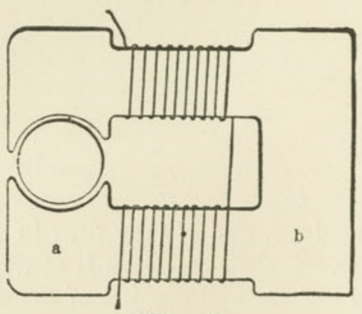


Fig. 29

such machines it is more generally used inverted, as indicated in Fig. 26. The advantage of the inversion of the magnet is that an iron bed-plate can be used without increasing magnetic leakage. If the form shown in Fig. 26 be set on an iron bed-plate, even with blocks of wood in between, as indicated in Fig. 28, the magnetic

leakage would be excessive; the dotted lines in Fig. 28 illustrate roughly this leakage.

Fig. 29 shows another arrangement of this type of magnet, which was used to limited extent some years ago, but is no longer

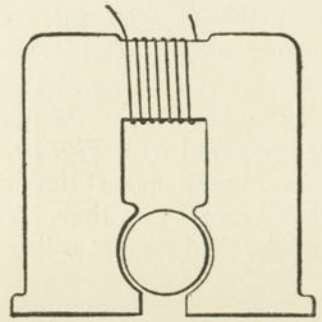


Fig. 30

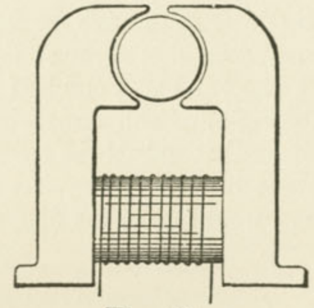


Fig. 31

built in this country. It is open to the same disadvantage as the vertical type of Fig. 26, namely, an iron base-plate cannot be used without increasing leakage; in this case the leakage being from the pole-piece, *a,* across to the back end of the magnet core at *b,* thus

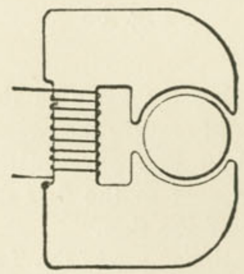


Fig. 32

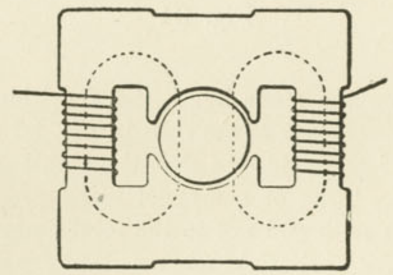


Fig. 33

shutting a large part of the magnetism away from the armature. Fig. 30 is precisely the same as Fig. 26, except that a single coil is wound on the horizontal portion of the field magnet instead of having two coils, one on each vertical pole. Fig. 31 bears exactly the same relation to Fig. 27, being simply an inversion from Fig. 30. Fig. 32 is an equivalent of Fig. 29, and is the only single bipolar magnet that can be mounted on a heavy hard-wood base. Fig. 33 shows a bipolar type which was in high favor in this country a few years ago, and is still used considerably in England. This is known as the Manchester type. It has a slight disadvantage of requiring considerably more wires in the magnetizing coils than the other types mentioned. In this machine there are two magnetic paths through the field magnet in parallel with each other, the magnetic flux through the armature separating at each pole-piece into two parts, one half passing to the left, and the other half to the right. Such a machine, as compared with Fig. 32, would require only one-half the cross-section in each magnet limb that the machine in Fig. 32 requires in its single magnet limb. This, of course, would make the diameter of the field magnet coils smaller,

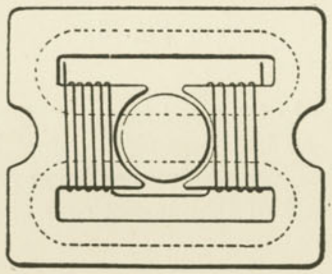


Fig. 34

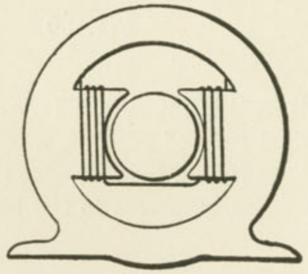


Fig. 35

but, on the other hand, the densities being the same in the two machines, each of the coils in Fig. 33 would require the same number of ampere-turns that the single coil in Fig. 32 requires, the ampere-turns of a magnet being proportional to the flux density in the path and not to the total amount of the flux.

All of the field magnets thus far mentioned are of the "open" type. A much better type of bipolar field magnet is that shown by Fig. 34, which is known as the Continental type. The difference between this form and that in Fig. 33 lies chiefly in the arrangement of the magnetic coils, the coils in Fig. 34 being placed directly on the poles, while in Fig. 33 they are placed on the portions connecting the poles. This difference, however, has the effect of transforming the machine from an open to an "iron-clad" one, in which the magnet coils are entirely protected from mechanical injury, and a smaller amount of wire is required. This form of magnet was used by many of the smaller manufacturers a few years ago, when the advantages of the multipolar field magnets became better known and adopted exclusively for the larger machines. The circular form of magnet frame used with these machines was then applied to the smaller bipolar machines, with the result shown in Fig. 35, which will be recognized as being precisely equivalent to Fig. 34, the only difference being in the shape of the two frames. Like the type of Fig. 33, the magnet circuit in Figs. 34 and 35 is divided into two parts, one-half of the flux passing through one-half of the yoke, and the other half through the other half of the yoke.

Multipolar Machines. As just stated, machines of appreciable

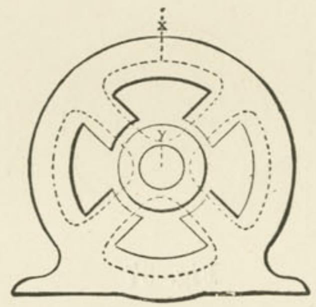


Fig. 36

size are now built with more than two poles, the form of magnet most generally used being that illustrated by Fig. 36, which shows a four-pole machine with the circular yoke mentioned above. The paths of the magnetic flux through each field circuit and the armature are indicated by the dotted lines, which show that there are four distinct circuits in the machine. In such a machine each magnet-coil supplies each pair of magnet circuits through its core in the yoke-ring midway between two poles to a point in the armature between the same poles, these points being indicated by x and y. That is to say, each coil creates all of the flux passing through the pole surrounded by the coil, and drives this flux through the two paths in parallel in the yoke and armature to the point indicated by x and y, the neighboring coil taking care of the remainder of the path from those points through its own core.

Other forms of multipolar field magnets are in use, but this is the recognized standard of modern practice, and is used for machines having large numbers of poles.

The advantages of multipolar field magnets over the bipolar type are (1) a simpler armature winding and one more accessible for repairs; (2) a smaller amount of material due to the subdivision of the magnetic flux. This is illustrated plainly by Fig. 37, which shows a bipolar, a four-pole and an eight-pole machine, all having the same total flux through the armature; (3) a greater ability to dissipate heat on account of the greater area of surface in each magnet pole and winding, and also in the armature.

It would naturally appear at first glance that the multipolar design must profitably be carried up to 16 or 32 poles or more,

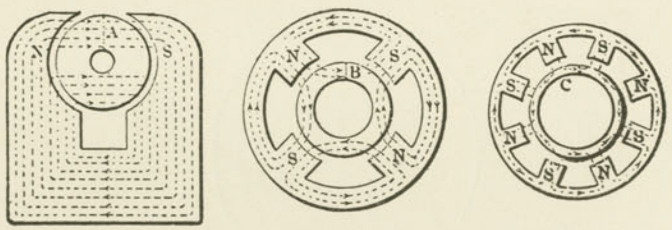


Fig. 37

but this is not true except for huge machines. Machines of moderate size are most economically built with four poles; making the number greater than this increases the expense of winding coils, machine work and other fittings, out of proportion to the gain in material.

Field Magnet Excitation. But for the property that iron and steel possess of retaining more or less magnetism, it would be necessary to magnetize the field magnet of a dynamo by current drawn from some independent source whenever the machine started up. This residual magnetism in the dynamo field magnets enables the machine to generate a low electro-motive force in the armature when it is first brought up to speed, and by connecting the field magnet windings to the brushes this faint electro-motive force drives a small current through a winding around the magnet cores, increasing the armature electro-motive force, which, in turn,

strengthens the current in the field winding, and so on until the machine has built up its electro-motive force to the normal point.

There are two fundamental methods of connecting field magnet windings to the armature brushes and two combinations of these. One is to connect the windings in series with the load as shown in Fig. 38, and the other is to connect it in parallel with the load as shown in Figs. 39 and 40.

Shunt Winding. The first arrangement is called a series field winding, and the second is a shunt field winding, the term "shunt" being employed in preference to the descriptive term "parallel" because the proportion of the total current that passes

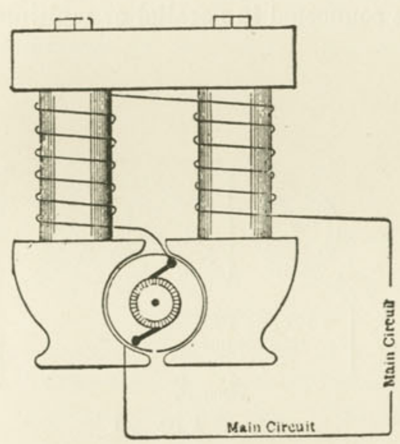


Fig. 38

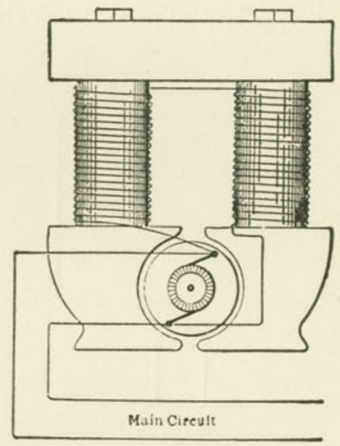


Fig. 39

through the field winding is very small, so that the winding is actually a shunt or by-path to the main circuit.

A dynamo with a shunt field winding maintains an almost constant electro-motive force at its brushes when driven at a constant speed; if there were no loss of volts in forcing the current through the armature windings, the electro-motive force would remain absolutely constant, but there is, of course, this loss or drop, and this makes it necessary to provide some means of regulating the electro-motive force. Even if there were no armature "drop," regulation would be necessary because of the "drop" in the wires connecting the dynamos with the load, a machine of this character being used to supply a load requiring a fixed electro-motive force. Consequently, an adjustable resistance is put in series with the field winding, as indicated diagrammatically in Fig. 41, where L is a metal lever arranged to swing around a pivot and touch at its free end any one of the semi-circular row of metal contacts; these are connected to points in a resistance coil. Moving the lever to the right increases the amount of dead resistance in series with the field winding, thus reducing the strength of the magnet and consequently the electro-motive force at the brushes. The contrary movement of the lever, of course, has the opposite effect. Such an arrangement is called a "rheostat."

The lamps or other devices constituting the load on a constant-potential circuit are always connected in parallel or multiple,

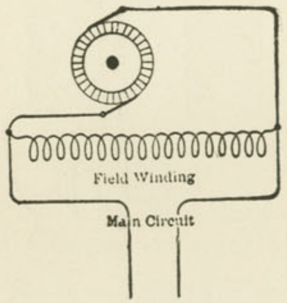


Fig. 40

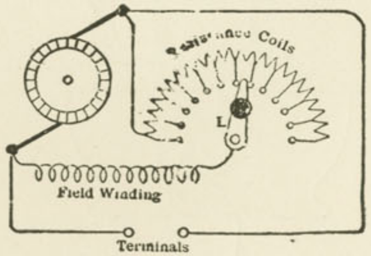


Fig. 41

or else in series groups which are connected in parallel with each other, and which constitute each a single constant-potential element, and must be thrown in and out of the circuit as such. Fig. 42 represents a constant-potential circuit having both single devices, a, and series groups, b. It will be evident that decreasing the load increases the resistance of it.

Series Windings. Series wound dynamos are employed only when the load is of a character requiring an unchanging current; these machines are commonly referred to as "constant-current dynamos." Fig. 43 represents a series or constant-current circuit, the respective devices being indicated by crosses. It is obvious that when one or more devices are removed from the circuit (the line

being, of course, made continuous where the devices were taken out) the total resistance is decreased; without dynamo regulation, therefore, the current would increase to an excessive strength.

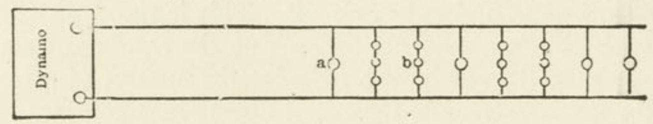


Fig. 42

Series wound dynamos are regulated to give a constant current strength, varying their electro-motive force according to the requirements of the load. One method of regulation consists of

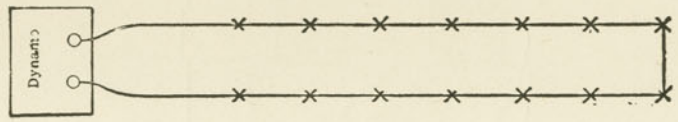


Fig. 43

varying the field magnet strength by means of an adjustable resistance or rheostat connected in parallel with the field winding, as indicated in Fig. 44. This shunts a greater or less amount

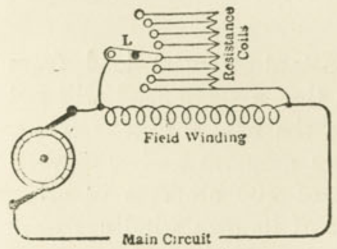


Fig. 44

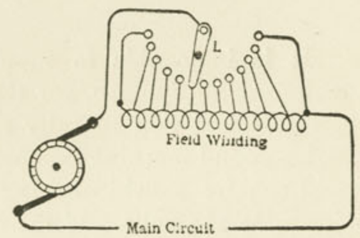


Fig. 45

of current from the field winding, according to the amount of resistance made active by the lever, L. Thus if the current in the armature and main circuit were 10 amperes, and the resistance of the field winding were 10 ohms, a resistance of 40 ohms in parallel with the winding would cause the current to split in the ratio of 40 to 10, or 4 to 1; 2 amperes would pass through the resistance and 8 amperes through the field winding. Another method of regulation consists of dividing the field winding up into two sections in and out of circuit. This is shown in Fig. 45. As the strength of any magnet depends on the number of ampere-turns in its magetizing winding, reducing the number of turns will reduce the magnet strength, the current being kept constant. This method of regulation is objectionable, however, for magnets of large size, because of the tendency to flashing at the contacts of the regulating switch.

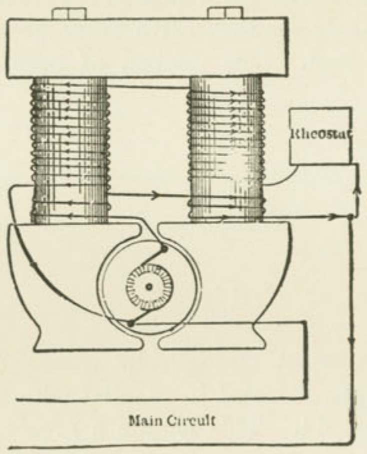


Fig. 46

It is impossible to supply a constant-potential load from a series-wound dynamo, for the reason that a small load will not allow sufficient flow to fully magnetize the field magnet. Thus, a series-wound machine designed for 100 amperes and 115 volts would require a field exciting current of 100 amperes in order to generate 115 volts. If the resistance of its own windings were 0.05 ohm, 5 volts would be used up in the windings at full load, leaving 110 volts for the load. So long as the resistance of the load and the circuit wires remained at 11 ohms the machine would operate perfectly, but if the load were reduced until the resistance of the whole circuit became 22 ohms, the current would be reduced about one-half; this would reduce the field magnet strength, cutting

down the electro-motive force and causing a further reduction in field magnet strength, and so on until the electro-motive force became reduced to a useless value.

Compound Windings. The two fundamental windings just described are combined in two ways, the more common of which is shown in Figs. 46 and 47. The magnet is provided with both windings, the shunt winding serving to give initial excitation and to maintain the proper electro-motive force when there is no load. The series winding is connected so as to magnetize in the same direction as the shunt winding, and as soon as any current flows in the work circuit, it strengthens the field magnet so as to increase the electro-motive force of armature and compensate for voltage

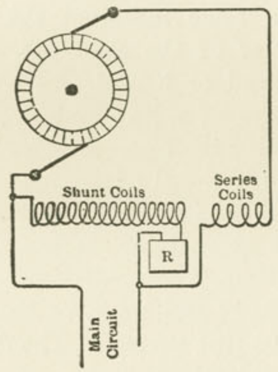


Fig. 47

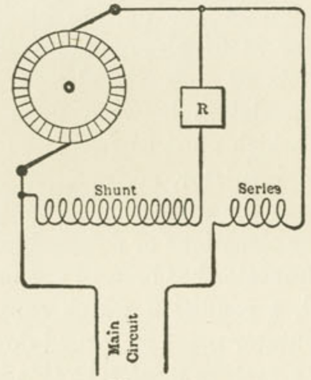


Fig. 48

losses in the connecting wires between the dynamo and the load. The effect of the series winding may be adjusted by some means such as those shown in Figs. 44 and 45, so that the field is strengthened precisely enough, as the load is put on, to raise the generated electro-motive force by just the amount lost in the armature and other parts of the circuit, and thus keep the electro-motive force at the load unchanged. The rheostat is provided in the circuit of the shunt field winding to adjust the initial electro-motive force to the proper value.

This arrangement of windings is called "compound" field windings, and the effect of the series coils is termed "compounding." The shunt field circuit is sometimes across the brushes, as in Fig. 48, instead of indirect shunt to the load circuit, as in Fig. 47, one arrangement being practically as good as the other.

The other method of combining shunt and series field windings consists of putting both windings on the magnet and connecting them so that they oppose instead of assist each other. The shunt winding usually gives the initial magnetization and the series winding partially neutralizes the effect of the shunt winding. When the current becomes excessive, the series coils weaken the field and reduce it. This action, of course, cannot be perfectly compensative, because some excess of current is necessary to make the series coils keep the voltage (and therefore the current) down. This arrangement has been tried on constant-current dynamos, but has never come into commercial use to any considerable extent.

Commutators and Brushes. The function of the commutator is to transfer by rubbing contact the current generated in the armature to the outside circuit. In some machines the commutator is of almost the full diameter of the armature. The segments or bars are always drop-forged or hard-drawn copper. The insulation between them is always of mica; amber-colored mica, which must be free from iron, being the best. Besides being a good insulator, amber mica has the additional advantage that it wears at the same rate as copper, so that after long use it leaves neither elevations or depressions on the commutator surface. After a commutator has been in use for some time, it becomes grooved and pitted, a condition which causes sparking and wear, so that the commutator must be turned down to the true surface. The design of an armature must take this into consideration.

In fastening the bars together there are various methods in use. Each of these methods must allow the bars to be thoroughly insulated from the clamping device, as well as to hold them firmly, so that any one bar cannot be pushed lower than its neighbor. An arrangement for holding the bars together which is employed by the General Electric Co. is shown in Fig. 49.

Brushes for high potential machines are made out of carbon. Carbon against copper causes less wear than copper against copper, and the greater resistance of the carbon brush results in less sparking when the brush is performing its proper function of collecting the current from the bars. Combination brushes of carbon and copper are sometimes used. Carbon brushes are generally set radially, and a surface of one square inch per 40 amperes is usual when this type of brush is used. On old makes of machines and low potential plating dynamos, copper brushes, set

at an angle of 45 degrees tangent of the commutating surface, are generally used. There is less tendency to spark on low voltages,

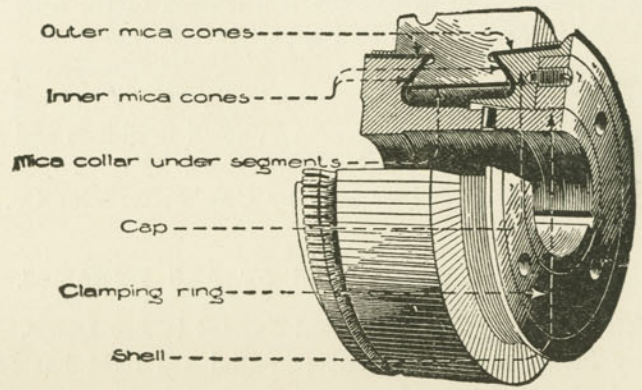


Fig. 49

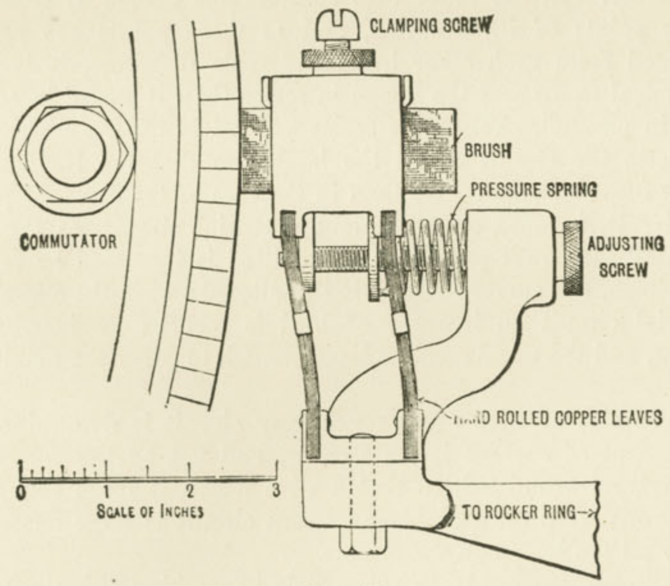


Fig. 50

and the resistance of the carbon brush is considered too high in relation to the whole circuit to be used efficiently. Wire gauze brushes are now more generally used when a metal brush is considered proper to use. Brush holders should permit of a low resistance contact between the brush and the leads. They should provide adjustment as to position and tension of the brushes, and they should be arranged so that the springs do not get hot or lose their temper by running under full load. The tension of carbon brushes varies from one to ten pounds per square inch of contact surface, the larger value being used in small machines and smaller value on large central station generators. Fig. 50 shows an arrangement of brush-holder used by Crocker-Wheeler Co.

CURRENT REGULATIONS OF ARC DYNAMOS.

Method for Supplying Constant Current to Arc Lamps. While in many instances the constant potential arc light has replaced the constant current arc lamp, yet for certain purposes, such as for street lighting, the constant current arc lamp is used extensively. In the latter case considerable energy is expended at the points of illumination, and as these points are usually separated from each other by considerable distances, it is more economical to connect the lamps in series than it would be to run them in parallel. When the series method is used, a single line completes the circuit of all the lamps, so that the line can be made of much smaller wire than in the case of the constant potential circuit, because on a constant potential circuit, as the load increases, the power or energy transmitted is increased by raising the voltage, the current remaining unaltered; while in a constant potential circuit an increase of load is met by an increase of current, and the wires must be large enough to carry the maximum current.

The size of wire necessary in any circuit is determined by the amount of current it must carry, and not by the voltage or the energy transmitted, so that a wire which is large enough to supply one lamp on a constant current circuit is large enough to supply all the lamps on the circuit.

An ordinary arc lamp, when it is in working order, requires between 45 and 50 volts to force its rated current through it. This current is used principally for heating the carbons to incandescence, across which an arc is maintained. The arc proper does not give out more than 5 per cent of the light, the light

coming principally from the heated end of the positive carbon. The tip of the positive carbon is called the crater, and when it is at the point of incandescence the temperature is about 3500 degrees centigrade. When burning, the positive carbon becomes hollow on the end, while the negative carbon becomes pointed by the flying carbon particles, but it does not reach such a bright degree of incandescence as the positive carbon. Owing to this fact, the positive carbon burns away about twice as fast as the negative carbon.

Arc lamps have what is termed a spherical candle power, and commercial lamps of 800, 1200 or 2000 spherical candle power are in use. The arc lamp of 800 candle power takes a current of 4.5 amperes, that of 1200 candle power takes 6.6, and that of 2000 candle power 9.8 amperes. The candle powers are rated according to their greatest brilliancy, which is about at an angle of 45 degrees to the center of the carbons. At any other angle the brilliancy is much less and the average will be about 800 candle power.

Since the brilliancy of the lamp depends upon the current passing through it, the current of an arc light machine must not exceed or fall below its normal value, no matter how the load is varied, for the slightest change affects the quality of the light at the lamps. As the voltage required per light is about 50 volts, and as commercial circuits contain from 60 to 100 lamps, the maximum voltage of an arc light circuit will be about 3000 for the 60 lamp circuit, and 6000 for 120 lamp circuit. Under these conditions it may happen that the load is variable, in which case the arc machine must regulate between wide fluctuations of voltage and at the same time maintain a steady current.

To perform this regulation quickly, all constant current machines rely on armature reactions for regulation, since they vary simultaneously with the current in the circuit. The following conditions are aimed at in all successful constant current generators. There must be a large number of armature turns; since the current is small, the magnetic field of the machine must be distorted; the path of the line of force of the field coils must be long and of small area, so that the magneto-motive force cannot readily be changed; the paths of the line of force due to armature magnetization must be short and of great area, so that the magneto-motive force of the armature will change with the slightest change of the current; and the pole pieces must have a high density of magnetization.

As will be noticed, there are so many conditions that must be met in order that a machine will produce constant current under all loads, that automatic mechanical devices are used to aid the regulation. These automatic devices are not the only regulators, but they are only secondary to the natural self-regulating tendency of the armature; that is, the regulating device acts like a governor on a steam engine and regulates for the gradual and greater changes of the load, while the armature reactions act like the fly wheel and take care of the smaller and more sudden fluctuations.

Of the two general methods used for regulating the current on arc dynamos, one method is to cause the machine to develop an electro-motive force just sufficient for the load; and the second method is to vary the magnetizing force in the field magnets just enough to put the required voltage on the line. The first method is performed by shifting the brushes from the neutral plane, which in a closed coil armature causes a counter electro-motive force to be developed in those conductors lying between the neutral and commutating plane, which reduces the voltage the right amount. In an open coil armature, the brushes when in the maximum position connect to the circuit those coils of the armature which at that instant have the maximum electro-motive force generated in them, and the amount of shifting regulates the pressure on the line.

The second method of regulating arc light machines by varying the magnetizing force in the field magnets depends upon the fact that the magnetizing force is dependent upon the ampere turns on the field coils. In practice, this is varied by either cutting out or short circuiting some of the turns, or changing the current in them by means of a variable resistance which is shunted across the field terminals.

The Brush Arc machine is regulated by a variable resistance in shunt with the field coils, and as the field current is changed, the position of the brushes is also changed. The Wood arc dynamo has an armature of the closed coil type, requiring a commutator of many segments with but a small potential between any two adjacent ones. The machine operates by generating full pressure at all times and by automatically setting the brushes to take off as

much potential as necessary. The Excelsior arc dynamo has a closed coil armature and is regulated by cutting out sections of the field winding, at the same time the position of the brushes is shifted. The Thompson-Houston dynamo employs an armature on which there are three coils. The outside ends of the coils are connected to three commutator bars, from which the current is collected by four copper brushes connected in multiple. Regulation is effected by shifting the brushes.

Whether, however, regulation is effected by changing the position of the brushes or by changing the field excitation, sparking will occur, unless there is some means taken to prevent it, and this is done in a different manner in the different makes of machines.

PRINCIPLES OF MOTORS.

Theory of Action. The ordinary electric motor is substantially identical in construction with the dynamo, the one is merely an inversion of the other, the function of the dynamo being the conversion of mechanical energy into electrical energy while the motor converts electrical energy into mechanical energy.

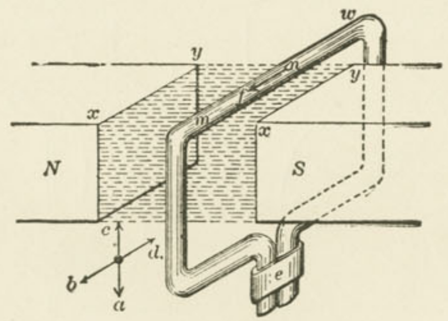


Fig. 51

If a loop of wire or other conducting material be located as shown in Fig. 51, so that it surrounds the magnetic field in an air gap between the poles of a magnet, any attempt to pull the loop out of the position shown, will cause some part of the wire to cut the magnetic flux and induce an electro-motive force in the loop. This in turn will force the current through the loop and cause a magnetic pull between the flux and the loop, in opposition to the effort made to displace the loop from its flux enclosing position. The reverse of this is also true, and forms the position underlying the operation of the electric motor. If the loop be opened at the ends, so that the current may be introduced into it from an ex-

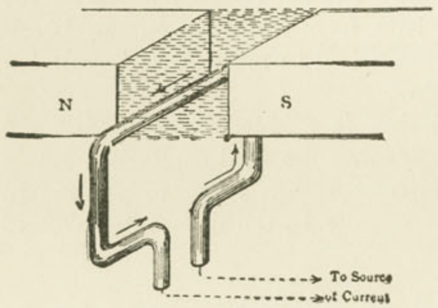


Fig. 52

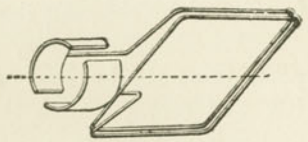


Fig. 53

ternal source, and then its position be changed to one unsymmetrical with the magnetic field, as indicated in Fig. 52, the passage of current through it will cause it to be either drawn into the position of Fig. 51 or forced out of the magnetic field, according

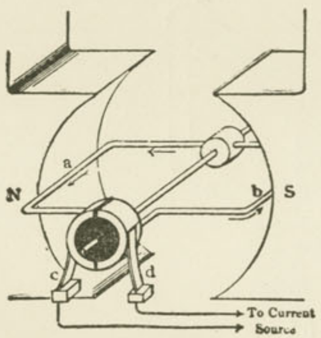


Fig. 54

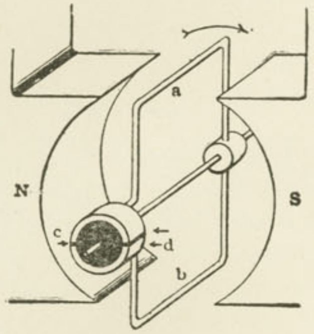


Fig. 55

to the direction in which the current flows through the wire. With current flowing as indicated by the arrows in Fig. 52 the loop would be pulled up in the position as shown in Fig. 51, the polarity of the magnet being as indicated by the letters N, S.

As in the case of the dynamo, continuous motion by the movable current carrying loops or coils of a motor is obtained by

arranging them so that they can rotate within the magnetic field. Fig. 53 shows a coil of two convolutions connected to two commutator segments and Figs. 54 to 57 show single loops similarly connected and occupying different positions in the magnetic field. At *d*, two arrow-heads are shown, to indicate the points of contact at both the front and back ends of the commutator.

If current be passed through the loop when it is in the position shown in Fig. 54 it will be immediately pulled around to the position shown in Fig. 55. Reaching this position, the brushes *c* and *d* touch both commutator segments, and the current passes from brush to brush through the segments instead of the loop. The momentum of the latter, however, will carry it past

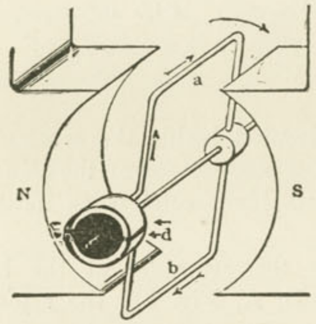


Fig. 56

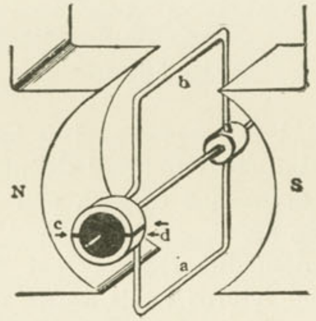


Fig. 57

this "dead center" and the instant that is done, the current will flow through the loop, in the opposite direction, as shown in Fig. 56, and the loop will be drawn by the magnetic field around through a half revolution to the position shown by Fig. 57, which is 180° from that shown in Fig. 55. Here the commutator reverses the current in the loop again, so that it is drawn around to the position shown in Fig. 55 again, and so on, as long as current is supplied to the loop and the magnetic field is maintained.

The movable part, or the armature, of a motor is exactly like that of a dynamo, consisting of a cylindrical iron core on which a large number of current-carrying loops are mounted. In an actual machine, therefore, every time the brushes pass from one commutator segment to the next, the direction of the current through the coil connected to those two segments is reversed. An analysis of the armature circuit will show that this occurs always when the coil has reached a position where there is no longer any pull or "torque" between the magnetic field flux and the current in the coil. Fig. 58 is a diagram of a 16-coil armature having only one turn per coil, like the loop of Figs. 54 to 57, the brushes,

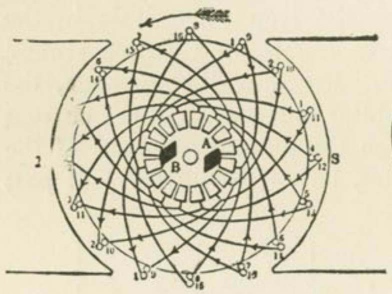


Fig. 58

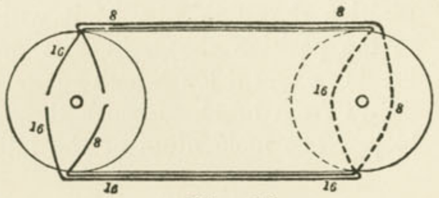


Fig. 59

A, B, being represented as being located inside the commutator barrel in order to avoid obscuring the connections of the winding. The disposition of each pair of coincident coils is as indicated in Fig. 59.

Assuming that current enters the armature at the brush B, and returns to its source at brush A, Fig. 58, the armature

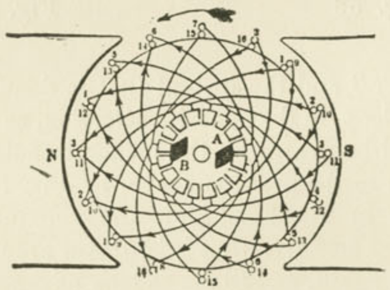


Fig. 60

will revolve in the direction indicated by the large arrow above it, and the path of the current through the winding will be as indicated by the small arrow-heads on the commutator connections. It will be obvious that the current in all of the wires on the left-hand half of the armature periphery will follow from front to

back—away from the observer—while the current in all the wires on the other half will flow towards the observer. This direction of flow is opposite to that indicated in Figs. 54 to 57; consequently the armature will revolve oppositely to the direction of the loop in the latter diagrams. As fast as a coil reaches the position occupied by Nos. 7 and 15 in Fig. 58, it is cut out of circuit and when it is restored again, on the other side of the "dead" line, the current flows through it in the opposite direction as shown in Fig. 60, which shows the armature after passing through $\frac{1}{16}$ of a revolution from the position in Fig. 58. Consequently, in this case, the current always flows from front to back in all wires on the right-hand half of the armature periphery. The result is a continuous torque between the magnetic field and the armature wires, always in the same direction, rotatively.

The actual pull or torque exerted by the magnetic field upon each wire of a motor armature is given by the formula:

$$\frac{B\,l\,c}{11{,}302{,}363} = \text{Torque per wire}$$

in which B is the average density of the magnetic field in lines of force per square inch; l is the length of the armature core parallel with the shaft, and c is the current carried by each wire (in a two-pole machine, one-half of the current entering at the brush). The total torque exerted, therefore, will be:

$$\frac{B\,l\,w\,c}{11{,}302{,}363} = \text{Torque in pounds}$$

in which formula, w represents the total number of wires all around the circumference of the armature.

Speed Conditions. Practically any direct current motor, if current be supplied to it, will operate as a motor, but the motor will not necessarily run in the same direction as it did as a dynamo. For example, a series dynamo when operated as a motor, will run in the opposite direction from that which it had as a dynamo, and to make it turn in the same direction it is necessary to reverse the direction of the current through the fields or armatures. A shunt machine used as a motor will turn in the same direction that it had as a dynamo. Reversing the direction of the current supplied to either the shunt or series motor will not change the direction of rotation of either shunt or series motor. To reverse them, it is necessary to reverse the direction of the current running through either the field or the armature. The compound motor, if the effect of the series coil is weak compared to those of the shunt coils, will behave like a shunt motor. If the series coils are stronger than the shunt coils it will act like a series motor.

Series Wound Motors. Series wound motors are used only for a special class of service, such as railways, cranes and hoists. As the armature current passes through the field windings, a series wound motor is capable of enormous starting torque, because the torque is proportional directly to the product of the field strength and the armature current, and the field strength and the armature current increase together. This feature makes the series wound machine preferable for any work where a motor must start up under full load or overload, where it is operated intermittently and where it need not run at any constant speed.

The speed of a series motor depends entirely upon the load, if the voltage is constant, and is determined by the field strength, the electro-motive force at the brushes and the drop in the armature. The speed must be such that the counter electro-motive force generated in the armature, is equal to the difference between the brush electro-motive force and the internal drop of potential. As the counter electro-motive force is proportional to the strength of the field, variations in the latter will cause an increase in speed with a decrease of current and *vice versa.*

The regulation of such motors is very frequently accomplished by cutting in and out sections of the field windings by means of an apparatus usually called a controller; but in some instances speed variations are obtained by varying a resistance connected in parallel with the field winding. Fig. 61 illustrates the controller method, and Fig. 62 the resistance method. Both methods are used on motors driving hoisting apparatus.

Street Car Motors. Street car motors are almost universally controlled by a combination method known as a "series-parallel" control, which consists of connecting two or more motors in series or in parallel and shunting the field winding with a resistance according to speed requirements. Fig. 63 shows the different

connections made by the controller usually provided on ordinary surface-railway cars. Two motors are used on a car, and the controller has nine positions, which are commonly termed notches,

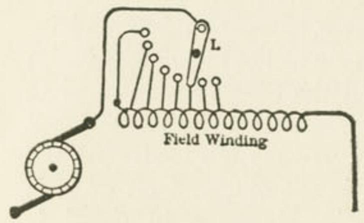


Fig. 61

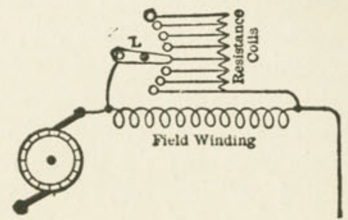


Fig 62

because a notched wheel and pawl are employed to insure the handle being brought to rest accurately, instead of being stopped

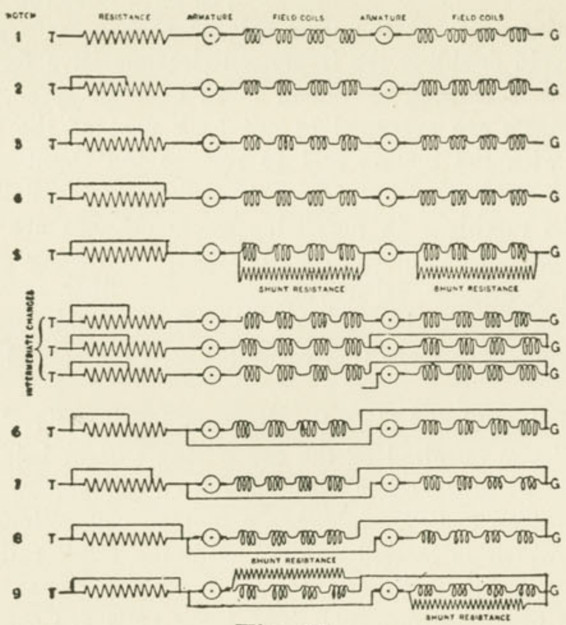


Fig. 63

between some two of the proper positions. In the diagram, the numbers down the left-hand margin, under the word "Notch," indicate the notches or positions of the controller handle, and the connections effected at each position are shown alongside the number of that position.

At the first notch the motors are connected in series with each other and the resistance coil; the next step short-circuits part of the resistance coil, allowing more current to flow and increasing the impressed electro-motive force at the motor terminals; the motors thereupon speeding up until the current is reduced to a value just sufficient to give (in conjunction with the also reduced field strength) the torque required to overcome the load. At the third position, more of the resistance is cut out, and all of it is out at the fourth position. No further increase in speed is possible with the motors in series, except by cutting off some of the field windings or shunting them; the latter operation is performed in the fifth position.

It is necessary now, in order to get a still further speed increase, to put the motors in parallel, so as to raise the impressed electro-motive force at the terminals of each armature. But in order to avoid doubling the impressed electro-motive force at one step, and thus causing a sudden burst of high speed, the controller contacts are arranged to put back part of the resistance in series with the motors and to remove the shunt resistances around the field windings (thus strengthening the field) before putting the machines in parallel. These changes are indicated in the diagram as "intermediate changes," occurring as they do while the controller is moving from the fifth to the sixth notch. The progression beyond the sixth notch consists of the same successive steps that occur between the second and fifth position.

The letters T and G in the diagram indicate "trolley" and "ground;" one terminal of the car wiring system being carried to the trolley, and the other "grounded" on the framework of the car truck. The trolley establishes a moving connection with the conductor which is located parallel with the track rails, and is connected ultimately to one terminal of the dynamos which supply the operating current. The track rails are connected to the other terminal of the dynamos, and together the wheels and truck frame of the car constitute the other line conductors for the motors.

Variable Speed Motors. Since the introduction of the electric motor for the direct driving of machinery, there has been a demand for a motor which can be run at variable speeds under all conditions of service. There are a number of variable speed motors which have been built to answer various purposes but they all seem to have some requirement that is lacking. One arrangement for giving different speeds, which has been used satisfactorily in silk and cotton mills, is known as the comulative winding. The motor in this case is compound wound, the lowest speed being obtained when it is run as a compound motor, other speeds being obtained by short-circuiting portions of the series winding and the fastest speed being obtained by running the motor as a shunt machine with all the series field cut out.

When driving machine tools, such as lathes and drill presses, a larger range of speeds than is obtained by the comulative winding is required, together with non-sparking under heavy loads, constant speed at all loads for which the motor is adjusted, and reversibility. One method which is said to do this satisfactorily is known as the inter-pole method, by means of which sparkless commutation is said to be obtained, the speed can be set at almost any point between the limits and the power output of the machine is constant.

In the usual constant speed motor, the two main causes of sparking are self-induction of the short-circuited coil passing under the brush and the action of this coil in generating an electro-motive force by cutting the lines of force of the armature field. These causes are overcome in part by the resistance of the carbon brushes and by the placing of the brushes so that the short-circuited coil cuts the lines of force thrown out by the main field in such a manner that the main field is used in preventing lines of force from the armature field from passing out in the region of the short-circuited coil, thus generating such electro-motive force in the short-circuited coil as will aid in the reversal of the current as the coil passes under the brush.

With the variable speed motor, however, these means are entirely inadequate. The reduction of the field strength necessary to obtain high speeds prevents its use in overcoming the magnetic field of the armature. The armature field is, therefore, not only present but the increased speed of the armature makes it become so large that the carbon brush cannot overcome it. The higher speed also increases the electro-motive force of self-induction so that it becomes impossible for the carbon brush to reverse the current in the short-circuited coil, and consequently there is destructive sparking.

This sparking is overcome in the inter-pole method, as shown in Fig. 64 by placing small poles between the main poles and generating a magnetic field independent of the main field of the motor. The inter-poles are provided with coils connected in series with the armature, so that the current flowing in the armature flows through the coils of the auxiliary field, thus producing a proper field for commutation. The auxiliary poles produce a field independent of the main field, so that the weakening of the field of commutation caused by an increased load or increased speed is prevented. When the direction of

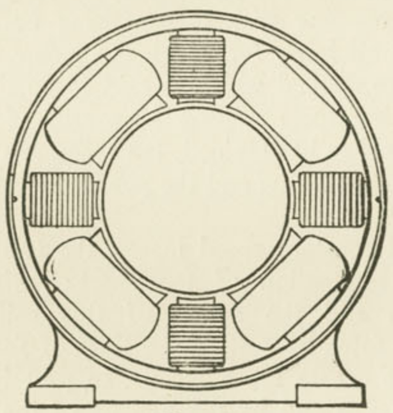


Fig. 64

rotation of the armature is reversed, the current in the auxiliary field is reversed, so that its function is not altered.

The speed of the motor is changed in the usual manner of cutting resistance in or out of the field circuit, in which case the power of the machine, which is the product of the torque and the speed, is constant.

WHERE DIFFERENT TYPES OF MOTORS SHOULD BE USED.

Modern electric motors may be divided into two general classes: those operated by direct current and those operated by alternating current. Direct-current motors may be subdivided

into classes: shunt wound for approximately constant speed and series wound for variable speed. There are, however, numerous combinations of the two types of field windings, forming a third class known as compound wound motors.

Alternating-current Motors. Alternating-current motors may be divided into two general classes: the induction motor and the synchronous motor. In operation the induction motor operates similarly to the constant potential direct-current shunt motor; that is, if the strength of the rotating field were maintained constant, the slip, the rotor electro-motive force and the rotor would vary with the load. The rotating field does not, however, remain constant under varying loads. As the load increases, more and more of the field flux becomes useless for turning the rotor, and the slip becomes greater and greater as the load increases. The speed of an induction motor is varied by altering the voltage, by altering the resistance of the rotor circuit, or by commutating the stator winding so as to alter the multipolarity.

Any excited single-phase or polyphase alternator, if brought up to speed, and if connected to an electro-motive force of the same frequency and approximately the same voltage will operate as a motor. The speed of the motor in revolutions per second will be the quotient of the frequency by the number of pairs of poles. This speed is called the synchronous speed and the motor when it has attained that speed is said to be running in synchronism. This exact speed will be maintained throughout wide ranges of load up to several times full load capacity. Whether the synchronous motor is single, two or three phase, it has the same general characteristics, the number of phases being taken care of in the design of the motor.

Direct Current Motor. Coming back to the direct current motor, shunt-wound motors should be used where an approximate constant speed and variable torque are required and the series-wound where the speed and torque are both variable. The compound wound motor is a combination of the shunt and series machine. Its most important use is where a very heavy starting torque is required and where occasional heavy loads must be carried, such as for motors connected to punches, shears or bending rolls. In these cases it is customary to give the motor just enough shunt winding to prevent its attaining a dangerous speed when the load is thrown off. In some cases a controller is furnished with compound-wound motors, which varies the number of series turns on the field. A motor with this regulation should only be used when the speed does not matter or where the torque required remains constant.

For driving a pump, a compound motor possesses the desirable feature of giving a strong starting torque with the least starting current, especially in cases where the momentum of a large body of water must be overcome. For traction purposes, the method for attaining speed control is accomplished by what is known as the series-parallel system. For slow speeds the motors are connected in series and for higher speeds in parallel, series motors being used.

Induction Motor. A motor which has sprung into wide use during the past ten years is the induction motor. The two attractive features of this type of motor are its simplicity and its ease of starting. The two methods usually employed for starting polyphase motors are by means of a low initial voltage or a variable resistance in the secondary. Motors having a fixed resistance in the secondary winding are started by applying to their terminals an electro-motive force lower than normal, which is secured from two small transformers. As the motor comes up to the speed the switch is thrown over, connecting the motor on the full potential for which it was designed. In motors with a variable resistance in the secondary, the full potential is thrown on the primary; but a resistance is inserted in the secondary winding which is cut out as the motor comes up to speed.

Synchronous Motors. Synchronous motors do not have sufficient torque at starting to satisfactorily come up to speed under load. They are therefore usually brought up to synchronous speed by some auxiliary source of power. In case of polyphase systems, an induction motor is very satisfactory. Its capacity need be but one-tenth of that of the large motor. Before connecting a synchronous motor to the mains it is necessary that the motor should not only be in sychronism but should have its electro-motive force at a difference of phase of about 180° with the impressed electro-motive force. To determine both these points, a device known as a synchronizer is employed. It sometimes consists of an incandescent lamp connected in series with the secondaries of two transformers, whose primaries are connected respectively with the line and with the motor terminals. The brightness with which the lamp glows is a measure of the phase difference between the two electro-motive forces. It is customary to so connect the transformer that when the motor electro-motive force is at 180° with the line electro-motive force, the lamp will have its greatest brilliancy. As a motor is coming up to speed, the lamp will be alternately bright and dark. The alternations will grow slower as sychronism is approached and will finally be slow enough to permit the closing of the main switch at the proper instant.

Owing to their different starting characteristics, the induction and synchronous motors are used under different conditions. The induction motor, on account of the greater ease with which it starts, is used where the motor is required to stop and start frequently. The synchronous motor, on the other hand, is used where the motor having once been started can be left running, its power being applied by clutches or by the regular system of line shafting.

DYNAMOTORS, MOTOR-GENERATORS AND BOOSTERS.

Dynamotors. A dynamotor is a transforming device equipped with two armatures or two separate windings on the same armature, the latter being the more usual arrangement. They are equipped with a commutator at each end, which are connected with the two windings respectively. These machines are used for transforming direct current at one voltage into direct current at another voltage. Either winding of the armature may be used as a dynamo winding and the other as a motor winding.

Dynamotors are used extensively in electro-plating establishments where voltage of from 5 to 10 volts is required; in telegraphic work, to take the place of batteries; in telephone circuits they are used for the purpose of charging storage cells; in fact in any place where a different direct current voltage is required from that supplied from the mains.

Motor-Generators. A motor-generator is a transforming device consisting of two machines, a motor and a generator mechanically connected together. They have the advantage over dynamotors in that the voltage of the dynamo armature can be made to assume almost any value within limits by means of a resistance placed in series with its field winding and capable of variation. They can furthermore, besides being separately excited, be shunt or compound wound. They are also used for charging storage batteries, in electro-plating establishments and for work requiring a variable direct current voltage.

Boosters. A booster is a machine inserted in series in a circuit to change its voltage and may be driven by an electric motor or otherwise. These machines are used extensively on Edison three-wire incandescent lighting systems which supply current at a constant potential. Feeders which run to feeding points at a great distance, if supplied by current from the same busbars as shorter feeders, will have too small a voltage at the feeding points to give satisfactory service. A booster with its field and armature windings in series when inserted in series in the feeder circuit will add electro-motive force to the feeder in proportion to the amount of current flowing in the feeder; that is, as the current increases, the field excitation of the booster increases and therefore the electro-motive force produced in the armature increases. A booster may therefore be so designed as to just compensate for any drop in the potential which is due to the resistance of the feeders and the current passing through them. As all the current must pass through the booster armature, the commutator must be large and the whole machine designed to carry heavy current.

Boosters are also used in trolley power houses to raise the voltage which is supplied to the feeders connected to distant sections of the line. They are also used in office buildings in connection with the elevator service. The excessive currents demanded by elevator motors on starting cause wide fluctuations of the voltage of the mains. A booster inserted in these mains may be made to raise electro-motive force in the mains when the voltage drops. Boosters are often operated in conjunction with storage batteries when the battery is allowed to "float" on the line. With this arrangement, when the voltage of the system tends to rise because of light loads, the battery receives current and is charged from the main dynamos; when, however, a large current is demanded, the battery discharges into the mains and assists the work of the dynamos. A booster is generally used to assist the regulation of the voltage.

ARC AND INCANDESCENT LAMP LIGHTING.

Up until a few years ago, the carbon filament lamp and the arc lamp were the two forms of lamps which were mostly used to transform the electric current into useful light. But with the advent of 1906 there has come into the lighting field the metallic filament lamp, the tantalum lamp, the osmium lamp, the Nernst lamp, the mercury arc lamp, and the magnetite arc lamp.

The bulk of the lighting of the interiors is still done by the carbon incandescent lamps, and exterior lighting is mostly done with lamps having carbon arcs. The principal advantage of the newer form of lamps is that they give more light per unit of power than the older types but they have the disadvantages, at the present time, of being more costly and having a shorter efficient life.

The Incandescent Lamp. The carbon incandescent lamp as perfected to-day consists of an entirely closed bulb, a filament of carbon inside the bulb, and two terminals on the outside, to which the filament is attached by "leading in" wires, which pass through the glass, the latter being sealed around the wires. The name of incandescent is attributed to the fact that when the current is passed through it, its resistance is such that the current raises its temperature to white heat or incandescence.

Construction. The carbon filament is made of cellulose, which is a solution of absorbent cotton in chloride of zinc. In this form it is a heavy, viscous, semi-transparent liquid. This is evaporated until it becomes as thick as molasses, and is then squirted through a fine nozzle, or forming die, into a tank of alcohol. This hardens it into a long, thin thread which can be handled. It is then washed, dried and cut into proper lengths, after which it is carbonized at a very high temperature, care being taken that no air is admitted to the filament during this process. The filaments are then ready for the "flashing process."

When a filament has been carbonized, it is found that its cross-section is smaller in some places than at others. The effect of this would be that the small section, having more resistance than the large section, would glow more brightly when the current is passed through it. In the "flashing process," the carbon filament is allowed to come to incandescence in the hydrocarbon vapor. The heated surface of the filament decomposes the vapor, and carbon is deposited on portions of the filament which glow the brightest, and the result is a filament which is uniform in resistance, uniform in brilliancy and more durable.

The finished filament is then mounted on the ends of two pieces of platinum, which have been previously sealed into a piece of glass, that ultimately becomes the enclosing part for the neck of the bulb. The bulb proper is then placed over the filament and sealed to a glass piece containing the filament, as shown in Fig.

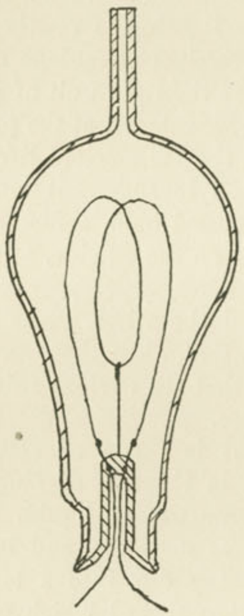


Fig. 65

CROSS SECTION OF LAMP READY FOR EXHAUSTION.

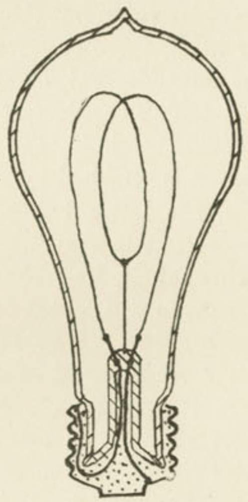


Fig. 66

EXHAUSTED LAMP WITH BASE READY FOR USE.

65. The bulb is then closed with the exception of the top, from which a tube extends, which is used for exhausting the air from the bulb so that a vacuum will exist around the filament. The air is withdrawn, because if the filament was heated in air, the oxygen of the air would combine with the carbon, and cause combustion, with the consequent destruction of the filament.

Another advantage obtained by putting the filament into a

vacuum is that there is no heat-conducting medium between it and the bulb, so that all the heat that is generated in the filament goes to produce light, a very small portion being lost by conduction. If there was any gas or vapor in the bulb it would conduct heat to the glass walls, and, consequently, give less heat to the filament for producing light. The fact that the bulb is seldom over 150 degrees, while the filament has a temperature of 2800 degrees, is proof that there is very little heat lost by conduction.

Notwithstanding the fact, however, that the filament is in a vacuum, the filament deteriorates and disintegrates. Just what causes this action is not exactly known, but small particles of carbon fly off from the filament and deposit themselves on the bulb, causing a gradual darkening of the glass, which, in oil lamps, can be plainly seen. After the air is exhausted from the bulb by the air pumps, any small amount of oxygen that is left is destroyed chemically, and the bulb is sealed by heating the tube which forms the tip of the bulb. The wires that lead into the bulb are made of platinum, because that metal has the same coefficient of expansion as the glass. If a metal were used that did not have the same amount of expansion, either the metal would expand too much and break the glass, or it would not expand as much, allowing the air to enter. In either case, the result would be the destruction of the lamp.

The wires leading to the outside of the bulb are then connected to the metal base of the lamp and the glass cemented to the base by plaster of Paris, as shown in Fig. 66. There are different styles of lamp bases used, of which the Edison, the Thompson-Houston and Westinghouse are the most in use. The lamps are then tested to find at what voltage they will give the candle power for which they are intended.

Carbon when it gets hot differs from all other conductors of electricity inasmuch as its resistance decreases as the temperature increases, while with other metals the resistance increases with the temperature. For this reason, the ordinary filament will have one-half of the resistance when hot that it has when cold. The lamps are therefore tested by bringing the voltage up to the point where they will give 8, 16, 32 or whatever candle power is required, they being labelled 8 C. P. at 108 volts, 16 C. P. at 120 volts, or whatever combination is found to be the most desirable for the lamp.

Candle Power. The candle power that a lamp gives out differs with the position from which it is viewed, so that, generally, when speaking of the candle power of a lamp, it means the number of candle power looking at the filament broadside on or with the plane of the filament at right angles to the line of observation. This candle power is obtained by means of an arrangement called a photometer, where the lamp under test is compared with some standard flame or light whose brilliancy is known never to vary. In the olden days, the sperm candle was the unit of light, which was supposed never to vary, and for this reason, the term candle power has come to be so widely used. A

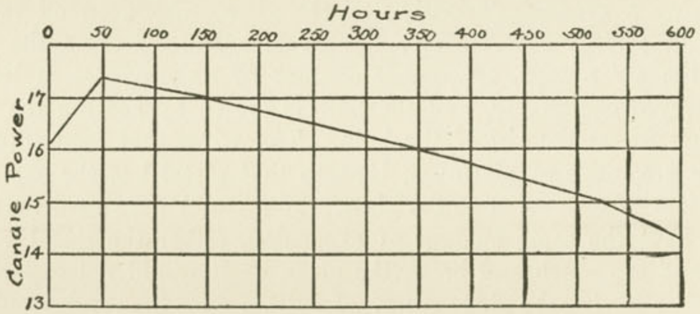


Fig. 67

RELATION OF CANDLE POWER AND LIFE.

sperm candle, in reality, is a very uncertain standard, so that a flame from a spirit or oil lamp is now generally used.

Since the illuminating power is rated in candle power the power consumption of the lamp is stated in watts per candle power. This power consumption of a lamp is by no means constant, as it varies continually with the number of hours the lamp is in service. When a new lamp is put into circuit, it usually, for a short time, gives a somewhat greater candle power than that at which it is rated, usually about 6 per cent to 8 per cent more. This gradually falls off, and the candle power is the lowest at the end of its life. This is plainly shown by the curve of a 16 candle power lamp shown in Fig. 67.

The decrease in candle power is not followed by a proportional decrease in current, because the filament gradualy wastes away,

and this, together with the blackened bulb, causes the candle power to fall without materially changing the current passing through it, as the electro-motive force at the terminals is constant.

Efficiency. The efficiency at which a lamp is run affects both the candle power and life of a lamp, the efficiency depending upon the voltage at which the lamp is burned. If a lamp is burned at a comparatively high voltage, the number of watts required per candle power is less, but the life of the lamp is materially shortened; but if the lamp is burned at a low voltage, which will give the filament a dull red appearance, then the life of the lamp may be almost indefinite, but the number of candle power obtained from the number of watts used will cause it to be very inefficient. For instance, suppose a 16 candle power lamp gives the ordinary efficiency of 3.5 watts per candle at 110 volts. Under these regular conditions, the life of the lamp may be 600 hours. If the voltage is increased to 115 volts, the candle power will increase so that the power consumed may be only 3.0 watts per candle power, but the life of the lamp may be lessened to only 300 hours. On the other hand, if the voltage was reduced to 105 volts, it is probable that the candle power would be so small that it would require 4.5 watts per candle power, but the life of the lamp under those conditions may be as much as 2000 hours or more.

Since the price of an incandescent lamp is now so small, this factor of candle power, life, the efficiency is one of supreme importance in the running of an isolated lighting plant. The conditions are something like these: A certain amount of power is generated to produce light, and a certain number of lamps are used to give out that light, and the question continually arises as to what is the voltage at which to run the lamps. If run at a low voltage, the lamps will be dim and inefficient, but the life of the lamp will be very long, and the cost of lamp renewals very small. If run at a high voltage, the lamps will be very bright and efficient, but the cost of new lamps will be great.

The choice of efficiency or voltage at which the lamps are to be run depends upon the cost of the power. If coal is cheaper, it pays to burn the voltage at a low voltage and long life. If coal is dear, the lamp burning at high efficiency should be used, provided that there are no great fluctuations of voltage on the circuit for which the lamp is intended, as this shortens its life very much. If all the exhaust steam from the engine is used for heating purposes, then it is probably more desirable to use the low efficiency and long life lamps.

The Nernst Lamp. A form of electric lamp which has more recently become a serious competitor to the carbon incandescent lamp was put in actual service by Prof. Walter Nernst, and is therefore known as the Nernst lamp. It has instead of the carbon filament of the ordinary incandescent lamp, a short strip of material which at ordinary temperatures is a non-conductor, but which at high temperatures becomes a fairly good conductor and a luminant. The "glower," as this strip is called, is made of a mixture of oxides and magnesium, zirconium, thorium, and cerium; it is made up in small sticks, one of the standard sizes being about 0.03 inch in diameter, and one inch long. As it is

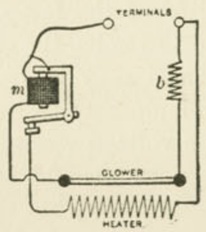


Fig. 68

made of non-combustible materials it is not necessary to enclose it in a vacuum.

As the glower is not a conductor at the ordinary temperatures a small coil of wire, heated by the passage of current through it, is employed to bring it to a temperature at which it becomes a conductor at 1750° Fahrenheit. The heater coil is of fine platinum wire wound on a thin porcelain tube and imbedded in cement, the latter serving as a protection to the platinum wire from the intense heat of the glower after the latter has become white hot. Fig. 68 shows a diagram of the lamp and connections, which shows that the glower and the heater coil are connected in parallel. When the lamp is thrown into circuit, current flows through the heater coil, which attains a high temperature and in a very few moments heats the glower to the conducting point. As soon as enough current passes through the glower to "light" it, the magnet, *m*, is strongly enough excited to raise its armature,

breaking the heater circuit but leaving the glower in circuit. When the lamp is turned off, the armature falls back into the position in which it is shown in the diagram, and is ready for operation when the lamp is to be lighted again.

Since the resistance of the material of which the glower is made decreases as the temperature rises, some means must be provided to prevent the fall in resistance from continuing to the point where the enormous current would flow, and destroy the glower, and possibly the connections. This is accomplished by putting in series with the glower a resistance coil, *b*, known as

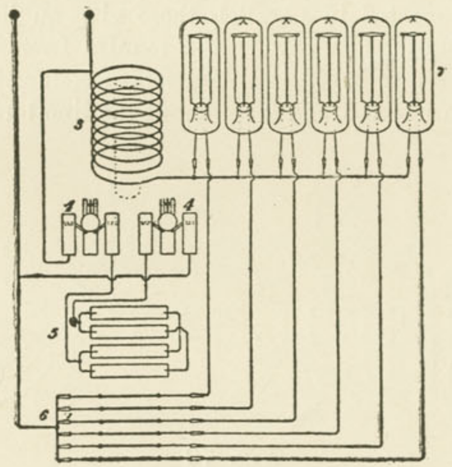


Fig. 69

the "ballast," and made of material which increases its resistance as its temperature rises, and thus compensates the fall in the resistance of the glower. The "ballast" is made of iron, which is used on account of its high temperature co-efficient; that is, its rapid increase in resistance due to its rise of temperature. Consequently a point is soon reached at which any increase in current would increase the resistance of the glower, and when this condition is obtained no increase of current can occur, the lamp being invariably used on a constant-potential circuit.

The glower is not subject to oxidation, but on a direct-current circuit it deteriorates rapidly because of electrolytic action, a black deposit being made on the negative end which extends gradually from the negative to the positive terminal. As this deposit increases the resistance increases, while the candle power and efficiency fall off. With alternating current there is no electrolytic action, but the glower deteriorates mechanically on account of the intense heat. The life of a glower on alternating current is from 400 to 800 hours, according to the rapidity of the current reversals; the life of the same glower on direct current being much less. Most of the deterioration occurs just before the glower breaks, so that the candle power remains high until near the end of its life.

Lamps are made with one, two, three, six and thirty glowers, all connected in parallel; these give an illumination of from 25 to 2,000 candle power, and require from $1\frac{1}{2}$ to 2 watts per candle power. Fig. 69 is a diagram of connections for a six-glower lamp, in which 1 and 2 represent the line terminals; 3, the

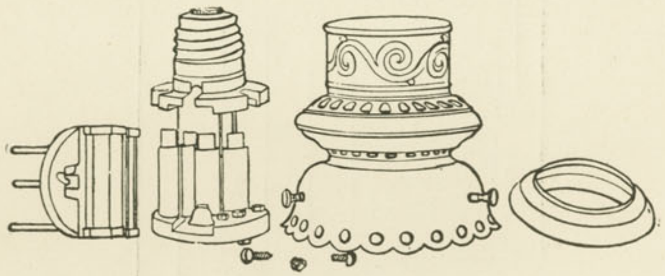


Fig. 70

cut-out magnet coil; 4, a double-pole heater cut-out; 5, the heater; 6, the glowers; 7, the ballasts; of which there is one for each glower. Fig. 70 shows the parts, except the globe, of a single-glower lamp, and Fig. 71 the holders for the six, two and three, and one glower lamp.

It is of interest to note what takes place in the lamp during the time of lighting, and Fig. 72 shows by means of a curve the current taken by a six-glower, 220 volt lamp during the lighting period. As the current was turned on, there was a sudden rush of nearly $3\frac{1}{2}$ amperes through the heater, which, however, owing to the resistance of the platinum wire was soon reduced to about 1.3 amperes. At the end of about 26 seconds the first glower began to light, at the end of 30 seconds the second glower lighted

and the heater was cut out; the current then dropped at once to $\frac{3}{4}$ ampere. The remaining glowers lighted rapidly from the heat given out from the first two, and at the end of 40 seconds, all the glowers were lighted.

The Tantalum Lamp. The newest commercial vacuum in-

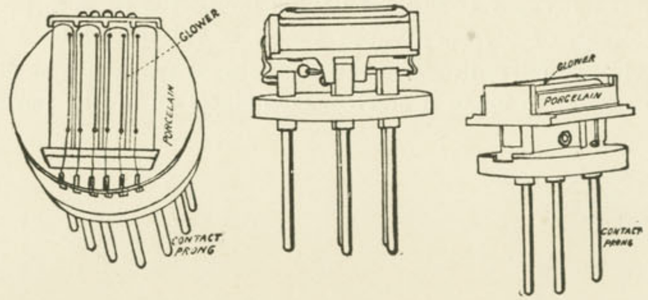


Fig. 71

candescent lamp is the tantalum shown in Fig. 73. The filament is made from a rare metal known as tantalum and it gives a beautiful white light on about 2 watts per candle power, compared with 3.5 watts for the carbon incandescent lamp. It cannot be used on

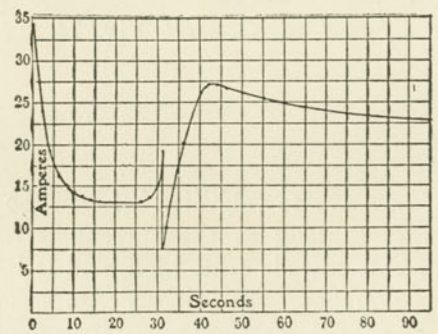


Fig. 72

alternating current circuits, but only on direct current circuits. It has a life of about 600 hours and its cost is about three times that of the carbon incandescent lamps.

Metallized Filament Lamps. A large number of lamp manufacturers in order to meet the demands are now producing what are known as metallized filament lamps. These lamps are similar to the ordinary carbon filament lamps except that the filament is treated with graphite, thus increasing its light-giving power. Lamps of this type give a candle power with 2.8 watts consumption and have a life which compares favorably with the carbon lamp.

Mercury Vapor Lamps. In these lamps the light is produced by a column of mercury vapor which is volatilized by the heat of the electric current. The tube contains a vacuum and must be tilted in order to make it start. This starts an arc by permitting

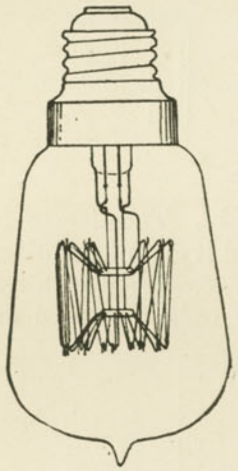


Fig. 73

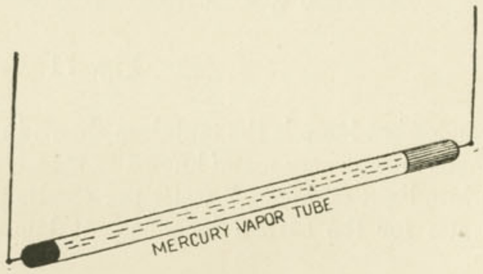


Fig. 74

a thin stream of mercury to volatilize between the electrodes and the light continues so long as the current is not interrupted. The efficiency of this lamp is quite high, and it is being used for lighting factories, warehouses and docks. On account of the fact that the light gives out no red rays, it cannot be used for ornamental or domestic lighting on account of the peculiar effects it has on the red colors. A mercury vapor tube is shown in Fig. 74.

Vacuum Tube Lighting. A form of illumination which gives very pleasant effects is obtained from a long vacuum tube which is filled with a certain gas. Alternating current is used, which acts upon the gas in a peculiar manner, and is transformed into a

particular form of light wave within the tube giving a uniform glow of pleasant character. No center of light appears and the diffused radiance makes it desirable for indoor illumination, as it practically casts no shadow. The tube usually extends all around the room in the form of a rectangle, and the absence of wires, except where it enters and leaves the tube at one end, makes

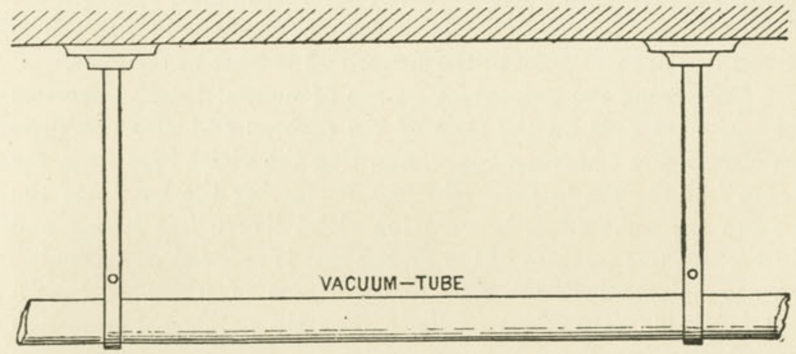


Fig. 75

it desirable for ornamentation. The tube is suspended by brass clamps and the light is estimated in candle power per inch or foot of tube. The method of suspension is shown in Fig. 75.

THE ELECTRIC ARC.

If two pieces of carbon, or similar material, be connected electrically to the terminals of a dynamo or other source of current, and the free ends of the carbon touch together, current will of course flow through the closed circuit thus established. Now if the pieces of carbon be drawn out of contact with each other, and separated to a limited extent, such as ⅛ inch, an arc will be formed between the two carbon ends, owing to the vaporization of the carbon by the intense heat of the spark which is caused when the circuit is first broken. Opening a circuit always causes such a spark, but an arc will not be established unless there is sufficient electrical energy available at the break to vaporize the conducting material there.

An arc formed between the pieces of carbon gives out an intense light, the color effect of which depends upon the length of the arc, quality of the electrodes and strength of the current. In general, taking the white arc as the starting point, increasing the length of the arc or decreasing the current will cause the arc to take on a violet tinge; on the contrary, a white arc takes on a yellowish tinge and then a reddish one, if the length of the arc be decreased. The inner part of the flame is of a violet color, and this is surrounded by a sheath of yellowish flame, in which the carbon vapor is apparently burned to carbonic acid gas. The carbon tips are white-hot at the center and red-hot at the ends.

Decreasing the current in an arc of normal length decreases the white-hot area on the ends of the carbons and also decreases the combustion of carbon vapor, allowing the violet rays from the "core" of the arc to predominate. Increasing the length of the arc has the same effect because the violet "core" is longer and the average temperature of the carbon tips is reduced. Shortening the arc reduces both the rays and the area of white-hot carbon that is visible (the edges of the carbon tip partly shielding the center) allowing the yellow rays from the burning carbon vapor to predominate; further shortening reduces these rays and still further shields the white-hot centers of the carbons, leaving the red-hot ends of them to supply practically all of the light. With an arc of normal length, increasing the strength of the current will increase the white of the arc and the quantity of light emitted.

In applying the electric arc to practical illumination, round carbon pencils or flat strips are used, butted end to end and mounted vertically. The carbon to which the supply wire is connected is known as the positive carbon, and the other one is the negative carbon. The upper carbon of the pair is made the positive one, for the reason that the principal consumption of energy occurs at the center of the end of this carbon and it throws the carbon particles off in such a manner as to hollow out the end and form a crater, the center of which is the most luminous part of the arc. If this carbon were the under one, the edges of the crater would shield the chief source of illumination.

The two carbon tips burn to the shape shown by Fig. 76. A large proportion of the carbon particles detached from the positive electrode are carried over and deposited on the negative tip, building it up as shown, and partially compensating for the wasting away due to combustion. Because of this action the positive carbon is consumed nearly twice as fast as the negative one. The wasting away of the carbon rods necessitates the continual adjustment of the relative positions of the two so as to keep the distance between the tips practically constant; otherwise the arc would grow longer and longer until it finally "broke" and be discontinued on account of the high resistance of its path.

This resistance, like that of any other electrical path, is

Fig. 76

proportional to the length of the arc and inversely proportional to its mean effective cross-sectional area and to the quality of the material in the path. These values are very difficult of determination, but fortunately are not of very great practical importance. With 9.6 amperes passing, the resistance of an arc per inch of length (distance from the crater center to the negative crest), is roughly 4 to 5 ohms, but it is not affected by the current density per square inch of crater area, as this affects the rate of vaporization of carbon, and consequently the conductivity of the path.

The amount of light given out by the arc of a commercial lamp depends almost entirely upon the current strength and the length of the arc. The effective illumination depends wholly upon the angle at which the light rays are received from the arc. The maximum is usually found at an angle at 40° to 50° below an imaginary horizontal line drawn through the center of the arc, as shown in Fig. 77, and is about 2,000 candle power in the case of an ordinary 9.6-ampere arc surrounded by a clear globe.

Regulating Mechanisms. One or both the carbons of an arc lamp must be constantly adjusted as the tips burn away, in order to keep the length of the arc approximately constant. This adjustment is accomplished by means of electro-magnets and suit-

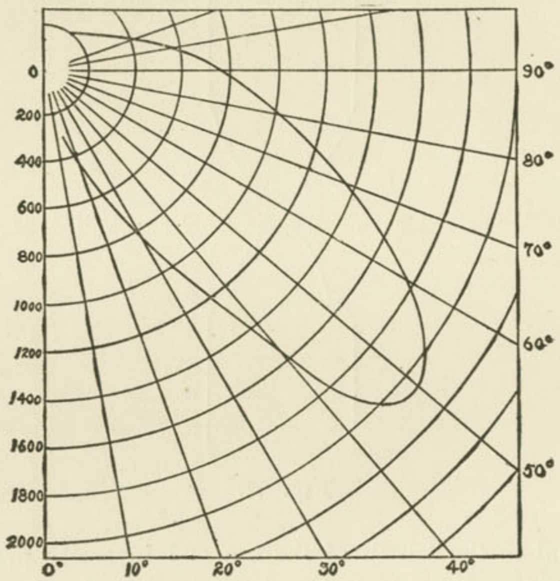


Fig. 77

able mechanism. There is also the operation of starting the arc to be done automatically. There are two types of arc-lamp mechanism designated "shunt" and "series," the regulating magnets of which are connected respectively in shunt and series with the carbons.

Fig. 78 represents diagramatically the elements of a shunt lamp mechanism, and Fig. 79 represents similarly the "series" lamp mechanism. The diagrams show the ordinary form of the arc lamp in which the upper carbon is held in a socket at the lower end of a sliding rod or tube which is commonly designated

"the carbon-rod," and the lower carbon is held stationary in a socket attached to the lower part of the lamp frame. Both types are used on the constant potential circuits.

In the simple shunt type of lamp shown by Fig. 78 the upper

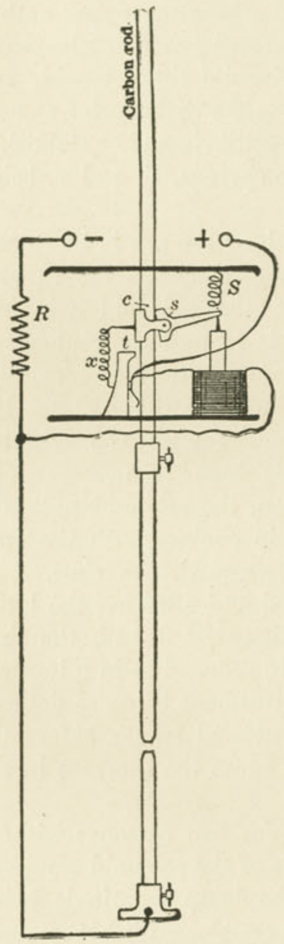


Fig. 78

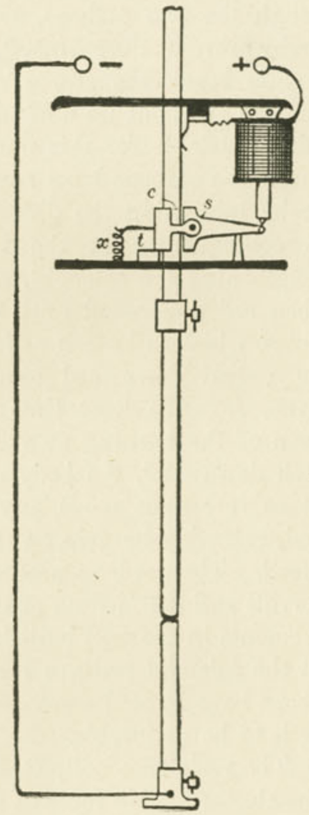


Fig. 79

carbon is held out of contact with the lower carbon by the spring, S, and the clutch, *c*, when the lamp is not in circuit. When it is connected to the circuit the current flows from the positive terminal, marked +, through the solenoid to the negative terminal.

The solenoid being thus energized, draws down the lever of the clutch shoe, *s,* allowing the light helical spring *x* to draw down the body of the clutch until it strikes the trip, *t,* which prevents the main part of the clutch from going any lower; the solenoid plunger continues downward, however, tilting the shoe, *s,* on its pivot until it releases the carbon rod and allows the upper carbon to drop on the end of the lower one. Current immediately passes through the two carbons, which short-circuits the solenoid, and thereby prevents the spring, S, from pulling the carbons far enough apart to break the arc. A state of equilibrium is established when the arc is at its normal length, the springs, S, and *x,* being made adjustable for this purpose.

As the carbons burn away, the length of the arc is increased, thereby increasing the difference of potential across the carbons and consequently at the terminals of the solenoid winding, strengthening the solenoid, and causing it to pull the clutch and carbon rod downward until equilibrium is again restored. This process, which is known as feeding, continues until the clutch has been pulled downward almost into contact with the tripping tongue, *t.* The next time that feeding becomes necessary by reason of the burning away of the carbon, the solenoid pulls the clutch downward, the body of it comes in contact with the trip, and as it cannot move any further downward, the shoe, *s,* is tilted, releasing its grip on the carbon rod and allowing the latter to feed. The feeding process is intermittent, but both the time intervals and the feeding of the carbon are reduced to infinitesimal increments in the well built lamp, the adjustment being so delicate that the solenoid restores the arc to its normal length before the carbons have burned away sufficiently to cause the increase in arc length to be noticeable.

The resistance coil, R, is necessary for two reasons: without it the electro-motive force at the terminals of the solenoid would be constant (the electro-motive force at the lamp terminals being constant) and no regulation would be possible. With the resistance coil in circuit, however, variations in the length of the arc cause corresponding variations in the difference of potential at the solenoid terminals. The resistance coil is also necessary for the purpose of steadying the arc. The resistance of an arc decreases with an increase of current, and it is, therefore, impossible to maintain a steady arc on a constant-potential circuit without in-

serting an appreciable resistance in series with the arc. The resistance of ordinary conducting materials increases as the temperature increases, consequently, an increase in current through the resistance coil, R, will cause its resistance to increase slightly. This tends to compensate for the decrease in the resistance of the arc when the current increases, and *vice versa.*

In the series type of lamp represented by Fig. 79 the carbons are in contact and the clutch is free when the lamp is out of circuit. As soon as the lamp is thrown into circuit, current passes through the solenoid winding and the carbons in series, energizing the solenoid and causing the same to jerk the clutch lever upward, pulling the shoe, *s,* into its gripping position, and through it raising the entire clutch and carbon rod together until the arc attains the normal length and reduces the rush of current to its normal value, when equilibrium is attained between the upward pull of the solenoid and the downward pull due to the weight of the moving parts and the tension of the small spring, *x.* This lamp is used only on constant-potential circuits, and the current passing through the lamp depends solely upon the resistance of the lamp circuit. Consequently, as the carbons burn away and the arc lengthens, increasing its resistance, the current decreases, weakening the solenoid, and allowing the carbon rod to feed downward until equilibrium is again established. This continues at small intervals until the clutch is almost in contact with the tripping block, after which the feeding is accomplished by the release of the grip of the clutch on the carbon rod, as in the case of the shunt lamp.

Arc lamps which are connected in series on a constant current circuit are provided with the regulating mechanism which is similar to those used in constant potential practice. One type of lamp commonly used is shown in Fig. 80 and is known as the differential lamp. When no current is on the lamp, the carbons are in contact as shown, but as soon as the current passes through the lamp the solenoid is magnetized by means of its series winding and picks up the carbon rod forming the arc between the two carbons. When the carbons have been separated to the normal distance, the current through the shunt winding of the solenoid will have increased to such a value as to neutralize the series winding sufficiently to produce a state of equilibrium. As the carbons burn away the shunt winding becomes stronger so that the resultant magnetic force exerted by the two windings is decreased, allowing the carbon rods to feed downwards until the arc becomes normal. Another form of differential lamp in common use has the series and shunt windings separate, but so arranged that the two solenoid windings have the same core, the series winding pulling the clutch up, and the shunt winding tending to pull it

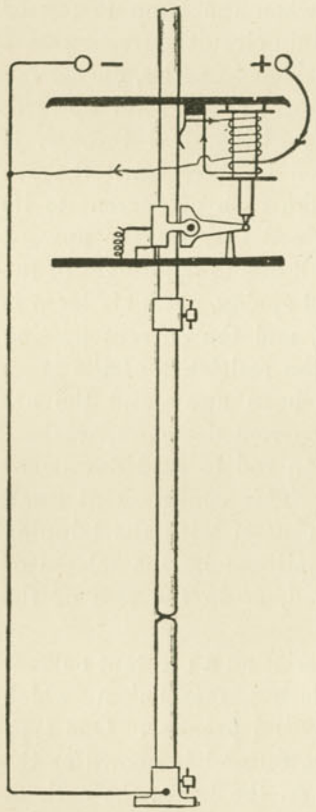


Fig. 80

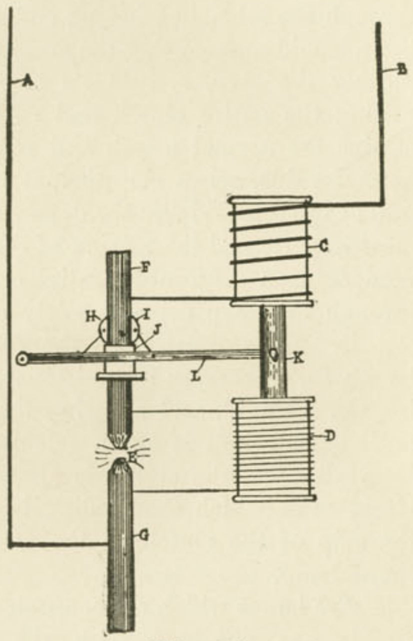


Fig. 81

down as shown in Fig. 81. A and B are the wires forming a loop in the series, C is the series magnet, and bears the same relation to the constant current lamp as it does to the constant potential lamp, D is the shunt coil, E is the arc, F and G are the carbons. When there is no current flowing the carbons F and G are together.

When current is turned in to the circuit, the series magnet C raises the carbon F and starts the arc at E; as the arc is lengthened the pull of both series magnet and shunt coil is equal, when the condition of the arc E will become steady. As the carbons F and G burn off, the voltage across the arc is proportionately increased; this causes the pull of the shunt coil D to preponderate and carbon F is drawn down proportionately, until the feed mechanism H and I is brought into action by striking against the stationary ring J. K is an iron core common to both series and shunt magnets, all movements of the core K being transmitted to the carbon F and feed mechanism H, I, by the lever L.

In some special forms of lamps it is desirable to keep the arc fixed in one place, as in the ordinary type of lamp, the position of the arc is gradually lowered. In such lamps the upper and lower carbon are both mounted in sliding holders, so that the lower carbon may be fed upward, while the upper one is fed downward, causing the upper carbon to feed downward about twice the rate that the lower carbon feeds upwards because the upper or positive carbon wastes away about twice as rapidly as the lower one.

In lamps operated on alternating current circuits the two carbons are of the same length, the rate at which they are consumed being approximately the same for both.

Practical Hints About Arc Lamps. When the lamp fails to light, assuming that it has been properly trimmed, one or all of the following causes may be looked for: 1st, the resistance coil may be burnt out; 2d, the magnet coils may be burnt out; 3d, the framework may be grounded, thereby preventing sufficient current to flow through the carbons to produce an arc; 4th, broken or grounded connections; 5th, when the movable carbon is continually in motion, thus preventing a steady light; 6th, when the clutch fails to lift the carbon. These six difficulties will be the principal ones met with in practice.

The mechanism of an arc lamp may vary with different manufacturers, but the underlying principles involved in its operation will be found practically the same. Some lamps have their resistance coils wound on separate spools, others have no spools, while still others have their resistance coils wound on one large spool. Again, some lamps are fitted with two magnet coils, while other lamps are only fitted with one. The mechanism of the carbon clutch also varies with the different lamps, as do the dash-pots employed to resist or counteract the solenoid magnet. The shell or outer casing varies in shape, the methods for taking off and putting on are different; in some arc lamps the resistance coil must be removed before the outer shell can be taken off, and in other cases the shell can be taken off without disturbing the lamp mechanism. Then again the method employed

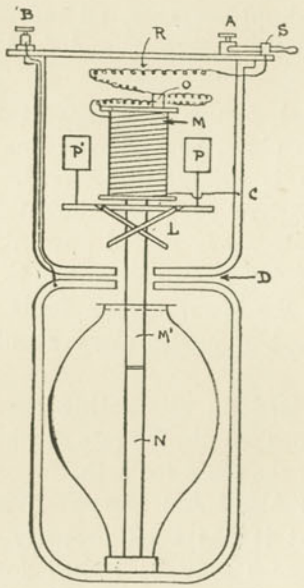


Fig. 82

to convey the current to the movable carbon is not always the same; some manufacturers solder a flexible wire to the carbon holder of the movable carbon so as to insure a positive supply of current, while others depend upon the frictional contact of the carbon holder to insure current supply to the upper or movable carbon.

Referring to Fig. 82, the mains carrying the current are connected to the binding posts A and B. The current flowing through A passes through the switch S and resistance coil R thence through the magnet M. The current is grounded on the upper framework of the lamp, and this wire is grounded on the

lower framework. Thus it will be seen that the framework of the lamp is divided into two parts and insulated from each other at D. It follows, therefore, that when the carbons are inserted at M^1 and N, a passage for the current is provided, and if we procure a mechanism to move the carbon M^1 upwards or the carbon N downwards, an arc will form between the carbons and light will result. If the carbons are moved only a slight distance apart, a poor arc will be obtained, accompanied with little light; hence, to obtain a more powerful light the length of the arc must be increased, the amount of which will depend upon two factors, namely, the amount of the resistance cut in the circuit at R and the lifting power of the magnet M. If the magnet M is in good order and the arc still remains short, too much resistance is cut into the circuit, which must be lessened by moving the clip at O, thereby reducing the length of the resistance wire. The length of the arc should now increase, and consequently a more powerful light should be obtained. If the clip O is moved so as to increase the resistance R, the arc will decrease.

Sometimes, no matter how much resistance is cut out, the arc will not increase in length. In this case it will be found that the magnet M is either wholly or partially burnt out, in which case the magnet must be replaced by a good one. Before discarding the injured magnet, however, it will be a good plan to test it, by allowing the current to flow around it and then by placing a screwdriver or some iron or steel tool against the magnet, its lifting power can be determined. Should the magnet be found strong and not burnt out, then the trouble will be either in the lifting mechanism shown at L or the dash-pots shown at P and P^1.

The object of dash-pots is to resist the lifting of the carbon too suddenly. Should the carbon be lifted with a "jerk," there is a possibility of drawing the carbon out of the field of the arc, thus breaking the arc and no light results. The correct working of the dash-pot is an important factor of arc lighting, and to determine if it does operate correctly, it should be seen that it requires considerable force to press the plunger into the pot quickly. From this it is learned that a blow or push will be resisted by the partial compression of the atmosphere, hence any sudden action of the magnet is controlled and the carbon is maintained within the length of the arc and light is formed the moment the contact of the carbon is broken.

Whenever a lamp becomes grounded, the movable carbon sometimes traverses its entire stroke without forming light. Of course, this ground must be removed, and the simplest way to do it is to remove the outer shell or casing, then trip the lamp, and throw on the current, when the ground should make its appearance and can be easily removed.

When continuous arcing occurs, it will be found that the plungers of the dash-pots are worn sufficiently to permit of a rapid lifting and dropping of the carbon, and in such a case as this satisfactory lighting is impossible. Sometimes the lamp will not burn satisfactorily, although the lamp mechanism and trimming are all right. This is often due to the arc traversing the perimeters of the carbon instead of being central. Impurities in the carbon will cause this, and to overcome this difficulty, hollow and cored carbons are employed. In the latter case, the centers of the carbons are filled with a soft carbon which is easily vaporized, thus lessening the tendency of the arc to traverse the circumference of the carbons, thereby preventing avoidable shadows. With enclosed arcs, when opalescent globes are employed, the shadows will not be noticable to any great extent, as this form of globe diffuses the light more equally than clear globes.

It is important to have the upper carbons the hotter, as this will deflect the light downwards. When an arc lamp is first connected to the mains, it may not be wired so that the upper carbon will be the positive carbon. If, however, the current is thrown on and the lamp allowed to burn for five minutes and then cut off the current, it can easily be seen which carbon is the hotter, and should the lower carbon be the hotter, the lead wires to the lamp should be reversed.

It is sometimes necessary to know what voltage is maintained across the arc. For this purpose, a portable voltmeter can be used and connected to the lower and the upper carbons. The arc being formed, the voltmeter can register the necessary voltage to maintain the arc, and by connecting the voltmeter to each arc in the circuit and by shifting the resistance in each lamp, an approximate equality of voltage can be maintained throughout the various lamps, and each lamp will properly do its share of the lighting.

The length of time a carbon will last depends upon the amount of air which is admitted to it; hence, to prolong the

life of a carbon, the inner globe is often made as air-tight as possible. The inner and outer globes should be kept clean, as this will materially assist in the proper diffusion of the light.

To Carbon a Lamp. The following directions are given by the General Electric Co. for the series enclosed arc lamps:

Be sure that the current is switched off. Hold the enclosing globe firmly and swing the bail to one side after pulling down on it. The globe will come off. Loosen the set-screw and remove the carbon. Remove the upper carbon and put in a new one, inserting it in the spring carbon holder of the upper carbon tube. Put a lower carbon of proper length in the lower carbon holder, and secure it with the thumb-screw. Replace the inclosing globe, being careful to set the upper edge squarely against the finished surface of the cap, so as to exclude the air from the arc. Secure the globe by placing the supporting ring on the projection around the bottom part of the globe. To insure proper electrical connection to the upper carbon, it must be well inserted in the spring carbon holder on the inside of the carbon tube. The inclosing globe should be cleaned periodically.

DISTRIBUTION OF ELECTRIC POWER.

There are two systems of electric distribution, the constant-current and the constant-potential systems. In the constant-current system there is always a current of the same intensity flowing through the circuit and the voltage of the generator must rise and fall as the resistance of the circuit varies under different conditions. In the constant-potential system the voltage is always kept as nearly constant as possible and the amount of current may vary from zero up to the capacity of the generator or generators.

Constant-Current Systems. As all lamps require a constant current they can be connected either in series on a constant-current system or in parallel on a constant-potential system. When a constant current is used, the distributing mains form a simple closed circuit, and when the lamps to be lighted are thrown off and on the circuit, the voltage of the generator will be lowered and raised in proportion to the voltage which the lamp takes up. As the lamps of all constant-current systems are connected in series, a constant-current system is also called the series system.

In the series system, the capacity of the wire in the circuit need be only that which is necessary to feed one lamp, as all the lamps in the series require the same current. The system is simplicity itself, as shown in Fig. 83, its principle objections being that each lamp in the circuit must take the same current; the voltage becomes very high as the number of lamps increases and for house lighting individual lamps cannot be extinguished because this would effect all others in the series, unless a resistance equal to the lamp be subsituted in the circuit when it is extinguished. This latter method is impractical if the number of lamps is large.

In arc lighting, fifty to one hundred lamps may be placed in one circuit which may be several miles in length; each lamp

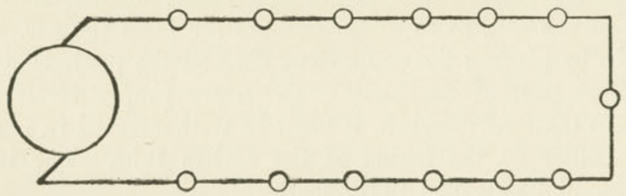


Fig. 83

requiring ten amperes of current and a drop of potential of fifty volts.

Series Incandescent Lamps. If incandescent lamps are used on arc light circuits, they must have thick filaments so that there will be a comparatively small potential difference across their terminals. If fifty incandescent lamps are connected in series it would require 5500 volts to drive one-half an ampere through them. In practice, for outdoor lighting, a 10 ampere, 100 candle power lamp is standard.

All lamps used in series lighting should be equipped with an automatic cut-out so that if the lamp should become broken, the current through the circuit will not stop. Should a lamp become broken, all the electro-motive force of the circuit becomes active at the broken terminals. Advantage is taken of this fact by dividing a circuit through a series lamp into two paths, one path going through the filament, and the other path going to two terminals within the lamp between which is interposed a piece of paper. Under ordinary conditions the current passes through the filament, but should the filament break, the voltage due to the

electro-motive force of the system will pierce the paper and the two free terminals will come into contact thus re-establishing the circuit. This, however, will cause an increase in current in the system, but the station attendant, recognizing the increased current, will throw one of the relief lamps provided for the purpose in the circuit thus establishing normal conditions until the broken lamp can be replaced.

Along many trolley lines, where the potential is 550 volts, five ordinary incandecent lamps are used in series to do the lighting of the road; the interior of street cars are also lighted in the same manner. This method is open to the objection that should one light burn out, the other four lamps will be cut out.

Constant Potential Distribution. For all interior lighting the constant-potential distribution is used because perfect independence of all the lamps is established, the maximum difference of potential is harmless and the electric energy utilized is proportional to the number of lamps lighted. The general voltage used is one hundred and ten volts, and as each lamp of 16 candle power requires one-half ampere, the resistance of the filament is 220 ohms.

The most simple case of parallel distribution is where two wires of the same thickness are carried through the district to be lighted and to have them of such size as to carry current enough to light the required number of lamps. This, however, is too expensive a method in practice as the total current at the dynamo determines the size of the wire, while near the far end of the circuit where only a few lamps are carried a much smaller wire could be used.

The size of a conductor is determined first by the amount of current it can carry without undue heating, and secondly the drop of potential allowable for economical lighting; the second condition usually being the determining factor, as the first condition will be met when the second condition is fulfilled.

In the design of a distributing system great care should be taken to obtain a good distribution of potential, as a variation of one per cent from the normal voltage means a considerable difference in the illuminating power of the lamp. In general terms, it may be stated that the drop of potential of one volt in a 110 volt 16 candle power lamp will reduce the candle power to 15 candles. All calculations for finding the size of wires are based upon Ohm's law and can best be worked out by allowing a certain predetermined drop before calculation. Feeders, mains and leads are thus all calculated separately.

System of Parallel Distribution. There are various systems of distribution that are used in practice among which may be men-

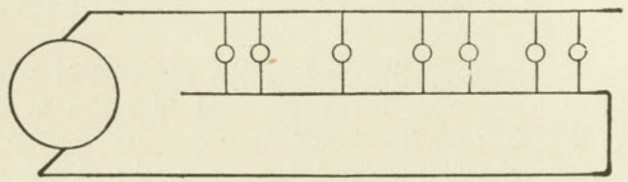


Fig. 84

tioned the loop system, the tree system, the closet system, the anti-parallel system, three wire system, etc. The loop system is shown in Fig. 84, which is arranged so that the current for each lamp goes through the same length of wire. While uneconomical with cop-

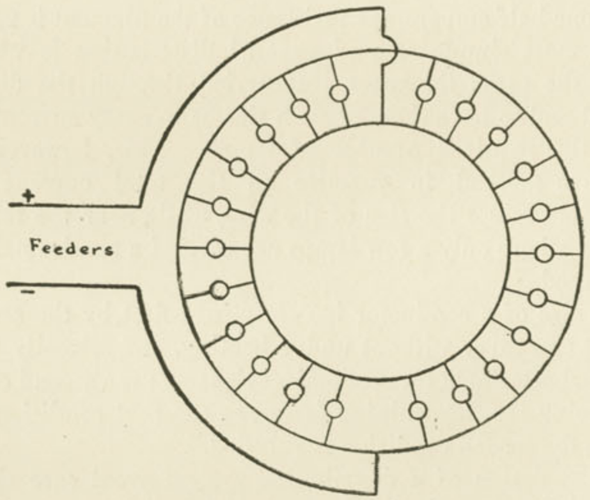


Fig. 85

per, it can be made to furnish a steady potential. Another used is the closet system, which arranges a number of lights in groups, each group having its own feeders. Fig. 85 shows a symmetrical arrangement which in practice is irregular-shaped. This method

is used in interior wiring, and the length of the main for each lamp is the same. The tree system merely consists of one set of feeders from which branches are led to the different lamps, and is so named because the diagram of such a system resembles a tree.

Three Wire System. The amount of light furnished by an electric lamp is directly proportional to the energy in the electric current that passes through it, and the amount of power delivered by an electric motor is also proportional to the amount of electrical energy in the current that operates it. The voltage of the current determines the ability to overcome the resistance that opposes its flow through the circuit, just the same as pressure in steam and water indicates its ability to force its way through the pipes. Voltage, in fact, is the equivalent of pressure. The amperes measure the amount of current that passes through the circuit. The energy value of an electric current is equal to the product of the volts by the amperes and is expressed in watts. Thus if a current of ten amperes is flowing through a circuit, and the voltage that forces it along is 100 volts, then the energy will be the product of 10 amperes by 100 volts; or, in other words, it will be 1,000 watts. If the current is 20 amperes, and the voltage 50, the watts will still be 1,000 for 20 times 50 equals 1,000. The size of wire required to carry a current is dependent upon the amperes, and not the volts. Thus if a wire can carry only 10 amperes when the voltage is 20, it can carry but 10 amperes when the voltage is 20,000, or any other amount. If the voltage is 20, and the amperes 10, the power will be 200 watts, but if the voltage is increased to 2,000, which is one hundred times as great, we also increase the power transmitting capacity of the current one hundred times, and this we accomplish without increasing the size of the wire. From this illustration it will be understood at once that to transmit power by means of electric current with the greatest economy we have to use the highest voltage admissible. Thus for incandescent lights the voltage of 110 is generally provided. The current required by a 16-candle power incandescent lamp of 110 volts is about one-half of an ampere. If lamps could be used that would require 220 volts, then the current strength would be reduced to about one-quarter of an ampere; hence, with the same size wire twice as many lamps could be fed. While 220 volt lamps are made, in the great majority of cases 110 volt lamps are still in use. With these 110 volt lamps as great an economy in the use of wire can be had by adopting what is known as the three wire system of distribution. This system, briefly explained, consists in so arranging the lamps that the current passes through two in series, instead of one, and, as each lamp requires a voltage of 110, the two combined will

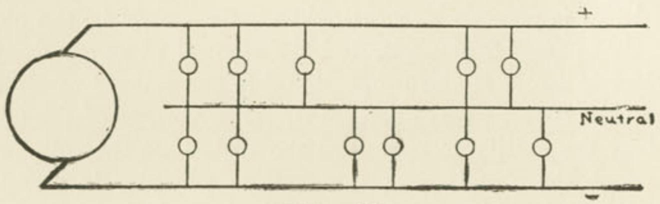


Fig. 86

balance a current having a pressure of 220 volts. A three wire system connected to one generator is shown in Fig. 86. A potential difference of 220 is maintained between the two outside wires; the third wire lying half-way between the others in potential. This wire is called the neutral wire. The outer conductors are generally made one-half the size of those in the two wire system of the same load, and the neutral wire is generally made one-half the size of

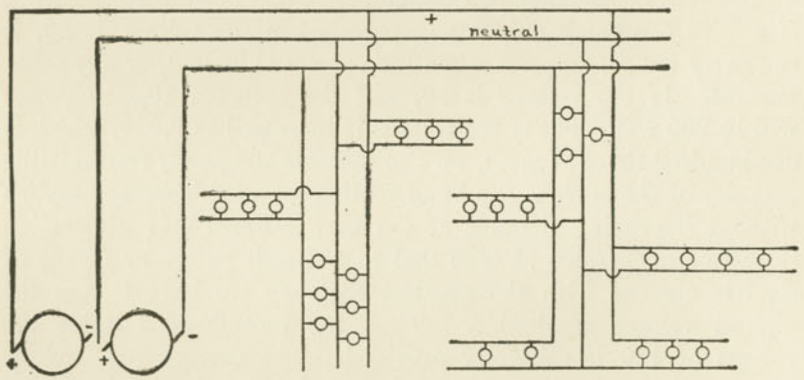


Fig. 87

the outer conductors. If there were always the same number of lamps on either side of the wire, the neutral wire could be dispensed with. If, however, all the lamps on one side were lighted, and all on the other were extinguished, the neutral wire would have to be

as large as the outside wire. In large distributions this is seldom the case, the aim of the central station manager being to always balance the load whenever possible.

The most usual arrangement of the three wire distribution is shown in Fig. 87. Two 110 volt generators are connected in series, which makes the two outside wires carry a difference of potential of 220 volts, the 110 volt difference of potential being obtained between one outside wire and the neutral. In practice,

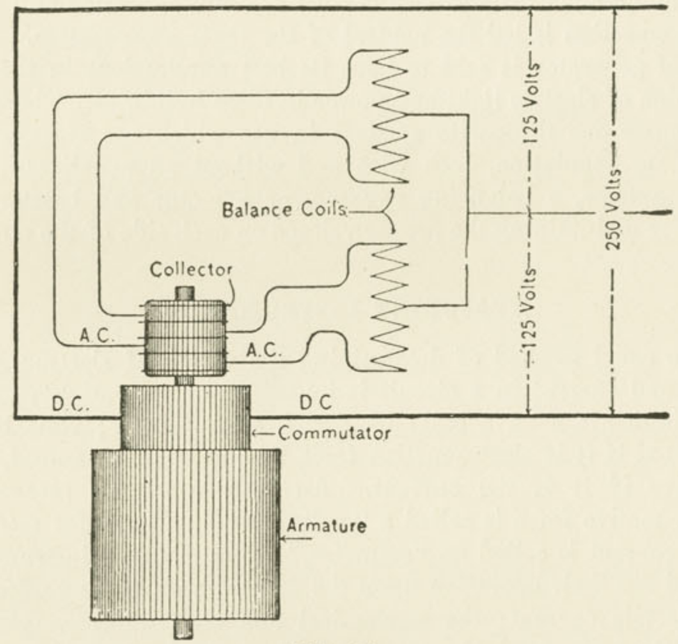


Fig 88

so as not to disturb the balance of the load on either side of the circuit, motors of any appreciable size are made to run at 220 volts and are carried across the outside mains, the lighting load being divided between the two sides as nearly as possible.

A new form of three wire generator shown in Fig. 88 has been recently introduced into the engineering field for the purpose of replacing the usual methods of operating the three wire systems. It is the same as the standard single voltage machine except that additional leads from the armature windings are connected to collector rings mounted on the armature shaft. This arrangement is exactly similar to that employed for the alternating current side of the armatures of rotary converters. This arrangement is of the two-phase type and across the two-phase collector a pair of autotransformers or balance coils are connected, as shown in the accompanying diagram. These balance coils have a single winding about a laminated iron core of the shell type and are immersed in oil and mounted in cases similar to the transformers. The mid-points of the balancing coils are interconnected and from this connection is led the neutral of the three wire system. This type of generator is said to have its best applications in the distribution of electric light and power in office buildings. There are also numerous three-wire systems in use which use storage batteries for regulation, both with and without an equalizer. For large systems, a balancing dynamo, or a motor and booster are used for maintaining the proper voltage on each side of the circuit.

MEASURING INSTRUMENTS.

The usual method of determining the values of electro-motive force and current in a circuit is by means of instruments which give indications on a scale by means of a pointer; volts being indicated if it is electro-motive force that is being measured, and amperes if it is the current. An instrument for measuring electro-motive force is called a " volt-meter " and one for measuring a current is called an "ammeter." Both class of instruments depend for their operation upon the magnetic or heating effect of the electric current; the mechanical and electrical arrangement being the same for both an ammeter and a voltmeter of a given type.

Classes of Voltmeters and Ammeters. Voltmeters and ammeters are generally divided into three general classes, namely, magnetic needle instruments, electro-magnetic instruments, and hot-wire instruments. The arrangement of the working part of a voltmeter of the magnetic needle principle is shown in Fig. 89. A soft iron needle, *n*, is pivoted inside of a coil, *c*, of a very fine wire and is held out of line with the axis of the coil by means of a permanent magnet, *m*, when the instrument is idle. In this position, a pointer, *p*, which is attached to the needle stands at zero point of the

scale, *s*. If a current is passed through the coil, magnetic lines of force are set up in its center, which tend to pull the needle in line with them, and therefore, with the axis of the coil. This pull is resisted by the permanent magnet, *m*, and the amount of deflection of the needle from the zero position depends upon the strength of the current passing through the coil. As the resistance of the instrument is constant, the current in the coil is directly proportional to the electro-motive force, and, therefore, the deflection of the needle depends upon the electro-motive force at the coil

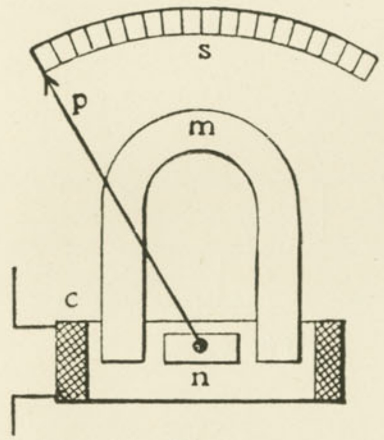


Fig. 89

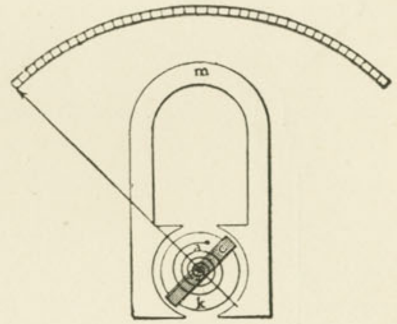


Fig. 90

terminals, so that if the scale is properly marked, the pointer will indicate volts.

The electromagnetic type of voltmeter is shown in Fig. 90, and represents the most usual type of instrument in general use. The coil, *c*, is pivoted between the poles of a permanent magnet, *m*, and moves between them and the fixed soft iron core, *k*. It is held in normal position by two spiral springs, *a*, one above the coil and one below it, which also serve the purpose of making electrical connections to the coil, *c*. When a current passes through the coil, magnetic lines are set up in it which differ from those in the permanent magnet, and the combination of the two fields produces a twisting action on the coil. This twisting action is resisted by the two spiral springs. The deflection of the coil, *c*, depends upon the current in the coil, and since the resistance of the coil is constant, the pointer, which is attached to the coil, will indicate volts on the scale if it is properly graduated.

Either instrument, as shown in Figs. 89 and 90, can also be used as an ammeter, the principle difference being that when used for an ammeter, the wire coil must be made of heavy wire, if it is to carry the full current in the circuit; or if the instrument is connected in parallel with the low shunt resistance, only a fraction of the current need pass through the coil, so that the coil is made light; but in both cases, the scale is so graduated that the pointer measures the whole current in the circuit.

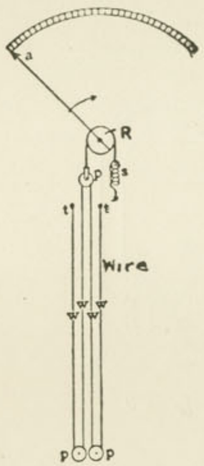


Fig. 91

Fig. 92

The hot-wire voltmeter depends upon the two principles that the current will heat a conductor when flowing through it, and, also that the length of the wire is increased when it becomes heated. An arrangement which utilizes these principles is shown in Fig. 91, in a diagrammatical form. A fine wire, *w*, of high resistance is connected to the two terminals, *tt*, which are rigidly fastened to the frame of the instrument. The wire passes around three pulleys, *ppp*, the two lower ones being rigidly fastened, and the upper one being free to move up and down. It is fastened by a metal band to the pulley, R, which is fastened to the frame. A spring, *s*, one end of which is fastened to the frame and the other to the pulley, R, tends to rotate the

pulley in the direction of the arrow. This tendency to rotate is resisted by the wire, *w*, and when no current is flowing the pulley is in such a position that the pointer, *a*, attached to it, indicates zero on the scale, *b*. When current passes through the wire, it becomes longer under the heating effect of the current and allows the spring to move the pointer over the scale, which may be marked so as to indicate either volts or amperes according to the purposes

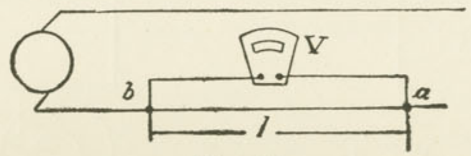


Fig. 93

for which the instrument is to be used. When used as an ammeter, it is always used in parallel with a shunt of low resistance, as it would not be practical to make the wire, *w*, large enough to carry heavy currents.

Voltmeter Connections. A voltmeter is always connected to the two points between which the difference of potential is to be measured. If, for instance, it is desirable to measure the electromotive force between the two sides of the circuit, as shown in Fig. 92, the voltmeter, V, should have one of its terminals connected at

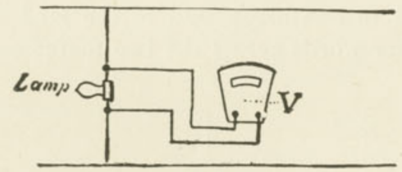


Fig. 94

x and *y* as shown. If the drop of potential through a certain length of wire is required, the voltmeter is connected to the terminals of the length of wire of the length, *l*, as shown at *a* and *b* in Fig. 93. If it is desirable to obtain the drop of potential of a lamp, one terminal of the voltmeter is connected to one side of the lamp and the other terminal to the other side as shown in Fig. 94. If the voltage of the shunt generator is required, the voltmeter should be connected across the terminals of the machine as shown in Fig. 95.

When a compound generator is used, it is necessary to be particular in connecting the voltmeter, for if it is connected to

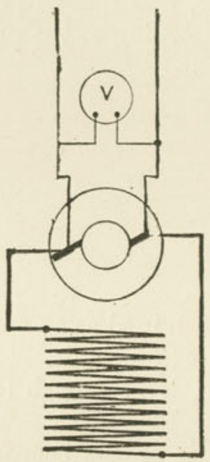


Fig. 95

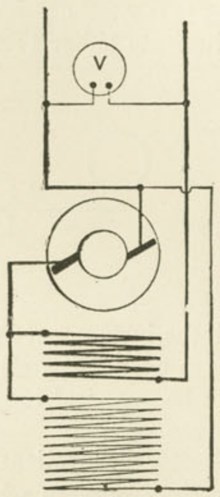


Fig. 96

the armature terminals it will show a greater number of volts than actually exists on the external circuit. The voltmeter should, therefore, be connected to one brush and to the lead from the series winding, or in other words across the two mains as they leave the

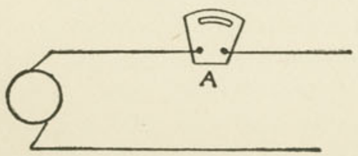


Fig. 97

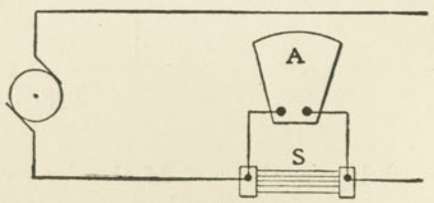


Fig. 98

machine as shown in Fig. 96. The voltage across the brushes in a compound machine is useful in obtaining the drop in the armature when making efficiency and other tests.

Ammeter Connections. As an ammeter is intended to indicate

the amount of current flowing through the circuit, it should always be connected in series in the circuit and *never* between the two sides of the constant potential circuit like a voltmeter. For comparatively small currents, the ammeter is connected as shown in Fig. 97. If, however, the currents are large, it is connected in parallel with a shunt resistance as shown in Fig. 98. This arangement is usual when the ammeter is in circuit a long period, as with switchboard instruments, because otherwise the coil of the armature would have to be very heavy, and consequently the instrument

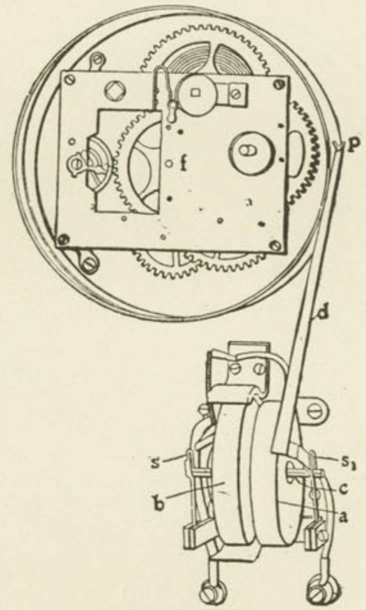


Fig. 99

would be very bulky. This arrangement of connections must always be used for a hot-wire ammeter.

Recording Instruments. In cases where a continuous record is desirable and a great degree of accuracy is not necessary, a voltmeter arrangement, as shown in Fig. 99, or an ammeter, as shown in Fig. 101, may be used. The operation of the voltmeter depends upon the principle that two solenoids will attract each other if placed near each other so that the adjacent ends are of unlike polarity, and the operation of the ammeter depends upon the principle

ple that the solenoid will attract a piece of magnetic material, such as a disc of soft iron, placed near it.

The voltmeter, Fig. 99, has two current coils, *a* and *b,* one of which, *a,* is rigidly fastened to the frame of the instrument while the other, *b,* is movable. It is carried by a pair of springs, *ss,* which support a shaft, *c,* the shaft being fastened to the coil, *b.* An arm, *d,* is attached to the spring, *s,* and moves with it, and hence with the coil. At the upper end of the arm, a pen, *p,* is fastened which rests upon a chart marked with radial lines which

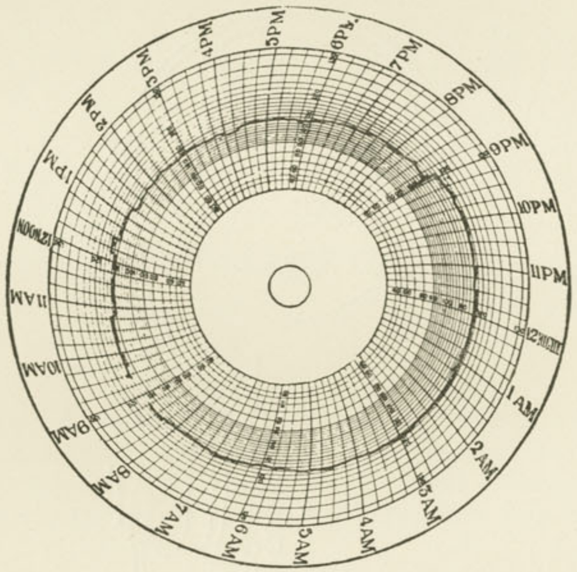


Fig. 100

indicate time, and circles which indicate volts. This chart, shown in Fig. 100, is uniformly driven by a clock, *f.* When current passes through the coils, the fixed one, *a,* attracts the movable one, *b,* thus causing the pen, *p,* to move away from the center of the chart, and the movement of the chart causes the pen to draw a continuous line, which indicates at any time the volts at the terminals of the instrument.

The arrangement of the ammeter, Fig. 101, is similar to that of the voltmeter, except that in place of a moving coil, a thin disc armature, *b,* of iron is used, the rest of the mechanism being exactly

the same. The method of operation of this instrument is precisely the same as that of the voltmeter. The chart in this case is graduated so as to read amperes. For currents up to about 1,200 amperes, ammeters of this description are made to carry the whole circuit current. For large currents, a low-resistance shunt is used in parallel with the instrument, as shown in Fig. 98.

The Wattmeter. A wattmeter is an instrument which shows the amount of energy, or power, in an electric current. These in-

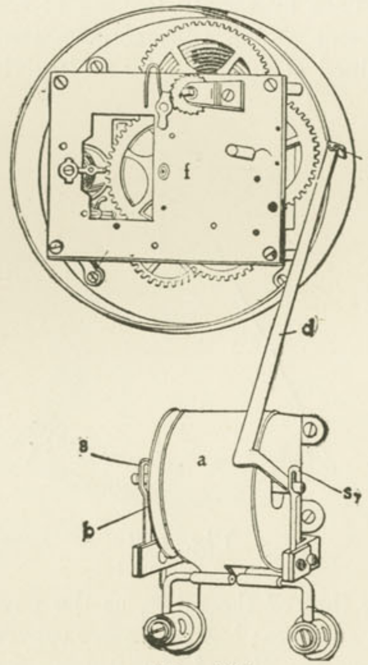


Fig. 101

struments are made in three different types: indicating, recording and integrating. The first named type, the indicating, has a pointer that swings over a dial and indicates the power in watts flowing through the circuits. The pointer responds instantly to any variations of the power, therefore, it is continuously changing its position. The recording wattmeter, traces on a roll of paper, or a disk, a line that is the record of the power in the circuit at every instant during the period covered by the record. The integrating wattmeter shows the amount of energy that has passed through the circuit in a given time. The unit of measure is a watt hour, that is, one watt acting for one hour of time, or any other amount of power and interval of time which when multiplied by one another will equal one watt hour. Thus five watts passing through the circuit for twelve minutes will be equal to one watt hour, and so will half a watt acting for two hours be one watt hour.

Indicating wattmeters are commonly placed upon switchboards so that the power delivered by the generators at any instant may be known at once by simply looking at the instrument. If there are an ammeter and a voltmeter on the switchboard, the power can be obtained at any time by multiplying the reading of

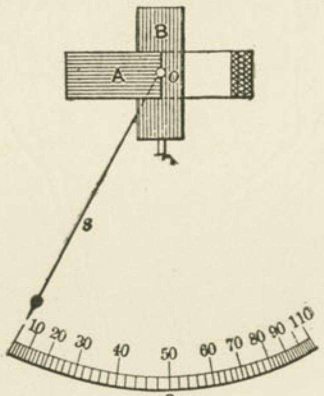


Fig. 102

one instrument by that of the other, as the power is the product of the volts by the amperes; but it is more convenient to be able to read the power from the dial of a wattmeter than to obtain it by making the multiplication just mentioned. In addition to the greater convenience, the indication will generally be more accurate, because it is next to impossible to take the readings of two instruments at the same instant of time; and, furthermore, a slight mistake in one or both of the readings may be made, and thus the calculation for the power may be considerably out of the way.

The indicating wattmeter is shown in Fig. 102, and it is evident from the above explanation that the readings of the pointer must be proportional to the product of the volts and amperes in the circuit. This is usually obtained by means of the electro-

magnetic reactions between a movable fine-wire coil and a fixed wire-coil; that is, a wattmeter is a combination of an ammeter and a voltmeter. As will be seen in Figs. 102 and 103, there are two coils set at right angles to each other. One of these coils is traversed by the whole current, and, therefore, acts as an ammeter; and the other coil is connected across the circuit, like the coil of the voltmeter, and acts like a voltmeter. The result of this construction is that if the current increases, the indicator moves forward, and if it decreases the indicator moves backward. If the voltage rises, the indicator will move forward, and if it falls the indicator will move backward. If the current and the voltage

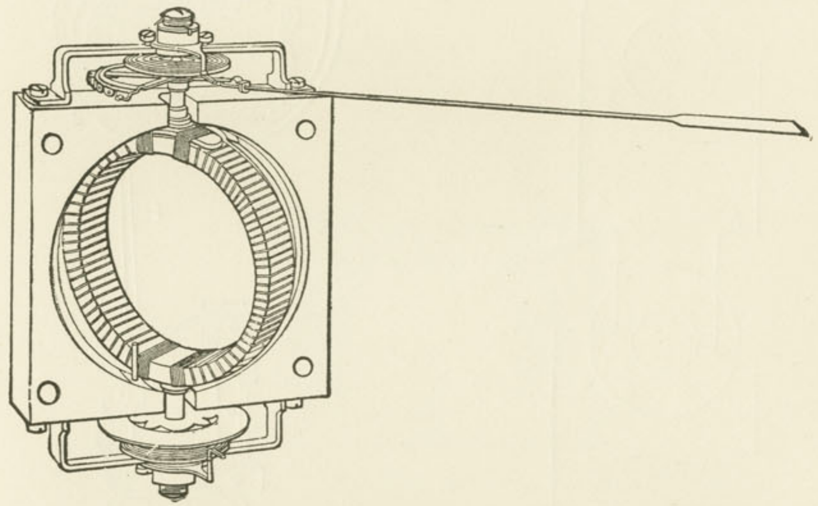


Fig. 103

both increase, the indicator will move forward through an angle that will correspond to the combined increase in the volts and the amperes.

Fig. 104 shows the general method of connecting a wattmeter to a circuit. The wire *b* from the generator connects with the lower binding post of the wattmeter W, and the upper post is connected with the wire *d*; thus the main current is passed through one of the coils. One of the wires *c* carries a branch current from *b* to the other coil of the instrument, and the remaining end of this coil is connected by a wire with the opposite side of the circuit, that is, with wire *e*. The binding posts of the wattmeter W are located at the top and bottom and at the sides, but this is not the position in which they are found in actual instruments. They are here so located to illustrate more fully the coils with which they are connected. As will be seen, the wires *b* and *d* connect with the instrument the same way as if it were an ammeter, while the wires *cc* connect it as if it were a voltmeter.

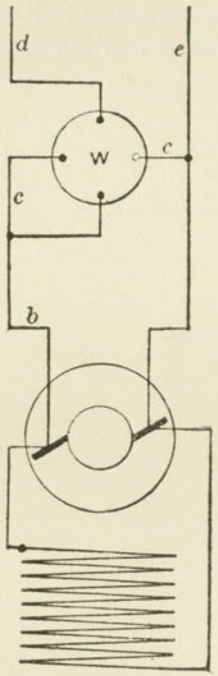


Fig. 104

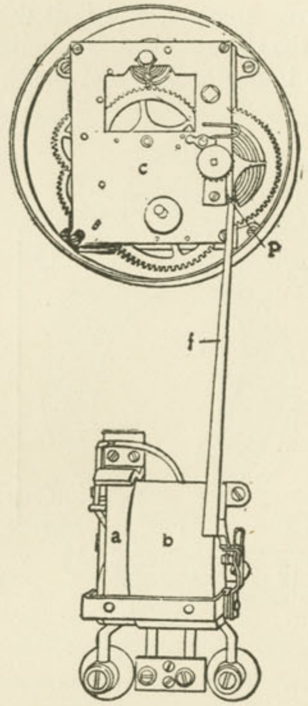


Fig. 105

As the resistance of the moving coil is constant, and is connected across the circuit, the current in it is proportional to the electro-motive force at the terminals of the instrument; and as the coarse-wire fixed coils are in series with the circuits, the current in them is the whole circuit current. If the fine-wire coil carried no current, the directions of the lines of force set up by the current in the coarse-wire coils would be approximately straight, but on account of the field set up by the current in the

movable coil, the lines are distorted, and in trying to shorten themselves tend to twist the movable coil through an angle. This tendency to run is directly proportional to the amperes of current in the stationary coils multiplied by the current (and, therefore, the electro-motive forces) of the moving coil.

Where a continuous record is desired and great accuracy is not required, a recording wattmeter arranged as shown in Fig. 105 may be used. The operation of an instrument of this description depends upon the principle that two solenoids will attract each other if placed near together and arranged so that the adjacent ends are of opposite polarity. The coil, *a*, which is of fine wire,

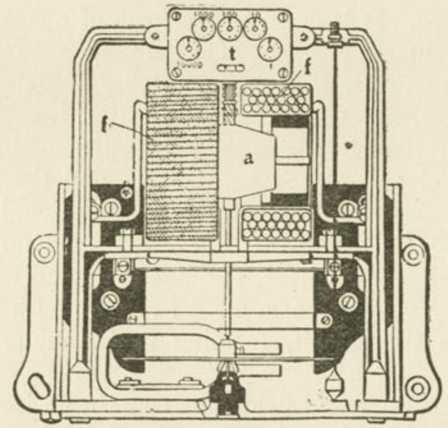


Fig. 106

is mounted on knife edge and spring supports, and is free to move towards the stationary coil, *b*, which is wound with wire heavy enough to carry the entire circuit current. The terminals of the high resistance coil, *a*, are connected across the circuit, and those of the low resistance coil, *b*, in series with the circuit, so that the magnetic effect of the coil, *a*, is proportional to the electro-motive force of the circuit, and that of the other, *b*, to the circuit current; therefore, the magnetic effect of the two coils upon each other is proportional to the product of the electro-motive force and the current of the circuit. The arm, *f*, is attached directly to the knife-edge of the moving coil, and moves with it, and hence with the coil. At the upper end of the arm a pen, *p*, is fastened, which rests upon a chart marked with radial lines, which indicate time, and circles, which indicate watts. The chart is uniformly driven by a clock, *c*. When current passes through its coils, the fixed one, *b*, attracts the movable one, *a*, thus causing the pen, *p*, to move away from the centre of the chart, and the movement of the chart causes the pen to draw a continuous line, which indicates at any time the watts of the circuit.

Integrating Wattmeter. A form of meter which is commonly used to measure the electricity furnished by electric companies to consumers is shown in Fig. 106. It is sometimes called an "Integrating Wattmeter" but really it is a watt-hour meter, because it registers the time as well as the watts. It is arranged so that it will run while the current is passing, and will stop when the current stops. It is made in the form of a small motor, which drives a delicate train of gears. On the gears are fastened pointers, which indicate on a set of dials the number of watt-hours supplied. The armature, *a*, which is made of fine wire, is connected in series with the high resistance across the mains, the combination forming the voltmeter circuit of the instrument, and the current in this part of the meter circuit is directly proportional to the voltage at the terminals of the instrument. The field magnets, *f*, *f*, are two coils of large conductors, and one is placed on either side of the armature. They are connected in series with each other, and in series with the circuit, forming the ammeter circuit of the instrument.

As the armature and field coils contain no iron, the magnetic field due to each of them is proportional to the current in them respectively. The resultant rotary effect is proportional to the product of the electro-motive force and amperes of the circuit. A wattmeter of this description does not run faster when the field current is increased as an ordinary motor would, because the load that is imposed on the armature is relatively great, and the resistance is so high that the counter electro-motive force is appreciable, so that the speed is controlled wholly by the torque between the field flux and the armature wires. An ordinary motor would run in the same way if its armature winding had a very high resistance and the field flux were weakened beyond the point where the product of the field flux and ampere turns is sufficient to give the torque required by the load. The dials, *t*, *t*, are usually graduated so that the pointers indicate kilowatt hours (1000 watt-hours).

How Wattmeters are Read. The figures, 1000, 100, 10, 1, and tenths, Fig. 107, refer to the division of the circles just below them. For example, the division of the circle at the right of the cut indicates one, two, three, etc., tenths of a kilowatt hour; a complete revolution of the pointer would indicate ten-tenths of one kilowatt hour, and at the same time the pointer on the second circle would move so as to indicate one kilowatt hour. The read-

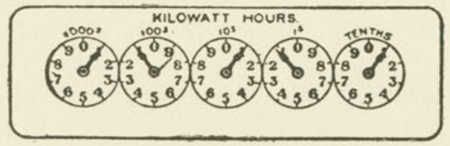


Fig. 107

ing of the instrument is 1111.1 kilowatt-hours; it is obtained by beginning at the right and reading each dial in succession toward the left. The first pointer indicates 0.1, the next 1, and the next 10, the next 100, and the last one toward the left 1000, so that the combined reading is 1111.1. Similarly, the reading of the dials shown in Fig. 108 is 9912.1.

In order to get the kilowatt hours supplied in a given time, the difference between the readings of the meter at the beginning and end of the time is taken; thus, if the reading of the instrument at the end of the month is 9912.1, and at the beginning

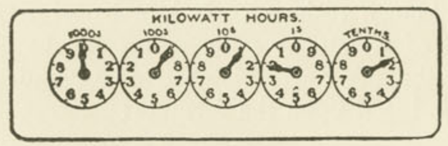


Fig. 108

1111.1, the kilowatt hours for the time are 9912.1—1111.1= 8801.0. With some of the meters of this general type, it is necessary to multiply the indicated wattage by a constant in order to get the kilowatt hours; in such cases, it is customary to mark the constant on the dial plate of the instrument.

Measurement of Resistance. There are two methods of measuring resistance of general use, one of which may be termed a laboratory method and the other a practical method. For measuring accurately the resistance of an electrical conductor the " Wheatstone bridge " method is frequently used. All laboratories where electrical measurements are made, possess this arrangement, but it is rarely to be found in engine-rooms. It consists of a combination of battery, resistance coils and galvanometer. The galvanometer, shown in Fig. 109, is constructed on the same principles as the magnetic-needle voltmeter, but usually registers degrees of a circle instead of volts.

In its simplest form, the bridge consists of two coils of known resistance, one coil whose resistance can be changed, the resistance which is to be measured, a galvanometer, and some constant source of electro-motive force. The diagram of connec-

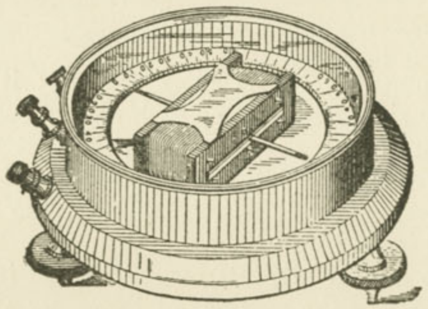


Fig. 109

tions of the "Wheatstone Bridge" is shown in Fig. 110. A and C are coils of known resistance, B is a battery, G is a galvonometer, D a set of resistance coils, which can be changed to any value, and X is the unknown resistance to be found. The principal of the bridge, is based upon the formula:

$$X : D = A : C$$

$$\text{or, } X = \frac{AD}{C}$$

When this proportion is fulfilled, the galvanometer needle indicates zero and the current in the circuit is balanced and hence the resistance.

The more usual method for finding resistances around an engine

room is by means of a voltmeter and an ammeter. This method is based upon Ohm's law, so that if current flowing through a

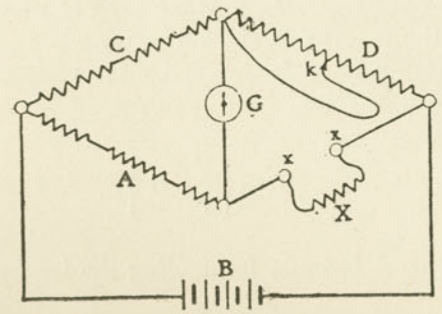


Fig. 110

resistance and the drop of potential are known, the resistance can be worked out from the formula:

$$R = \frac{E}{C}$$

in which R is the resistance, E the drop in potential and C the current. If E is in volts and C is in amperes, then R will be in Ohms. The connection for this arrangement is shown in Fig. 111. X is the unknown resistance, V the voltmeter, A the ammeter, B the battery or some source of electro-motive force, and R a variable resistance with which to regulate the current so that

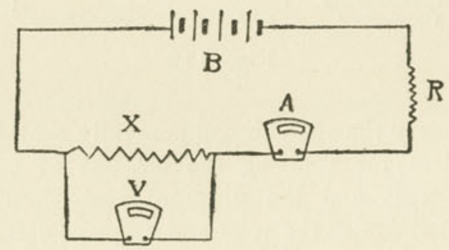


Fig. 111

proper readings on the Voltmeter and the ammeter can be obtained. Suppose, for instance, that the ammeter A reads 0.5 amperes, and the voltmeter reads 1.2 volts, then the resistance will equal 1.2÷0.5=2.4 ohms.

Insulation Resistance. When measuring the insulation resistance of a dynamo or wire, first measure the drop of potential across the circuit; then remove one voltmeter lead, and ground it, and take another reading. If V is the drop of potential across the leads and v is the reading of the voltmeter when grounded, R the insulation resistance to be found, and r the resistance of the voltmeter, then R can be found from the formula

$$R=\left\{\frac{V}{v}-1\right\}r$$

which is the general formula for finding the insulation resistance.

SWITCHBOARDS.

Switchboards are arrangements by means of which various electrical circuits are centered and different combinations of electrical connections are performed. Besides the various switches

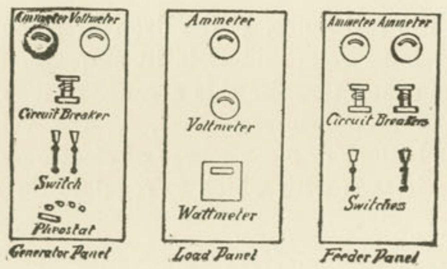


Fig. 112

which are necessary the switchboard generally contains the various protective devices for limiting the amount of current flowing through the circuit and the different instruments which give the necessary readings of the volts and amperes carried on the different circuits. In a small isolated plant, where a single generator is used, the current can be conveyed to the distributing mains in a comparatively simple manner, but if there are several generators feeding into a complicated system of distributing mains, then a systematic method of arranging the connection must be used.

The general system used is to arrange the switchboard in panels, side by side, the number depending upon the character of work it is to do. Some panels are used for connecting the generators to the board, some are for the motor control, others for

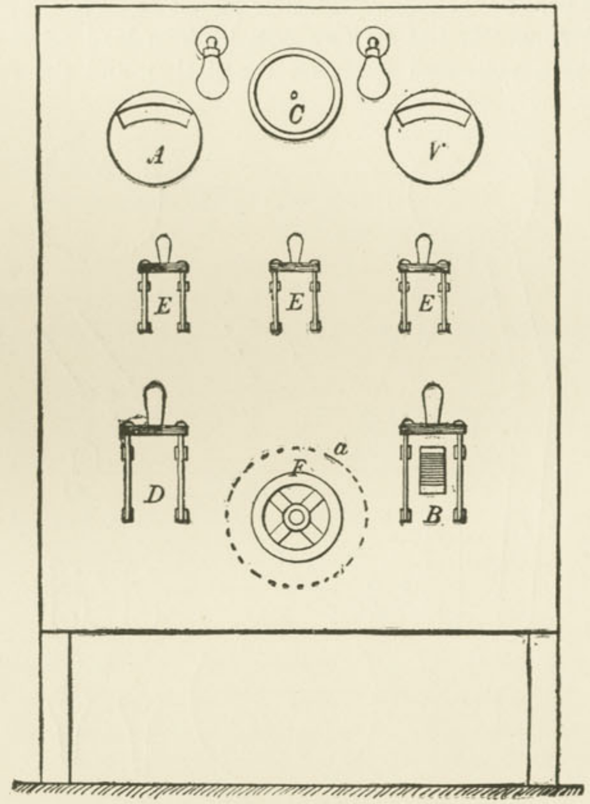


Fig. 113

operating the distributing circuits, others may be used for charging storage batteries and so on.

For continuous currents, there are two classes of switchboards in use, one for the constant current and one for the constant potential systems. In alternating current distribution the character of the switchboard will depend upon whether single-phase or polyphase current is used.

To operate a single constant potential generator all that is required is a field regulator, a circuit breaker, an ammeter, a voltmeter, a switch to open the circuit, and switches for the several branch circuits. A simple switchboard for the single generator connected with other generators is shown in Fig. 112. It is divided into three panels, the generator, load panel and feed panel. There are as many generator panels as there are generators, and each generator has its own panel. The load panel indicates the amperes, volts and watts on the station, and the feed panel

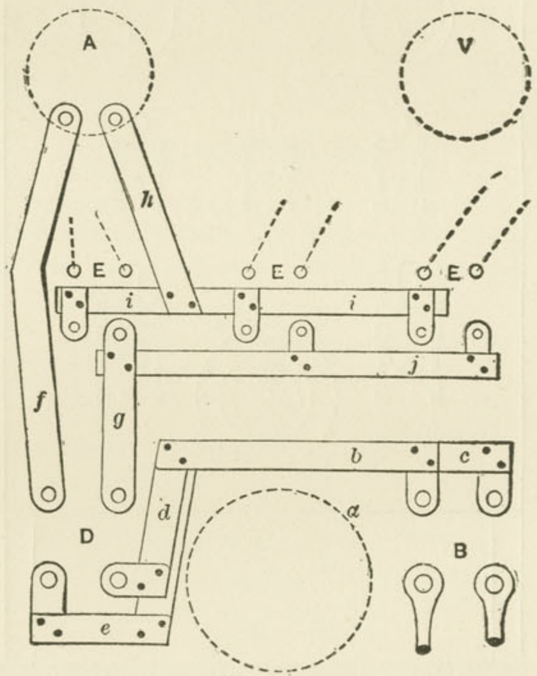


Fig. 114

indicates the amperes on each feeder. An arrangement showing all the instruments and switches on one panel is shown in Fig. 113. Here the field regulator is shown at the back of the board, and the hand wheel F on the front of the board is mounted on an extension of the switch pivot. With the regulator in this position, the engineer can watch the voltmeter at V while adjusting the voltage. At A the ammeter is located so as to balance the appearance of the voltmeter. A clock, which is a desirable thing to have

in an engine room, is placed at C, and at either side of it is located an incandescent lamp. The three distributing switchboards are located at E E E and the main generator switch is located at D, while at B is placed the circuit breaker. The back of the switchboard is shown in Fig. 114, which illustrates the connections at the back of the board with the instruments as arranged in Fig. 113. The circles A and V are the ammeter and the voltmeter, and the dotted circle *a* shows the location of the rheostat. This rheostat is connected to the field coils of the generator for regulating the voltage. The connections from the binding posts of the generator run to the lower terminals of the circuit breaker B, and the upper terminals of the latter are connected with the lower terminals of the main switch D. The bar *b* runs above bar *c* and must be separated from it by about one-half inch clear space. The bar *e* is the left end of *c*, just as *d* is the left-hand end of *b*. From the upper left terminal of the main switch D a rod is run to one of the binding posts

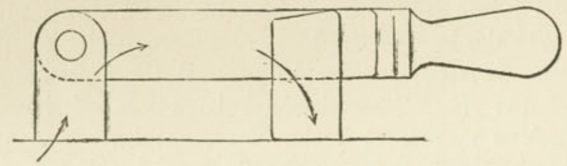


Fig. 115

of the ammeter as shown in *f*. This rod clears the ends of the bars *i* and *j*. From the other binding post of the ammeter, a bar *h* is run from the top horizontal bar *i*, and from the right-hand top terminal of the main switch D a bar *g* is run to the lower horizontal bar *j*. The bars *i* and *j* are called busses, and from these the current is taken off for the distributing circuits. It will be seen that the right-hand lower terminals of the three E switches are connected with the buss-bar *j*, and that the left-hand terminals are connected with buss *i*. The upper terminals of these switches are connected with the wires leading to the three sections of the distributing mains; hence, by opening or closing any one of these switches the current can be turned off or on to any of the sections.

No general rule can be given for the location of the various devices or for circuit connections owing to the fact that in each case the number of machines and the circuits are different, but in every case, simplicity of connections is aimed at. As a rule, the cross-section of the bus-bars is designed so as to allow a current density of from 600 to 1,000 amperes per square inch. Bus-bars of an appreciable size are made of flat bars, as they present a greater radiating surface and will not heat up to the same extent as a round wire with the given current strength. Bus-bars and other conductors on the back of the board are such that they can be securely held by means of bolts that form the connections with the various switches, circuit breakers and other apparatus.

The conductor bars of switchboards are made of pure copper, and one piece should be used whenever possible. When one bar is looped over another, the surfaces in contact should be about one square inch for each 150 or 200 amperes transmitted. The contact surfaces should be as true as they can be made without scraping and should be held together with iron bolts. The supporting frame of a switchboard consists of vertical angle-irons placed at the side of the board and intermediate angles located where the marble slabs join. These angle-iron bars run down to the floor and thus form the legs of the board.

The underwriters require in general the following rules to be adhered to: Switchboard must be made of incombustible material such as marble or slate. It must have a space of ten inches between the board and the floor, and eighteen inches between the board and the ceiling, except where both are fireproof, and it must be accessible from all sides. In general switchboards should be mounted about two feet from wall to allow access to the back, and gates should be provided to keep unauthorized persons from getting behind them. All dynamos must have each side of the circuit protected by a circuit breaker or fuse, and a knife switch and a detecting device which must be installed to detect grounds. Bus-bars of opposite polarity must have an air-space between them when held free from any surface of at least one inch where the current carried does not exceed 3,000 amperes.

The bottom of the switchboard should be of such a height that the attendant can see the lower instruments or reach the lower switches without inconvenience, and the top should be of such a height that the highest instrument can be reached from the floor. If this is not permissible, then the board should be made in two stories, with a platform from which the upper part may be manipulated. The space between the back of the board should be, however, four feet or more if possible, and every means should be

taken to prevent moisture from coming into contact with any of the exposed conductors. Switchboard panels are usually made of marble and marbleized slate, which must be free from seams and metallic veins.

Switches and Safety Devices. There are various forms of knife

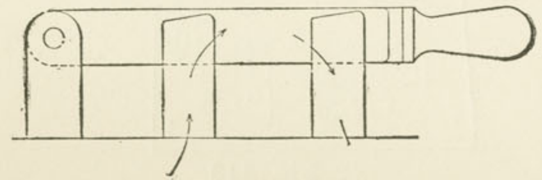


Fig. 116

switches used on switchboards, known as single-pole, double-pole and three-pole switches, and as single- and double-throw. The simplest form of knife switch is shown in Fig. 115, and is known as the single-throw, single-pole and single-break switch. Fig. 116 is a double-break, single-pole switch. The object of having a double-break switch is to divide the arc into two parts and also to prevent the hinge of the switch from carrying any current.

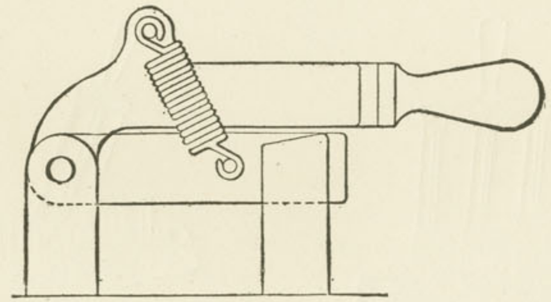


Fig. 117

When, however, the hinge must carry current, it must be equipped with a spring washer held by lock-nuts or pins so arranged that a secure connection will be maintained at all positions of the switch blade. It would not be advisable to provide more than two breaks for each pole, because it would greatly complicate the construction.

and, moreover, it would be almost impossible to make more than two separate contacts at exactly the same time.

For heavy circuits, "quick-break" switches are used. A single-pole switch of this type is shown in Fig. 117. A principal

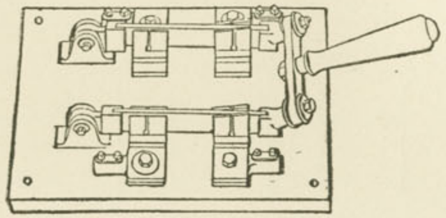


Fig. 118

or leading blade is attached directly to the handle, and a second blade is attached to the leading blade by means of a stiff coil spring. When the leading blade is withdrawn from the clips to an angle of about 30°, its heel releases the following blade which is then forcibly opened by the spring being under tension, thus making an extremely quick break. Both blades are of equal carrying capacity.

For constant potential circuits, a form of switch most commonly used is called the double-pole switch, shown in Fig. 118.

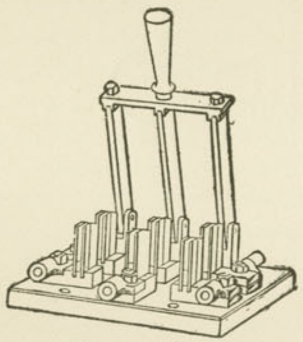


Fig. 119

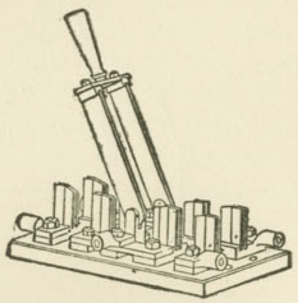


Fig. 120

As will be noticed the circuit is broken in four places at the same time when the switch is open. For three wire circuits three-pole switches as shown in Fig. 119 are used. It is similar to that shown in Fig. 118 except that it has three poles instead of two, both

switches being of the double-break type. A type of switch frequently used is known as the double-throw switch. A switch of this kind is used whenever one circuit is to be opened, and another immediately closed, or when one or more connections are to be quickly transferred from one circuit to another. A double-throw two-pole switch is shown in Fig. 120.

On switches carrying less than 500 amperes, single blades are used for each pole; on switches carrying more than that, it is customary to use multiple blades depending upon the current to

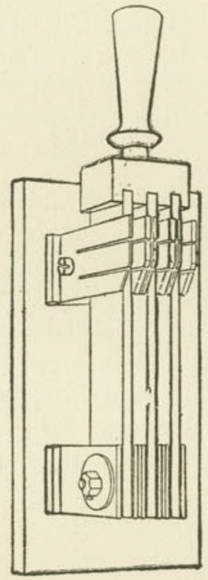


Fig. 121

be carried. The single-pole switch shown in Fig. 115 has only one blade, while that in Fig. 121 has three blades. By this means, more contact surface is obtained with the same amount of metal in the blades; for the particular case shown in Fig. 121 there is three times as much contact surface as there would be if the metal of the three blades were put into one blade of equivalent cross-section.

The handle of a switch must be always perfectly insulated from the current-carrying parts, even if the switch is only to be used for low-tension circuits. When cross-bars are less than three inches long, they should be made of insulating material. When greater than three inches in length, they may be made of metal, provided they are sufficiently separated from the jaws of the switch to prevent arcs following from the contacts to the bar when the switch is opened.

Fuses and Circuit Breakers. There are two principle forms of safety devices used to protect electric circuits from overheating, namely, the fuse and circuit breaker. The fuse in its simplest

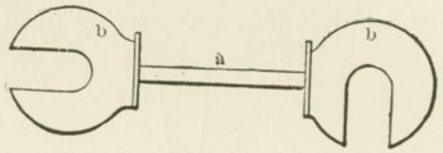


Fig. 122

form is a wire or strip of soft metal, which melts before the current reaches the point that is dangerous to the remainder of the circuit. Fig. 122 shows a fuse of this description. It consists of a wire, *a*, made of low-melting alloy fastened to two copper or brass terminal pieces or clips *b*, *b*. When subjected to a large current, after a short time the wire melts and thus opens the circuit. Fig. 123 shows a fuse, which, instead of a wire, has a flat strip of fusible metal between the terminal pieces. Its action is precisely like that of the one just described. Sometimes, a fuse is enclosed in a

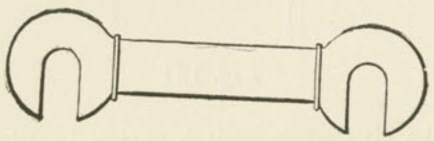


Fig. 123

casing, which, being made of non-combustible material, eliminates danger from fire when the fuse " blows." Fig. 124 shows a fuse of this description. A very small conductor on the outside of the casing, which is connected in parallel with the enclosed fuse, and which is melted at the same time as the fuse, shows when it has melted (or " blown ").

A fuse must be inserted in each wire of every circuit; that is,

for a two-wire system two fuses are used, and for a three-wire system three fuses are used. Fuses are placed at every point where a change is made in the size of the wire. The size of fuse is determined by the maximum safe carrying capacity of the part of the circuit it protects.

For protection against overloading due to excessive currents of short duration, a device known as a " circuit-breaker " is used. A well known form of circuit-breaker is shown in Fig. 125. The current passes through the solenoid coil, B, and tends by magnetic attraction to draw the movable plunger, C, upward into the coil. As the current increases, the attraction increases correspondingly, and finally when it becomes great enough to overcome the weight of the plunger, the latter is caused to strike against the push pin, E, which in turn strikes the trigger N. This releases first the switch

Fig. 124

arm, by the displacement of the retaining latch, F; next, the upper part, H, of the trigger strikes the plate, K, and starts the movement of the switch arm. The movement is continued by means of the spring, O, which acts through the plunger J, against the plate K, on the switch arm, and pushes it beyond the point at which the contact is broken and the circuit is opened. The final break is made between carbon plates, in order that the arcing may not take place between the terminals and injure them. When, however, the circuit breaker is entirely closed, contact is made between the copper plates, because the conductivity of the copper is much greater than that of the carbon, and also for the reason that better contact can be obtained with copper. The screw, M, at the lower part of the device is used to adjust the plunger so that it will operate at the desired current strength; the farther up the plunger, the less the current required to make the cicuit-breaker open. The lock-nut T serves to hold the adjusting screw in place. Double-pole circuit-breakers are also used, but their mode of operation is precisely the same as the single-pole type.

Circuit-breakers are also arranged so that in addition to operating under the influence of excessive current, they will act when the current is entirely interrupted or is reduced to a certain minimum value. The former type is used on motor circuits, so that if the current is cut off, the motor will come to rest and cannot be injured when the current is again thrown on before the starting resistance is in. Those of the latter types are used for protect-

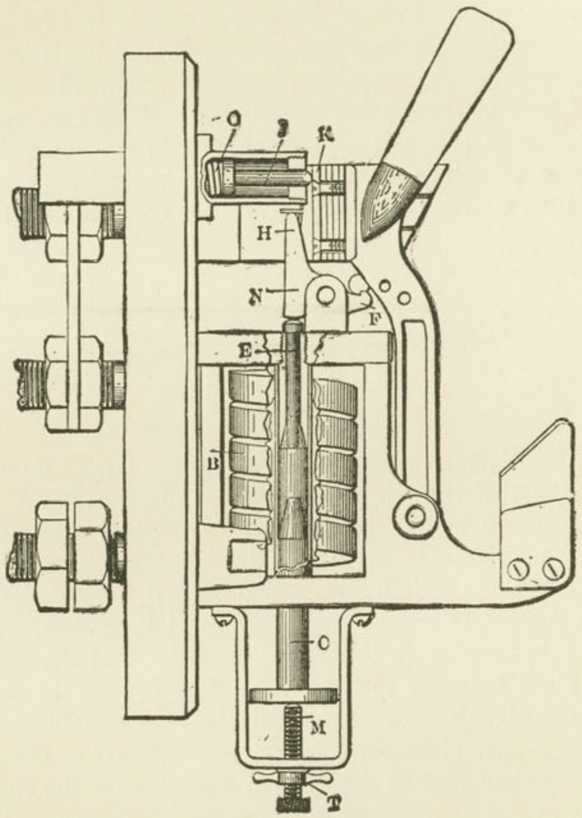
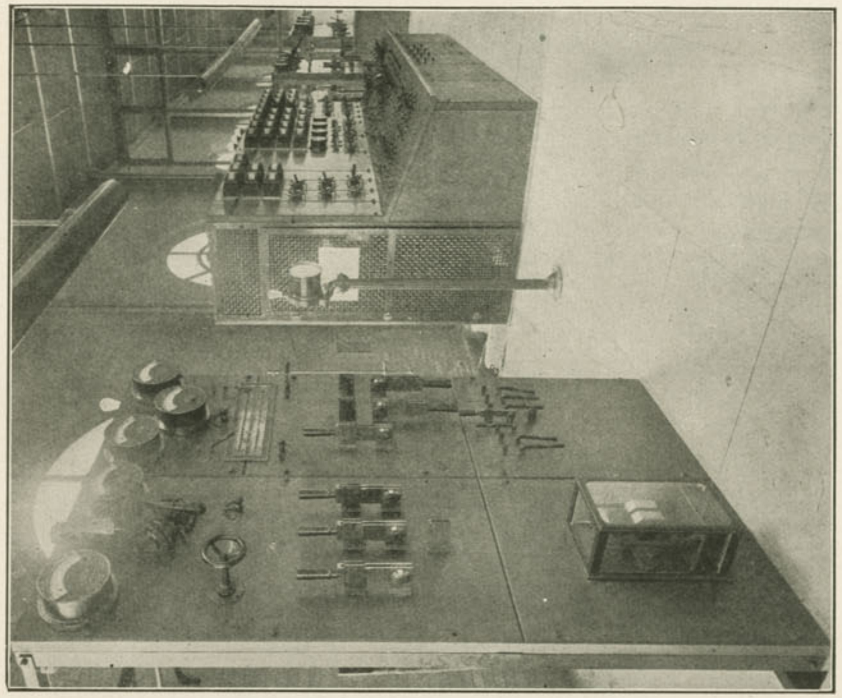


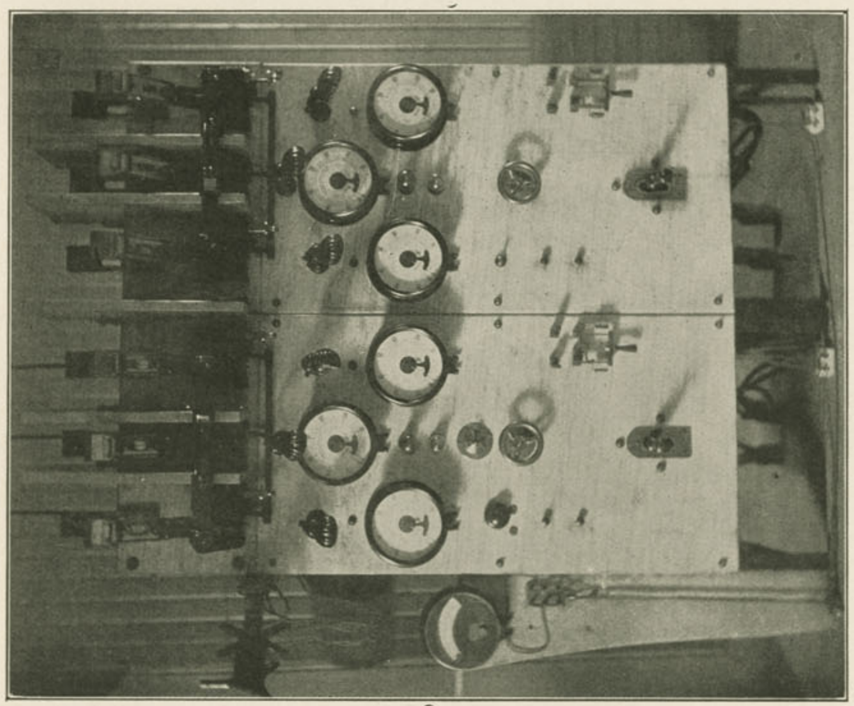
Fig. 125

ing storage batteries, and operate either on a short circuit or when the current reaches the smallest value at which it is safe to operate the battery.

Arc-Lighting Switchboards. Switchboards for arc-lighting circuits are very simple compared with constant potential boards.



REMOTE CONTROL SWITCHBOARD IN THE NEW YORK CENTRAL POWER HOUSE AT PORT NORRIS, NEW YORK



HIGH TENSION SWITCHBOARD IN SOMERSET STATION OF THE APPLE RIVER POWER CO., WISCONSIN

The difference arises from the fact that each machine is arranged so as to feed into a single circuit, and also because circuit-breakers are not required.

Alternating Current Switchboards. The construction of alternating current switchboards is substantially the same as that of continuous current boards, except that more instruments must be used, and insulation must be of increased strength. Where currents of high voltage are handled the switches are generally placed at a considerable elevation above the floor, and are separated from each other by means of marble or concrete slabs so as to prevent arcing from one to another. The construction of the switches is also considerably modified, and for strong currents they are frequently made so as to operate by electro-magnets or compressed air. Switches are also made so as to be immersed in oil for the purpose of reducing the sparks, when the contacts are separated.

When alternating current generators are run connected in parallel, it is necessary to provide apparatus to make it known when the machines are running in proper relation to each other to be connected. With continuous current generators all that must be done in connecting them in parallel is to look after the voltages of the machines, which must be the same; but with alternating current generators, it must be seen that they are running at velocities that will make the frequencies the same, and, further, that the currents are in phase with each other; in other words, the machines must be synchronized as to frequency, and the currents must be brought into phase before they can be connected in parallel.

High Tension Switches. In power transmission plants, where the energy of waterfalls is transmitted to a long distance by means of polyphase currents, very high electro-motive forces are used, ranging all the way from 10,000 to 40,000 volts, and the switchboards made for such installations have to be arranged so as to safely stand such pressure. The switches and circuit-breakers used are of special construction so as to produce a long break when they are open. In addition, these devices are separated from each other by barriers made of suitable insulating material, so that the arcs produced on opening the circuit may not jump across from one to another.

THE ELECTRIC STORAGE BATTERY.

In the earlier days of engineering, when storage batteries were first used, nothing gave the attending engineer such trouble as did the storage battery room, and many were the hard things said about these nasty smelling liquid electricity storehouses. There is not a piece of apparatus used in engineering that can be said to be ideal, and whenever a list of advantages of a machine or piece of apparatus is mentioned, there can always be presented a list of disadvantages, especially in a comparative degree. Take the reciprocating engine; many as are its advantages, numerous disadvantages can easily be thought of; the same is true of the steam turbine, the water-tube boiler, the fire-tube boiler, and so on all along the line.

Use of Storage Battery. There are two cases in which the use of the storage battery has come to be of the highest benefit in spite of its numerous disadvantages. The first is to take care of light loads, allowing the moving machinery to shut down and the boilers to be put out of commission as is often done at many plants in the summer, and the second is to take care of what is called the peak of the load. In the first case, the expense of running a power plant on light loads is excessive, so that the doing away with the necessary expense at such times will often result in great saving by using the storage battery. In the second case, in almost no electrical plant is a uniform amount of power used. In lighting work there is a variation, something like that shown in the diagram, Fig. 126, where during the hours of from four to six or eight comes a very heavy load. The storage battery can be used to great advantage in supplying the power represented by the upper part of this curve, the batteries being charged while the load on the dynamos is light, and used in parallel with the generators so as to take a part of the load between the hours when the "peak" occurs. In this way the boilers, engines and dynamos are able to work at a more uniform load, and therefore they run more economically than they otherwise would.

Troubles with Storage Cells. The principal troubles of storage cells are short circuiting, buckling, sulphating, weakened electrolyte and worn-out plates. Short circuits are usually caused by buckling of the plates, or by the dropping of portions of active materials of the plate which, in time, form between the positive and

negative plates a connection which causes loss of charge and destruction of the plates if not noticed. It can be caused by the sediment in the bottom of the jar or tank. A buckled plate is usually caused by a continued excessive overcharge, or a heavy discharge. To assist in preventing it, the plates are separated by glass or rubber distance pieces. If the plates are not badly damaged by buckling, they can be driven apart by a wedge and operated, but when they are burned together, the plates must be repaired before again

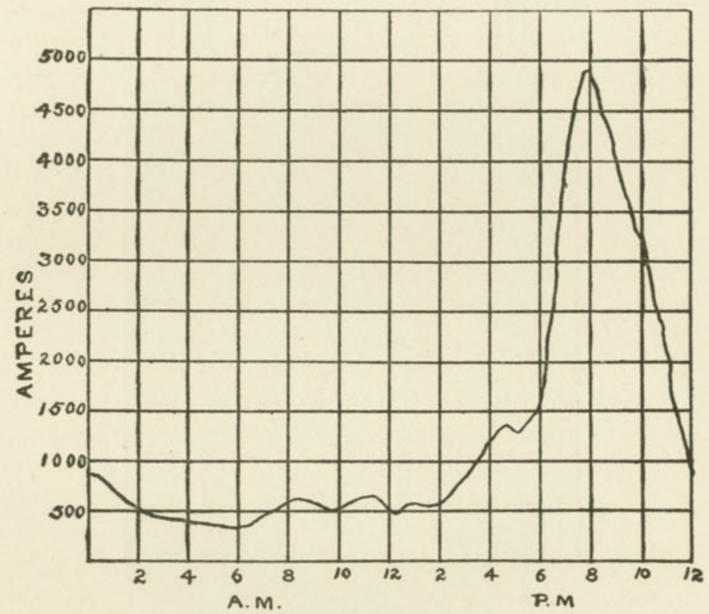


Fig. 126

General Variation of Lighting Load.

using. Sulphating is caused by carrying the discharge of the battery too far, or letting it stand too long without recharging. This is remedied by constant charging.

Short circuiting may also occur from sediment in the bottom of the cell. The depth of this sediment usually increases with the age of the cell, until the bottoms of the plate are submerged in it. This will either completely short circuit the cell, or will cause it to rapidly deteriorate, and the proper remedy is to draw off the acid and remove the sediment either by washing or scraping it out. A source of trouble and a cause of much expense is the wearing out of the plates. This always happens to every plate after being in use a certain length of time, the positive usually being the one to wear out first. This trouble can generally be found by noting the voltage of discharge or charge.

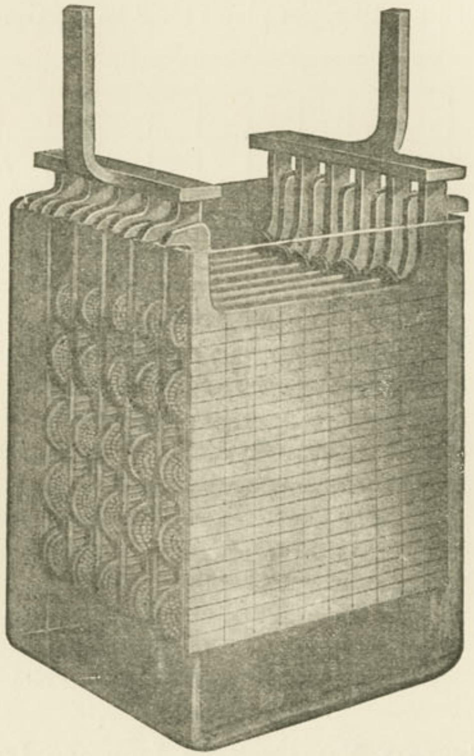


Fig. 127

The fact that many of these troubles are frequent has not interfered with the use of these batteries, as with careful attention and constant repairs many of the inherent defects are so lessened as to make them as reliable as any other piece of mechanism which requires attention, and which will also act mean and spiteful if not properly treated.

Care of Storage Cells. In the care of cells, the frequent use

of a voltmeter and hydrometer is necessary, as the greater part of the troubles found in storage cells can be attributed to the improper voltage or a wrong specific gravity. The voltmeter should be connected in succession to each cell of a battery and the readings compared to see if they are uniform, the cells giving low reading requiring attention. The hydrometer gives the density or specific gravity of the solution. The regular use of these two instruments, a careful attention to the discharge rate, regular inspection of the cells, and the making good of water lost by evaporation, so as to keep the tops of the plates always covered, constitute the most vital points connected with the use of the storage battery.

Charging. There are three ways in which a battery may be charged: at constant voltage, at constant current, or at constant wattage, the most usual method being that of charging at constant current. This is done by regulating the voltage of the charging current so that the proper current will flow through the cells, the proper charging current being one-eighth the capacity of the cell for an eight hour discharge. If a cell be rated at 2,000 ampere hours for an eight hour discharge, then the proper charging current would be 250 amperes.

Chloride Cells. Before going further, it may be well to describe, briefly, the storage battery as it is made and used in practice. The type in most general use is known as the chloride cell, manufactured by the Electric Storage Battery Co., as shown in Figs. 127 and 128. It consists of two or more lead plates suspended in sulphuric acid, and derives its name from the fact that lead chloride is used as the active material between the leaden bars that go to make up the body of the plate. These plates are then suspended in a bath of zinc chloride, together with a zinc plate, with the resulting formation of zinc chloride and pure lead, instead of the lead chloride. The zinc chloride dissolves away and leaves the active material in the form of a finely divided or spongy lead. The object of securing this spongy form of lead is to present as much surface as possible to the action of the sulphuric acid in the cell. To form positive plates they are taken and suspended in dilute sulphuric acid, and a current sent through them. The positive plates become coated with a reddish-brown substance, which is known as peroxide of lead. Hydrogen bubbles collecting on the negative plate attack any oxide that may have remained on it and leave a clean surface of lead. After the plates are charged, they are discharged, and in order that the oxidation of the positive plates should go further, they are charged and discharged again. As this peroxide is the active material of the cell, the amount of it produced determines the capacity of the cell; therefore, the plates are alternately charged and discharged, so that the layer of lead which becomes oxidized during the charge may be as deep as pos-

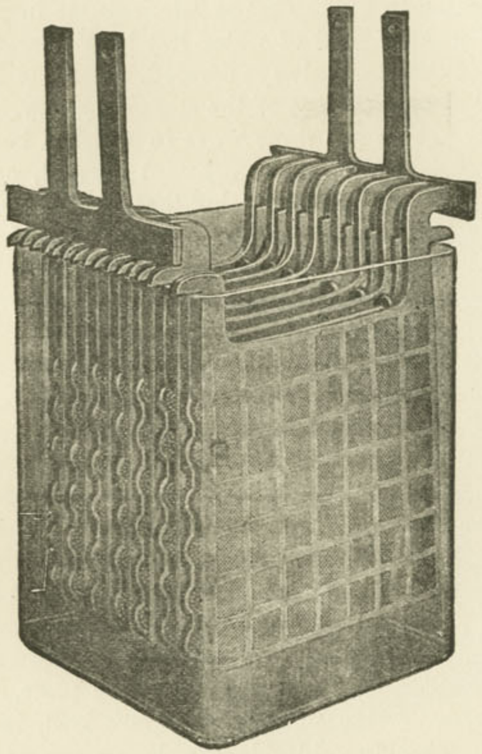


Fig. 128

sible. There is a limit to the depth of this peroxide, beyond which the chemical action will not penetrate, and when this is reached the forming process is stopped. The peroxide plate, which is reddish in color, is the plate from which the current flows during discharge and is called the positive plate. The grey colored plate is the one toward which current flows during discharge, and is consequently called the negative plate. In making up a storage cell, a negative plate is used on the outside, then a positive plate,

then a negative, and so on, there always being one more negative than positive plates. All the negative plates are connected together with a lead strip and similarly all the positive plates. Each of the plates is separated from the other by a space about one-eighth of an inch wide, which is filled with dilute sulphuric acid.

After the completely formed positive and negative plates are put in a jar or tank with sulphuric acid, and are electrically connected so that current flows from them, the plates are chemically changed. The red peroxide on the positive plate is changed to lead sulphate, and the pure spongy lead on the negative plate is also changed to lead sulphate. This is called sulphating of the cell, and the discharge should never be allowed to go below a certain voltage in order to prevent injury to the plates due to this cause.

When the cells are recharged by sending the current through the cell in the reverse direction, the sulphate of lead on the positive plate is again changed to peroxide of lead, and the sulphate of lead on the negative plate is changed to metallic lead, and with each charge and discharge of the cell these chemical actions take place.

When a cell is completely charged, large amounts of sulphuric acid gas are given off. The positive plate will assume a dark chocolate-brown color, and the negative plates will have a greyish or slate color. When the cells are discharged, the color of the positive plate will change to a yellowish-brown, while the negative will darken considerably.

The looks of the battery have, however, very little to do in determining when the charge or discharge of a battery should be stopped, the voltage and specific gravity being the determining factors. In general practice, a battery may be said to be fully charged when the voltage does not increase for at least fifteen minutes with a constant current flowing through it. This voltage will be the maximum, as will also be the specific gravity of the cell. The effect of charging a cell is to increase its specific gravity, and when this is the maximum the cell may be said to be fully charged. The normal charging voltage is usually 2.5 when the battery is new, and 2.4 after it has aged, when the temperature of the electrolyte is about 70 degrees.

Voltage of a Cell. The voltage of a cell will be about 2.2 when fully charged, and should never be allowed to fall below a voltage of 1.7. When a cell has reached this point, any further discharge will cause a very rapid falling off in the voltage, and when it has reached this point, not only should it no longer be used, but it should be immediately recharged. A battery that is left standing when it is discharged will deteriorate very rapidly, the above-mentioned sulphating doing the damage. The variation of the electro-motive force during the time of charge and discharge can be shown by the accompanying diagram, Fig. 129, the curve showing the rise and fall of the voltage of each cell compared with the number of hours of charge or discharge.

The specific gravity also rises and falls as the cell is charged and discharged. This variation should not in general exceed 35 points. That is, if the specific gravity of a cell be 1.21 when it is

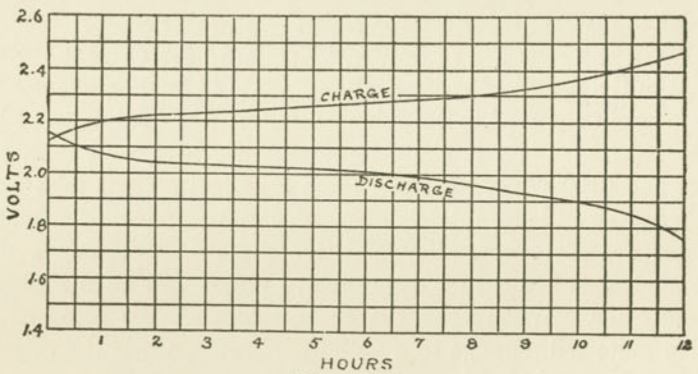


Fig. 129

VARIATION OF ELECTRO-MOTIVE FORCE DURING CHARGE AND DISCHARGE.

fully charged, it should not be less than 1.175 when it is fully discharged.

Methods of Charging. Owing to the fact that the electro-motive force of a cell increases with the charge and decreases with the discharge, it is necessary to have special arrangements by which a dynamo while supplying lights may charge a battery of cells, and by which the electro-motive force of a set of electric cells may be kept constant while they are supplying lamps. Suppose on a 110-volt circuit we have the usual number of 60 cells. When fully charged, as each cell has an electro-motive force of 2.2 volts, the total electro-motive force of the 60 cells is 132 volts. As the charging goes on and as it is desired to run 110-volt lamps and charge the cells at the same time, it is, of course, impossible to raise the voltage of the lighting dynamo, so an auxiliary dynamo or booster is employed, its armature being put in series with the cells, and its field varied by its rheostat so as to give enough additional volts for charging at the proper rate. The general arrangement for doing

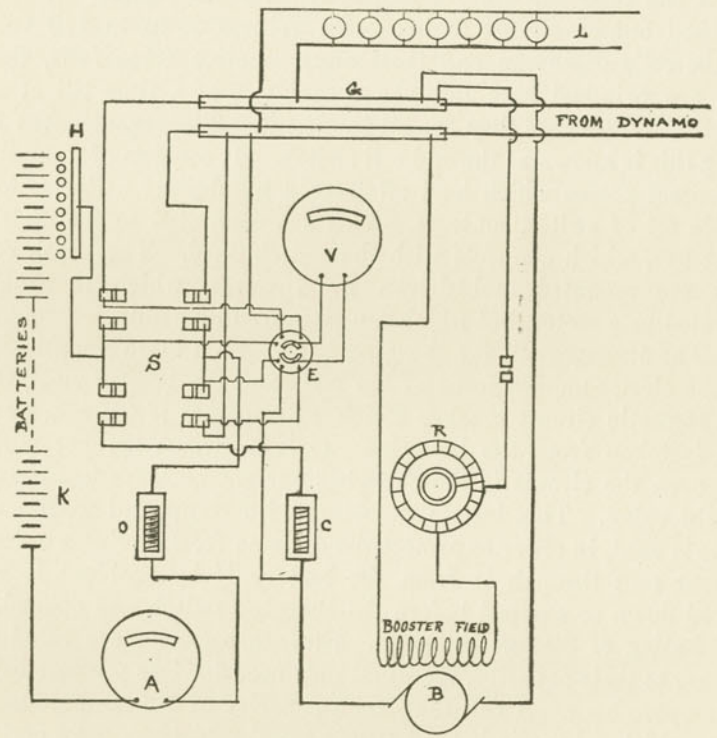


Fig. 130

ARRANGEMENT FOR CHARGING AND DISCHARGING USING BOOSTER.

this is shown in Fig. 130. B is the booster and R is the rheostat, V is a voltmeter and A an ammeter, so arranged that its needle stands at zero when no current is passing through it, moving to one side when the charging current is passing through it, and to opposite side for a discharge current. K represents the main battery and H the end cell switch which throws the cells in and out. S is a double-throw switch, which, in one position, connects the batteries to the lamps to be supplied with current, and in the other position connects it to the dynamo for charging. E is a switch for connecting the voltmeter, so as to give the voltage of the battery, the line, the charging dynamo and the booster respectively. When nearly discharged, as each cell would give out 1.8 volts, the combined voltage would be 108 volts, or just what is desired. When the cells are fully charged, a sufficient number must be switched out of circuit to bring the voltage down to 110 volts. As the cells discharge and their electro-motive force falls, these cells are switched back into the circuit one at a time till at the end of the discharge they are all in circuit. The arrangement for doing this is known as the end cell switch. It consists of a number of contact pieces which lead off from a number of batteries to a double set of switch contacts, which are connected to the distributing bar, which connects with the switchboard. The brush contacts are mounted and driven by a worm, which is usually operated by a motor, but which can be moved by hand.

The arrangement for charging is somewhat more complicated. As the electro-motive force of the cells and the booster rises, O is an automatic circuit breaker which will operate if too much current is taken from the batteries. C is a circuit breaker which will open the circuit if the charging current becomes less than a certain value. This last is necessary if a compound wound dynamo is used, in order to protect the dynamo from having a reverse current sent through it from the battery if by accident it was slowed down or stopped before the charging switch was opened.

Rating of Storage Batteries. Storage batteries are rated according to their capacity, the usual unit used for this purpose being the ampere-hour. A cell that has a capacity of 500 ampere-hours is one which, when discharged at its normal rate, gives out a certain number of amperes, so that the product of the current times the number of hours gives the capacity of a cell; that is, if a cell gave out 50 amperes for 10 hours, without carrying the voltage below 1.8, the cell would be said to have a capacity of 500 ampere-hours.

When a booster is not available when charging the cells from a dynamo whose voltage cannot be raised, a method often resorted to is to split the battery in half and charge each half separately, throwing resistance into the circuit in order to cut down the voltage to the required amount. Fig. 131 shows a circuit of this kind in

which BB are the two halves of the battery, O is the overload switch, C the underload switch, R the rheostat, A the ammeter, which shows both the charge and discharge current, G is the generator, L the lamp circuit and S and J the double-pole double-throw switches. When S is shut one way and switch T is thrown to the left, the battery is charging. If S is shut the other way and switch T thrown to the right, the battery will discharge in series, the connection being so arranged that the underload switch is cut out.

As a storage battery must be charged with direct current, when

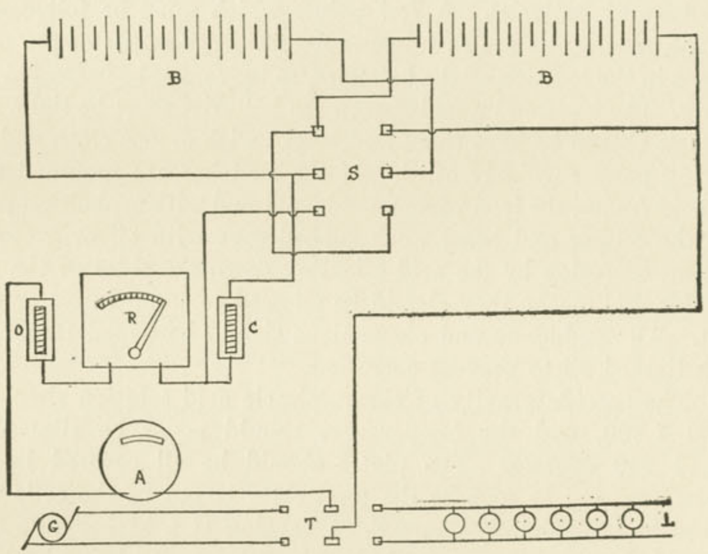


Fig. 131

SPLIT BATTERY ARRANGEMENT FOR CHARGING STORAGE CELLS.

used in connection with an alternating system, a rotary transformer must be inserted to straighten out the current. As usually installed, an induction motor is connected to a generator which charges the batteries in connection with a booster set.

Storage batteries are extensively used for train lighting in connection with a generator and booster. This system is one in which the load on the generator is kept constant by the automatic distribution of its output through the medium of the counter electromotive force booster to the electric lights and the batteries, according to requirements. If the number of lights burning requires the total energy of the generator, the batteries will receive no charge. If the number of lights is equal to only one-half the capacity of the generator, the other half of the capacity will go into the batteries, the voltage of the generator remaining constant. The booster set automatically furnishes what additional voltage is necessary to charge the batteries. The batteries supply the lights when the train is at rest. There are many other modifications of the booster system in connection with the storage battery, such as with a 500-volt system, a three-wire system, etc.

Care of Batteries. A few points which must be followed to get the best results are as follows: Accessibility is one of the main objects in the location of the batteries, as they must be inspected regularly. The bolts and nuts between the batteries must be tight. All contacts should be kept clean and bright with crocus cloth and the moving parts regularly oiled. If the switches are mounted near the acid fumes, the iron parts must be painted with asphaltum paint and the copper and brass work rubbed over with oil or grease to prevent corrosion by the acid trickling down the sides of the cell, and for this reason they should be allowed to stand in oil or sawdust. All conductors and connections should be wiped frequently with linseed oil to prevent corrosion.

The specific gravity of the sulphuric acid solution should be about 1,200, and the temperature should never be allowed to exceed 100 degrees. The plates should be all covered by the electrolyte, and as soon as the electrolyte is put in the cells they should be immediately charged. Charging at a higher rate than allowable is worse than over-discharging, the results being buckling or blistering of the elements, owing to the rapid formation of gas and its slow liberation. The effect of over-discharging is to cause sulphating, which increases the internal resistance of the cell and is difficult to get rid of. Frequent small charges and discharges keep the cell in better condition than when left standing for a long period. In adding water or acid to a cell to change its specific gravity, do it after a charge and never during one.

METHODS OF TESTING ELECTRIC MOTORS.

When testing an electric motor for efficiency, there are two methods which may be used: one which is strictly electrical, and

one which is a combination of mechanical and electrical methods. Before touching upon these methods employed, however, it might be well to see what are the variables which affect the efficiency of a motor. To begin with, there is the self-evident friction load of the motor, which includes the friction of the bearings, the friction of the brushes and the windage loss due to the revolving armatures. Then there is the hysteresis and eddy current loss in the iron discs which make up the body of the armature; there is the loss due to the heating of the armature conductors, due to the current passing

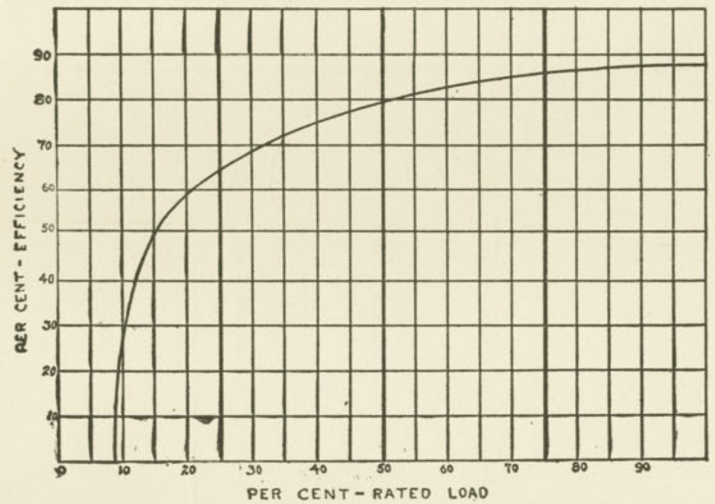


Fig. 132

through them, and finally there is the loss due to heating of the field coils.

Efficiency of a Motor. The efficiency of a motor depends directly upon these losses. The greater they are, the less is the amount of useful work given out in proportion to power absorbed and the less, therefore, the efficiency. Some of the above-mentioned losses are constant, so that it is very evident that a motor which is lightly loaded is very much less efficient than one run at or near its rated capacity. If a curve be plotted between the per cent of rated load and the efficiency of an average well-designed shunt motor, the curve of efficiency will take the form shown in Fig. 132. From the curve it will be noticed that while the efficiency of the motor is about 65 per cent at one-quarter load, it is 80 per cent at half-load, 86 per cent at three-quarters load and 88 per cent full load.

Electrical Method for Finding Efficiency. When testing a motor, there are two electrical instruments which are necessary: the voltmeter and the ammeter, and for commercial purposes these will be sufficient if the voltmeter and ammeter can be read to a fraction of a volt and ampere. If the voltmeter and ammeter have only high reading scales, then some other instruments or methods must

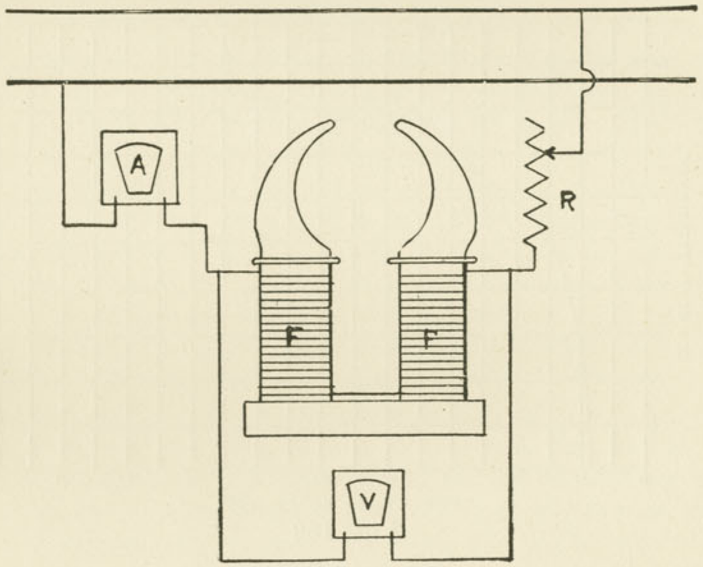


Fig. 133

be used for finding the armature and field coil resistance when testing the motor by the electrical method.

Assuming, then, that the voltmeter and ammeter can be read to a fair degree of accuracy, the first step that is necessary, when testing the motor according to the electrical method, is to find the resistance of the armature and fields. To find the resistance of the fields, the field terminals are disconnected from the armature terminals and should be connected as shown in Fig. 133. Before making this test, however, the amount of current passing through the field should be determined when the motor is running under

load by placing the ammeter in series with the field. This amount of current should be maintained when the test is being made for resistance and the readings should be taken when the field coils are warm, because the resistance of wire is greater when it is hot than when it is cold.

Referring to Fig. 133, FF are the field coils, A the ammeter, V the voltmeter, and R the adjustable resistance. If the voltmeter reads 110 volts, and the ammeter reads 1.5 amperes, then the resistance of the fields is equal to the volts divided by the amperes, or $110 \div 1.5 = 73.3$ Ohms. Since the number of amperes flowing

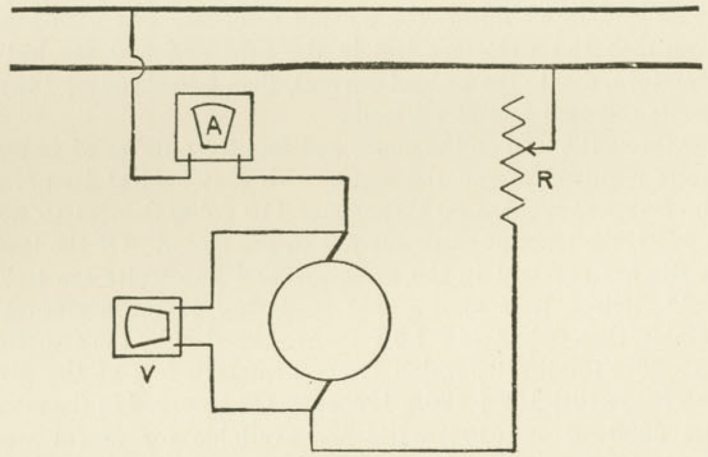


Fig. 134

through the field coils is low, the accuracy of the result is based upon how accurately the ammeter can be read.

In making the test for the resistance of the armature, care should be exercised that too great a current is not passed through the armature coils, or they will be burned out. The voltage should not exceed about 2.5 per cent of that used by the motor. When the service mains are used for furnishing the current, there should be a resistance put in series to cut down the voltage to that amount. The arrangement of connections is shown in Fig. 134. A is the ammeter, which is connected in series with the armature, R is the adjustable resistance, and V is the voltmeter connected across the brushes of the commutator. Suppose, then, the voltage is 2 volts and the current passing through the armature coils 80 amperes, then the resistance will be 2÷80=.025 Ohms. In making the test for the armature resistance, care should be taken that the brushes are set exactly on the commutator bars directly opposite each other.

Having found the resistance of the field and armature, the motor should be connected up and run with no load on it, and the amount of current and voltage which it requires found. Suppose that at 110 volts it requires 8.5 amperes to turn it at its normal speed, then 110×8.5=935 watts. This power represents the heat lost in the armature and field plus the losses which are considered as constant at all loads. These constant losses are those due to hysteresis, eddy currents, windage and friction. They are equal to the no-load input minus the no-load armature and field losses. Suppose that 165 watts are lost in the field and 560 are lost in the armature, due to the no-load current, then 935—(560+165)= 210 watts constant loss at all loads.

Now throw the load on the motor and find the number of amperes and volts required to run the motor with that load at its normal speed. Suppose it takes 60 amperes at 110 volts, then 110×60= 6600 watts, the amount of power put in the motor. Of the losses, 210 watts are constant in the armature and 165 watts are lost in the field. Since it is known that resistance of the armature is .025 Ohms, then 60×.025=1.5 volts are absorbed by the armature, or 1.5×80=120 watts, which is the armature loss at the given load. Then, 210+165+120=495 watts are absorbed in the motor, so that 6600—495=6105 watts are available for useful work. Then, 6105÷6600=92.5 per cent efficiency.

If the above steps are understood and there are two voltmeters and two ammeters available, the process can be applied by making the connections as shown in Fig. 135. Run the motor at no-load, as before, and take readings of the voltmeter and ammeter in the armature circuit. If the resistance of the armature is known, the constant losses can be obtained by subtracting the C^2R losses in the armature from the total power. Then throw on the required load and read the instruments in the armature and field circuits. The product of the readings of the voltmeter and ammeter in the armature circuit, added to the product of the readings of ammeter and voltmeter in the field circuit, gives the total power put in. The total losses are the constant losses and the losses due to heating of the armature and field coils. These latter can be obtained by multiplying the square of the current by the resistance of the coils, or if

the drop of voltage is known, it can be multiplied by the current to get the power lost. In all cases, the machine at the time of no-load test should have the same temperature as it would have under the load for which the efficiency is being calculated.

In case a compound wound motor is being tested for efficiency, the same method applies, except that the resistance of the series coils must be known, and since they are in series with the armature, the armature current squared and multiplied by the series field re-

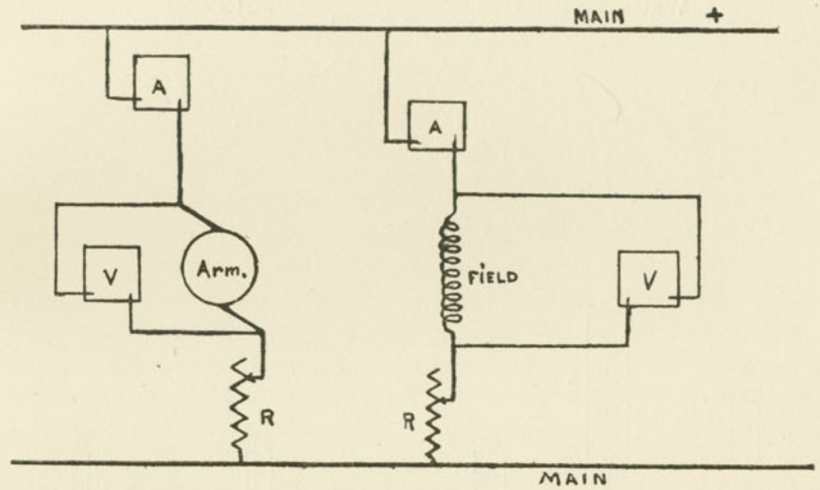


Fig. 135

sistance gives the loss in those field coils. This loss must be added to the shunt field loss to get the efficiency. Unlike the shunt field loss which is practically constant for all loads, the series field loss varies proportionally with the load.

Prony Brake Method for Finding Efficiency. The best and most satisfactory method for the practical man and one which applies to all kinds and forms of motors is the mechanical-electrical method. The electrical input is measured by a voltmeter and ammeter, and the mechanical output is measured by some form of dynamometer, usually of the kind known as the Prony brake. Then the efficiency is found by dividing the number of watts absorbed by the brake by the number of watts put in the motor. There are many kinds of brake or absorption dynamometers that may be used for this test.

A very simple one used for motors of small size is the strap brake, shown in Fig. 136. A piece of leather belting and two spring balances are all that is necessary, except a form of turn-buckle, which can be used for raising and lowering one of the balances to give the proper tension to the belt.

The formula for finding the amount of power absorbed by the dynamometer can be obtained from the following:

$$\text{Watts absorbed} = \frac{6.28\ rV(P-P')}{33{,}000} \times 746$$

in which r=radius of pulley in feet.
V=number of revolutions per minute.
P=pull on one balance.
P′=pull on other balance.
(P—P′)=difference in pounds.

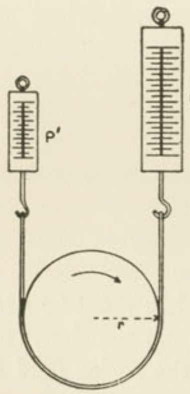


Fig. 136

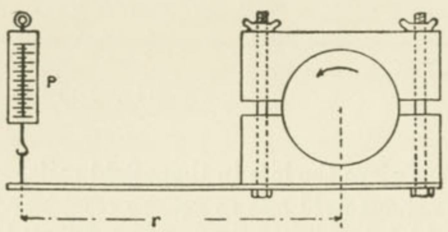


Fig. 137

The factor 33,000 is used to get the number of foot pounds absorbed into horse power, and the factor 746 is used for getting the horse power into watts.

Fig. 137 shows a form of brake which is applicable to larger machines. It may be made, as shown, with wooden blocks, or it may be made with a metal strip having spaced blocks on its under surface which rests against the wheel. In the place of the spring balance, a platform scale may be used, the lever arm of the brake in

that case being allowed to rest on a prop which in turn rests on a scale. The formula for the power absorbed is

$$\text{Watts} = \frac{6.28\ rVP}{33{,}000} \times 746$$

in which r=perpendicular distance from the center of the pulley to the line of action of the scale in feet;

V=number of revolutions per minute
and P=the scale reading in pounds.

The value of P represents the value due to the turning of the pulley, so that the weight due to the brake should first be found and subtracted from the reading when the test is being made, or the brake can be poised so as to give a zero reading on the spring at no-load.

One objection to the dynamometer method is that when large motors are tested, excessive heat is generated at the surface of the pulley. Some means are therefore necessary to carry the heat away. This is generally accomplished by flanging the inside of the brake wheel, which forms a trough into which water is kept running. Centrifugal force throws the water against the internal circumference of the wheel and the hot water is removed either by a scoop or it may be allowed to evaporate.

When testing alternating current motors for efficiency, the dynamometer method should be used. The input of the motor should be determined by a wattmeter, and the ratio of the amount of watts absorbed by the brake to the amount put in as read on the wattmeter will give the efficiency. The readings of the ammeter and voltmeter are not sufficient to find the power absorbed on alternating current circuits on account of the power factor involved; the only exception to this is on circuits which have only a non-inductive load, such as a circuit containing incandescent lamps. A circuit of this kind has a unity power factor, but a circuit like this is very rare in commercial practice. Any iron in the circuit will cause the current to lag behind the electro-motive force, and any condenser effect in the circuit will cause the current to lead the electro-motive force.

CONNECTIONS FOR STARTING MOTORS.

Motors for ordinary service are provided usually with a simple shunt field winding, but sometimes with a composite winding. When the armature is at rest, there is, of course, only the resistance of its winding and connections to oppose any flow of current through it, and this resistance is always made as low as possible in order to secure good efficiency. The rush of current through it, if connected directly to the circuit when the armature is motionless, would be many times greater than full load current; therefore when the motor is to be connected to the supply circuit, it is customary to put extra resistance in series with the armature in order that the initial rush of current may not be so excessive as to damage the winding, the general arrangement of connections being shown in Fig. 138.

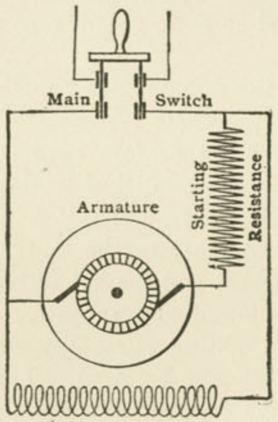


Fig. 138

The starting resistance is so chosen that the current, which will pass through the armature before it gets into motion, will not be sufficient to damage it. After the first rush of current, the armature starts to turn and immediately generates a counter electro-motive force which cuts down the current; some of the starting resistance is then cut out of the circuit, allowing the armature to increase its speed and hence its counter electro-motive force. This process is continued until all the starting resistance has been cut out, leaving the brushes connected directly to the circuit. The arrangement for cutting the resistance out of circuit is called a motor-rheostat or starting box. When shutting the motor down, the main switch must be opened first, and then the rheostat moved back to its starting position.

In all modern motor-starting rheostats, the lever is held in the running position either by a magnet or by a latch which is under magnetic control. The magnet coil is connected in series with the field winding, so that when the main switch is opened the magnet is de-energized, and, therefore, releases the starting lever. A spring is permanently attached to the lever, and serves to throw it back to the starting position automatically as soon as the magnet releases it. Fig. 140 shows the connections of such a starting box, the lever-retaining magnet being shown at m, and the lever being provided with an iron armature, a, which is brought into contact with the magnet poles when the lever is moved to the running

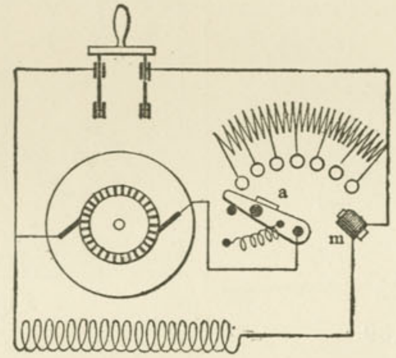


Fig. 140

position. The object in providing this arrangement is to insure that the lever will be returned to the "off" position whenever the current supply to the motor is cut off, either intentionally or accidentally, so that when it is desired to start up again there will be no liability to having the motor thrown into circuit while all of the starting resistance is cut out by the lever.

The reason the magnet is inserted in the field winding circuit is that it may cause the lever to be thrown to the "off" position in the event that the field circuit should be accidentally broken. If this should occur with an arrangement like that shown in Fig. 139, while the lever is at the right-hand end of its travel, thus cutting all the resistance out of the armature circuit, an enormous current would flow through the armature, as the field magnet would be demagnetized and thus stop the generation of the counter e. m. f. by the armature. With the arrangement shown in Fig. 140, the opening of the field circuit demagnetizes also the retaining magnet m, and the lever opens the armature circuit.

When the main switch is opened in order to shut down the motor, and the lever is thrown back by the spring, the field-winding circuit is opened, and the sudden cessation of magnetism in the magnet core induces an instantaneous e. m. f. in the winding, which is very much higher than the e. m. f. applied to it in ser-

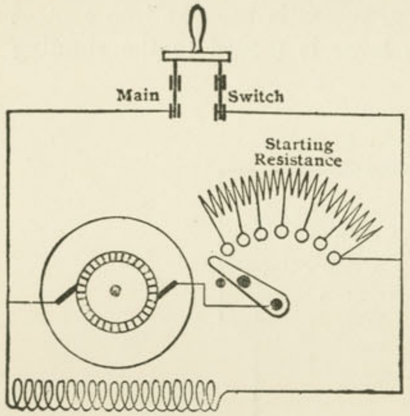


Fig. 139

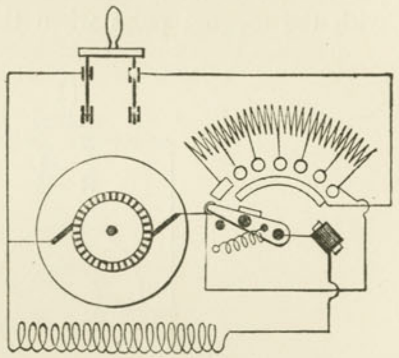


Fig. 141

vice. The self-induced e. m. f. is likely to puncture the insulation of the winding, and in order to avoid this liability the arrangement indicated in Fig. 141 has been used. This serves to connect the field winding to the armature immediately after the lever has disconnected the armature from the wire leading to the main switch, and while the armature is still turning over; this connection is shown by the diagram. The result of this connection is that the counter e. m. f. of the armature supplies a small current to the field winding, which prevents the rapid decline of magnetic excitation that induces the dangerous e. m. f. under the conditions just described.

Even if the armature has come to a standstill before the lever flies back, the fact that the field winding is not open-circuited is a

protection, because a close-circuited coil on a magnet core tends to "kill" any self-inductive effect by providing a path for the induced current, the direction of which is such that it tends to maintain the original magnetization of the magnet core. In other words, the self-induced current is allowed to "choke" out the e. m. f. that causes it to flow. The method shown by Fig. 141, however, is not so effective as the method of connection shown in Fig. 142, which is commonly used by American builders. Here the field winding is always connected to the brushes through the starting resistance, and when all the resistance has been cut out of the armature circuit, the field winding receives current from the supply circuit through

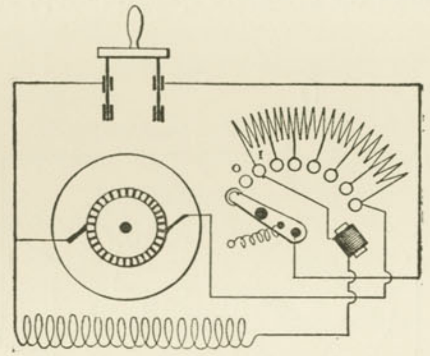


Fig. 142

the resistance. The exciting current is so small, however, that the "drop" due to its passing through the resistance is never serious.

When compound-wound motors are used for ordinary service, the function of the series field winding generally is to supply an extra strong field during the process of starting the machine up, so as to obtain an extra torque. In most cases, the arrangement of the starting box is such that the series winding is cut out of circuit after the machine has been brought up to speed. The connections of such a starting box are shown by Fig. 143, where the series winding is indicated by the coil S, and is connected between the last two buttons of the rheostat. The result of this arrangement obviously is that the series winding remains in circuit until all the starting resistance has been cut out, when the movement of the lever from the seventh to the eighth button cuts out the series winding.

With the lever in the full running position, the shunt winding receives its current, as in the case of Fig. 142, through the starting resistance. The exciting current also passes through the series winding, S, but passes through it backwards, so that this winding is magnetically opposed to the shunt winding. The ratio, however, between the number of turns in the shunt winding and the number in the series winding is so great that the demagnetizing action of the series winding is practically negligible. If it were appreciable, the effect would be to reduce the variation in the speed of the armature by weakening the field as the load increases and strengthening it as the load decreases; as explained previously, strengthening the field causes the armature speed to drop, and weakening it

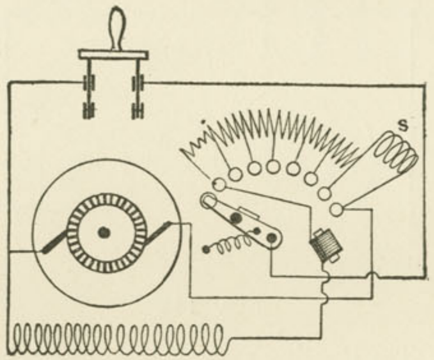


Fig. 143

has the reverse effect so long as there is sufficient field to give the torque required by the load; this action of the series winding in the case under discussion would tend to compensate for the variation in speed due to the variation in voltage drop in the armature when the load varies.

In some cases the series winding is left permanently in circuit, but this is not usually advisable, for the reason that it entails excessive irregularity in the speed of the machine. With a series winding constantly in circuit the strength of the field is greater with a heavy load than with a light load; consequently the drop in speed will be greater as the load increases than it would be if the series winding were cut out.

METHODS OF REVERSING MOTORS.

In order to reverse the direction of rotation of a motor, it is necessary to reverse either the armature or field terminals, but not both at the same time. If both the armature and field terminals are reversed at the same time, the direction of rotation will not be altered.

If a motor is in operation and it is desired to reverse it, allow the speed of the armature to fall a large per cent below normal, or to come to a stop before throwing the switch to the reverse position. If the switch is thrown to the reverse position while the motor is up to speed, its counter e. m. f. will be added to the applied e. m. f. instead of opposing the latter, as under ordinary conditions, and will send a large current through the armature which would be equivalent to a short-circuit.

In the case of a shunt-wound motor, a starting resistance must always be inserted in series with the armature, as the field coil is shunted across the line, thus leaving the armature to be connected directly to line. If the "dead" armature of the shunt-wound motor were connected directly to line, a large current would flow through the armature, owing to the low resistance of the latter, and in the failure of the fuse or circuit-breaker to open the circuit promptly a "burn-out" would result.

Reversing Alternating Current Motors. To change the direction of rotation of alternating current motors, proceed as follows: If the motor is a single-phase synchronous motor, simply drive it up to synchronism in the opposite direction, and when in synchronism connect it to the alternator. If the machine is a single-phase induction motor, having a phase splitting arrangement, reverse the terminals of one set of coils of the motor, leaving the other two connections unchanged. When the motor comes up to speed, the ohmic resistance and the inductive resistance are short-circuited so that the machine runs as a single-phase motor. For a two-phase motor, reverse the two wires of one phase, leaving the two wires of the other phase the same. If the machine is a three-phase motor, reverse the connections of two of the three line wires.

PRINCIPLES OF ALTERNATING CURRENTS.

While the alternating current generator was one of the earliest forms of generators, yet its commercial application dates back only a few years when compared with the extended use of its direct-current brother. It is very probable that had the practical utilization of alternating currents been foreseen, the use of the direct-current generator would to-day be very much restricted, but as the earliest inventors could only see the application of a current which flowed in one direction, naturally they bent their efforts to perfecting this type of machine.

It was not until the transmission of power in large quantities and over long distances came into vogue that the limitations of the direct-current machine and the direct-current method of distribution began to be felt. The transmission of power with direct currents, on account of the limitations of the commutator, necessitated a comparatively low voltage, which demanded lines as large in diameter as one's wrist, while with alternating currents almost any voltage can be transmitted over wires no larger than the finger. This advantage, together with the flexibility of the alternating current voltage, the use of the transformer and other important features, has caused it to become widely used.

In the development of the alternating current, many terms were used which even to this day are enigmas to those who have not had the opportunity of being connected with an alternating-current plant, and even to those who do use the various terms connected with the alternating-current industry, their meaning is not clear.

Unlike the current from the direct-current generator, the alternating current rapidly changes its value and direction at periodic intervals. Such a current reaches a maximum, declines to zero, attains a maximum in the opposite direction and decreases again to zero. This variation of the current or of the impressed electro-motive force in its simplest and ideal form follows the law of simple harmonic motion and may be represented by the projection of a point moving in a circle with a constant velocity, as shown in Fig. 144.

In this figure the point P on the circle is considered as moving with a constant velocity, and its projection on the diameter is the value of the pressure at any instant of time. The circle represents a complete revolution, or cycle of change, of the current or the electro-motive force, while the straight line to the right is the development of the circle expressed in degrees, 360 of which constitute one complete period. On this line the instantaneous value

of the current or electro-motive force for every position of the point P is plotted, and the curve drawn through these points, obtained for the complete revolution, gives a sine curve. In practice, however, the true sine curve is never obtained owing to the irregular magnetic field, but for most commercial purposes the variation is not so great but that the electro-motive forces may be considered as simple harmonic quantities.

In its general form, the formula for the flow of current in alternating systems is similar to that used for determining the flow in a direct-current system. It differs from Ohm's law only in the introduction of certain factors which, however, are sometimes so complicated as to disguise the equation between the current, electro-motive force and the resistance. The value of these factors depends upon the properties of a conductor when under the

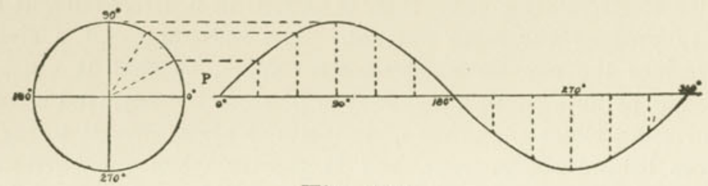


Fig. 144

influence of an alternating current. They are the inductive, capacity and virtual resistance.

When a current flows through a wire, the wire is surrounded with a magnetic field, which, in the case of a direct current of constant potential, has no effect upon the circuit. Since this counter electro-motive force is greatest when the current in the circuit is passing through zero, it is a maximum 90 degrees later than the flux and the current producing the flux.

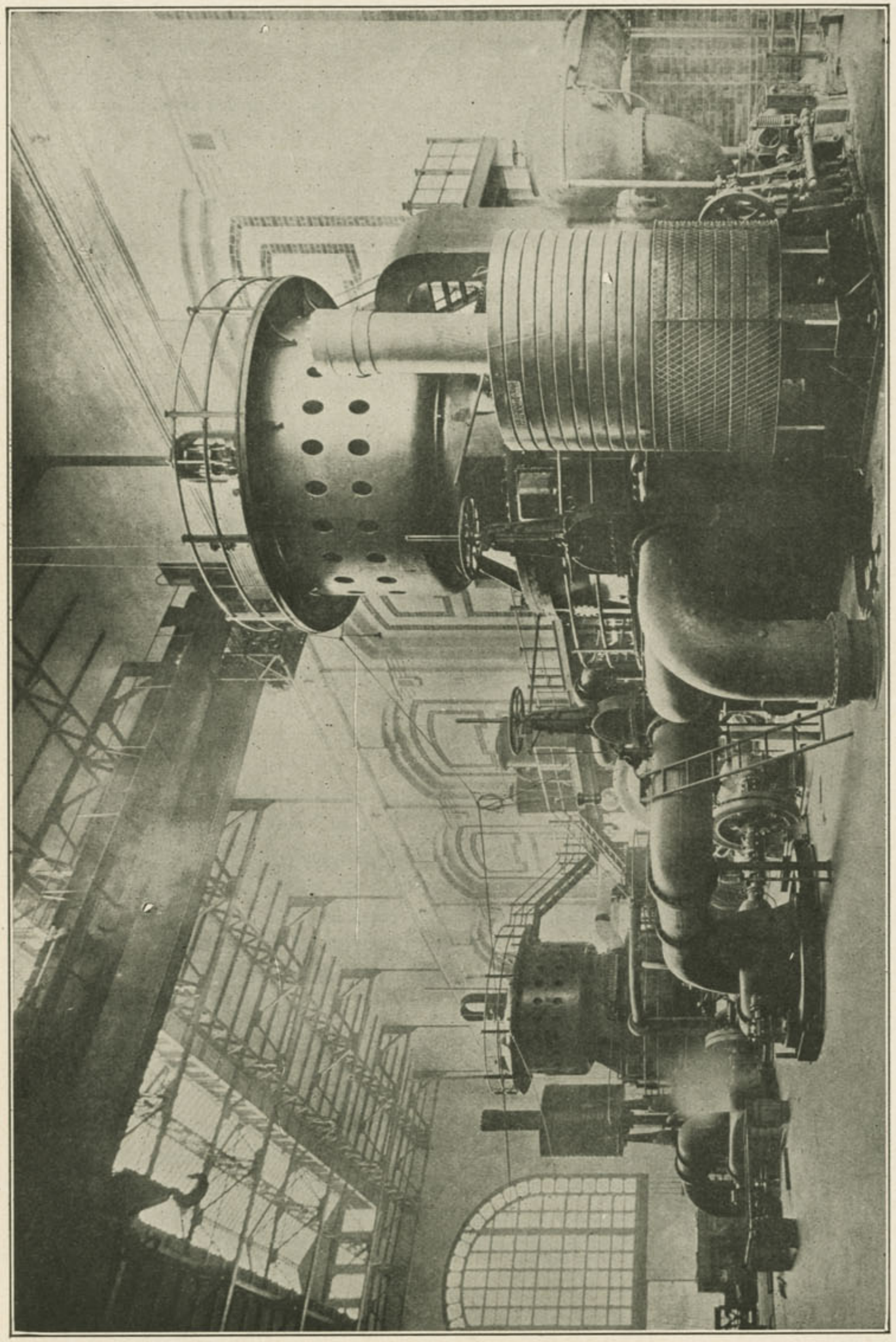
The effect of this counter electro-motive force is such that, when an external electro-motive force is applied the current does not attain its maximum immediately, and when the impressed electro-motive force is withdrawn the current still flows in the circuit. The effect then of self-induction is to cause the current to always lag behind the electro-motive force in much the same manner as the inertia of a flywheel keeps it moving when the driving power is withdrawn. The strength of the induction is determined by the current and also upon the kind of circuit. One circuit can also be acted upon by an adjacent circuit, causing in the first circuit an electro-motive force of self-induction to be set up. This is called mutual inductance. Inductance can, therefore, be defined as that quality of a circuit which determines its inductive effect. The unit of measurement is called the *henry.*

Capacity. The capacity of a circuit depends upon the quality which it possesses of being able to hold a quantity of electricity. An arrangement of conductors so placed as to have a large capacity is called a condenser. Insulated lines act more or less like condensers. The effect of capacity is opposite to the effect of inductance. It gives a leading current, so that in a circuit where there is capacity the current may lead the impressed electro-motive force in phase. The unit of measurement of capacity is called a *farad.*

Inductance. To drive a certain amount of current through an alternating system of conductors having inductance requires a greater electro-motive force than is needed in a direct-current system to produce the same current. The inductance of a circuit determines the counter electro-motive force, so that it must be overcome by an amount equal to it to produce the required amount of current. Since the effect of inductance always tends to lag 90 degrees behind the current, and is greater when the current is reversing its direction of rotation, the relation of the resultant electro-motive force, impressed electro-motive force and the inductance electro-motive force can be shown by a right angle triangle, shown by Fig. 145.

The horizontal line represents the amount of electro-motive force necessary to drive a current through a circuit without inductance, but if there is an amount of inductance in the circuit represented by the vertical leg of the triangle, the length of the hypothenuse will represent the amount of impressed electro-motive force necessary to produce that same current in the circuit.

The impedence in an alternating-current circuit is the total opposition to the flow of current. It determines the maximum current that can flow with a given impressed electro-motive force. It is made up of two factors: the resistance and reactance. Reactance is the effect of self-induction expressed in ohms. The relations of resistance, reactance and impedence are shown in Fig. 146, the length of the two legs of the triangle being laid off to their respective values, from which the hypothenuse gives the total value of impedence.



A MODERN TURBO-ALTERNATOR PLANT

5000 K. W. Turbines directly coupled to three-phase alternators supplying current at a pressure of 6600 volts at a frequency of 60 cycles per second
Plant of the Edison Electric Co., Boston, Mass.

When capacity is in a circuit the current may lead in phase, and since the reactance due to capacity acts in the opposite direction, it is laid down on the diagram in the opposite direction, as shown in Fig. 147, and the impedence in the figure is the resultant of the resistance and the capacity reactance.

When capacity and inductance are both present, the reactance is the difference between the numerical values of the capacity reactance and the inductive reactance. The resultant impedence is then readily found.

Power Factor. The power factor of a circuit is also a term which is very much used in alternating-current practice. It is especially useful in determining the true energy in a circuit when the apparent energy is known, and is the ratio of the true watts in the circuit, as measured by a wattmeter, to the apparent watts, which are obtained by multiplying the volts and amperes together

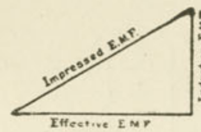


Fig. 145

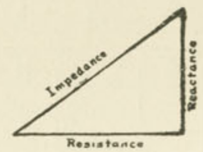


Fig. 146

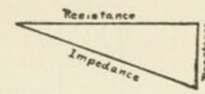


Fig. 147

in the circuit. The best conditions of a circuit are reached when the ratio comes as near to 100 per cent as it is possible to get it. If a circuit has a low power factor, it is possible to tax the full capacity of the generators and of the conductors and still transmit very little useful energy.

ALTERNATORS.

As in the case with direct current machines, alternators have a field and an armature, but instead of the commutator, slip rings are used, and the current, instead of being rectified, is led out as alternating current. In practice it is quite common to have the field of an alternator revolve inside the armature, the advantage being that it avoids the collection of high-tension currents through brushes, since if the armature is stationary it can be permanently connected up, and low voltage direct current can be most easily fed to the fields through rings.

Single-phase Alternators. Single-phase alternators give out only one series of pulsations as shown in Fig. 144, and the armature is connected with a continuous coil of wire, the number of cycles given out being the product of the number of revolutions per second by the number of pairs of poles. Since alternating current as used in modern engineering practice must be of high frequency, from 25 to 60 cycles per second, it is necessary that all machines be built of multipolar construction. The single-phase winding may be either of drum or ring type, or of the lap or wave type as explained in direct current armatures. The general rule for single-phase winding is that the armature and field are interchangeable. If a direct current is supplied to the field, electro-motive force will be generated in the armature, or if the armature is supplied with direct current, electro-motive force will be generated in the field.

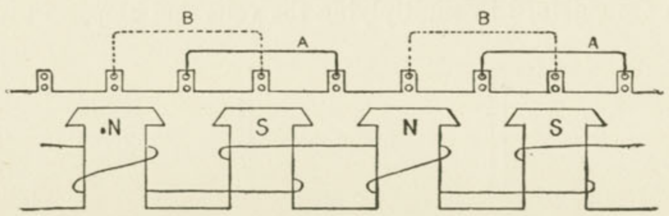


Fig. 148

Two-phase Alternators. If it is desired to send out two independent currents of equal periodicity, but differing as regards the phases of electro-motive force producing them, two single-phase machines, mechanically coupled, could be used. An easier method, and the one most generally used, is to have a second independent winding on the armature, by means of which a single machine produces a two-phase current. Fig. 148 shows this principle. The conductors AA are parts of a continuous conductor that go all around the armature in every second grove. The windings BB do the same. The ends of each winding go to their own pair of collecting rings, of which there are four.

Three-phase Alternators. What has been said of the two-phase machine is true of the three-phase, except that there are three independent windings. These windings may be variously connected. They may be treated as if they were windings of three separate

machines, in which case two conductors would be required for each of the three outer circuits which they would supply. Almost always other systems are used which enable the distribution to be effected with three or four wires. A star or Y-connection, as it is called, requires four wires to distribute the power from a three-phase alternator, three active and one neutral wire. The latter passes current when the balance is disturbed, exactly like the neutral wire in the three-wire system. The connections are made in the machine and on the outer circuit.

The three windings for a three-phase alternator can be taken as beginning at three adjacent points on the armature. For the Y-system, three of these ends, symmetrically distributed with reference to each other, are connected together, and one lead is taken from them to the distributing circuit when it is the neutral lead. From each of the other ends of the three windings a lead is taken, thus giving a total of four leads. In the utilization of the four mains, each lamp or other appliance is connected from one of the active wires to the neutral wire. The balance is kept as true as possible by taking the same amount of power from each active lead.

Regulation for Constant Potential. Alternators feeding light circuits must be closely regulated to give satisfactory service. The pressure can be maintained constant by a series booster transformer, but it is generally considered better to regulate the dynamo by altering the field strength. The simplest method is to have a hand-operated rheostat in the field circuit of the alternator, when the latter is to be excited from a common source of direct current, or in the field circuit of the exciter if the alternator is provided with one. The latter method of regulation is generally employed in large machines because the exciter field current is small, while the alternator field current may be of considerable magnitude.

A second method of regulation is that employed by the Westinghouse Company on their revolving armature alternators. A composite winding is employed and the compensating coils are excited by current from a series transformer placed on the spokes of the armature spider. The primary of this transformer consists of but a few turns, and the whole armature current is conducted through it before reaching the collector rings. The secondary of this transformer is suitably connected to a simple commutator on the extreme end of the shaft. Upon this rests the brushes which are attached to the ends of the compensatory coil. This commutator is subjected to only moderate currents and low voltages. The current in the secondary of the transformer, and hence that in the compensatory coil, is proportional to the main armature current. The machine is wound for the maximum desirable over-compounding, and any less compensation can be secured by slightly shifting the brushes. A differential action, therefore, ensues and the voltage is maintained at any desired value.

The third method, used by the General Electric Company, employs a composite winding, similar to compound windings of direct-current generators. This consists of one set of coils, one on each pole. They are connected in series and carry a portion of the armature current which has been rectified. The rectifier consists of a commutator, having as many segments as there are field poles. The alternate segments are connected together forming two groups. The groups are connected respectively with the two ends of a resistance forming part of the armature circuit. Brushes bearing upon the commutator connect with the terminals of the composite winding. The magneto-motive force of the composite winding is used for the regulation only, the main excitation being supplied by an ordinary separately excited field winding. The rectified current in the composite coils is a pulsating current that increases the magnetizing force in the fields as the current in the armature increases. The rate of increase is determined by the resistance of a shunt placed across the brushes. By increasing the resistance of this shunt, the amount of compounding can be increased and can be made to compensate for any percentage of potential drop in the distributing line.

Inductor Alternators. Generators in which both armature and field coils are stationary are called inductor alternators. Figs. 149 and 150 show the principle of operation of these machines. A moving member, carrying no wire, has pairs of soft iron projections, which are called inductors. These projections are magnetized by the current flowing in the annular field coil. The surrounding frame has internal projections corresponding to the inductors in numbers and size. These latter projections constitute the cores of the armature coils. When the faces of the inductors are directly opposite to the faces of the armature poles, the magnetic reluctance is a minimum, and the flux through the armature coil accordingly a maximum. When the inductors are in an intermediate position,

the flux linked with the armature coils is a minimum. As the inductors revolve, the flux changes from a maximum to a minimum.

The advantages of this type of machine are absence of moving wire, absence of collecting devices and increased facilities for

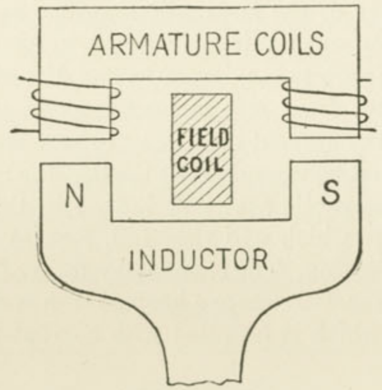


Fig. 149

insulation. The Stanley Electric Manufacturing Company manufacture inductor alternators, as do the Warren and Westinghouse Companies.

Revolving Field Alternators. In this type of alternator, the armature windings are placed on the inside of the frame and the

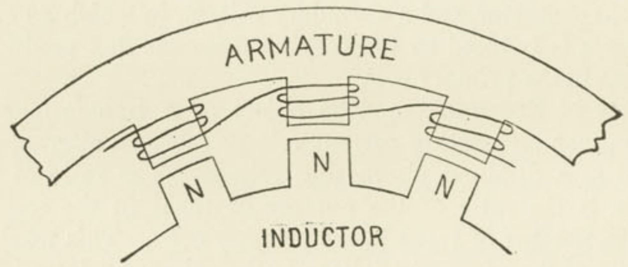


Fig. 150

field poles project radially from the rotating part. This type of construction is used in large machines in which either high voltages or high currents are required. Most all electric companies make machines of this type.

THE TRANSFORMER.

The passage of a current through a wire coil about a bar of iron or steel will magnetize the bar. If the magnetizing current be alternating, the magnetism in the bar will be alternating; that is, the polarity of the ends will alternate in accord with the alternations of the magnetizing current. As the magnetizing current rises from zero to maximum in one direction, the magnetic flux in the bar rises from zero to maximum in the corresponding direction, and as the current dies away to zero the flux dies away. Now, if a second coil be wound about the bar, the rising, falling and reversing of the magnetic flux will induce in this second coil an electro-motive force which will rise, fall, reverse and so on due to the variations of the flux. The elementary form of such an arrangement is shown in Fig. 151, where a hoop of iron is shown wound with a primary coil P which is supplied with current from an alternating current generator, and a secondary coil, S, in which an electro-motive force is induced by the varying magnetic flux produced by the current in the primary coil.

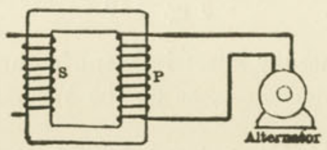


Fig. 151

Object of Transformer. The object of a transformer is to receive a given alternating current voltage from an alternator and deliver it at a different alternating voltage. The ratio of transformation is the ratio of the number of turns in the secondary coils to the number of turns in the primary coils. This would also be the ratio of the secondary voltage to the primary voltage if there were no loss in the transformer.

Step-up and Step-down Transformers. A transformer that raises the voltage of a system is called a step-up transformer; if it lowers it, it is called a step-down transformer. Step-up transformers find their chief use in generating plants, where, because of the practical limitations of alternators, the alternating current generated is not as high as is demanded by economical transmission. Step-down transformers find a wide use at or near points of consumption of energy, where the pressure is reduced to meet the service it is to perform.

Methods of Connecting Transformers. There are numerous methods of connecting transformers to distributing circuits. The simplest case is that of a single transformer in a single-phase circuit. Fig. 152 shows such an arrangement. The voltage is led to the transformer at 1000 pressure and is reduced to 100 volts, this being called a 10 to 1 step-down transformer.

In many types of modern transformers it is usual to wind the secondaries in two separate and similar coils, all four ends being brought outside the case. This allows connections for a two-wire system or for a three-wire system, this latter arrangement being more economical than using two transformers of half the size, both in first cost and cost of operation.

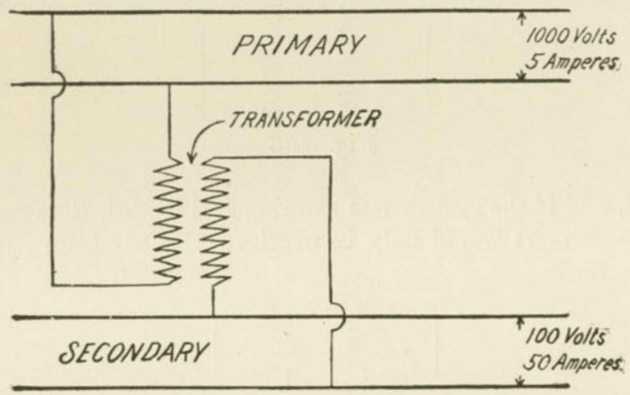


Fig. 152

A two-phase four-wire system can be considered as two independent single-phase systems, transformation being accomplished by putting single-phase transformers in the circuit, one on each phase. For three-phase circuits, it is common to use one transformer on each phase of the circuit. They may be connected either in the Y or delta fashion. They may be Y on the primary and delta on the secondary, or *vice versa*. Fig. 153 represents both primary and secondary connected delta fashion. Fig. 154 shows both primary and secondary in Y-form. With the delta arrangement, continuity of service is well maintained, because if one of the transformers is cut out, the remaining transformers will take up

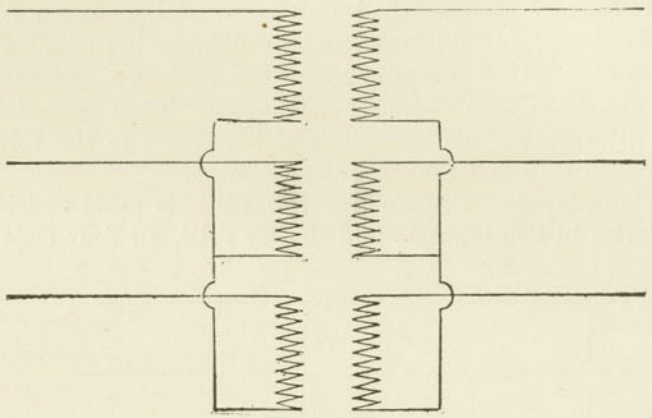


Fig. 153

the load, and if the system was running full loaded, the remaining two transformers would only be overload $16\frac{2}{3}$ per cent. Even if

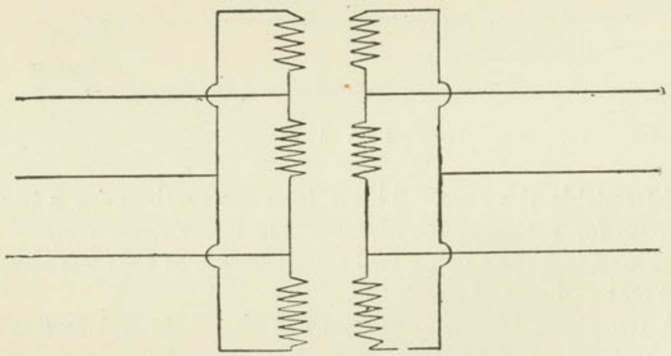
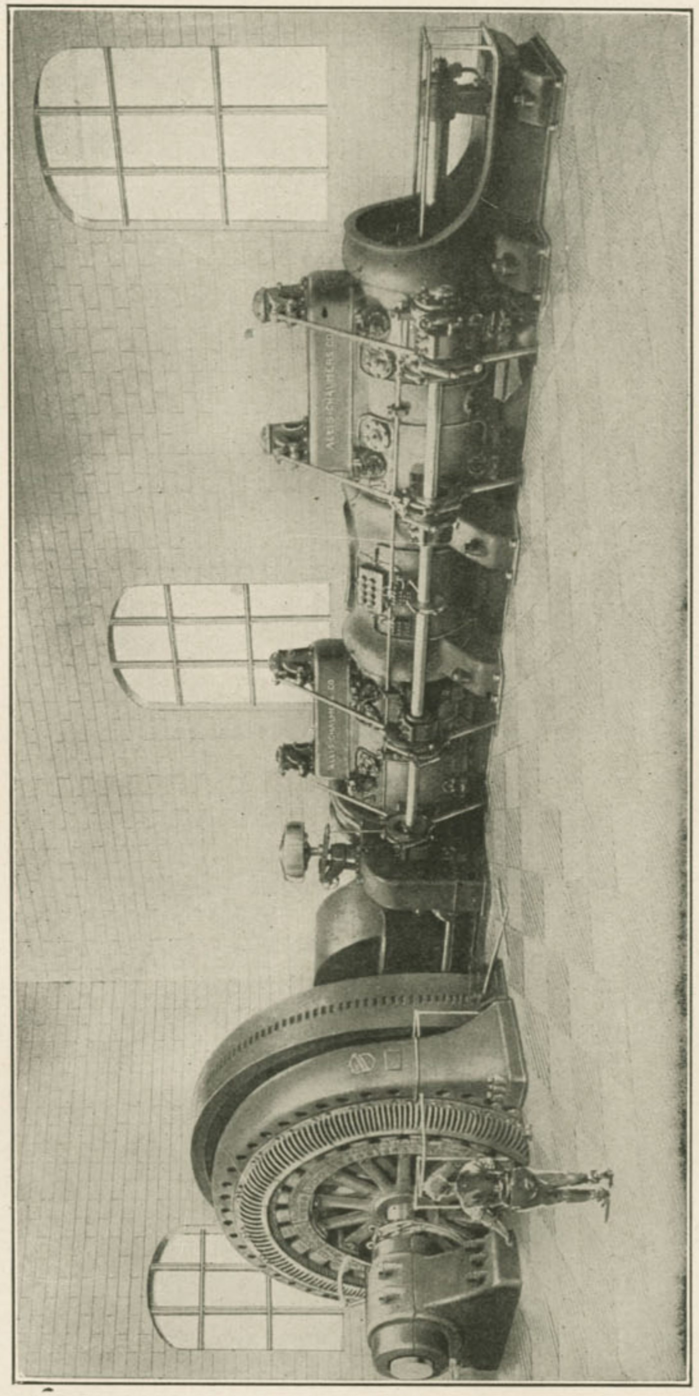


Fig. 154

two transformers were cut out, service over the remaining phase could be maintained.

With the Y-arrangement, if one transformer is cut out, one wire of the system becomes idle, and only a reduced pressure can



GAS ENGINE UNIT FOR TRACTION PURPOSES

1000 K. W. Allis-Chalmers Gas Engine directly coupled to three-phase, 25 cycle, 405 volt alternator in the plant of the Milwaukee Northern Railway, Milwaukee, Wis.

be maintained on the remaining phase. The advantage of the Y or star connection lies in the fact that each transformer need be wound for only about 58 per cent of the line voltage. In high tension transformers, this permits the transformers to be built smaller than when connected delta fashion.

Types of Transformers. There are various types of transformers in use, the difference of construction depending on the method in which they are wound. The shell or jacket types are those in which the coils are surrounded by masses of laminated iron. The core types are those in which the insulated primary and secondary coils surround the core. The coils are wound in various forms, the principal object being to get as many coils in a small space as possible, at the same time maintaining good insulation.

Cooling Transformers. Transformers become heated when in use, so that cooling of some sort must be adopted. For small transformers this is effected by the circulation of air about them and by the natural radiation of heat. Larger transformers that are air cooled and that supply their own natural draft are used to some extent in central stations and other places where they can be properly protected and attended to. A forced draft is, however, more common, when there are usually a number of them, and they are set up over a large chamber into which air is forced by a blower. Transformers are also cooled by oil which assists in the dissipation of the heat. In large sizes the oil is circulated by a pump. Cold water is often used to cool large transformers, the water being forced through coils of pipe in the transformer case.

ALTERNATING CURRENT MOTORS.

The Induction Motor. This type of motor depends for its action upon the induction produced on the armature by the field windings. The stationary part is called the stator, and the moving part is called the rotor. The rotating field exerts a torque on the armature and causes it to revolve. The inductors on the armature are usually copper bars imbedded in slots in the laminated steel core. They are connected in parallel to copper collars. They offer but a small resistance, and the currents induced in them are forced to flow in a direction parallel with the axis. The reaction against the field flux is, therefore, in a proper direction to be most efficient in producing rotation. Fig. 155 represents the field arrangement of a typical two-phase induction motor. The coils are placed in slots around the inner periphery of a laminated iron core. They are uniformly spaced and divided into two groups. When the two currents, differing in phase by one-quarter of a cycle, are impressed on the windings, the magnetism sweeps around the inner face of the core. The armature used with this type of motor is shown in

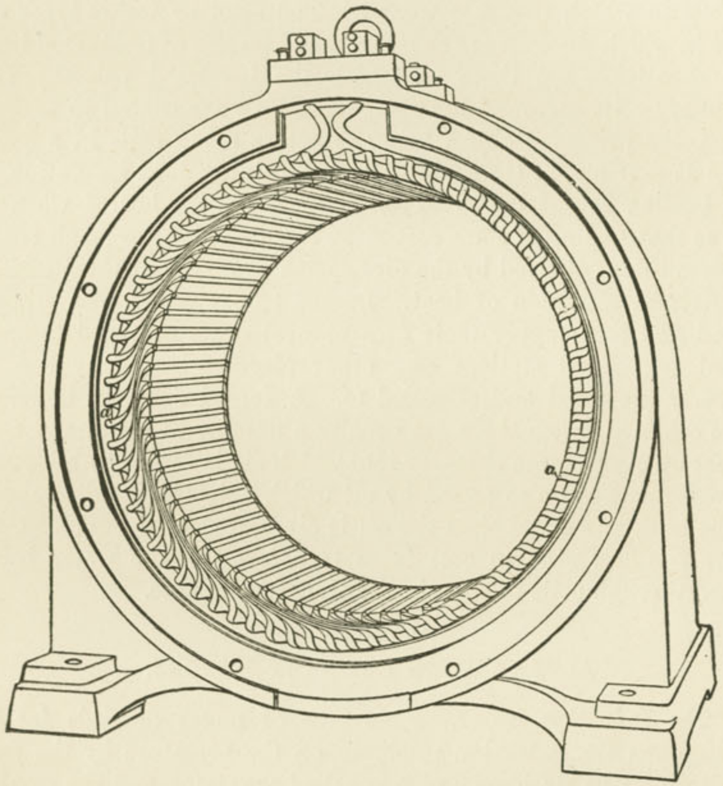


Fig. 155

Fig. 156. It can thus be seen that an induction motor requires no commutator or brushes—a feature which has had great influence in promoting its use.

The methods of starting induction motors depend upon their construction and the condition under which they are used. If an ordinary induction motor is switched on to the mains, there will be a rush of current, the same as there would if a direct-current

motor were switched onto the mains. It is necessary, therefore, to provide some means for limiting the starting current, and this is generally done by cutting down the applied pressure.

If an induction motor is loaded to excess, it will stop. If the load is not left on very long no danger results, because the motor can stand a current considerably in excess of the normal for some time without over-heating. On account of this action of the induction motor, these machines are often installed without special protec-

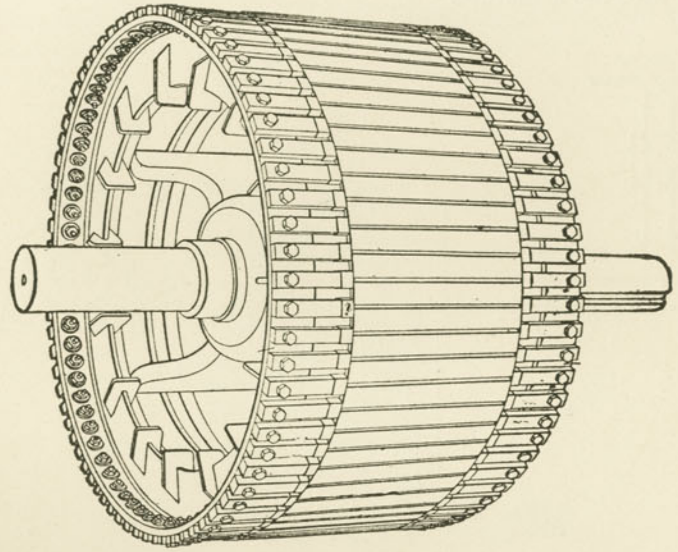


Fig. 156

tive devices, in the shape of fuses or circuit breakers, which are always needed with direct current motors. If, however, there is danger of an excessive current being left on the induction motor for a considerable time, it is advisable to place fuses in the circuit. In Fig. 157 a main switch is shown connected between the line and the compensator. This is not always used, since the compensator can be made to serve as a switch, but it is better to have a main switch in series so that the compensator can be entirely disconnected from the line if necessary.

The compensator method of starting is well adapted for ordinary factory purposes, where the motor is not usually started under full load and where full-load starting torque is not needed. In order to exert full-load torque, an induction motor with squirrel-cage armature requires a current much in excess of the full-load running current. A motor which has to be started under heavy load, and which at the same time must not take an excessive line current, should be provided with an armature arranged so that resistance can be connected in series with the windings so as to limit the secondary current while the full line pressure is applied to the primary. This method of starting is similar to that used with direct-current motors where a starting resistance is inserted in series with the armature.

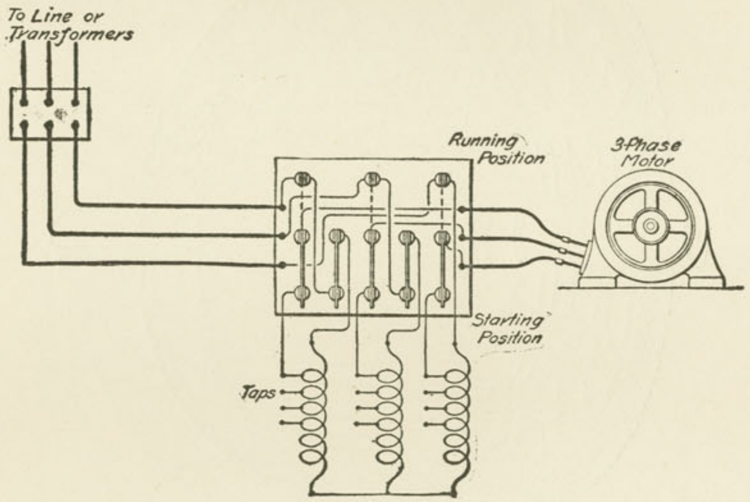


Fig. 157

Speed Regulation. The induction motor is essentially a constant speed motor, and, generally speaking, it is not as well suited to variable speed work as the direct current motor. For work where a large torque with moderate current and large range of speed is desired, as for electric hoists and cranes, the induction motor is not considered equal to the direct current motor. However, the speed of an induction motor can be varied within certain limits by inserting a resistance in series with the armature winding. The speed can also be cut down by inserting a resistance in series with the primary, but this method is not as effective as where the resistance is placed in the armature circuit. The speed-regulating resistance is inserted in exactly the same way as for the starting

resistance, only it is necessary to mount it separately from the motor and use collector rings, because a resistance used continuously for speed-regulating purposes would be too bulky to place within the armature, and, moreover, the heat developed in it would be objectionable and limit the useful output of the motor. The greater the resistance of the secondary the greater must be the slip between the field and armature, because with a high resistance a greater e. m. f. is necessary to maintain a given current than with a low resistance, therefore, the slip corresponding to a given load is increased, or, what amounts to the same thing, the speed of the armature is decreased.

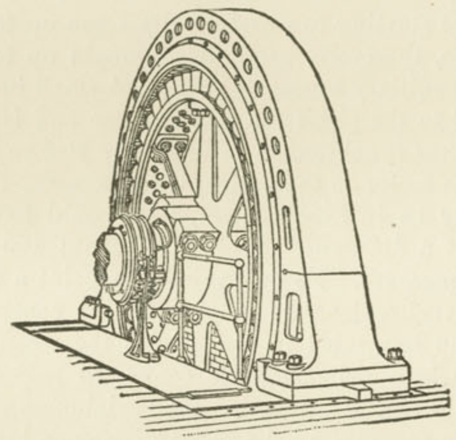


Fig. 158

The Synchronous Motor. If an ordinary alternating-current dynamo be driven at normal speed by some outside source of motion (such as a belt from a motor or a running line-shaft), with its field separately excited by direct current, and then connected to an alternating-current circuit at some instant when its impulse of e. m. f. coincides exactly with that of the circuit, the mechanical connection with the source of motion may be removed and the machine will continue running, being now driven as a motor by current from the circuit. Such a machine is a synchronous motor. This type of motor, shown in Fig. 158, is like a direct-current motor in one respect, and that is, its construction is, fundamentally, exactly like that of the dynamo that generates the sort of current on which the motor is designed to operate.

Synchronous motors run at precisely the same rate of speed as that of the alternator supplying the circuit on which they run, if the number of magnet poles is the same; hence the name "synchronous." If the poles differ, then the relation between the speeds of the motor and the generator is given by the simple equation.

$$P\,S = p\,s$$

in which P represents the number of poles on the generator; S, its speed; p, the number of poles on the motor, and s, its speed.

Starting Synchronous Motors. These motors do not have sufficient torque at starting to satisfactorily come up to speed under load. They are, therefore, preferably brought up to synchronous speed by some auxiliary source of power. A small induction motor is often geared to the shaft for this purpose and is mechanically disconnected after synchronism is reached. Before connection of the synchronous motor to the mains, it is necessary that the motor should not only be in synchronism, but should have its electromotive force at a difference of phase of about 180 degrees with the impressed pressure. To determine this point a simple device, known as a synchronizer, is employed. It consists of an incandescent lamp connected in series with the secondaries of two transformers, whose primaries are connected respectively to the line and with the motor terminals. The brightness with which the lamp glows is a measure of the phase difference between the two electro-motive forces. It is customary to connect the transformers so that when the electro-motive force is 180 degrees with line pressure, the lamp will have its greatest brilliancy. As the motor is coming up to speed, the lamp will be alternately bright and dark. The alternations will grow slower as synchronism is approached, and will finally be so slow as to permit the closing of the main switch at the proper instant. Synchronous motors may be brought up to speed without any auxiliary source of power, in which case the field circuits are left open and the armature is connected to the mains, either directly or through a starting compensation. The magnetizing effect of the armature coils sets up a flux sufficient to supply a small starting torque. When, after running a sufficient time as an induction motor, synchronism is nearly attained, the

fields may be excited and the motor will come into step. The load may then be applied. There is danger, however, of perforating the insulation of the field coils when starting in this manner.

Rotary Converters. The converter is a machine having one field and one armature with both a direct current commutator and alternating current slip rings. When brushes, which rub upon the slip rings, are connected with a source of alternating current of proper voltage, the armature will rotate synchronously. While so revolving, the direct current can be taken from brushes rubbing upon the commutator.

Rotary Converter Operation. At the present time, aside from the mercury vapor rectifier which has just come into use in small sizes for rectifying alternating current, the only practical method of transforming large quantities of alternating current into direct current, or direct current into alternating current, is by means of a rotary converter. This machine is in reality a combination of a motor and a generator, and when used to convert alternating current into direct current it acts as a synchronous motor driving a direct current generator. It can, however, just as readily be used as a direct current motor driving an alternating current dynamo.

It has its largest use in substations of an alternating current plant where alternating currents are generated at a high voltage and direct current at a low voltage is needed. The substation which contains the rotary converter is often miles away from the generating station, so that the transmission of high voltages is necesssary for the sake of economy, and the direct current is made available almost at the exact point of distribution. Many trolley roads are now making use of this system of distribution, and instead of generating 550 volts direct current and distributing it to various sections of the road over large feeders, alternating current of from 6,000 to 11,000 volts is generated and sent to the substations for conversion and distribution.

There are three possible ways of starting up a rotary converter: (1) From the alternating current side; (2) from the direct current side, and (3) by the use of an auxiliary alternating current starting motor. When started from the alternating current side, it is necessary to have a field-splitting switch in order that the shunt winding may be opened before starting, otherwise the insulation would break down owing to the excessive electro-motive force induced at the moment of closing the alternating main switch. If the rotary converter is compound wound, the series field windings must also be open circuited.

All switches on the direct current side must be left open before switching the rotary on the alternating current line. By reason of the hysteresis lag in the pole faces, and in a lesser degree due to the eddy currents set up, the rotary will start as soon as the alternating switch is closed, and will immediately run up to synchronous speed. As soon as synchronism is attained, the field-splitting switch and the direct current field switch can be closed. With self-exciting sets care must be taken to see that the field switch is closed, so that the machine is building up the right polarity. The reading of the direct current voltmeter will indicate this. The rotary, which is now running in synchronism with the main generators, can now be paralleled on the low tension bus-bars in the usual way.

This method has some serious disadvantages, principally on account of the large current at low power factor which it draws from the supply lines and the possibility of generating direct current of the wrong polarity. For traction work this method has been employed, but should not be used on lighting circuits.

To start a converter from the direct current side, first see that all switches are open, that the direct current brushes are all properly set and that the series field is cut out or short-circuited. Next, close the alternating current circuit-breaker and positive switch. Close the field switch with all the rheostat resistance cut out and try the field coils to see that they are magnetized. Now, start the converter as a direct current motor by cutting out the starting resistance slowly; when this is cut out, close the negative switch. Then adjust the speed to synchronism by means of the field rheostat and the synchronizing lamps. It is also necessary to have the alternating current voltage of the rotary converter equal to the voltage of the mains. Shifting the brushes will assist in making this adjustment.

When the voltage is correct and the lamps indicate the proper phase relations, close the alternating current switches and adjust the rheostats for minimum alternating current and set the direct current brushes at a non-sparking position. The connections of the direct current side are shown in Fig. 159.

The third method consists in starting up the converter by

means of an alternating current starting motor. In following this method, see that the alternating current and direct current brushes are all in their correct position, and see that all switches are open on both the alternating and direct current sides and that the resistance of the rheostat is all in the field circuit. Close the alternating current main circuit-breakers and see that the synchronizing lamps, or synchroscope, are in and that the lamps burn dimly, and that the direct current voltmeter is in circuit.

Start the rotary by closing the starting switch for the small motor, and build up the direct current voltage by cutting out

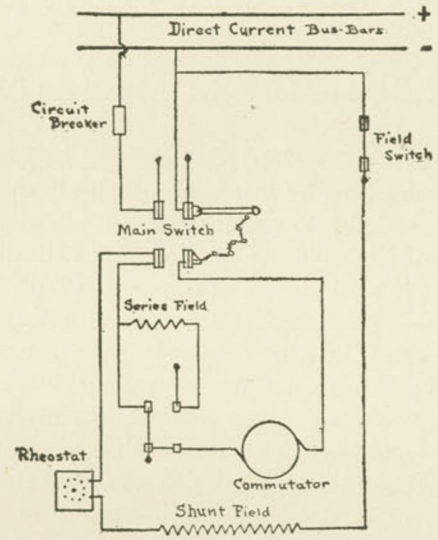


Fig. 159

resistance in the rheostat until the voltage is equal to the bus-bar voltage. Note the synchronizing lamps and adjust the speed by means of the field rheostat, until the lamps dim slowly and regularly. It may be necessary to shift the direct current brushes back to the neutral point in order to get the proper speed. When the lamps show pulsations at the rate of about every ten seconds the alternating main switch should be closed quickly when the lamps are getting dark. Now open the starting motor switch and adjust the converter field excitation so as to get minimum current in the alternating current ammeters. Next close the direct current circuit-breakers and switches and see that the brushes are in the proper position.

The starting up of synchronous motor sets presents no especial difficulty, and is often done from the direct current side, synchronizing on the alternating side as described. For lighting systems, the starting current required for large units, according to this method, might occasion a heavy drop on the distributing mains, so that it will become necessary to use either an induction motor-generator set to supply the necessary direct current, or the use of a small induction motor for starting the set will be necessary, as described in the third method above.

To shut down a rotary converter, which is operating in the usual manner, simply open the direct current circuit-breaker and the direct current switches; then open the alternating current switches; cut in all the field rheostat and pull out the synchronizing plugs.

Mercury Vapor Converter. A converter in general is a piece of apparatus or machine by means of which alternating and direct currents are converted into each other. As usually applied, alternating current of high voltage is converted into direct current of low voltage. It is used chiefly in connection with alternating current circuits, where the application of alternating current is impossible, such as for charging storage batteries, or where the direct current is more suitable than alternating current, such as for running elevators or hoisting motors or street car motors.

Since the transmission of alternating current is very much more economical than the transmission of direct current, and since only direct current is suitable for many purposes, it will often be advantageous to be able to obtain direct current from alternating. At the present time, all alternating currents are transformed into direct currents by means of a "rotary converter," which is a machine very similar to a generator, with one field and one armature, the latter being designed with a direct current commutator and alternating current slip rings. They are usually quite large and expensive and are not practically efficient.

The mercury vapor converter, as shown in Fig. 160, was designed to replace the rotary converter. As shown in the accompanying diagram, it consists of a large glass bulb or globe, L, which contains a perfect vacuum, a small puddle of mercury, E, at the bottom, constituting the negative electrode, and two electrodes of

iron, R and S, at the top. Platinum wires run from the electrodes to the outside wires. For starting the converter there is a projection G, connected by a wire resistance to one of the alternating current mains. A and B are the alternating current mains, which are connected across with an inductive resistance, such as a transformer secondary. M is a choke coil placed in series with the converter so that the current will lag behind the electro-motive force

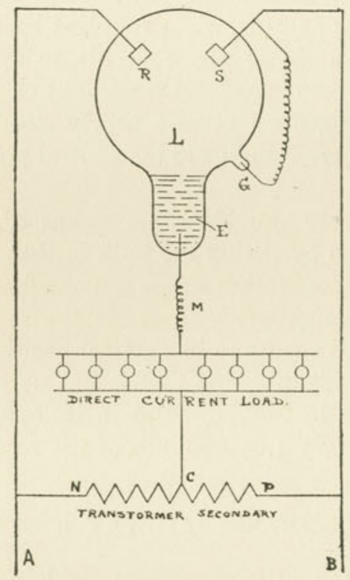


Fig. 160

and keep it in operation when the alternating current passes through zero.

The operation of the converter is as follows: Suppose at one instant the main B is going through that portion of its wave which is positive, and the bulb L is filled with highly heated mercury vapor, then current will flow through electrode, S, through the lamp and choke coil to the middle point C of the transformer, and back through line A. As the electro-motive force drops to zero, the current has not yet reached zero as it lags behind. The converter does not go out at this instant, but would a little later when the current finally did reach the zero point; but the electro-motive force between the terminals P and C, which is exactly opposite to that between N and C, is trying to force current from electrode E to electrode R, and on account of the lag of the current from R, it will pick up this current before it again becomes zero and maintain it through the rest of the alternation, until this electro-motive force again approaches zero. Again, since the current is lagging behind, the electro-motive force between N and C will pick it up from P and C before it actually becomes zero, preventing the converter from stopping, and so on. The introduction of the choke-coil M enables the apparatus, when supplied by the proper electromotive force from a single phase circuit, to operate without the use of auxiliary direct current. On account of the choking power of the coil the arrangement gives a nearly steady current by connecting the direct current mains to the neutral point of the alternating supply.

It is necessary to provide some means of starting the converter, which is done by tilting the bulb so that the mercury flows into G and makes a connection across the terminals. This forms a circuit through the mercury and starts the mercury vaporizing, when the bulb can be swung to its vertical position.

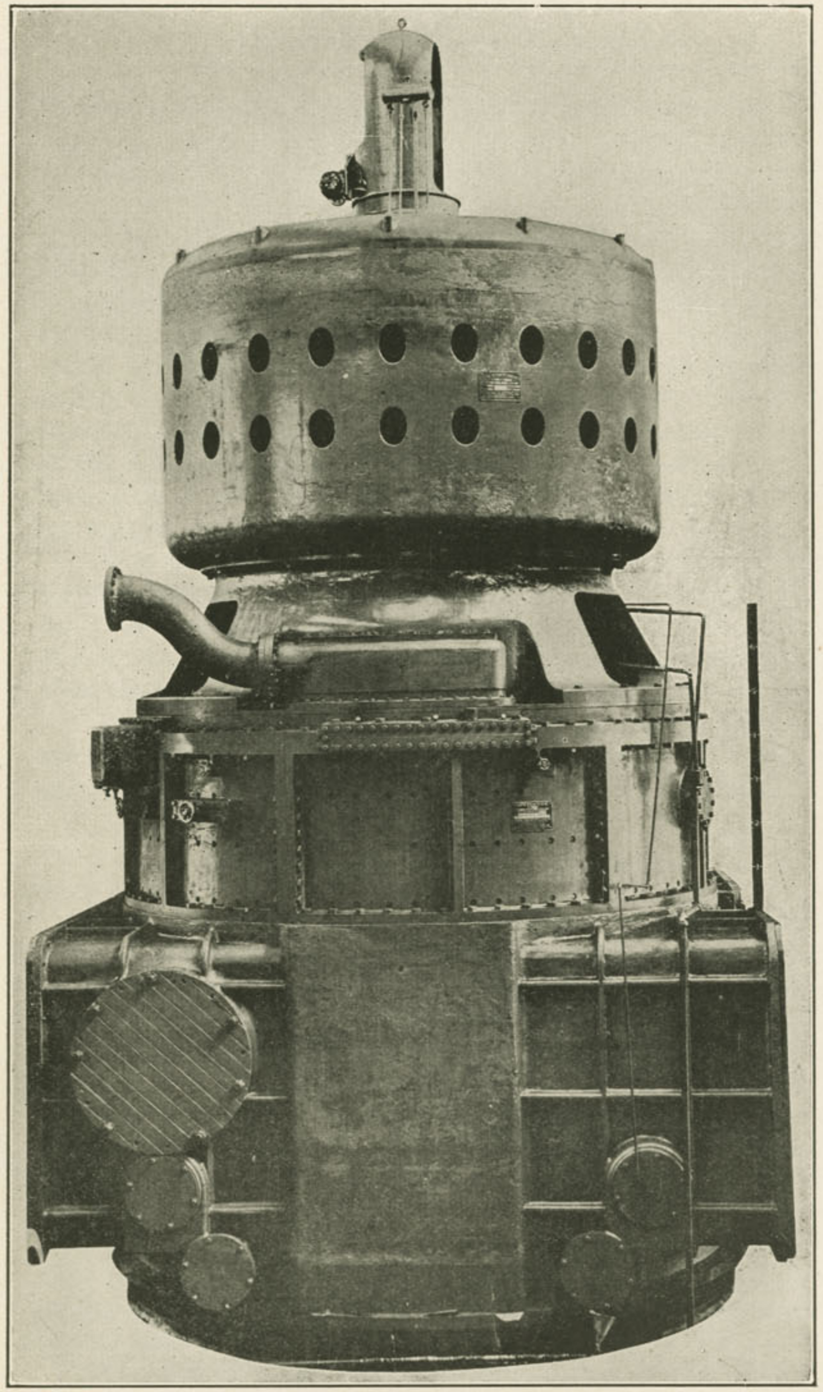
Its particular advantage is that it has no moving parts, consumes only 14 volts loss of potential in its operation and weighs only 8 pounds for every 1,000 pounds of the rotary converter.

SINGLE-PHASE RAILWAY SYSTEMS.

The single-phase railway system, which is now attracting universal attention, interests a great many stationary engineers, because, while the design of the power house may not be materially affected, yet the system of distribution is somewhat changed, and it will probably affect the kind of prime mover to be seleeted in the future.

The first electric railway, in this country, to place a single-phase system in operation was the Indianapolis and Cincinnati Traction Company, who, on January 21, 1905, opened service between Rushville and Morristown, 16 miles apart. The latest road which is installing the single-phase system is the New York, New Haven and Hartford Railroad, so that the single-phase alternating current system can now be said to have passed the experimental stage.

The use of high voltage for distribution is the attractive



A TURBO-ALTERNATOR SET

The newest type of prime-mover, which is being extensively used in all modern central stations and power houses for generating alternating current

feature of this system, as is also the fact that single-phase motors can be used on direct current circuits. The method of distribution consists of a power house generating a voltage of 30,000 or higher, and at every 10 or 12 miles the voltage is cut down by means of oil-insulated step-down transformers to a comparatively low pressure of about 3,000 volts. The high-tension current is carried from the central power station to the transformer stations on No. 4 bare copper wires, there being two wires to each transformer station. This makes a complete circuit and permits the placing of circuit breakers and switches at the central power station, so that everything along the line can be governed from the central point.

When the alternating current lines reach a city or town, they can either be replaced by low-voltage alternating current, or by 550 volt direct current, the single phase motor working equally well on either circuit. Two trolleys are used, one with a trolley wheel for low-pressure direct current, or low pressure alternating current, and the other of the bow type for high-speed, high-voltage service.

From the above it can be seen how very flexible such a system is, and since the length of trolley lines is constantly increasing, and since steam roads are now adopting it, the single-phase system should become an important factor in that class of service.

LONG DISTANCE TRANSMISSION OF ELECTRICAL POWER.

When Niagara Falls were harnessed only a few years ago, and the electric power conducted to Buffalo, twenty-three miles away, it was a question among engineers which achievement deserved the greater credit—the utilization of the waste energy of the falls, or the successful transmission of the electrical power for commercial purposes to such a distant market. In the enthusiasm of the moment, some newspapers predicted that in time the power of Niagara would reach New York City, and the electric energy generated at the falls would turn all the car wheels and factory machinery within a radius of five hundred miles; but the electrical engineers scouted any such absurd idea, for they realized the great cost and difficulties of sending an electric current over thirty or fifty miles of wire in quantities sufficient to be of commercial use.

The practical limit of electrical transmission appeared to be within sight when Buffalo was supplied with electrical energy from Niagara, and the engineers who had finally tamed a part of the stubborn waters of the great falls proceeded to build up groups of electrical industries within a few miles of their power houses to use the energy they developed. The extension of their wires to more distant markets did not concern them, and, working on this assumption, long-distance transmission of electrical energy received no further encouragement at the falls.

But there were other parts of the country which had no Niagara, but which sorely needed current in large quantities for solving perplexing industrial problems. There were water-falls and high streams and rivers whose head indicated ideal conditions for power development. But, strangely enough, nature had located most of these ideal sites for power houses so far from the great industrial centres that their usefulness seemed somewhat uncertain. If the industries had to go to the water-falls and mountain streams, electrical development from hydraulic power had a very limited field. We could not abandon our great coast cities and manufacturing towns and move inland simply to secure cheaper electrical energy. There was only one other alternative. If the mountain would not come to Mahomet, Mahomet would have to go to the mountain.

This was the problem facing the engineers in many parts of the country. On the Pacific Coast, in particular, it was a perplexing question. Coal was scarce and high-priced, and the cost of power production on a large scale was almost prohibitive. It is true that when oil was discovered in large quantities the question of generating steam power was simplified somewhat; but by this time the electrical engineers had already gone to the mountain streams for hydraulic power, which was destined to revolutionize industrial conditions on the Pacific Coast.

The mountains skirting the Pacific Coast are from 50 to 200 miles back from the ocean, and among their summits are numerous small but powerful streams of water that flow westward. Their great altitude makes them of special value for hydraulic power. Some of them rise two thousand feet above the sea level, and fall in sparkling cascades down the steep declivities. Others seek the ocean by a series of sharp declines which make their waters bubble and boil in torrents. The question of harnessing these turbulent mountain streams and conducting electrical power from them to the coast cities has been so satisfactorily solved in the past few years that in no other part of the world are there rivals. San

Francisco, Los Angeles, Spokane and other Pacific Coast cities are to-day drawing their power from the mountains over the longest-distance transmission lines in the country. Even Niagara's achievements are in a manner dwarfed by the success of these younger power companies of the Pacific Coast.

We first heard of the achievements of the 83-mile transmission line to Los Angeles. Far up in the Nevada Mountains were Santa Ana River and Mill Creek, two rather insignificant streams that flowed toward the ocean. There seemed to be no earthly value to these streams perched up among the mountains and so far from civilization and all industrial centres; but their fall of water was so great that enormous hydraulic power could be developed from them. The harnessing of these two streams was undertaken only after the engineers had made plans for conducting the power to the coast. At the foot of Mill Creek a power house was constructed so that the water flowing down the flume had a fall of nearly 2,000 feet, each cubic foot generating thereby 214 horse power per second.

To increase the efficiency of the line, two other power houses were constructed on Mill Creek, and two on the Santa Ana River, and connected in multiple to send 40,000 volts across the country to Los Angeles. When this powerful current was introduced into Los Angeles there was great rejoicing and the prediction of a great future for the city. Houses and streets were lighted by the power of the inland streams, and the wheels of factories and street railways were run by the same agency. It was the longest transmission of electricity in large current for commercial purposes in the world, and it heralded the beginning of a new era of electrical revolution.

If the current could be sent over 83 miles of country, why not extend it indefinitely? This question immediately received answer by a number of other electrical companies on the Pacific Coast and elsewhere. Hundred-mile transmission lines have been put into operation in the past two years by three different American companies, while two Canadian companies have constructed lines of 93 miles each.

The Kern River Transmission Company essayed to build a line to send 10,000 horse power over one hundred miles, working at a voltage of 45,000 at the power house. In time it was proposed to increase the voltage to 50,000, and the length of the line to 125 miles. The completion of this line further emphasizes the possibilities of sending heavy voltages over wires especially prepared for the purpose. A sixteen-mile line was constructed, and experiments made in sending 80,000 volts over the wires. It was found that 65,000 volts could be sent without giving any difficulty or trouble whatever. As the final limit of long-distance transmission of electrical current must depend upon the amount of voltage that can be developed at the power house and sent over the lines without destroying them, this experiment proved most profitable and satisfactory. The experiments of the Pacific Light and Power Company with their 80,000-volt Kern River line have thus opened the way for the commercial development of many streams located long distances from towns and cities, and the ultimate end will make revolutionizing changes in many parts of the country.

The completion of the 110-mile transmission line of the Spokane Water Power Company corroborated the impression that the limits of sending electricity commercially long distances were far from being reached. The power house at the foot of the falls in the Spokane River develops 60,000 volts, and sends the power to the city of Spokane, the line being approximately 110 miles to the furthest power user. The power is sent over three lines, each receiving at the power house about 20,000 volts. There are six substations equipped with water-cooled transformers which can step the voltage down from 60,000 to 4,000 volts. The power is used not only by consumers in the city of Spokane, but by mining companies all along the route. At the Standard and Hecla mines four three-hundred horse power electric induction motors drive compressors, hoists and mining machinery. The construction of the long-distance line has completely transformed mining operations along its course. Mines that were formerly impossible, from a financial viewpoint, are now paying investments. The current is tapped from the main line and used in working all sorts of mining machinery. Owing to the scarcity of coal in this mining region, it was too expensive to work low-grade ore, and the change effected by the building of the electric line has been little short of marvelous.

During the year 1905 the greatest hydro-electric engineering feat of the world was completed by the California Gas and Electric Corporation, which has succeeded in bringing power from the mountains over a line 232 miles long. This is the longest distance

over which electrical current has ever been transmitted for commercial purposes. The line stretches from the De Sabla power house in the mountains to Sausalito, opposite San Francisco. The same California company operates another line running from Colgate to Oakland, a total distance of 142 miles, developing at the power house 14,000 horse power from a head of water 702 feet. Closely rivaling this last line is that owned by the Standard Electric Company, which runs from the Electra power house in the mountains to Stockton, San Jose and San Francisco, a distance of 147 miles. The high voltages of all three of these lines range from 50,000 to 60,000.

At the Colgate power-house, water is received from Lake Francis through 9,000 feet of 36-inch wooden stave pipe, one-half mile of natural channel, and 3,000 feet of rapid flume. The water pours down the pipe with such force that it resembles a great Niagara torrent. Sixteen huge water wheels are turned by it, but the surplus water is allowed to flow unchecked down the incline.

The Colgate power house is the centre of the whole system on this line, and its power has been increased by conducting water from the North Yuba River through nearly 8 miles of wooden flume. The water thus delivered at the top of the hill, 700 feet above the power house, is conducted down the incline as needed. In order to tap the waters of the Yuba, great artificial bridges had to be constructed, and the sides of the mountains skirted, so that the flume appears to hang on the edge of steep precipices in places. The heavy machinery for the work had to be carted up the steep sides of the hills by dozens of teams of horses, and it took a full month to transport one dynamo a single mile. Elaborate precautions had to be taken to prevent any weakness in the long-distance flume, and watchmen have to inspect every part of it frequently. The force of the water at the power house is so tremendous that only gigantic machinery can pen it in its narrow channel.

Yet in spite of the great outlay for making the line perfect, the commercial profits of the enterprise are great. The sale of the power in the cities and along the line of transmission pays the company for all its efforts. In San Francisco, Oakland, Stockton, Los Angeles and Spokane, electric power can be purchased to-day cheaper than in most of the Atlantic Coast cities.

The Canadian Niagara Power Company have completed a plant which to-day develops 60,000 volts at the power house, and current is sent over a transmission line of 93 miles. The Electrical Development Company, of Ontario, has likewise finished a line of 93 miles, and the Winnipeg General Power Company has in operation a 60-mile line, with a capacity of 10,000 horse power and a working voltage at the generating station of 60,000 volts.

In recent years, American electrical engineers have turned their attention with ever-increasing interest to Mexico as a field for possible development. Under the advice and practical work of Americans, Mexican plants have been constructed that compare favorably with any in this country. There are two long lines of transmission in Mexico. One is the Quanajuato Power and Electric Company, which owns a 101-mile transmission line, developed from a head of water 300 feet high, and working under a pressure of 60,000 volts. An even longer transmission line in Mexico is that of the Mexican Light and Power Company, of the city of Mexico, which, under a working voltage of 60,000, sends power 110 miles to market. The working head of water for this plant has an altitude above the power house of 1500 feet.

It will readily be seen that American electrical engineers have solved the question of long-distance electrical transmission better than those of any other country, and apparently those working on the Pacific Coast have slightly led those from the East or Middle West. It may be that the peculiar conditions of the country were responsible for this, but it is certain there are no such long-distance transmission lines in the East. There are greater water powers than any on the Pacific Coast, but few lines more than 50 miles in extent. We have harnessed Niagara, and sent its power to Buffalo, 23 miles away; subdued Spiers Falls, and transmitted its energy forty miles away to Troy, Schenectady and Albany; conquered the falls at Massena and delivered enormous current to nearby factories and mills; and built model power houses to utilize the waters of the Sault St. Marie and Apple River, of Michigan. But we still must look to the Pacific Coast for anything like a 200-mile transmission system. It probably will be a long time before the 232-mile transmission line from the De Sabla power house to the coast will be duplicated; but meantime great things may happen in the electrical field, and the tendency is toward the development of higher voltages and longer transmission. Where either will end it is difficult to prophesy to-day even approximately.

REVIEW QUESTIONS.

PRACTICAL ELECTRICITY.

1. If your ammeter read 250 amperes and the voltmeter read 110 volts, what would be the resistance of the circuit?
2. Upon what does the resistance of a given length of wire depend?
3. Large cables are designated by their diameter in circular mils. What is a circular mil?
4. What effect has a current on a wire?
5. To get the maximum heating effect from a coil of wire, what two conditions enter into consideration?
6. If three circuits of 3, 8, and 12 ohms respectively are connected in parallel, what is the resistance of the combined circuits?
7. If 400 amperes are being supplied to a circuit at 125 volts, how many kilowatts of energy are being transmitted?
8. What is the difference between a permanent and an electro-magnet?
9. How many poles must a magnet have and how are they named?
10. For what purposes are electro-magnets used?
11. Why is iron the usual substance used in an electro-magnet?
12. What is meant by permeability?
13. Upon what does the magnetizing force of an electro-magnet depend?
14. Why are armature cores laminated?
15. What is the difference between a ring and a drum armature?
16. Why are commutators used?
17. What three conditions enter into the production of a certain electro-motive force in a dynamo?
18. What is the difference between a lap and a wave armature winding?

19. Why are multipolar dynamos used in preference to two-pole machines?

20. Explain the difference between a series and a shunt dynamo.

21. What kind of machine is used in series arc lighting?

22. What type of machine will be found to be generating constant potential?

23. What is a compound generator and why is it used?

24. What kind of motors are used on street cars?

25. What are the particular advantages of the inter-pole motor?

26. For what general purposes are alternating current motors used?

27. Would you use a synchronous motor if it had to be started and stopped frequently?

28. For what purposes are dynamotors used?

29. For what purposes can boosters be used to advantage?

30. In an incandescent lamp, how does the candle-power vary with the life of the lamp?

31. What is the difference between the Nernst lamp and an incandescent lamp?

32. Explain the action of the heating coils in starting Nernst lamps.

33. Which carbon in an arc lamp burns away the faster?

34. When the carbons burn away how are they brought together again in order to maintain the arc?

35. What is a constant current system?

36. What is meant by constant potential distribution?

37. What are the advantages of the three-wire system?

38. How would two 110-volt dynamos be connected to work on a three-wire system?

39. Of what use is an equalizer when running dynamos in parallel?

40. What is the principle difference between a voltmeter and an ammeter?

41. Into what three classes are voltmeters and ammeters divided?

42. What difference is there between the method of connecting a voltmeter and an ammeter in circuit?

43. When would you use a shunt in connecting an ammeter to read the current in a circuit?

44. What are recording instruments and how do they operate?

45. What is a wattmeter and for what purposes is it used?

46. Explain two methods in general use for measuring resistance.

47. For what purposes are fuses used?

48. What is a double-pole, double-throw switch?

49. Under what conditions would you use circuit-breakers?

50. What instruments are necessary on a switch board.

51. Describe briefly how you would construct a switchboard for three constant potential generators to be used to supply a number of lighting circuits.

52. For what purposes are storage batteries generally used?

53. Name a few of the troubles usually encountered with storage cells.

54. How would you care for storage cells in your plant? At what voltage should they be charged and what precautions are necessary when discharging?

55. Describe several methods used for charging storage batteries from lighting circuits.

56. How does the specific gravity vary with the charge?

57. Describe two methods for finding the efficiency of a motor.

58. When is a motor generally the most efficient, at light loads or heavy loads?

59. Describe several methods used for starting motors.

60. What are the advantages of alternating currents over direct currents?

61. What is a cycle and what is meant by frequency?

62. If the ammeter reads 50 amperes, the voltmeter 110 volts, and the wattmeter 5200 watts, what would be the power factor of an alterating current circuit?

63. What is inductance?

64. How does capacity affect an alternating current circuit?

65. Why is a poor power-factor objectionable to large central stations?

66. Name the principle parts of an alternator.

67. In what manner does an inductor alternator differ from regular alternating current generator?

68. What is step-up transformer and for what purposes is it used?

69. Describe two methods in general use for connecting transformers.

70. How are large transformers usually kept cool?

71. Upon what principles does an induction motor work?

72. How are synchronous motors started?

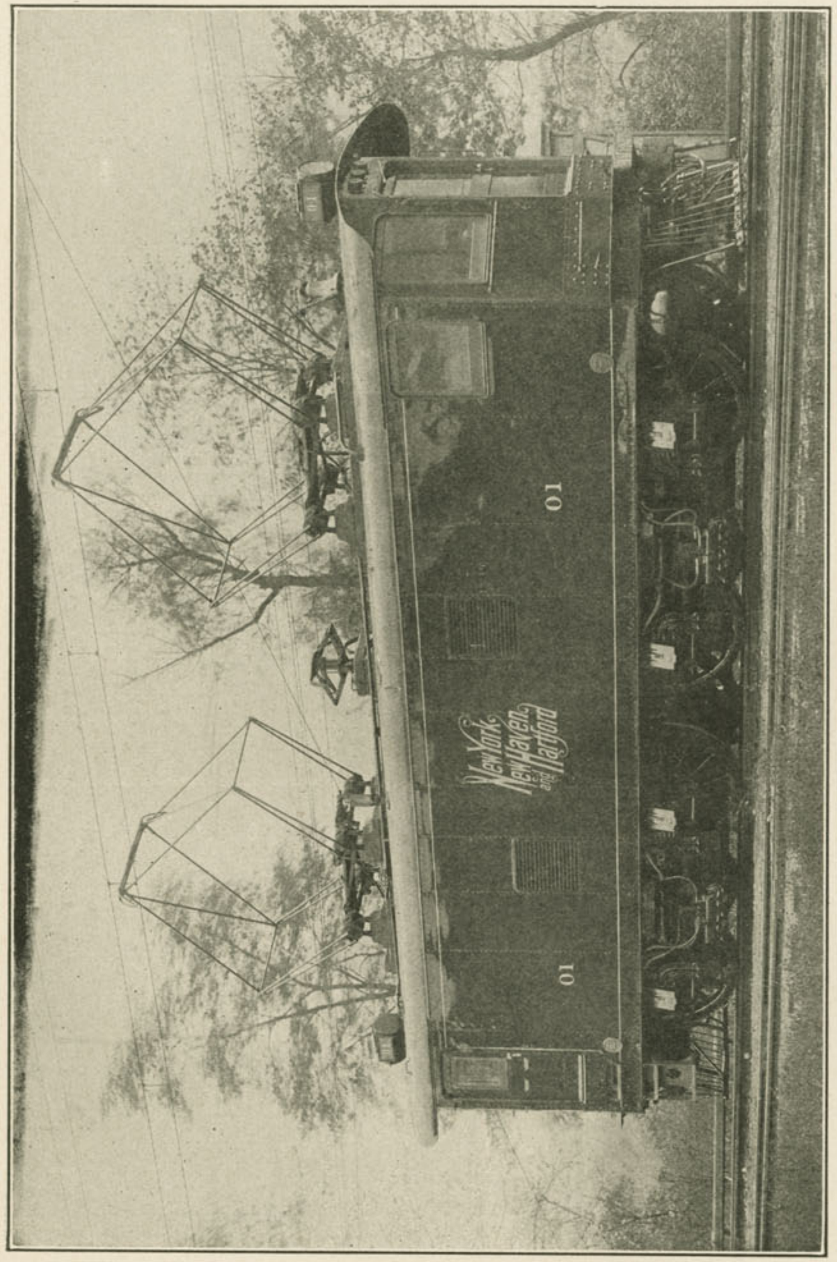
73. What is a rotary converter?

74. What precautions should be taken in starting rotary converters?

75. What is a mercury vapor converter?

76. What are the advantages of a single-phase railway system?

77. Name a number of the most important electrical transmissions in this country and explain why they have attracted so much attention.



SINGLE-PHASE LOCOMOTIVE USED ON THE NEW YORK, NEW HAVEN AND HARTFORD RAILROAD

Electric Locomotives.

Developments in Electric Traction. During the past decade there has been considerable development in the use of the electric locomotive for many purposes for which the steam locomotive was formerly used exclusively. This has been particularly true in interurban, suburban, tunnel and terminal work. For a number of years electric locomotives have been used on the St. Louis & Belleville Railway, on the Baltimore & Ohio Railroad, on the New York Central & Hudson River Railroad, on the Grand Trunk Railway, on the New York, New Haven & Hartford Railway; while such roads as the Pennsylvania, Long Island Railroad, Spokane & Inland Railway, Lackawanna & Wyoming are using trains which derive their power from the electrical current.

Although these electrical developments have extended over a considerable period of time, yet the fact must not be overlooked that it is but a small beginning of what will eventually be a considerable factor in railroad engineering. The best engineers in this country, however, differ as to their opinion of what the eventual outcome of trunk line practice will be.

The results already obtained in extensive railway operations show that a fairly frequent service can be more economically maintained by an electric equipment than by steam locomotives. Particularly is this true of elevated lines and the crowded short-haul traffic between the larger cities and neighboring towns; besides, tunnel operations and transportation over heavy grades have become recognized as advantageous fields for the employment of electricity, all of which have caused several of the larger railway systems to change their equipments for such service.

The substitution, however, of the electric locomotive for the steam locomotive must necessarily be a slow one, and must be developed according to the needs of the particular roads upon which it is to be used.

Difference in Power Conditions Between Steam and Electric Systems. There is a large fundamental difference in power conditions between the steam and electric systems. The steam unit of locomotion is self-contained, converting the energy of the coal into that of the moving train. In the electric system this process of converting the energy is divided; for instance, the power energy must be converted into electric energy in a power house. This energy must be transmitted to the car by a wiring system, and then converted into mechanical energy by an electric motor. This means that before construction starts the capacity of the road, its train service, the size of the car and its load, and the alignment and profile of the road must be more or less accurately determined. From these the energy required and its distribution must be calculated.

It is this necessity for determining the demands upon an electric system that calls for the present care in the design of both transmission and power plants, as the steam road has a flexibility which is not possessed by the electric system, and it is this flexibility which has been one of the principal reasons why railroads have been more or less conservative in changing from the steam to the electric motive power.

Characteristics of Electric Traction. The distinguishing characteristics of electric traction, as contrasted with that of steam-driven locomotives, is that the motive power is utilized at variable and varying distances from the point of generation, whereas in a steam-driven locomotive the power is generated in each individual unit as required. A system of electric transmission must, therefore, be adopted which combines efficiency, flexibility, simplicity and low first cost of installation.

Advantages of Electrification. While the excessive cost of steam railroad electrification is quite an important matter, as well as the necessity of maintaining a continuity of service, yet at the same time the electric road possesses a number of advantages.

The application of electric traction to heavy railway service is governed by other and more important considerations than its mere relative cost as a motive power under similar conditions. In steam service the weight and speed of trains are limited by the horse-power capacity of the locomotive, which generates its own power, and there are but few locomotives which can generate sufficient steam to utilize their full cylinder tractive power at speeds in excess of twelve miles an hour. Consequently, any increase of speed beyond certain limits can only be attained by sacrificing train tonnage in a corresponding degree. The division of the train mile cost by the lesser number of tons increases the ton mile cost proportionately.

The high cost of fast freight service is principally due to this effect of a diminishing divisor, while electric traction permits high speeds without sacrificing commercial tonnage, as, with a relatively unlimited source of power at command, the maximum drawbar pull permitted by the motor design may be maintained at all speeds.

The train capacity cannot be reduced without loss below the point where the earnings equal the train mile cost, and if this cost cannot be reduced proportionately with reduced capacity, the inferior limit of capacity may be uneconomically large. In steam service the irreducible elements entering into the train mile cost are so large that it is rarely profitable to operate trains earning less than forty to fifty cents per mile. In contrast, electric service permits an extreme reduction of the train length to single car units, costing to operate but ten to fifteen cents per car mile. Hence, the frequency of service may be increased and rates reduced, which in turn will react upon the volume of traffic, with the final result of increasing both gross and net earnings. It may, therefore, be claimed for electric traction that it will extend the limits of profitable operation of high-speed heavy trains, and also of light trains of low capacity.

One great advantage of electrification is the low cost of locomotive maintenance. Generally speaking, it may be said that a fair advantage for the maintenance of a steam locomotive in a hilly country on a 2 per cent grade is about fourteen cents per mile. Under these same conditions it is claimed that the cost of electric locomotive maintenance will not exceed four cents per car mile, or a saving of about 70 per cent. While in ordinary practice the electric locomotive can take a 2 per cent grade at 25 miles per hour, the steam locomotive with the same load can hardly do half that speed. Another advantage of the electric locomotive over the steam locomotive is the cost of stopping. It is estimated that the cost is $4.00 to stop a six train running 30 miles per hour; the cost of stopping an electric locomotive is estimated to be about 10 per cent of this amount. Further than this, when stopping the electric locomotive is "dead" in that no power is going to waste, whereas a steam locomotive keeps on using coal when standing still. Still another advantage of the electric locomotive is the long continuous runs which it is able to make. On the New York Central Railroad electric locomotives have been run 2,000 miles without being hauled up for inspection or repairs, which it is claimed no steam locomotive can do. Ordinary locomotives on through trains are changed every 100 or 200 miles, whereas the electric locomotive could run ten times as far.

Other, but relatively minor, advantages are possible in the effect upon earnings, due to the elimination of smoke, gases, dust, cinders, and heat, the better ventilation of cars, the extension of electric train lighting and heating; and of the effect upon expenses due to the concentration of power production in large and economical power houses, a reduction of engine repairs, an increase of effective engine and train mileage, a more or less complete elimination of engine houses, turntables, fuel stations, water tanks, cinder pits, and other operating facilities, the consolidation of power requirements for traction, pumping, operating shops, elevators and general uses, and the use of current for lighting switch lamps, stations and other buildings.

Difficulties of Changing from Steam to Electricity. In changing the method of motive power on existing railways, the conditions are by no means so simple as in the construction of new lines, as in the former case a great amount of capital already invested must be sacrificed, and the problems of adaptation to existing conditions are peculiarly severe. In particular, the transition stage in bridging over the gap between steam and electric operation is both expensive and difficult, as the change affects train lighting and heating, telegraph and telephone service, signaling, and track maintenance, for which both temporary and permanent provision must be made. The simultaneous maintenance of facilities and working forces for both steam and electric service within the same limits will be rarely profitable, for the reason that a large proportion of expenses incident to both kinds of service is retained without realizing the full economy of either. To secure the fullest economy it is necessary to at least extend the new service over the whole length of the existing district, and to include both passenger and freight trains.

Types of Electrification Systems. There are five different systems which may be adopted by railroads when electrification is used. These are: First, the direct current system such as is used on street railway and interurban lines; second, the alternating direct current system which, so far as the car is concerned, does not differ from the first; (the electro-motive force is generated by an alternator, transmitted at high proportional to a sub-station and changed from a direct current by a motor converter); third, an alternating current commutator motor system which is a low pressure system, the motor running on alternating current in interurban districts and on direct current in the city districts or where dense traffic prevails; fourth, the single phase high pressure trolley system, chiefly alternating, in which the trolley voltage may vary between 3,000 and 6,000 volts; fifth, the polyphase system, which requires more than one trolley or collector.

Direct Current System. When the direct current system is used, the power house generates direct current at about 600 volts from where it is distributed directly to the points of application of power by means of either a third rail or trolley. For short hauls this system has been in successful use for a number of years. Its particular advantage is simplicity, as no transforming apparatus is used. Its particular disadvantage is the costly distributing system necessitated by the high currents transmitted at comparatively low voltage. Except for terminals and for short hauls, its future for electric roads is very limited.

Alternating Direct Current System. When the direct current system is used, the current is generally obtained from a third rail, which is supplied either directly from the power house, or by means of sub-stations which transform the high-tension alternating current generated in the power house to low-tension alternating current which is conveyed by means of rotary converters to direct current at about 650 volts for supplying the third rail. The latter method is the one in most general use, as economy of transmission demands high potential, and as alternating current is the most available for transforming purposes, it is almost universally used.

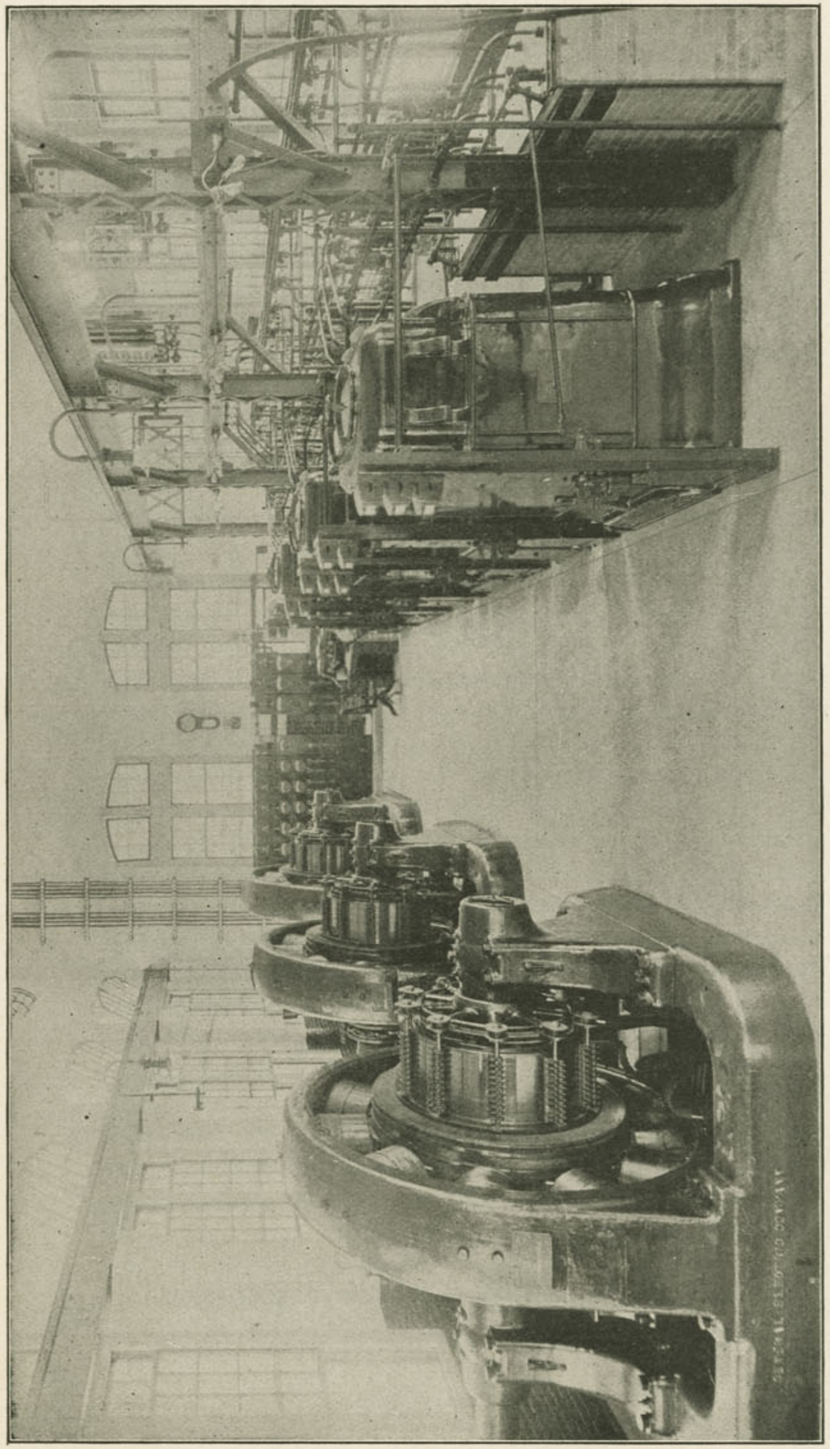
The direct current motor is used on the cars, as the series direct current motor gives an excellent torque at starting, and gives a very flexible control and comparatively high efficiency.

This alternating direct current system demands sub-stations along the road which contain transformers, rotary converters, high and low tension switches, etc., all of which means considerable cost of first construction and maintenance.

Sub-stations. When direct current is used for operating the electric road and alternating current is secured in the power house, the use of synchronous or rotary converters for changing the three-phase alternating current to 600 volts direct current is almost universal. The location and capacity of such stations depend upon the character of the service and local conditions. The converter sub-stations consist of the following: Ingoing and outgoing primary feeders, provided with switches and lightning arresters; high-tension bus bars, with automatic wire switches controlling them; current transformers in the primaries counter circuit, and feeding ammeters and relays for operating the switches; step-down transformers, either of the air blast or wire cooled type; inductive coils connected in the transformer secondary circuit, extending to the alternating current of the converter; synchronous converters; direct current outgoing feeders; switch board panels controlling both the alternating current side and the incoming feeders, as well as the direct current incoming and outgoing feeders.

Transformers. The transformer which is used for changing the voltage of an alternating current circuit consists of simply two individual wirings surrounding an iron core. It is called a step-up transformer when the voltage delivered is greater than the supply voltage, and a step-down transformer when the delivered voltage is less than the supply voltage. Step-up transformers are used in power houses to increase the voltage for transmission in the lights, and step-down transformers are used in sub-stations for cutting down the voltage for use where the rotary converters are in the railroad motors themselves.

Alternating Current Sub-stations. Alternating current sub-stations, used with alternating current railroad motor equipment,



ROTARY CONVERTER SUB-STATION

750 K. W. Rotary Converters, operating at a speed of 300 revolutions per minute and supplying continuous current to railway feeders at 900 volts pressure. The step-down transformers on the right are 825 K. W capacity and lower the voltage from 13,200 to 430 volts, the current being conducted to the rotary converters at the latter voltage

do not make use of a rotary converter, but such stations contain step-down transformers, generally in duplicate, together with the necessary switch board apparatus. Both primary and secondary circuits are provided with automatic wire switches designed to open on short circuit or extreme overload, only in those serving as a safety device to protect the transformer from burn out. As such sub-stations have no operator and are subjected to violent fluctuations in load, the protective devices are arranged to guard against short-circuit and in overload. Step-down transformers are generally of the self-cooling oil type.

Starting Synchronous Converters. There are three methods which may be used for starting synchronous converters. First, by means of the direct current starting through a rheostat; second, starting from the alternating current side by means of an induction motor; third, starting from the alternating current side from transformer taps. When starting from the direct current side there is no disturbance in the primary distributing system, and it is used more generally when the converter is carrying a lighting load. The principal objection to this method is that should there be a fluctuation of the direct current voltage supply, it might be quite difficult to synchronize the motor, as it must be in this condition when it is thrown on the alternating current mains. With an induction motor for use for starting, the converter also requires synchronizing of the converter, so that it is usual in railroad practice not to use either of the two above-mentioned methods, but to make use of the method of starting directly from the alternating current side.

When starting trolley converters from the alternating current side, a required voltage is obtained from taps in the transformer, and in a 25-cycle system, starting by this method, may be effected without disturbing the full load current on the primary. The advantages of this system are that it does not require any starting motor, and it can be thrown into service without having to synchronize it.

Method of Starting Synchronous Converters. The general method for starting a synchronous converter from the alternating current side is as follows: First, see that all switches about the negative main on the machine are open; second, close the line switch feeding busses; third, close the high-tension transformer switch on low voltage taps, that is, on upper throw if the converter leaves synchronous speed; fourth, close equalizer switches; fifth, close series shunt switches; sixth, close the field break up switch, bringing converter to full voltage; seventh, throw starting switch quickly from upper to lower throw; eighth, close direct current circuit breaker; ninth, adjust field rheostat; tenth, close the main switch, making further adjustments of field rheostat to obtain the desired division of load, power factor and voltage.

Synchronous Converters. The synchronous or rotary converter is a machine for converting alternating current into direct current, and consists of a synchronous motor and a direct current generator combined in one machine. It resembles a direct current generator with a large commutator and a usual set of collector rings. On the alternating current side it operates as a synchronous motor, and on the direct current side as a direct current generator. When driven by alternating currents, its operation is governed by the alternations of the supply quite individual of all other conditions. While the operation of a synchronous converter corresponds closely to that of a direct current generator, its action is much more satisfactory in operation. For instance, there is no field distortion, because the converter is both a generator and a motor, there is less friction loss, and there is considerably greater output from the same alternator.

Types of Synchronous Converters. There are two types of synchronous converters which may be used, the compound converter and shunt converter. The compound synchronous converter with a series field is used on those systems in which the station output is very fluctuating, such as is experienced in sub-stations feeding suburban and interurban railway systems. The shunt wound converter is used principally for supplying city service lines, where there is practically uniform load with small fluctuations.

Electrification of West Jersey & Seashore Railroad. As illustrating the alternating-direct current system of electrification, the West Jersey & Seashore Railroad, which is one of the divisions of the Pennsylvania Railroad, is perhaps the best known. It extends a distance of 65 miles, from Camden to Atlantic City, New Jersey, and from Newfield to Millville, a distance of 10 miles. The road is double track throughout, and has three tracks part of the distance. It is equipped with a third rail for the larger part of the

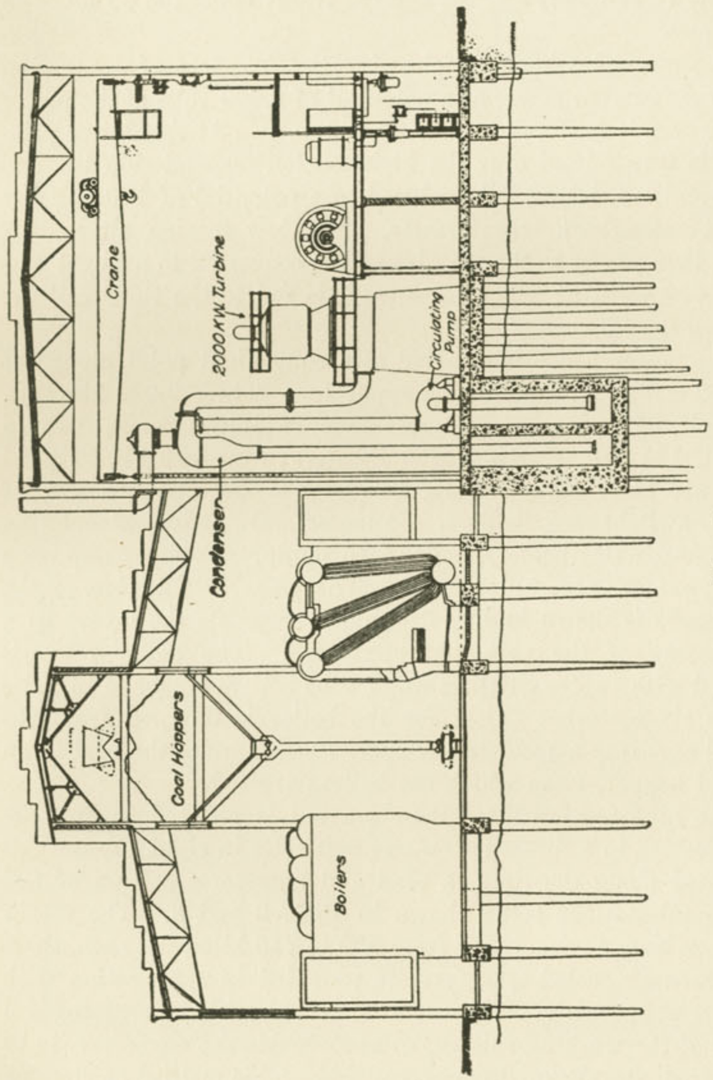


Fig. 1.

Arrangement of Apparatus in Power House of the West Jersey & Seashore R. R.

route, especially for a stretch of about 4½ miles where the tracks pass through the city streets at grade, and here the cars are operated from overhead trolleys. The travel on this road is quite large, especially in summer, and the express trains make the 65 miles in 90 minutes.

The general scheme of electrification consists of generating alternating current power at a potential of 6,600 volts at the power house, where it is stepped up to 33,000 volts. At this latter pressure it is transmitted over the high tension transmission lines to the sub-stations, where it is reduced to a potential of 430 volts by means of step-down transformers. The low tension alternating current then passes to the rotaries and is converted to a direct current at 650 volts, at which pressure it is fed to the third rail for operating the cars.

The power house is situated at a convenient point along the road and contains the following apparatus: Three 2,000 kilowatt, 6,600 volt, 25 cycles, three-phase Curtis Turbo generators; two 75 kilowatt, 125 volt, Curtis Turbo Exciters; nine 700 kilowatt, 25 cycles, air blast transformers, besides the usual equipment of blowers, switchboard, boilers, condensers, air pump, circulating pumps, feed water heaters, boiler feed pump, make-up pump, step bearing pumps, accumulator, etc. The transverse section of the boiler house is shown in Fig. 1, which represents the layout in a general way of the principal apparatus. The boiler room is equipped with twelve Stirling water tube boilers arranged in pairs to form six batteries. Coal for the boiler is dumped from the railroad cars into a receiving hopper, which carries the coal to an overhead hopper, from which the boilers are fed.

The high tension three-phase current is reduced in pressure and converted to a direct current at 650 volts in eight sub-stations distributed along the lines, a plan and transverse section of one of these sub-stations being shown in Figs. 2 and 3. The rotary converters have a capacity of from 500 to 750 kilowatts each, there being three air-cooled transformers provided in conjunction with each rotary. Each transformer is supplied with taps giving 1-3 and 2-3 of the working voltage, so as to enable the converters to be started from the alternating current side. This method of starting does not need any synchronizing, and any rotary converter can be

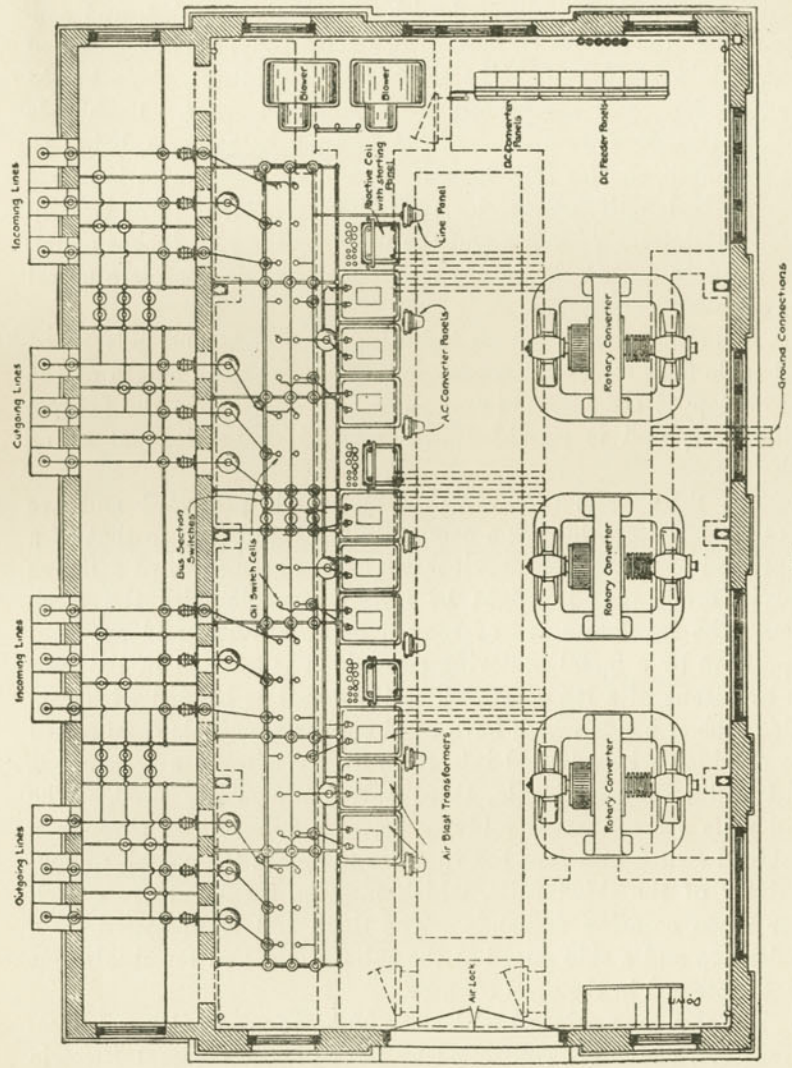


Fig. 2. Plan of Typical Sub-station, Used on the West Jersey & Seashore R. R.

started, run up to full speed and be delivering power to the line within a minute.

The 33,000 volt high tension transmission line is in duplicate throughout. It is Y-connected with a neutral grounded, and consists of six No. 1 B. & S. hard-drawn solid copper wires mounted on porcelain insulators. The poles are of chestnut, their height being 45 feet, and are spaced about 125 feet apart. Each pole contains two cross arms, as shown in Fig. 4; the top arm, being 12 feet in length, carries four insulators, and the lower arm is 8 feet 6 inches in length and carries two. The six wires form two inverted equilateral triangles and the insulators are 42 inches apart. The wires in each triangle are transposed by one complete spiral between each sub-station.

To protect the line from lightning, a seven-strand galvanized steel cable 5-16 inch in diameter is strung the entire length of the line on top of the transmission poles four feet above the nearest active wire, and is provided with ground connections at every fifth pole.

The third rails used weigh 100 pounds per yard and are about 33 feet long, having a conductivity about equal to that of a copper rod of 1,200,000 circuit miles. This type of third rail was used in order that it might be interchangeable with the track rails. The insulators are of reconstructed granite, and are held in position by a metal centering cup which is secured in the long ties by means of a lag screw. The third rail is bonded with concealed ribbon bonds which have solid copper terminals compressed into one-inch wires drilled into the rail. Wherever a continuous third rail is impracticable, third rail jumpers are used. The third rails are connected midway between sub-stations through a combined switch and fuse box in order to obtain the combined conductivity of the third rails, which may be insulated from each other when occasion demands. The third rail is protected by a wooden top and a side guard at the sub-stations and terminals, but is not protected in the open country.

The cars are equipped with two 200 horse-power General Electric motors, which are controlled by the Sprague General Electric Automatic multiple unit type. The controllers are so arranged that current is cut off from the rotaries through the train, and the brakes are automatically operated should the rotary release be

held on the controller handle. The total weight of each car fully equipped is 89,000 pounds. Each car is equipped with hand and track service automatic air brakes, the controller line extending through the entire train. These brakes enable the motorman to

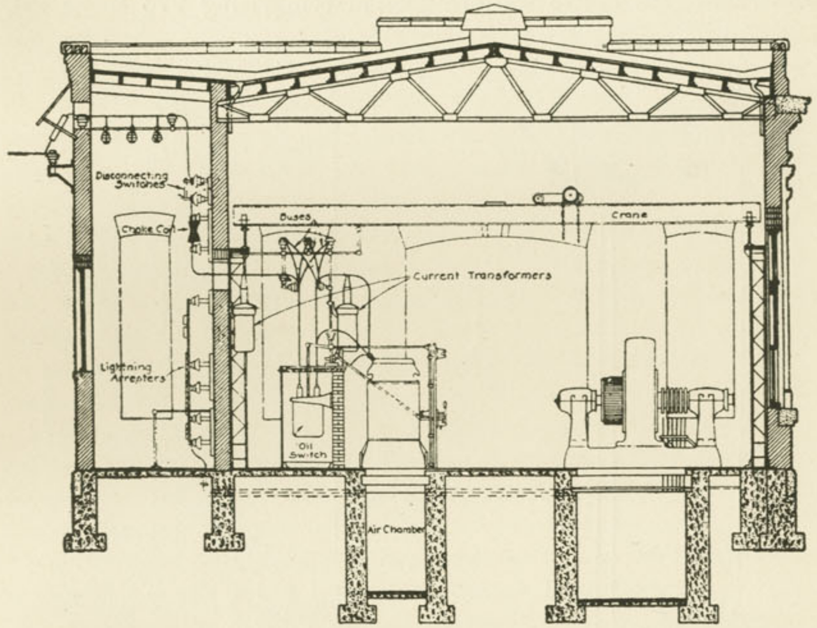


Fig. 3.

TRANSVERSE SECTION OF SUB-STATION, USED ON THE WEST JERSEY & SEASHORE R. R.

divide the release into as many sub-stations as may be desired, and give the same flexibility as with the straight air brake equipment. The auxiliary reservoir pressure is maintained by means of a quick recharge feature, which enables a large number of brake applications to be made in quick succession. The brake system also includes a quick service feature, which, when a service application is made, establishes communication between the brake cylinder and brake pipe pressure, thus materially assisting the auxiliary reservoir in building up the brake cylinder pressure in the usual manner. The motor driven air compressor consists of a duplex single acting air pump driven by motors of the railway type.

Long Island Railroad. Another extensive substitution of electricity for steam in the operation of a large railway system has been made by the Long Island Railroad, which has completely reconstructed the entire western section comprising 97½ miles of

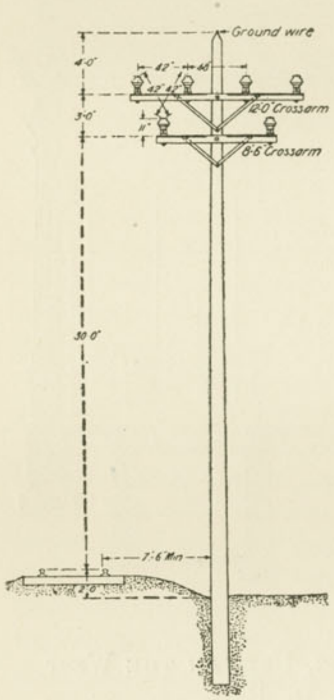


Fig. 4.

HIGH-TENSION TRANSMISSION POLE, Used on the West Jersey & Seashore R. R.

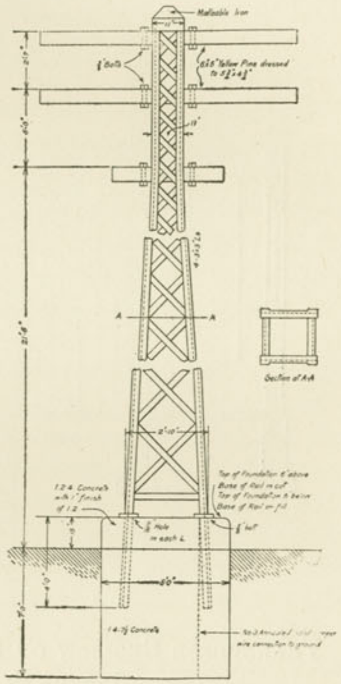


Fig. 5.

TRANSMISSION LINE POLE, Used on the New York Central & Hudson River R. R.

track. The direct current third rail system has been adopted, to permit interchange of cars with the subway and elevated lines of New York City, after the completion of the Pennsylvania Railroad's tunnel between Manhattan and Long Island.

The power house is equipped with 5,500 kilowatt Westinghouse turbo-generating units, and will have a total ultimate rated

capacity of 66,000 kilowatts. Three-phase alternating current is transmitted at 11,000 volts to five permanent sub-stations, which may be assisted if necessary by two fully-equipped portable sub-stations which can be run to any part of the line. Steel cars equipped each with two 200 horse-power Westinghouse direct-current motors, operated by the unit switch system of multiple control, are used. They are geared for a maximum speed of 55 miles per hour, and will maintain a schedule speed of 25 miles per hour.

Low Pressure Alternating Direct Current System. In this system the road is so equipped that the car motors run on alternating current in interurban districts, and on direct current in the city districts, or where the traffic is very dense. This system is made possible by the fact that a series motor will run equally well on single phase alternating current and on direct current. This fact has made it possible for the New York, New Haven & Hartford Railroad to adopt this system.

New York, New Haven & Hartford R. R. Electrification. The electrification of the New York, New Haven & Hartford Railroad is according to the low pressure alternating direct current system, because the road is being extended considerable distances from New York City with alternating current, the equipment of which must adapt itself to the direct current system of the New York Central & Hudson River Railroad over whose tracks entrance is obtained to the Grand Central Station at New York.

At the New York terminal direct current at 660 volts is used for a distance of 34 miles. Power is generated in two large stations at Yonkers and Port Morris, each having an ultimate capacity of 30,000 kilowatts. Alternating power is generated and transmitted at 11,000 volts to eight sub-stations along the line. The sub-stations contain reducing transformers and rotary converters, which transform the alternating current to direct current at 660 volts, at which potential it is delivered through distributing feeders to the third rail. Each station is equipped with Westinghouse rotary converters, and contains storage batteries capable of taking care of the load fluctuations, and, in case of emergency, able to operate the entire system under normal conditions for one hour. Five of these batteries have a normal output of 2,250 amperes each for one hour, and the others 3,750 and 4,020 amperes respectively.

The local service is handled by means of trains made up in part of motor cars equipped with the multiple control system, and the through service by electric locomotives capable of making the trip between the Grand Central Station and Groton with a train of 435 tons in 44 minutes without stopping. The fastest trains handled weigh approximately 375 tons, and are drawn by two locomotive units at a maximum speed of from 60 to 65 miles per hour. Each locomotive weighs 97 tons, 68 tons of which is upon

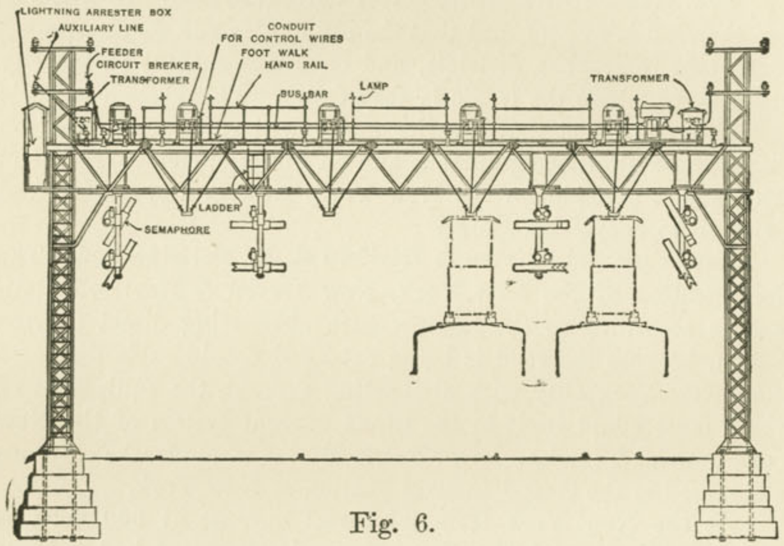


Fig. 6.

TROLLEY SUPPORT, USED ON THE NEW YORK, NEW HAVEN & HARTFORD R. R.

the four pairs of drivers. The motors are of the gearless type, with armatures mounted upon the driving shaft without spring couplings of any kind.

From the junction of the New York Central and New York, New Haven & Hartford Railroads to Stamford, Conn., a distance of 22 miles, the New Haven line is equipped for alternating-current operation. The generating station, located at Riverside, is three miles from Stamford, and contains Westinghouse steam turbines, driving generators having a capacity of 3,750 kilowatts each when operated single-phase, and 5,500 kilowatts each when operated three-phase, the armatures being suitable for either con-

nection. They are wound for 11,000 volts, and are connected direct to the trolley system. Neither transforming stations nor reducing transformers are required along the line.

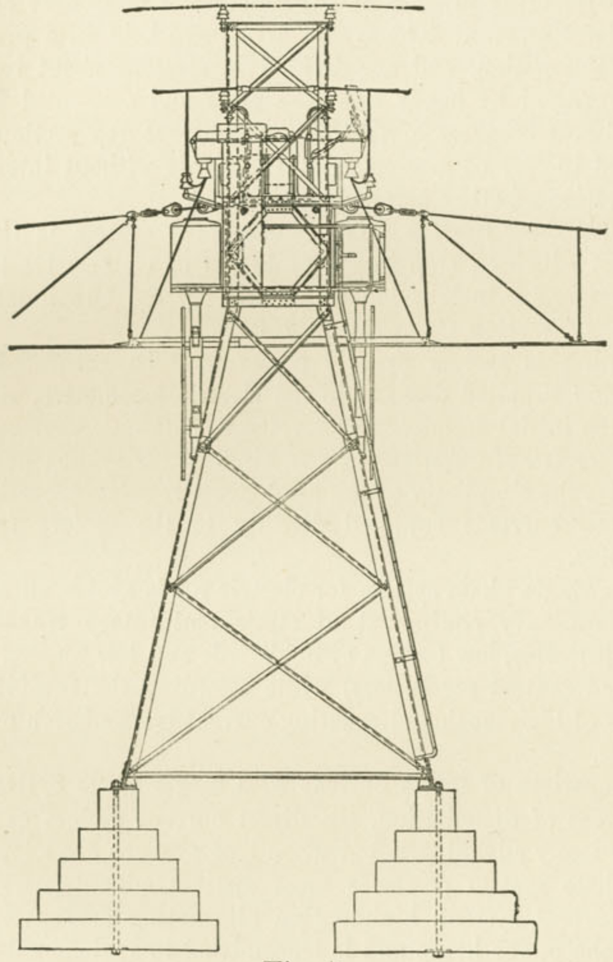


Fig. 7.

TROLLEY ANCHOR BRIDGE, USED ON THE NEW YORK, NEW HAVEN & HARTFORD R. R.

The trolley system is suspended from steel bridges located at intervals of 300 feet, which will span four, six or more tracks, as may be required, shown in Figs. 6 and 7. Every two miles an anchor bridge of heavier construction is erected. Massive insulators mounted on these bridges support steel cables from which the trolley lines are suspended by a double catenary construction, each trolley wire being hung from a pair of steel messenger cables by triangular supports. The trolley wires are held in a practically horizontal position, and are divided in sections about two miles long, separated by heavy line insulators and connected by automatic circuit breakers of the oil type, so that any section can be insulated in case of ground or other trouble without interrupting the operation of other portions of the road.

Single-phase System. The single-phase system is the latest and most advanced step in the evolution of electric traction, the first commercial installation being used by the Cincinnati & Indianapolis Traction Company in 1904.

With this system electric power may be generated, transmitted and supplied directly to the electric locomotive, substantially at the initial frequency and voltage, without intermediate reductions or transformations of any kind. This system practically duplicates the simplicity of the local street railway operating with continuous currents supplied directly to the motors from the trolley line.

The single phase system for electric roads avoids all necessity for the ordinary equipment of static and rotary transformers, storage batteries, low tension switchboards and low tension distributing and contact conductors, while affording the flexibility and economy of high-tension alternating current transmission over long distances.

Comparison of Direct Current with Single Phase System. For small areas of distribution, the direct current system of propulsion has many advantages, but when long systems are adopted, the single-phase system possesses some distinct advantages. In the direct current system, high-tension alternating current is generated at the power house and is transmitted to various sub-stations along the line. These sub-stations are generally equipped with static and rotary transformers, storage batteries, low-tension switchboards, distributing and contact conductors, all of which require considerable maintenance. The single-phase system does not require these auxiliaries, as the motors are directly fed from the dynamos.

The efficiency of a third rail direct current transmission is about 75 per cent between bus-bars and engine shoes, as compared with 95 per cent for the single-phase system. The total cost of a single-phase system is claimed to be much less than that of a continuous current system, and, besides having a higher electrical efficiency, it has lower fixed charges, maintenance and operating expenses.

Advantages and Disadvantages of the Single-phase System. The principal advantages and faults of the single-phase system, in comparison with the ordinary direct current system, are as follows:

The advantages are: Low voltage motor; no flashing or bucking; balanced magnetic pull on armature; motors will operate on direct current; voltage control avoiding rheostatic losses; fewer notches on controller; greater number of efficient running speeds; multiple unit control is simpler; greater ability to make up lost time; overhead contact line; more reliable contact line; sliding contact collector; no feeders; sub-stations are fewer, simpler, more reliable, more efficient, cheaper, and require no attendance; fewer insulators on transmission line; entire system is simpler and more flexible and may have decreased first cost and operating expenses.

The disadvantages are: Motor has 3 per cent to 5 per cent lower efficiency; more brushes; heavier and more expensive car equipments; more expensive contact line (neglecting third rail); transmission line may take more copper or higher voltage; larger and more expensive generators.

Application of the Single-phase System. The single-phase system is not adapted to all branches of traction work. For instance, in cities the trolley voltage would probably be limited to a value that would preclude the use of single-phase apparatus. Again, it is evidently not suited to mine haulage in general, where space is limited and the necessary high voltage trolley would be within easy reach of the workman. Also short interurban roads may show an advantage in favor of the 550 to 650 volts direct current system.

The single-phase system is especially suited to general interurban work for moderate and long distance, chiefly because of the reduction in the number and cost of sub-stations and low-tension distribution system, and because of the absence of constant sub-station attendance. It is also well adapted for heavy service, frequent or infrequent, such as the electrification of an existing suburban steam service, branch lines of steam roads, through steam lines, and mountain grades.

Single-phase Motors. The single-phase motor, as its name implies, operates with single-phase currents, and its characteristics are essentially identical with those of the more familiar continuous current series motors.

Single-phase motors are adapted for operating with either alternating or continuous currents, and this valuable feature makes it possible to design electric locomotives which may be operated at will by high-tension alternating currents from an overhead conductor, or on low-tension continuous currents from a third rail.

Frequency of Single-phase Systems. The frequency of single-phase railway systems is practically fixed by the manufacturing companies of electrical apparatus within limits of fifteen and twenty-five cycles per second.

A frequency of fifteen cycles per second has the advantage of a reduction in weight, size and cost of the motors required; there are less conductor losses and induction disturbances, and there is an increase in the power factor of the motor. The principal objection to the use of a frequency of fifteen cycles per second is that it restricts or prevents the use of the electrical current for many other uses incidental to railway operation.

The standard power and railway frequency in general use is twenty-five cycles, as the lighting of stations and other buildings is an important factor, and 25 cycles is the lowest frequency at which carbon filament lamps in general use can be satisfactorily operated.

Voltage Used on Single-phase Systems. The standard voltage for single-phase systems is 3,300 volts on the trolley, especially for short roads and light service. For high-class interurban service on roads of moderate length, and some cases of steam road electrification, 6,600 volts is altogether satisfactory. For very long interurban roads operating trains, and for the electrification of steam roads, with frequent service, 11,000 volts trolley pressure will ordinarily work out to the best advantage. Up to the present time this is the highest voltage to which it has been necessary to go in this country, but heavier traffic and longer lines may in the near future make advisable the consideration of even higher voltage, and it is altogether probable that within a few years we shall see lines in every-day operation under a trolley pressure of from 15,000 to 22,000 volts. In many cases it is feasible to use sufficiently high voltage on short roads, so that only one feeding point is required, and to locate the power plant at that point. Otherwise additional feeding points must be provided in the form of transformer stations.

Single-phase Transformer Stations. The transformer station contains one or more transformers with switching apparatus and lightning protection on both the high and low tension sides. The absence of rotating machinery, polyphase switching apparatus, and direct current switchboard leaves a station of unusual simplicity, and one not requiring constant attendance. The transformer itself is simple and one of the most efficient pieces of electrical apparatus. It also has an exceedingly large momentary overload capacity. Since the station contains no rotaries and the transformer takes power direct from the high-tension line and delivers it direct to the trolley, sufficient station capacity may be obtained in one unit, or at most only a few large units, instead of the numerous units required by having a bank of small transformers for each rotary.

Comparison of Single-phase and Direct Current Sub-stations. In comparison with the alternating direct current sub-station, with its rotary converters or motor-generator sets, the transformer station is much simpler and more reliable. The transformers are not affected by short circuits as are rotary converters. There is no flashing, dropping out of step or synchronizing. Throughout the system accidents are less apt to be destructive with high voltage alternating current than with direct current, because of the smaller currents and conductors used on the self-induction of the circuits and apparatus employed. This difference is probably nowhere more noticeable than in the sub-station operation of the two systems. Since the transformer station contains no moving machinery, and only such apparatus as is highly reliable, it is not necessary to provide constant attendance for these stations.

There is also a large gain because of the absence of rotary converters. The average efficiency of the rotaries on a system would probably not exceed 92 per cent, because of the periodic heavy overloads and low average load factor, which is even less than that of the power house. The reduced number, greater simplicity and better efficiency of the sub-stations, together with the absence of constant attendance in the same, constitute the second large item of saving in first cost and operation by the single-phase system in comparison with the direct current system.

Application of Single-phase Systems. The first single-phase railway in America was opened between Indianapolis and Rushville, Ind., during December, 1904, and the road has been extended so that now a single power station supplies 85 miles of road.

Three-phase current at 33,000 volts is transmitted from the central power station and reduced to 3,300 volts before connection to the main trolley sections, and within the limits of Indianapolis the cars run over direct current lines fed at 550 volts. The control equipment is capable of operation on either direct or alternating current. The overhead structure of the high potential trolley is of the catenary type.

Spokane & Inland Railway. The system of the Spokane & Inland Railway connects the cities of Spokane and Colfax, Wash., with a branch running to Palouse City—making a total length of track of 106 miles. Current is purchased from the Westinghouse Water Power Company at 60 cycles, and transformed to 25 cycles by frequency changes. The alternating current is then transmitted at 45,000 volts to 15 transforming stations, in which it is reduced to 6,600 volts, the potential of the trolley circuit—except within the limits of Spokane itself, where the alternating current cars are operated over present direct current lines at 575 volts. Each car is equipped with four 100-horse-power single-phase motors and unit switch multiple unit control. Locomotives, each equipped with four 150-horse-power motors for heavy freight service, are used, each locomotive unit weighing 40 tons, and can be operated separately, or any number can be coupled together and controlled as a single machine.

Toledo & Chicago Single-phase Railway. As an illustration of an extensive interurban single-phase railway system, the Toledo & Chicago Railway is typical. It runs upon single-phase current most of the distance, but through towns and at the terminal cities direct current is used.

The general scheme of electrification is as follows: Single-phase current is generated in the power house at 3,300 volts, at which pressure it is fed direct to the trolley for those sections of

the road nearest the power houses. For the more distant sections, the generator voltage is stepped up by transformers in the power house to 33,000 volts and fed to the sub-stations over the transmission line before being reduced to the trolley voltage.

The generators are two-pole revolving field machines connected on the Y-principle. Although the windings are of the three-phase type, the generators are normally connected for single-phase operation. While with this arrangement only two-thirds of

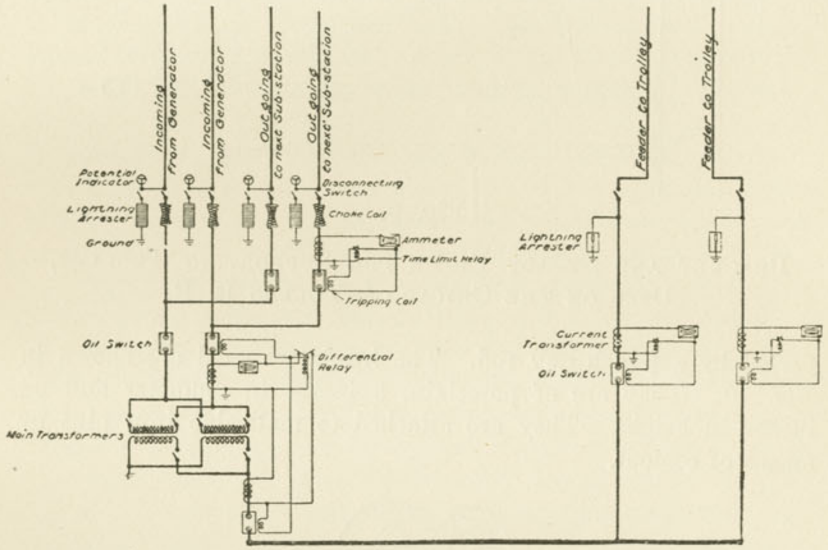


Fig. 8.

WIRING DIAGRAM OF SUB-STATION, USED WITH THE SINGLE-PHASE SYSTEM OF THE TOLEDO & CHICAGO R. R.

the copper is active, there is a spare phase for use in case of an accident to any winding.

The method of wiring the sub-stations is shown in Fig. 8. A three-phase transmission will ultimately be employed on this road, but for the sake of clearness the third phase is not shown.

The trolley construction is of the catenary suspended type, which consists of grooved No. 000 hard-drawn grooved copper wire and a seven-strand No. 11 steel wire messenger cable. The trolley is supported 20 feet above the track. When bracket construction is necessary the method shown in Fig. 9 is used. The bracket arms are made of $2\frac{3}{8}$-inch steel pipe. They are fastened to the poles by means of a flange and two lag-screws and are sup-

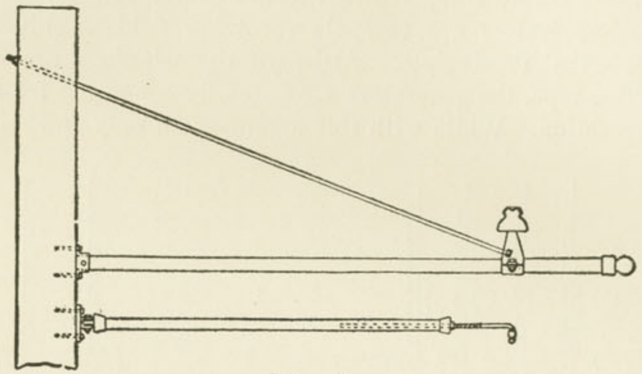


Fig. 9.

BRACKET AND STEADY BRACE FOR SUPPORTING TROLLEY, USED ON THE CHICAGO & TOLEDO R. R.

ported by a $\frac{5}{8}$-inch guy rod. The insulators used are shown in Fig. 10. They are of porcelain, 5 inches in diameter and $3\frac{7}{8}$ inches in height. They are attached to malleable iron pins by means of cement.

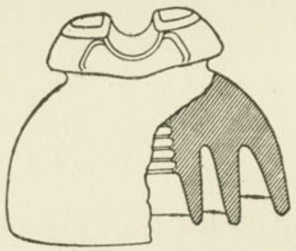


Fig. 10.

ALTERNATING CURRENT TROLLEY INSULATOR.

Changing from alternating current to direct current operation, or *vice versa,* is accomplished by means of a dead section in the trolley wire, which is made as long as possible without exceeding the span of the two trolley poles. At the instant the car enters

this dead section, whichever main switch is closed will open, owing to the fact that the circuit energizing its retaining coil is broken. The car can run over this dead section at full speed, and all the motorman has to do to make the proper connections is to throw the commutating switch and close the main alternating current or direct current switch, as the case may be.

In the event of the motorman closing the wrong main switch it will open the moment his hand is removed, since its retaining coil will not be energized. No harm will result from a motorman's closing the wrong main switch. If the alternating current switch is closed on the direct current trolley, the high-tension fuses will immediately open the circuit. Again, if the direct current switch is closed on the alternating current trolley, resulting in the trolley fingers of the commutator switch being subjected to 3,300 volts, no damage can be done, as they are insulated for 5,000 volts.

There are a large number of other roads using single-phase alternating current, but the above described transmission is representative of the most important points to be found on all of them.

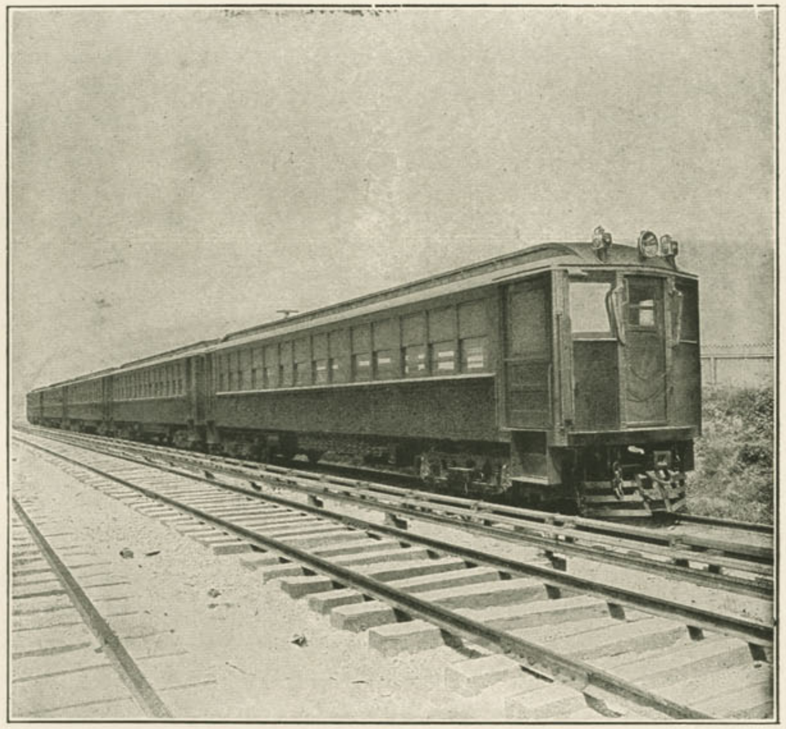
Polyphase Systems. Of the polyphase systems in use the three-phase system is the only one of importance to be considered. If the three-phase current is used for the distributing circuit, the system requires more than one trolley or collector. When three-phase generators are used in the powerhouse, however, the simplest means of alternating current railway distribution is to carry out the transmission scheme and sub-station connections by using one leg of the three-phase system and neglecting the other two phases as though they did not exist. In other cases the three-phase current may be carried to the trolley circuit, which may be divided into sections, each section being fed from a separate phase of the three-phase primary distribution system. This system secures the advantages of three-phase current generation and transmission, but requires a larger secondary distribution system. When the three-phase induction motor system is used, the same method of sub-station connections and primary distribution may be used as is used in the three-phase system which is converted by rotary converters to direct current, with the exception that in the place of the rotary converter sub-station transformer sub-stations may be used. This system, however, has had larger application in Europe than in this country.

Comparison of the Three-phase and Single-phase Systems. In comparison with the three-phase railway system using induction motors on the cars, the single-phase system shows the following advantages: Correct motor characteristic; all motors working at all speeds; greater number of efficient running speeds; voltage control; single contact line and collector; higher voltage on contact line; fewer and simpler transformer stations.

The disadvantages are: Less efficient motor; epuipments may be heavier; transmission line may be more expensive; larger and more expensive generators.

On lines with numerous or long, heavy grades, recuperation of power when running down-grade is practicable with single-phase equipments, as well as with three-phase equipments. The polyphase induction motors will return power to the line at only two speeds without resistance in the circuit, whereas single-phase equipments will do so at practically all speeds. In the act of recuperation of power the train is braked, and a large amount of the wear and tear on the wheels, brake shoes and track is avoided. To accomplish this result with single-phase equipments it is, of course, necessary to provide a certain amount of special control apparatus in addition to that ordinarily required.

Single-phase and Three-phase Transmission Lines. When alternating current is used directly in the car motor, it is possible to use either three-phase or single-phase transmission. Three-phase transmission to transformer stations is ordinarily equivalent to that for rotary sub-stations. When transformer stations are fed from a single-phase circuit at a given voltage, more copper will be required than for three-phase transmission at the same voltage, but at the same time the number of insulators is reduced with single-phase. The amount of copper required for single-phase operation may be reduced by going to a higher transmission voltage. On many interurban roads increase of voltage for this service is not necessary, because the 22,000 or 33,000 volts which would be ordinarily used for three-phase transmission would still be sufficient for single-phase transmission when making use of No. 6 B. & S. copper wires, and it is not desirable to go below this size on account of mechanical strength. In fact, many engineers prefer taking No. 5 B. & S. copper wire as the minimum size for transmission circuits.



FIVE-CAR TRAIN—LONG ISLAND RAILROAD
(Westinghouse Electric & Mfg. Co.)

With three-phase transmission and the transformer stations distributed among the phases, a sectional trolley is necessary, each station supplying its own section. With single-phase transmission there is a continuous trolley between feeding points, with the attendant reduction in the number of feeding points. Where three-phase transmission is employed the number of transformer stations may be made the same as with single-phase transmission by making use of three or two-phase transformation, the trolley being sectionalized in front of the station, and the two secondary phases feeding alternate sections of the trolley. In this case, however, there is a multiplication of apparatus in individual stations.

Consequently, the question of transmission reduces in general to either a single-phase line with a certain amount of copper and a certain number of insulators, or a three-phase line with one-third less copper and fifty per cent more insulators, together with either more feeding points or more apparatus per station. If the total cost for transmission and transformer stations is found to be greater with single-phase than with three-phase transmission, it is still a question whether it is not better to put the additional money into copper, which has a small rate of depreciation, and may even appreciate, rather than to have the additional units of transforming and switching apparatus and the increased number of weak points on the line which accompany three-phase transmission.

The maximum drop in the high-tension line should be not more than 10 per cent. With this maximum drop in the line the average loss will usually be 5 per cent or less.

Power Station for Single-phase Roads. The power house for a single-phase road will contain alternating current generators, D. C. exciters, switchboard, raising transformers, lightning protection, and high-tension switching apparatus. Aside from the generators, the power house apparatus does not concern the system particularly.

The generators may be either single-phase or polyphase. Polyphase generators have the advantage in first cost, but labor under the disadvantage of having the load unbalanced between the phases, with the attendant bad effect on voltage regulation, and of inability to concentrate all power along one section of the line if necessary. Single-phase generation requires larger and more expensive machines than three-phase, but the total power of the generating station is available on any section of the line, and the power house voltage may be maintained constant by the use of the Tirrill regulator, irrespective of the load conditions.

In this country the manufacturers of single-phase railway apparatus have up to the present time held to the frequency of 25 cycles. If power is available at a different frequency, and can be purchased to better advantage than it can be independently generated, the power house will be replaced by a frequency changing station containing motor generator sets. The motor generator sets may be driven by either induction motors or synchronous motors. In connection with them storage batteries may be used for reducing the peak load by the addition of a direct current machine which will act alternately as motor and generator.

As to prime movers, steam turbines operate particularly well under conditions of varying load, such as railway service, and in addition have a high economy. Gas engines also have been found to give excellent service in this class of work, even when operating alternators in parallel. In selecting the capacity of gas engines, however, it is necessary to determine fairly accurately the maximum load to which they will be subjected, because of the small definite overload capacity of this type of prime mover, with the present method of rating.

The generators may be wound for the trolley voltage, and power may be supplied to the trolley direct without any intervening transformers. Protection from lightning is furnished by choke coils in the trolley circuit before it leaves the power house, and by having the trolley line itself well protected.

With single-phase generators, shop power may be obtained by using single-phase induction motors or single-phase series motors, or direct current from the spare exciter may be utilized for this purpose.

Electric Locomotives. Until recently the field of electric locomotives has been largely confined to industrial, mine, and light freight haulage. The introduction of electric locomotives on various steam roads entering New York City, namely, the Pennsylvania, New York Central, and New York, New Haven & Hartford Railways, and their adoption for the St. Clair and Simplon tunnels, and for general freight haulage on the Spokane & Inland

Railway, indicate that another and heavier field for electric traction is open.

Different Kinds of Electric Locomotives. The electric locomotive may be divided into several classes, depending upon the kind of current used, the methods of mounting the motor and the body design. The electric locomotive can be made in different shapes, there being no standard outline at the present time. In

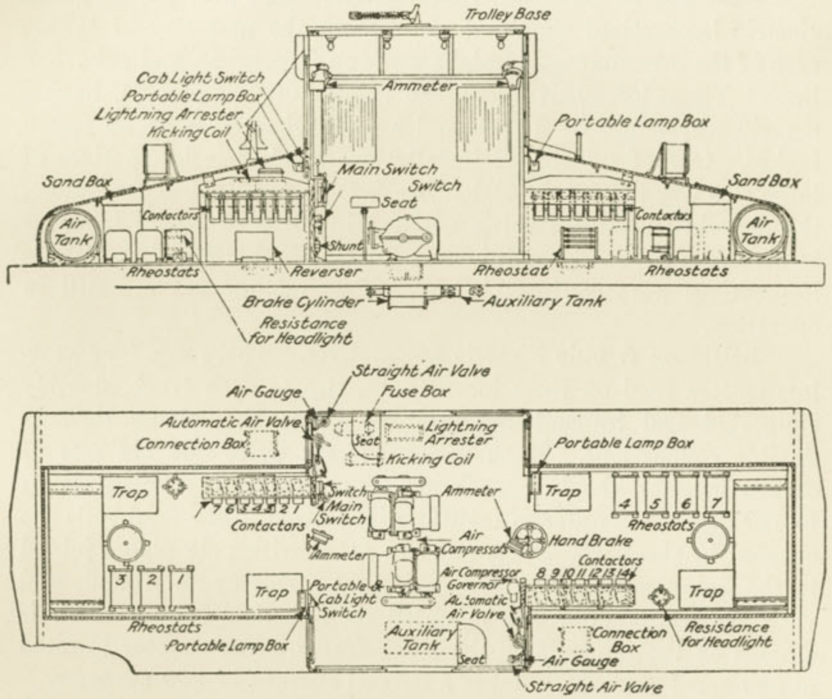


Fig. 11.

Arrangement of Apparatus on an Electric Locomotive.

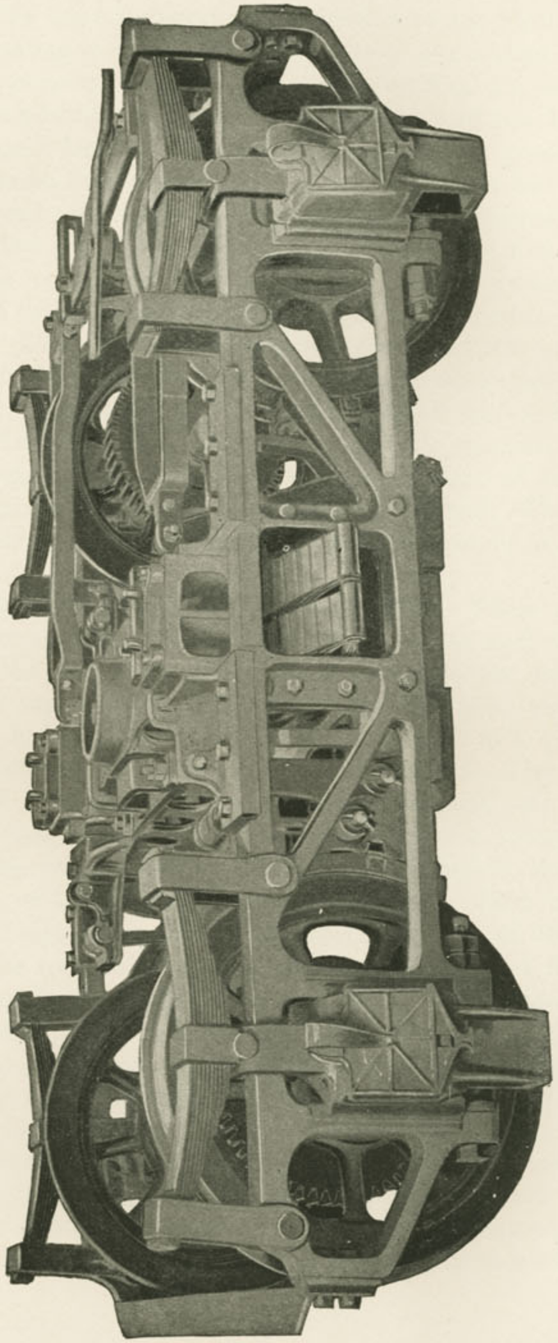
the smaller locomotives the motor is generally geared to the driving axle by what is called single reduction; that is, there is a small pinion on the armature shaft and a large gear wheel on the driving axle. By this method the armature can run much faster than the axle, and thus can produce counter electromotive force and speed. On the large electric locomotives, the motors are generally connected to the axle directly, no gearing being used.

The most important classification of the electric locomotive is according to whether it uses direct or alternating current. The direct current locomotive, as shown in Fig. 11, has many particular advantages for heavy propulsion and has been the more developed, but the alternating current system possesses so many advantages over a direct current system that it has of later years been used extensively for electrifying steam railroads.

First Use of the Electric Locomotive. The first use to which electric locomotives were put arose from the necessity of taking care of the miscellaneous freight work on interurban and suburban lines. These locomotives weighed about 100,000 pounds, having a rigid wheel base of 6 feet, and a total wheel base of 20 feet 6 inches. One of the earlier installations of electric locomotives of large size was that of the Baltimore & Ohio terminal at Baltimore, the electric locomotive being adopted in place of steam in order to overcome the smoke nuisance in the terminal. The first electric locomotives were equipped with gearless motors and are still in operation.

Baltimore & Ohio Electric Locomotives. There are four gearless motors used on these locomotives, two to each truck, flexibly supported and transmitting their power to the wheels through flexible connections. Each motor has six poles and six sets of carbon brushes, the brushes being connected to a yoke revolving to 360 degrees in order to facilitate inspection. The field coils are encased in sheet iron cases, and are fitted with pole pieces joined to the field frame. The armatures are series drum wound, and with the commutator are mounted on a hollow sleeve which is carried on the journals on the truck frame. Each motor is rated at 360 horse power, and takes a normal current of 900 amperes.

The controlling devices occupy the interior of the cab, which is placed in the center of the locomotive. The controller is located in one-half of the cab, and is of the series parallel type. The resistances are placed around the frame beneath the floor of the cab. The locomotive is equipped with an automatic circuit breaker, a magnetic cut out, and an ammeter and a voltmeter. Compressed air is used for the whistle and brakes, the air being supplied by an oscillating cylinder electric pump, the air tanks being placed at each end of the complete locomotive. The current is collected from the overhead wire by means of a sliding shoe of brass, which



MOTOR TRUCK—LOCOMOTIVE FRAME, SWINGING BOLSTER, USED BY THE NEW YORK CENTRAL AND HUDSON RIVER RAILROAD
(American Locomotive Company)

is fixed to a flexible support fastened to the top of the cab. This trolley support is diamond shape, and is coupled, contracting and expanding, as the height of the wire varies. It is also arranged to lead to one side or the other as the locomotives run on one side of the other of the overhead conductor.

The latter type of electric locomotive is used on the Baltimore & Ohio terminal road at Baltimore, and they are of the 160,000 pound geared type. The complete locomotive consists of two such units coupled together. As this type of locomotive is equipped with multiple control, the two units comprising the complete locomotive can be operated by a single operator in the leading cab. Owing to the rigid wheel base construction and the low center of gravity of this type of locomotive, its use is necessarily restricted to operation upon tracks having curves of large radius and for low speed operation.

New York Central Electric Locomotives. One of the most interesting types of electric locomotives is used on the New York Central Railroad, due to the fact that the motors of the gearless type were adapted in this construction. They weigh 200,500 pounds total, of which 142,000 pounds is on the four pairs of driving wheels. The tractive effort is 34,000 pounds, giving a ratio of 1 to 4.18 with the weight on drivers and 1 to 5.9 with the total weight. The normal horse power which can be developed is 2,200, or 550 horse power per motor. This, however, can be increased to 3,000 horse power at starting or for short intervals in running. The motors are of the gearless type, the armatures being mounted directly upon the axles of the driving wheels. The specifications call for a maximum speed of these locomotives of from 60 to 65 miles per hour, which, with the 44-inch driving wheels, will give about 460 r. p. m. of the motors. This speed is to be made with a 500 ton train. For trains of greater weight two of the locomotives can be coupled together and operated on the multiple unit system.

Power is transmitted from the drivers through the two main frames to the end casting, in which is located the draft gear. The cab is simply superimposed on these frames, and is built of light structural steel shapes and plates. The side frames are outside of the driving wheels and are made of cast steel. They extend continuously from end sill to end sill, and have the driving boxes fitted into pedestals in the ordinary manner, there being a difference from steam locomotive practice in that there are no wedges, both pedestal jaws being fitted with cast iron shoes. The end frames are heavy steel castings securely bolted to the side frames, and are fitted with pockets for the draft gear and platform springs. In addition to these there are five transverse steel castings, or cross ties, fitted and bolted to the side frames, there being one between each pair of drivers and one at either end just outside of the driving wheels. These transverse castings support the field magnets of the motors, the three center ones supporting a coil on either side, and the end ones supporting a coil on the inner side only, and having lugs on the opposite side for attaching the pony truck radius bar. The pony trucks, of which there is one at either end of the locomotive, are of the usual locomotive design.

The central portion of the superstructure, or the cab proper, consists of a large open room in which are located the motorman's controlling apparatus, which is in duplicate, one at each end, the electric air pump, and also a space in which is installed a boiler for steam train heating.

The engineer has at his right a large sliding window, and ahead a double sash window, the lower sash of which can be swung out and adjusted at any angle. At his left is the main controller with a long lever, resembling a throttle lever, in a position easily reached when leaning out of the side window. Immediately in front, below the front window, is located the engineer's brake valve, alongside of which is the air gauge. Within easy view are also located a volt and ammeter. To his right just below the side window is the valve controlling the raising and lowering of the trolleys, which are operated by air pressure, and just behind him is a valve for the air sanders, a bell rope and whistle cord are withinn reach, and two electric heaters are located on the front wall near the floor. All gauges are illuminated by shaded lamps. The switches for electric headlights, cab light, etc., are in the corridors.

The current is collected from the third rail by four shoes, shown in Fig. 12. These are carried from wooden blocks fastened to the locomotive frames, and are spring supported and arranged for a vertical play of about two inches. They are adapted for making contact with either over or under running third rails.

There are also two pantagraph type sliding trolleys, mounted on top of the locomotive for collecting current from overhead rails when necessary. These are raised and lowered by air pressure. Both the shoes and trolleys have a fuse placed in boxes lined with fireproof material and located on the outside of the locomotive, close to the point of contact.

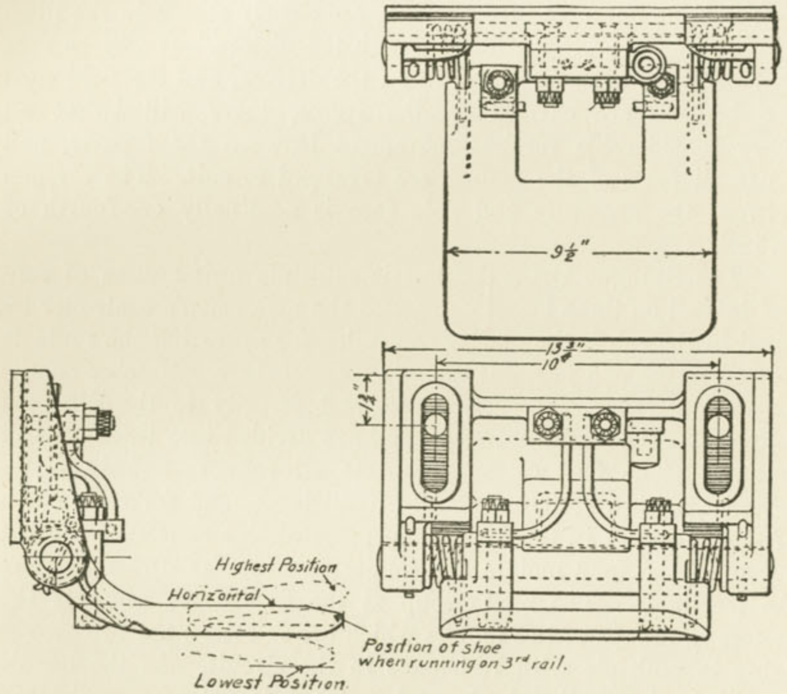


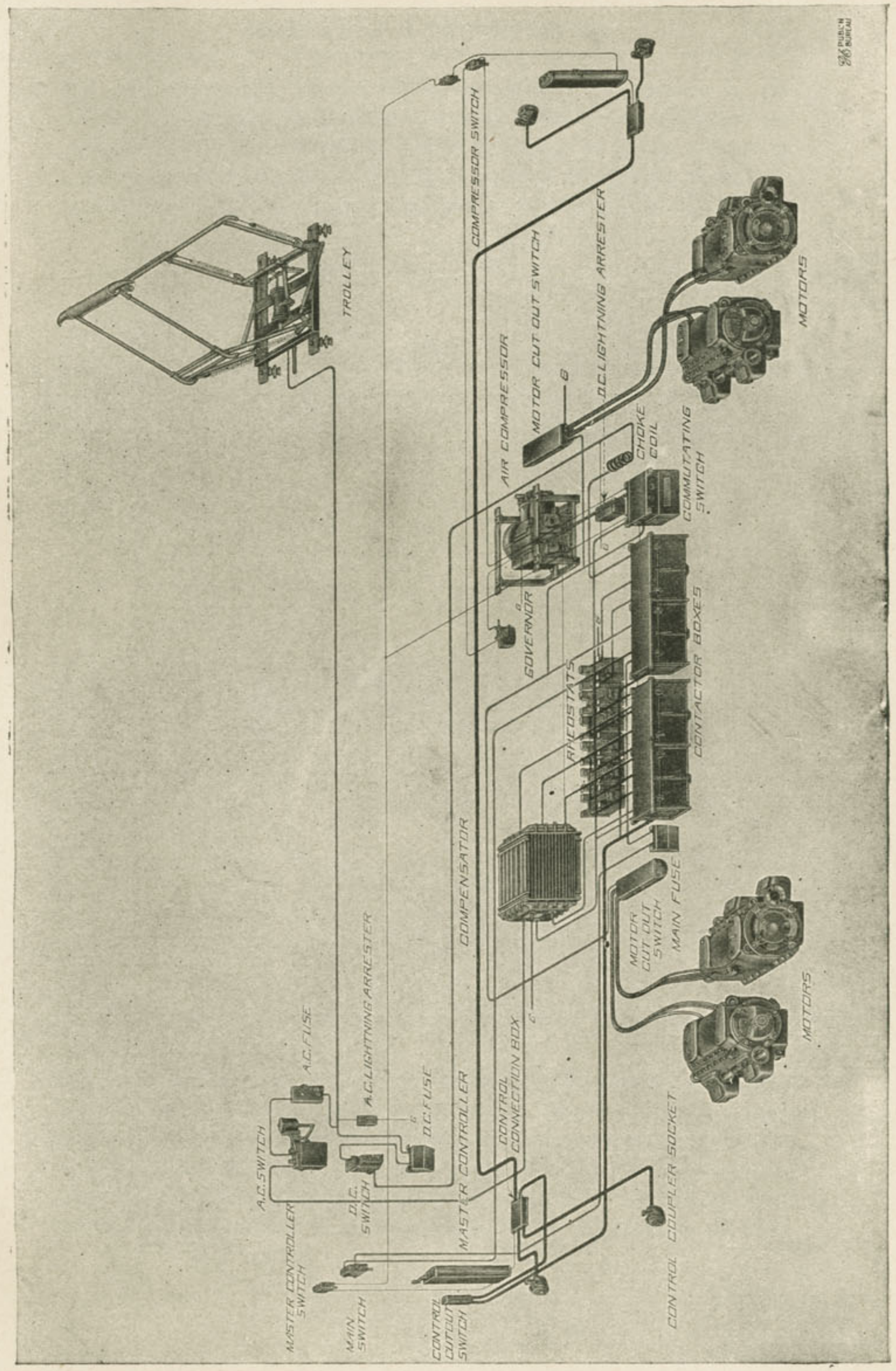
Fig. 12.

THIRD RAIL SHOE, USED ON THE NEW YORK CENTRAL ELECTRIC LOCOMOTIVES.

The motors are two-pole direct current series wound and are rated at 550 horse power each. They are built to withstand an overload of 50 per cent for one hour, with a rise of temperature not to exceed 75 degrees. The pole faces are made practically flat, so that the driving wheels with the armature can be removed by means of a drop pit without disturbing the field coils. The core of the field coil, as above mentioned, is integral with the steel cross ties, the faces being made up of laminated soft iron sections dovetailed into the cast steel cores and held in position by the field coils.

The brush holders are mounted on insulated supports secured to a lug cast on the frame cross ties, and are arranged to allow a considerable degree of vertical adjustment. This construction, as well as other features of the motor, are clearly shown in the illustrations of the cross sections through the motors. It will be seen that since the armature is rigid on the drivers, and the field coils and brushes are carried on the frame, there will be at all times considerable vertical movement between these parts, and hence all parts of the motors are arranged to suit. The air gap between the armature and pole face is nominally one-fourth of an inch.

The Sprague General Electric multiple unit system of control is used on these locomotives, and the motorman's controller located in the cab is the master controller for operating the contacts located in the end portions of the superstructure. Notches on the master controller, however, correspond directly to the different contacts on the main controller, and are divided into three general sections. The first section connects all four motors in series together, with a certain amount of resistance, and for each notch of the controller in the first group parts of this resistance are cut out until the four motors are connected in series directly across the terminals. The next group at the first notch connects the motors in groups of two motors which are in series, the two groups being in multiple with resistance in the circuit. As the handle is still further pulled back, each notch cuts out more resistance until it has all been cut out. The controller then passes to the third group, where all motors are connected in multiple, there being at the first notch of this group resistance in the circuit, which resistance is again gradually cut out until finally at the last notch the motors are given the full amount of current when connected in multiple. The resistance consists of flat grids of cast iron mounted in cast iron frames from which they are insulated. The connection to the controller contacts is made by heavy copper bars. Cast iron is used for resistance because it is cheaper, has a high specific resistance and will stand a large amount of heat before any danger of short-circuiting. In order to prevent burn-



ARRANGEMENT OF SPRAGUE GENERAL ELECTRIC TYPE M CONTROL ON CAR ing out the motors by too rapid reduction of resistance in the circuit before they have come to speed, there is an electrical arrangement in the controller, which prevents it being moved to another notch before the motors have reached the proper speed. It is also impossible to move the controller handle unless the revers-

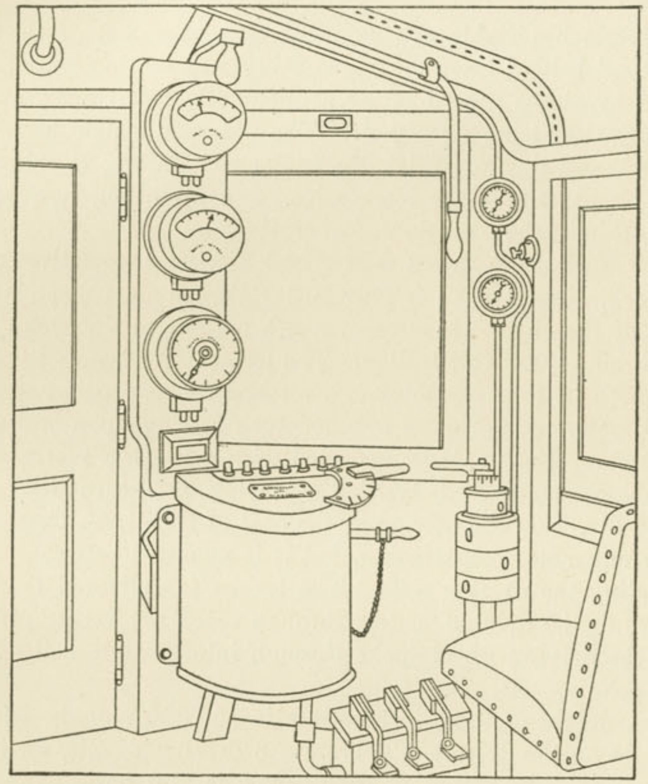


Fig. 13.

INTERIOR OF CAB, NEW HAVEN ELECTRIC LOCOMOTIVES.

ing lever is fully thrown either forward or backward; this prevents burning out, caused by the controller handle being in a mid position before the current is thrown on by the reversing lever.

For the air brake and other pneumatic devices there is located in the cab a double cylinder air compressor driven by two general electric 600-volt series motors. The appearance of this compressor is shown in one of the illustrations, and its construction is made clear by the cross-section. It has a capacity of 75 cubic feet of free air per minute, and is controlled by a governor, which automatically cuts the motors in and out of the circuit when the air pressure falls below 125 pounds, or exceeds 135 pounds.

Electric headlights are mounted on either end of the locomotive, and behind them on one end is a regular locomotive bell, operated by either a cord or by a pneumatic bell ringer, and on the opposite end is an air whistle. The end upon which the whistle is located, and toward which the brake rod pushes, is called the "A" or front end of the locomotive. No attention, however, is given to this in the direction of operation.

New York, New Haven & Hartford Electric Locomotives. The New York, New Haven & Hartford Railroad uses electric locomotives of the single-phase type, which operate at 25 cycles from an overhead 11,000 volt trolley. The locomotives are more or less unique both in type of motor and method of suspension adopted. The locomotive comprises a sub-structure resting upon two 2-axle bogie trucks. Each axle is equipped with a gearless motor of the single-phase compressed type, the motor armature not being mounted direct on the axle as in the case of the N. Y. Central direct current motor construction, but it is mounted between a quill surrounding the driving axle. The torque is delivered from the armature to the driving wheels through seven projecting pins engaging the driving wheel spoke through intermediate coil springs in the spoke sockets.

The weight of these locomotives is 190,000 pounds, with all the weight on the drivers. There are 8 driving wheels, 62 inches in diameter. The rating of each motor is 250 horse-power, the operating voltage of each motor being 225 volts. In these locomotives both the step-down transformer and the motors themselves are cooled by forced ventilation. Fig. 13 shows the interior of the cab of this type of locomotive.

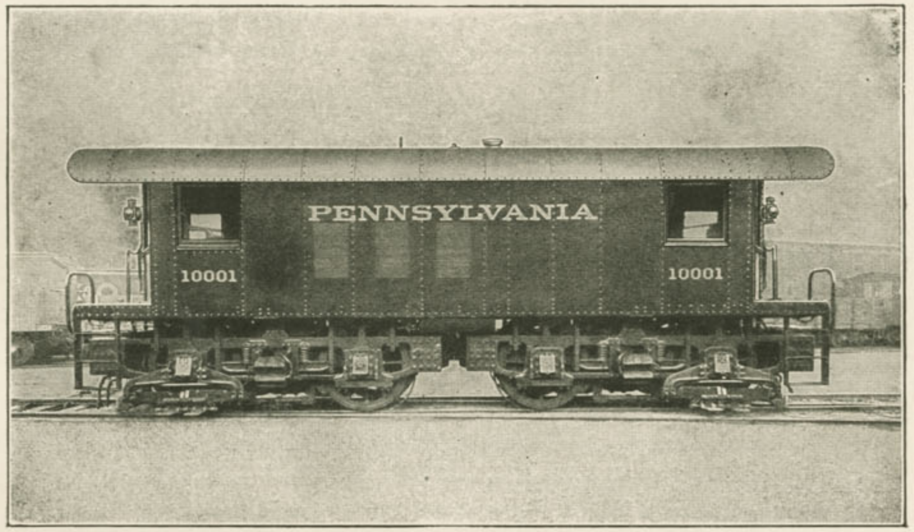
Comparison of Steam and Electric Locomotives. Some of the general points in favor of electric locomotives for heavy traction work as against steam locomotives are as follows:

The steam locomotive develops its maximum horse-power at high speeds, consequently in starting large loads and in ascending heavy grades the locomotive is working at reduced output and reduced efficiency. The electric locomotive will, with few exceptions, give increased horse-power with increased load up to the point of slipping the wheels. The electric locomotive may be designed with the entire locomotive weight on the drivers, and thus the percentage of dead weight in a train be reduced to a minimum. Two or more locomotives may be operated as a single unit without increase in train crew over the number necessary for one unit, the limit in the number of units so operated being determined by the maximum draw-bar strains which the draft gear of the train is capable of withstanding. This multiple operation without increase of train crew becomes an important factor in the electrification of mountain grades, where there are heavy trains operated at frequent intervals. A system using electric locomotives obtains the benefit of a centralized power house and its consequent economy. The great flexibility of electric systems is also an important item. Practically all of the power of the generating station may be concentrated on a particular section if necessary. With electric locomotives stops for taking on water and coal are abolished. Increased speed on grades is possible. This is an important item where a section of road has reached the limit of its capacity with steam operation, both as to the number and size of trains. With three-phase or single-phase locomotives there is the additional advantage of recuperation of power from trains on descending grades. The building of electric locomotives in capacities comparable with existing steam locomotives is no longer a mere possibility. It has been accomplished in recent years with direct current equipments, and within the past two years two distinct types of single-phase locomotives have been developed and built, whose operation may be compared to that of steam locomotives. The locomotives for the St. Clair tunnel are comparable to steam freight locomotives, and the locomotives of the New York, New Haven & Hartford Railroad are for a distinctly high-speed service.

Tests of Electric Locomotives. Some very satisfactory figures have been obtained in respect to the acceleration and high-speed qualities of the electric locomotive. One of the most interesting tests was made in actual competition, or race, between electric locomotive No. 6000 of the New York Central and a large Pacific type passenger locomotive, which had approximately the same weight on drivers, both locomotives hauling the same weight train. A series of runs with varying conditions were made, and it was found at that time that the electric locomotive was capable of an acceleration of .394 miles per hour per second to about 50 m. p. h., while the steam locomotive was capable of but .246 miles per hour per second. Also that the time required to reach a speed of 50 miles per hour with a six-car train weighing 407.5 tons for the electric and 427 tons for the steam, was about 127 seconds for the electric and 203 seconds for the steam, which shows wherein the biggest advantage from an operating standpoint of the electric service lies. In this series of tests it was shown that the electric locomotive was capable of attaining over 85 m. p. h. when running, although this locomotive was not designed for specially high speeds. Accurate figures were also obtained on the cost of operating and maintaining the electric locomotives, as compared with similar figures for the steam locomotive, which were very low.

Rating and Capacity of Electric Locomotives. The rating of a steam locomotive is based on the maximum tractive effort which it is capable of giving, while its capacity depends on the maximum speed at which this tractive effort may be developed. The maximum rate of doing work, therefore, for which it is possible to design a steam locomotive is established by practical limitations as to steam capacity of the boiler and width and length of the firebox. The electric locomotive, on the other hand, does not generate its own power, but merely acts as a transmitting medium through which electric power delivered to the locomotive is converted into mechanical power at the driving axles. Each driving axle of an electric locomotive being equipped with a motor, the size and horse-power of which is limited by the speed at which it operates, by the gauge of the track, and by the diameter of the wheels, it becomes only necessary to provide a sufficient number of driving axles to permit the electric locomotive to deliver the greatest tractive effort that the draw bars of a train will stand at any speed permitted by considerations of safety in operation and reasonable cost of track maintenance.

The rating of the electric locomotive, like the steam locomotive, is based on the maximum tractive effort the locomotive will exert for short periods of time, fixed by mechanical considerations,



87-TON ELECTRIC LOCOMOTIVE USED IN THE PENNSYLVANIA TUNNEL, NEW YORK CITY
(Westinghouse Electric & Mfg. Co.)

such as weight on drivers, and by electrical conditions, such as overload capacity of the motors. The capacity of the electric locomotive, on the other hand, is determined by the heating of the motors in continuous operation, this heating being dependent upon the operating conditions, such as length of run, grade, curves, weight of train, schedule speed, number and duration of stops and lay-overs.

In order to provide a margin to cover changes in assumed operating conditions and possibility of occasional increase in duty, the estimated temperature rise in service operation should not, as a general rule, be greater than 60 to 65 degrees C., although occasions may infrequently arise where a higher value may be safely taken.

Types of Motors Available for Railway Service. There are three types of motors available for railway service, which depend upon three systems of distribution. First, the direct current series motor of 600 to 1,200 volts, fed from rotary converter or motor generator sub-stations which are operated upon high potential, three-phase, alternating current transmission systems; second, the alternating current series motor, which is fed directly from an alternating current high potential transmission system through intermittent step-down transformers; third, the alternating current three-phase induction motor fed directly from an alternating current three-phase transmission through step-down transformers.

Series Motors. Owing to the fact that all railway motors are subjected to a heavy load on starting, a series wound motor has been found far superior to that of any other type. The series wound machine is one in which the current which goes to the armature also flows with the same intensity through the field circuit, and consequently, the windings of the field being large, they are able to withstand heavy overload currents which at times come upon them. They are built with a commutator having brushes which are used to distribute the current. The armatures are built of thin, soft iron laminations which are keyed to the shaft. The windings of the armature are of the series drum type, the number of coils on the armature depending upon the class of service which the motor is to render.

Since a series motor is always operated upon a constant potential circuit, the armature speed will increase until it reaches a value where the counter electro-motive force cuts down the armature current to such a point that the power of the motor is equal to the sum of the fixed losses, the variable losses and the usual mechanical power taken out to the car. Upon the removal of the load a series motor tends to increase its speed, and in this manner increases the counter electro-motive force, which, however, results in weakening the field, which causes a small change in load to give a wide change of speed. It is evident in a series motor that while the motor is at rest and the circuit is closed an enormous result of current would occur giving an enormous torque, which if allowed to continue would cause destructive heating and probably damage to the motor. To prevent this it is usual to insert a series resistance in the circuit, which may be cut out as the speed is increased sufficiently to give the proper counter electro-motive force. In practice, controllers are used for this purpose. Series wound motors, however, have been perfected to such an extent that they will stand a wide amount of abuse. They are consequently built stronger, and they are either water-proof or encased in a waterproof shell in order to protect them from the weather. They are suspended under the car either by means of the side bearing, the cradle, the nose or the yoke suspension. In each case one end of the motor frame contains bearings which run on the wheel axle.

Characteristics of Series Motors. The series motor, whether direct current or single-phase, is particularly suited to traction work because of its characteristics. At heavy loads the speed is low and the tractive effort large. At light loads the speed is comparatively high and the tractive effort low. One result of these characteristics is that when starting with a given acceleration the motor is running at full voltage sooner than would be the case with a constant speed motor, and so is subject to control losses for a shorter period, thus reducing the power consumption. In addition to this, the speed of the motor accommodates itself to the profile of the road, running slower on grades where a large amount of tractive effort is required, and speeding up on the level where the necessary tractive effort is small. The result of this characteristic is to somewhat equalize the horse-power drawn from the line under varying conditions, and to minimize the heavy loads drawn from the line in ascending grades or starting.

Single-phase Motor. The single-phase motor is of the series type; that is, the same current passes through the field and armature windings. Its operation on alternating current depends on the same principle which makes it operate on direct current. The armature of the motor may be considered as a single coil between brushes. The brushes are so placed that this coil has the maximum torque. The direction of rotation depends upon the relative direction of the magnetic field and the current in the armature. When alternating current is applied to the motor, the direction of field magnetism changes each time the direction of current changes; consequently, with fixed relation between field and armature windings, the rotation is always in the same direction on alternating current as on direct current.

Series Motors Used on Single-phase Circuits. In adapting the series motor to alternating current operation, certain difficulties are encountered which are not present in the operation of a series motor on direct current. In the coils, which are short-circuited by the brushes, the alternating field magnetism induces a local current which may be comparatively large, the action being similar to that of a transformer. As the armature revolves, the short-circuit currents are broken every time a commutator bar passes from under a brush, and this produces more or less sparking at the brushes. In order to overcome this sparking, preventive leads are inserted in the armature circuits between the commutator bars and the main coils, thus introducing additional resistance into the short-circuit portions of the armature and consequently reducing the short-circuit current. These preventive leads are proportioned to minimize the armature copper losses.

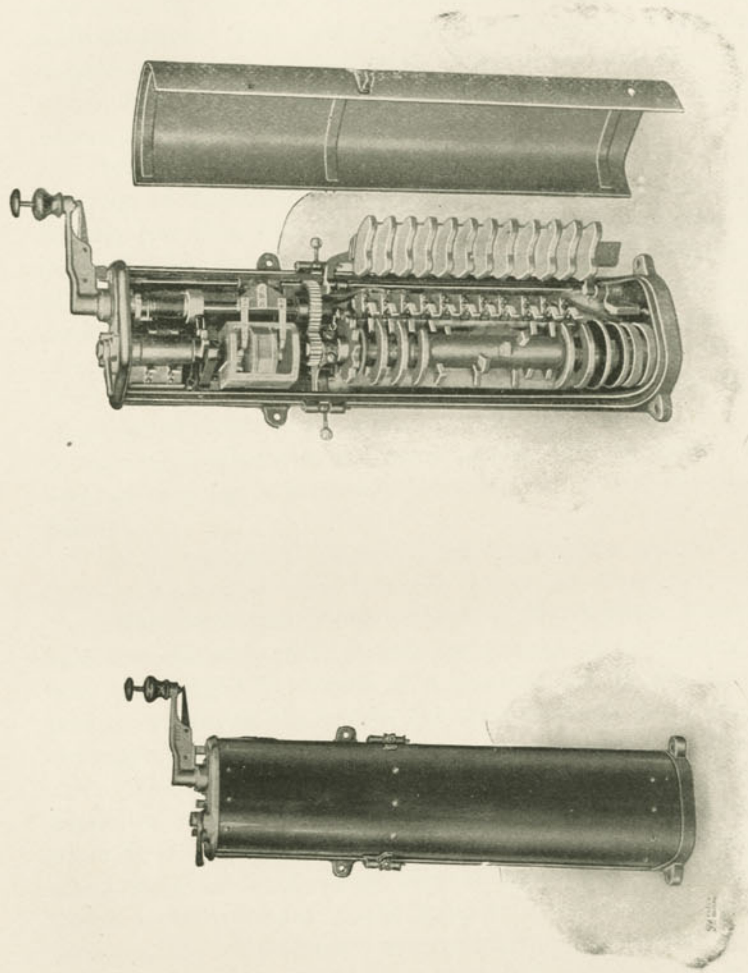
Power Factor of Single-phase Motors. The power factor of the single-phase motor is less than unity because of the self-induction of the field and armature windings. It is advisable to keep the power factor as near unity as possible, for additional current must be supplied for a given amount of actual work when the power factor is low. The self-induction of the field cannot be entirely done away with, but it may be reduced by using a weak field. The effect of using the weak field is to reduce the air gap of the motor and the number of turns in the field coils.

The self-induction of the armature is additive to the self-induction of the field, thus tending to lower the power factor of the motor. However, it is not an unavoidable adjunct of any feature necessary to the operation of the motor. This self-induction of the armature is neutralized by the auxiliary or compensating winding, which is connected in series with the other motor windings, and is so disposed that its resultant magnetic field is directly opposed to, and equal in amount to, the magnetic field due to the armature's self-induction. This neutralization of the armature self-induction decreases the total self-induction of the motor, and thus raises the power factor above what it would be without the neutralizing winding.

Torque of Series Motors. In series motors the torque is a function of the current, the torque with alternating current being slightly less than with the same direct current and same arrangement of fields, partly because of the decrease in the effective value of the field magnetism with alternating current, and partly because of the demagnetizing effect of the short-circuit current. The torque, in starting with a given current, is practically the same as when running with the same current, and consequently the single-phase series motor is not subject to the difficulty which is present in starting single-phase induction motors, and no special arrangement of winding is necessary for obtaining all the starting torque desired.

In the matter of efficiency, the single-phase motor is of from 3 to 5 per cent less effect than the equivalent direct current motor.

Advantages and Disadvantages of Single-phase Motors. The ease and efficiency with which the voltage of alternating current may be changed by means of a transformer on the car make it possible to design the motors for comparatively low voltage without regard to what trolley voltage may be desirable in a particular case. The use of a multiple circuit winding on motors above 50 horse-power balances the magnetic pull on the armature even when it is slightly out of center. The single-phase motor will stand some kinds of abuse without experiencing the bad results which such treatment would bring to direct current motors; for instance, the brushes may be grounded or short-circuited without producing bucking or flashing, and full voltage may be applied directly to the motor at standstill. Over against these advantages there is the disadvantage that when stalled the motor cannot be subjected to a heavy current for so great a time as could a direct current motor without danger of injury to the preventive leads.



MASTER CONTROLLER USED ON THE SPRAGUE MULTIPLE UNIT CONTROL
(General Electric Company)

This is not a matter of great importance, however, as intelligent operators will not subject their motors to such treatment, whether they be operating single-phase or direct current equipments.

Construction of Single-phase Motors. Mechanically the motor is of the box type. The field is laminated and held in a solid steel shell. It is built with inwardly projecting poles, around which the strap-wound main field coils are placed, as in the direct current motor. The pole faces are slotted for the reception of the neutralizing winding, which resembles in appearance the stator winding of an induction motor.

The armature is similar to a direct current armature in general construction, and is strap-wound for capacities above 50 horse-power. The regular armature winding is connected to the commutator bars through the preventive leads, instead of directly, as is the case with direct current motors. The arrangement of the preventive leads is such that two leads are in circuit with each short-circuited coil, where a proportionately high resistance is required to reduce the short-circuit current, and yet only two leads are in the circuit between adjacent brushes, where a comparatively low resistance is desirable in order to reduce the C^2R loss due to the working current.

The commutator is similar to the direct current commutator, but is somewhat larger. To reduce the voltage induced by transformer action upon the short-circuit coils, the armature winding has a single turn per coil and a larger number of coils per circuit than a similar direct current motor. Consequently the commutator has a relatively large number of bars. In operation, perfect commutation is obtained and the commutators take a good polish. Where sparking has occurred with excessive overloads, or due to improper adjustment of the brushes, it has been found to be less destructive than direct current sparking.

The brush holders are of the sliding shunt type, and are supported by babbitted seats on the frame. The use of multiple circuit windings necessitates supplying one set of brushes per pole. The low voltage used gives comparatively large current, which necessitates increased brush capacity. The bearings are similar to those supplied with modern direct current motors, and oil and waste lubrication has proved altogether satisfactory.

Operation of Single-phase Motors on Direct Current Circuits.

The refinements in the design of the series motor, which adapt it to operation on alternating current, result in making it an improved direct current. Its operation from direct current is, however, somewhat more severe than for a similar direct current motor, because of the greater insulation strains due to the fact that the field discharge is more severe with laminated field poles than with solid field poles. The torque on direct current is somewhat higher than on alternating current. Equipments which are to operate on both alternating and direct current may be arranged to operate on alternating current with the fields in multiple. This enables a suitable speed for direct current suburban operation, and may be obtained by utilizing full voltage with the fields in series.

The satisfactory operation of the direct current series motor has made it possible to use the single-phase system of railway operation with its attendant advantages.

Three-phase Induction Motor. The three-phase induction motor has its greatest use when long distances are run without stops, as it is generally unfitted for rapid transit service with frequent stops, owing to the fact that it is a constant speed motor, its speed dropping only about 15 per cent from no load to full load. During the period of acceleration, therefore, this type ot motor has the disadvantage of requiring a high speed at all speeds, a condition which requires a heavier load on the power house as compared with either the direct current or alternating current series motor, and for this reason it has been very little used.

While this type of alternating current motor possesses certain advantages, there has been only one installation of this kind used in America, but for certain classes of work the three-phase induction motor is well adapted. This type of motor is perfectly reversible without entailing the addition of auxiliary apparatus required with the direct current series motor. It can be made to regenerate on down grades, which constitutes one of the strong claims presented for this type of equipment for a down grade service. By this method not only is some of the energy of the train reclaimed, but this system of control offers a separate means of holding trains on down grades other than exists from the present air brake control. The three-phase induction motor being practically a synchronous motor, there is but a maximum of 10 per cent difference in speed between full load and when running free. It follows practically the same law as the direct current shunt motor, without having the advantage of this latter type and without being able to vary the field intensity. The three-phase induction motor is practically a constant speed motor, its speed dropping only approximately 12 per cent to maximum at tractive effort developed during this acceleration period. This type of motor has the disadvantage of demanding full current up to its free running speed, and consequently is unfitted for rapid transit service where frequent stops are demanded.

Factors Governing Choice of Electric Motors. In the choice of an electric motor for a given service, the first determining factor is the maximum tractive effort required. This must be determined from the examination of the grades, alignment, loads and schedule of the road. As the same tractive effort may be obtained with different gear ratios, it is in the choice of this factor that considerable care is required. Continued overloads will cause the temperature in the coils to rise to a point where the insulation chars and finally breaks down. This is a factor that is entirely absent in steam railroad practice, because if a locomotive will give the required tractive effort at the required speed it will do its work. If it is overloaded or even becomes stalled no harm is done, consequently the selection of a motor which will not overheat is also an important factor in the choice of a motor.

The motor which best answers these requirements is a series wound slow speed machine. It is suspended in various ways from the truck, and is geared to the axle with a single reduction system. Double trucks have either a two or four motor equipment. The features of this type of motor are a tractive effort that varies more or less inversely as the speed, compactness, heavy overload capacity, and durability and reliability under more adverse conditions. Owing to the great variation in its load under ordinary conditions, it cannot be rated in horse-power for a given time, but must be rated by a uniform current and voltage necessary to produce a certain standard temperature rise in a given time over that of the surrounding air. The diameter of wheels used for this service is either 36 or 42 inches.

The speed of a series wound motor is always directly proportional to the voltage, proportional to the wheel diameter and inversely proportional to the gear ratio. The tractive effort is directly proportional to the gear ratio.

Geared and Gearless Motors. Railroad motors which are now used may vary from the small seven horse-power motors double geared to trucks to the large 550 horse-power gearless motor which is used on large 100 ton locomotives. The rearly direct current series motor was designed with double gearing. This was substituted for the single gearing, which is common practice to-day. With the electrification, however, of the electric motor to high

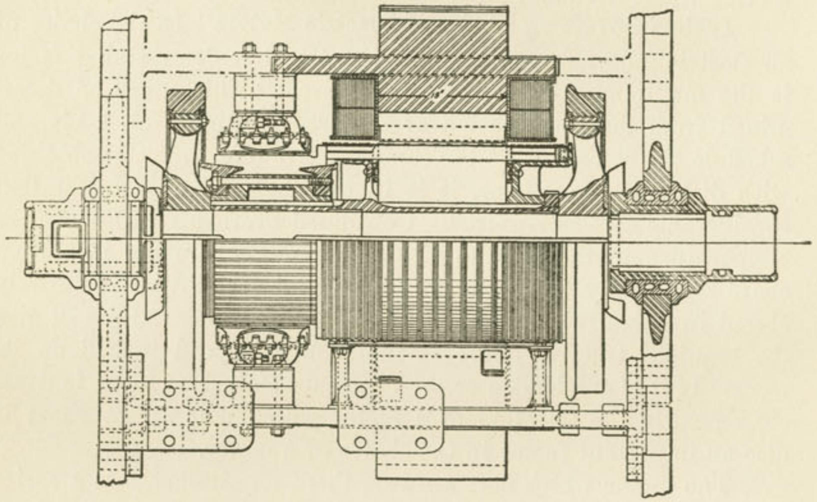
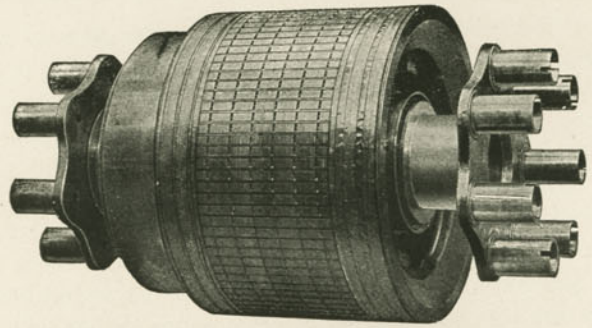


Fig. 14.

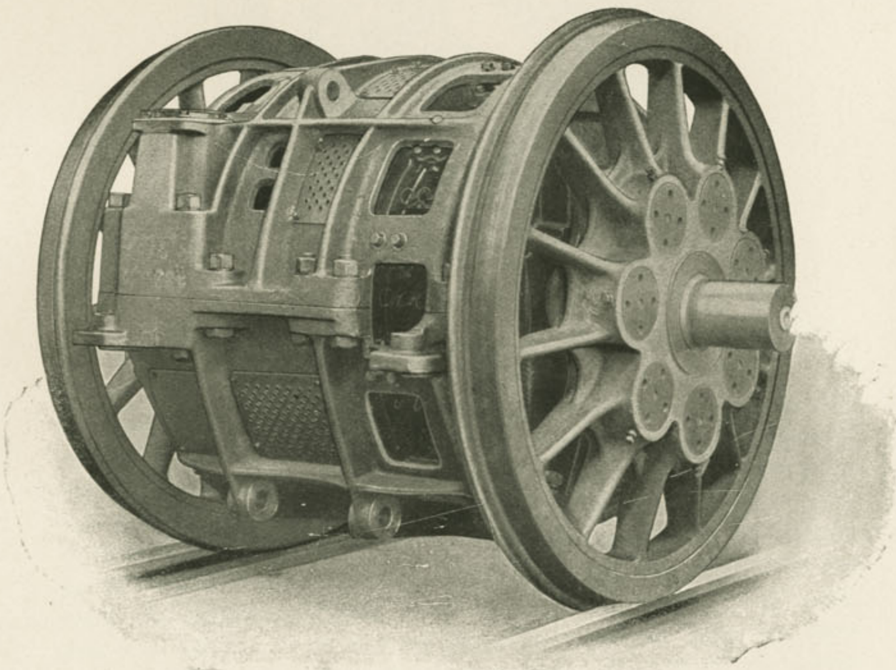
PLAN AND SECTION OF GEARLESS MOTORS, USED ON THE NEW YORK CENTRAL LOCOMOTIVES.

speed locomotive service, the gearless motor is the latest make in direct current series motor design.

The type of motors, as shown in Figs. 14 and 15, known as the "gearless" or "direct connected," belongs to the class in which the armature speed and the axle speed are the same. The power is transmitted either by a parallel rod from a crank on the motor shaft to a crank on the axle, or the armature is made concentric with the axle; that is, the axle is practically the armature shaft. When the armature is concentric with the axle, it is sometimes



ARMATURE AND DRIVING DRILLS, A. C.—D. C. NEW YORK, NEW HAVEN & HARTFORD RAILROAD



SINGLE-PHASE MOTOR AND DRIVING WHEELS, A. C.—D. C. LOCOMOTIVE, NEW YORK, NEW HAVEN & HARTFORD RAILROAD

(Westinghouse Electric & Mfg. Co.)

fixed rigidly thereon, or is placed in a hollow spool or sleeve which surrounds the axle and drives it by means of a clutch or drag link.

Among the objections to the gearless motor are the following: First, it is undesirable to have more dead weight than is necessary on the axle, owing to the damage to the rail by the shocks produced by rigid masses going over the joints. Second, the shocks from rigid weight are detrimental to the axle, and the jarring of the motor, armature and commutators with a rigid construction causes deterioration of the insulation and rapid wearing of the bearings. The shocks cause loose parts to shave and cut through

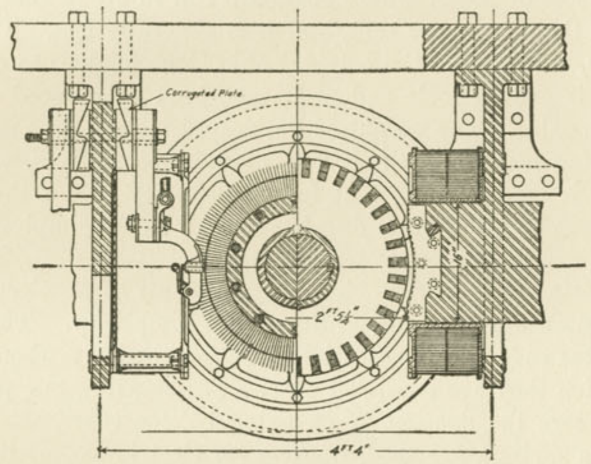


Fig. 15.

End Elevation and Section of Gearless Motor.

the insulation. Third, the sleeve construction is complicated and expensive, as the sleeves must be made of the best quality of forged steel. The bearings of the sleeves in the field magnets are difficult to keep cool. The oil from the driving boxes of the locomotive is thrown on the motors, and is liable to damage the insulation. In this form of construction, as well as where the armatures are rigid, the repairs to wheels, axles and motors are difficult to make, and it is impossible to remove the axles or wheels from the locomotive without removing the motors also. To rewind the armatures or fields often requires the removal of the axles from the driving wheels by hydraulic pressure.

Among the advantages of the geared motor are the following: With a geared motor the speeds of the armatures and axles are independent. The ratio of the gearing regulates the relative speed, and the gearing can be changed so that an express locomotive for high speed can be made suitable for freight work by simply changing gears, without any other change in the machine. The wear on the gears is small, and, as they are made in halves, they are easily replaced without removing the wheels or motors from under the locomotive. The axles and motors being independent, one can be removed without disturbing the other.

The loss of power where gears are run in oil in gear cases is not more than three per cent, and it is generally less. The noise and wear, which were the original objections to the use of gears, have, by improved tools and materials, been so reduced as to be unobjectionable. The weight of the geared motors is so much less as to reduce materially the cost of electric locomotives, while the efficiency is increased; so that for all ordinary speeds the geared motor is efficient, light and durable, as well as the simplest in construction and the easiest to maintain.

Electric Motor Trucks. The requirements of an electric locomotive truck are strength, stiffness and simplicity. They must also possess easy riding qualities, more particularly when the car upon which they are equipped carries passengers. For passenger types of cars the floating or swinging bolster types, with trucks carried on springs, are used, whereas for electric locomotive trucks rigid bolsters are sometimes used on account of their simplicity. In the swinging bolster type the bolster is solidly fastened to the side frame, the spring suspended car body being sustained by means of swinging springs placed between the side frames and the journal boxes. Since this type does not allow for the swaying of the car body, it is not generally adapted for high speed or track service.

The swinging bolster truck is the one most generally used for high speed passenger service. As shown in Fig. 16, the type used on the Delaware & Hudson Railroad, the swinging bolster construction, comprises a movable bolster traveling in a guide and mounted upon elliptical springs somewhat similar to the floating bolster type. It is built with wrought iron frame, channel iron transoms, cast steel transom gussets, swinging bolsters, and two

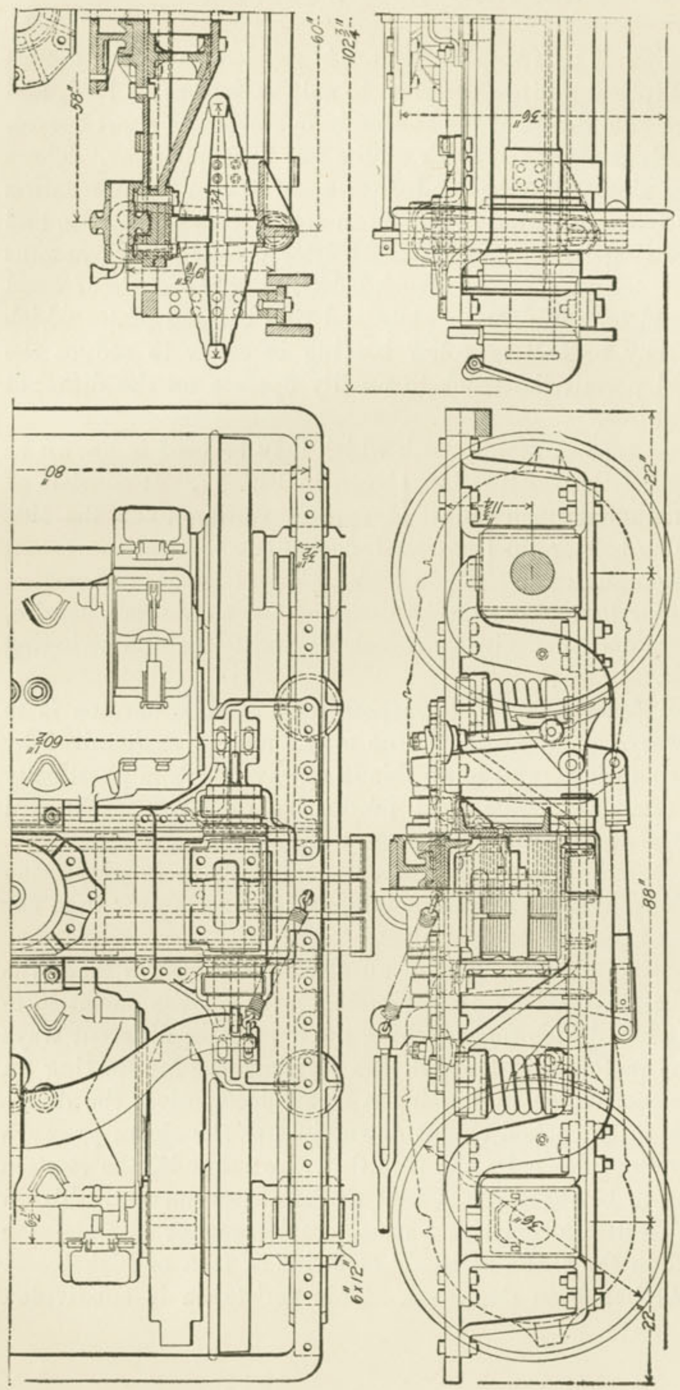


Fig. 16.
Motor Truck—Bar Frame, Swinging Bolster, Used by the Delaware & Hudson Company.
(American Locomotive Co.)

bar equalizers. The swinging bolster is carried on either double or triple elliptical springs designed to suit variations in load, and allowing for side thrust of the bolster in operation on short curves. The coil springs carry the truck on the two bar equalizers. There are rubbing pieces between the bolster and transom for preventing the bolster from clamping or tilting in starting and stopping, and for transmitting the strains on the bolster through the transoms to the side truck frame. The truck bolsters may be made of wood or metal, and both the center plate and side bearing plates which it carries may be ball or roller bearing in order to reduce the friction and permit the truck to readily operate on the different track curvatures.

Another type of motor truck which may be used is known as the floating bolster construction, shown in Fig. 17. It consists of a bolster mounted upon elliptical springs resting upon the side frames. The bolster thus has an independent vertical movement and travels on guides on the side frame. This type of construction is adapted for locomotive trucks designed for slow speed service. It, however, does not give as much flexibility as the swinging bolster type.

Control Apparatus. The purpose of control apparatus is to supply power from the contact line to the motors as required by operating conditions, and to do this in a way which is practically the most economical, the least productive of large mechanical strains in the equipment and the most comfortable for passengers. The ideal control takes power from the contact line in proportion to the work being done by the motors, and the apparatus used for this purpose is called the controller.

Controller. A controller on an electric locomotive takes the place of the throttle and the reversing lever on the steam locomotive. It is a device for switching the current in different ways through the motors and through the resistances. In starting an electric locomotive, as in starting a steam locomotive, the direct current has to be choked or cut down, just as the steam pressure is choked or cut down by the throttle valve; that is, the electric current has to be throttled as well as the steam current. To do this on an electric locomotive a considerable amount of resistance is provided in the shape of bands or strips of iron or nickel-steel arranged as has been described. This resistance is subdivided

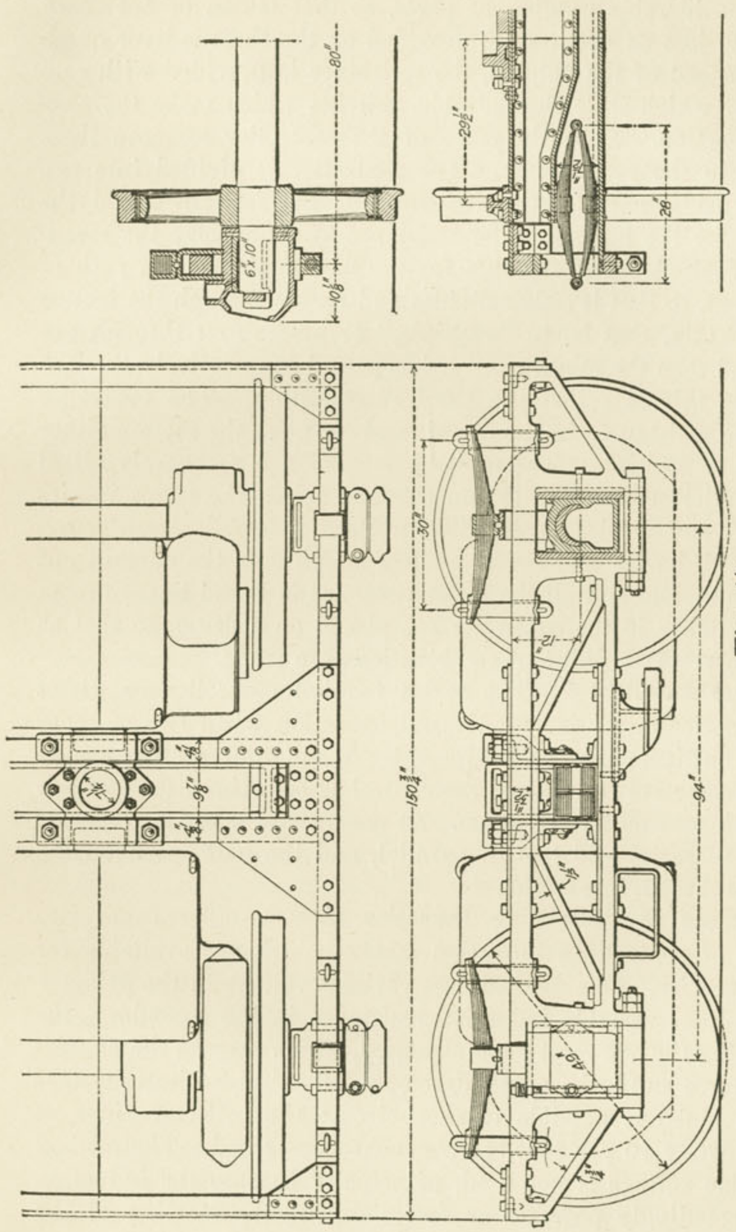


Fig. 17.
Motor Truck—Locomotive Frame, Floating Bolster.
(American Locomotive Co.)

into a considerable number of parts, so that it can be cut down gradually, just as notches are provided on the throttle-lever quadrant. Instead of the notches, the resistance is provided with contacts over which slide the movable switches which make the electric connection. It is the office of the controller to move these switches in the proper way. The controller is divided into two distinct parts, namely, the switches for the resistance and the switches for the motors. The resistance switches vary the resistance as desired. The switches for the motors change the path of the current, so that it either divides and passes through the motors independently, that is, in "multiple," or passes first through one motor and then the other, until it has passed consecutively through them all; this is called the "series" condition. The controller varies the resistances in the circuit and connects the motors either in series or multiple. The multiple condition is frequently called the "parallel" condition. From this has arisen the terms "series multiple" and "series parallel" controller. Controllers are generally provided with a "cutout" switch, which cuts the current out of all the motors and all the resistances. It is found to save room if the switches in the controller are placed on a drum, so that as the drum revolves different combinations are made.

Series Paralleling. The series parallel controller or direct current series motor is in universal operation when two or more motors constitute the car equipment. When four motors constitute a locomotive equipment the control is sometimes designed to start with four motors in series. At one-quarter speed two motors are run in series and two in parallel, and the half speed on the motors is thrown in parallel.

Methods of Controlling Induction Motors. There are two methods of controlling induction motors which are available for railway service. One method uses variable voltage in the primary and the other variable induction resistance in the secondary, the latter being the one most generally used, which absorbs the electromotive force until the speed develops full counter electro-motive force to make it possible to short-circuit the collector rings at approximately 10 per cent below synchronous speed. The method of variable voltage is not used, principally because the induction is an exceedingly poor power factor during the starting of the motor, and it produces a considerable heat in the secondary.

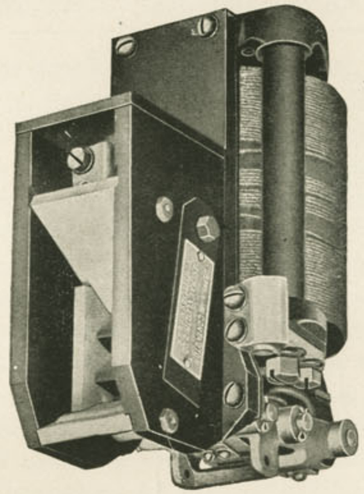
Concatenation. As the speed of an induction motor is fixed by its frequency of supply and not by its voltage, it is not possible to get two such motors in series in the same manner that direct current motors are connected. It is possible, however, to connect the stator winding of motor No. 1 to the right, the rotar winding of motor No. 1 to the rotar winding of motor No. 2, and short-circuit the stator winding of motor No. 2. This method is known as concatenation. With induction motors so connected stability is obtained with half speed of the rotors, which acts the same as a single induction motor having double the number of poles in its field, and gives the same result to the series windings connected to the direct current series motors. Concatenation work is feasible only when motors are low frequency, owing to the low power factor incidental to such a combination. This method, however, is used with railway motors to provide an efficient running speed for the low speed requirements in terminal yards.

Electrical Control Systems. When two or more electrical locomotives or trains are operated by means of one controller, some special method of connecting must be used for this purpose, and at the same time give each car its individual control system when desired. The simplest case is of two locomotives which are connected up with a master control system, the control and operating circuit being identical on each locomotive. Each locomotive has one or more master controllers, which receive current from the trolley and supply current to the control circuit only. In the control circuit magnets are provided which operate contractors or switches in the operating circuit. The operating circuit receives current directly from the trolley through the contractor switches. These contactor switches are operated by the control circuit, the same as with the direct series parallel controller.

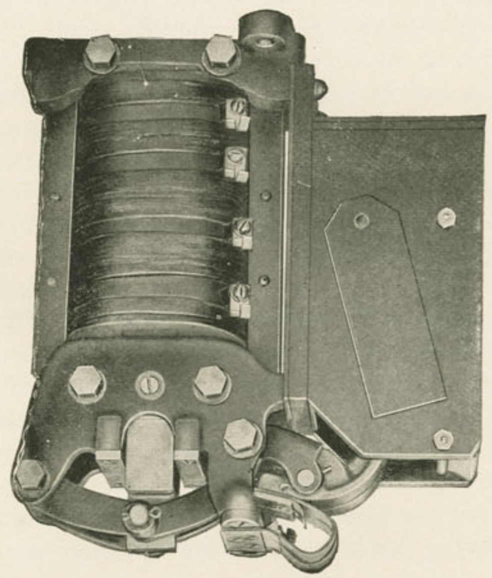
Westinghouse Multiple Control System. In the Westinghouse system of multiple train control, compressed air is used for moving the current controlling apparatus. Electric magnetic valves govern the admission of air to the controlling cylinders, and low voltage electric circuits running from car to car control the action of the magnet valves. The connections for the low voltage circuits are the only ones which have to be made between the cars of the train, no air connections being used, except the ordinary hose for braking purposes. The complete equipment for each motor car, therefore, consists of one controller with an operating head, the electric motors, multiple control switches, circuit breakers, connectors and storage batteries. The controller is similar in design to that which is used on electric street cars. The operating head consists of an operating head cylinder, a release cylinder, a repeating switch, a limit switch, magnetic valves, and safety switches. The multiple control switches are placed at each end of the car, and by means of the one in the front of the train the motorman or engineer directs the action of the controllers or of the motor cars in the train. These switches control only the low voltage battery circuits, which operate the magnetic valves, which in turn operate the valve drum.

General Electric Type M Control System. In the General Electric control system, known as type M, the control consists of two parts, the series parallel motor controller, which is composed of a number of electrically operated switches or contractors and two multiple controllers, one located at each end of each motor car, which operate the controlling contactors and reversers. A cable connects each multiple controller with the other multiple controllers along the entire length of the train. When the multiple controller is used, all of the motor controllers move in synchronous action with the multiple controller handle, so that the motorman absolutely controls at all times the current flowing into all of the motors. For reversing the motors, the multiple controller is provided with a special reversing handle, the movement of which directs the reverser end forward or in a reverse position. The multiple controller, the contactors, the reverser, controlled cut-out, switches, the control cable couplers, the control circuit rheostat and other auxiliaries are all of special design for use in this heavy power electrical surfaces.

Westinghouse Single-phase Control Systems. In the Westinghouse single-phase alternating current control system the speed of the series motor is varied by means of a transformer, which has a number of taps, the voltage from each being obtained as desired. Since varying the voltage varies the speed of the motor, it is only necessary to connect the motor to the proper lead to obtain the desired speed. With some controllers the motors may be connected permanently in multiple. In order to obtain a multiple unit control a group of switches is provided, which are operated by air



DIRECT CURRENT CONTACTOR



ALTERNATING CURRENT CONTACTOR

admitted to the cylinders by means of magnets, and receive the current from a 50-volt tap on the transformer. The action of the circuit controlling the valve magnets is regulated by the air supply to the switches of the main control, and is governed by a multiple controller which is operated by the engineer.

Single-phase Control. Single-phase control provides for the collection of power at high voltage and its application to the motors at low voltage. For starting from rest a definite voltage is required at the motor terminals. To increase speed an increase in the applied voltage is necessary. By means of the car transformer the voltage may be applied to the motors as required, and power taken from the line in proportion to the work being done.

This method of control avoids rheostatic losses, and by making the successive increments of voltage sufficiently small an acceleration of any degree of uniformity may be attained. The choking effect of the apparatus on alternating current makes it possible to get a very smooth acceleration with few notches on the controller, usually about one-half of the number required with direct current equipments.

With single-phase equipments multiple unit control becomes simpler than for D. C., because it is not necessary to provide for series parallel connections. Direct current has usually only two, and at most only three, efficient running speeds, which are fixed by the line voltage and load and are beyond the motorman's control. Single-phase control may be arranged so that each notch is an efficient running point, and thus give the motorman more complete control over his car, and provide for more efficient operation under varying conditions. A high voltage tap may be provided for making up lost time or supplying normal voltage to the motor when the voltage of the contact line is low. This provision is not possible with direct current.

Changing from High to Low Voltage. The change from high to low voltage on single-phase systems is accomplished by means of an auto-transformer on the car. This transformer has a single winding, one end of which is connected permanently to the ground, and the other end to the collector through a fuse or circuit breaker. Speed control of the motor depends upon the voltage control. For supplying the various voltages, taps are brought out from the transformer winding at points to provide the desired voltages. In addition to supplying reduced voltage efficiently to the motors, the auto-transformer supplies power for the compressor motor and light circuit and protects the car equipment against lightning and line disturbances. This, in connection with the lightning protection provided for the contact line, makes it unnecessary to use lightning arresters on the cars themselves. On locomotives or car equipments using forced ventilation air-blast, transformers are used. Otherwise the transformer is of the oil-insulated self-cooling type.

Preventive Coils on Single-phase Circuits. In order to avoid opening the entire motor circuit when going from point to point in the process of starting up the car, and to do so without short-circuiting part of the transformer winding, preventive coil is used. This is simply a low resistance coil wound around an iron core so that the coil is highly inductive. The terminals of this preventive coil are connected to the several taps of the transformer winding by means of the controller, and the connection to the motor terminals is made from the middle point of the preventive coil. This arrangement avoids any excessive drop in the preventive coil, and at the same time bridges a certain portion of the transformer winding without short-circuiting the same. The terminals of the coil are alternately detached from the transformer taps and connected to higher taps. With the larger equipments groups of from three to five preventive coils are used.

Unit Switch System of Control. With equipments exceeding 300 horse-power total capacity and for train control, the unit switch system of control is always used, and is similar to the direct current unit switch system. The place of the main drum of the hand controller is taken by the unit switch group, which consists of a number of individual switches electro-pneumatically operated. Each of these switches is provided with its arcing box and magnetic blowout. This, together with the quick positive action of the switch, makes it unnecessary to provide a preventive resistance. The switch group is assembled in a form which is at once accessible, compact, and well protected.

Secondary Control System. For operating the unit switches which are in the power circuits, a secondary control system is provided. This consists of a storage battery for supplying current to the control magnets, and a master controller for making the necessary contacts in the secondary circuit. By means of a system of interlocks, provision is made for the proper sequence of switches. Automatic acceleration may be provided for, and thus the amount of current drawn from the line in starting predetermined and made independent of the motorman. When automatic acceleration is used, the motorman can still operate his car at any of the reduced voltages obtained in coming up to full voltage by moving the master controller handle back one point at the proper time, which prevents further progress of the unit switches.

A small motor-generator set may be provided for charging the battery with direct current. Aside from the strictly electrical apparatus required for the unit switch control, it is necessary to provide a set of air apparatus for supplying compressed air to the cylinders which operate the main control apparatus. This set of air apparatus comprises an auxiliary reservoir, check valve, reducing valves, cocks, etc.

Sprague General Electric Multiple Unit Control for Alternating and Direct Current Operation. With this method of control, both single cars and trains equipped with single-phase motors, when operating on lines supplied wholly with alternating current, or with alternating current on one portion of the line and direct current on the other, may be operated. The system provides for the control of motor cars when operated singly or in trains of several cars, being adapted to either single cars of a capacity too great for a cylinder controller, or to all types of cars which may possibly be operated in a train.

The circuits are arranged in such a manner that when a number of cars are coupled together the motors may all be operated collectively and simultaneously from either end of any car. The cars composing the train may be coupled in any desired relation with each other, and every motor will at all times perform its equal share of the work.

The multiple-unit system may conveniently be divided into two parts, the first consisting of a motor controller, composed of a number of electrically operated switches called "contactors," which take the place of the ordinary cylinder controller, and may be considered as a more refined development of such, designed to handle currents of too large a magnitude to be dealt with by the ordinary controller. This apparatus is usually installed underneath the car.

The second part comprises a "master controller," the function of which is to operate the contactors, and a multiple cable, which extends the length of the train, and is provided with couplers between cars.

The train line apparatus, such as connection boxes, couplers, cut-out switches and cables, are identical with those used for direct current operation.

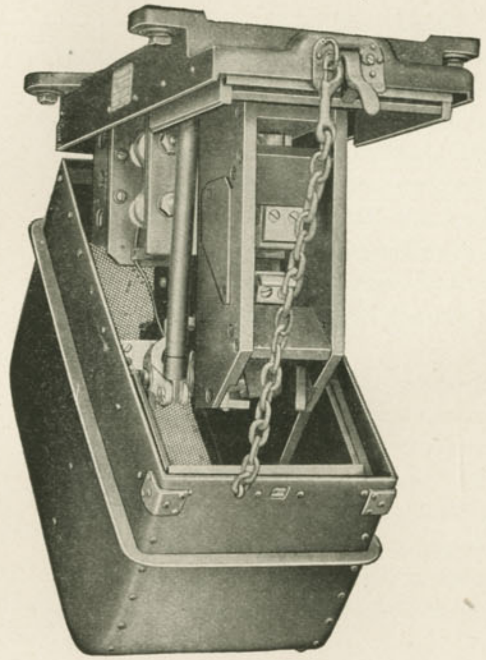
To adapt such a system for both alternating and direct current operation, changes are made in the circuits of the contactor coils when the car passes from an alternating to a direct current section, and *vice versa;* the motor fields are also connected in series for direct current operation, and in parallel for alternating current. These changes are made as the car passes the short dead section separating the alternating and direct current portions of the trolley line, and at the same time either the resistance or compensator leads are put in circuit, as required.

For alternating current operation "potential control" is used; that is, acceleration is obtained by increasing the potential at the motor terminals by connecting compensator taps of successively increasing voltage to the motors in proper sequence, corresponding to the resistance steps of the direct-current equipment.

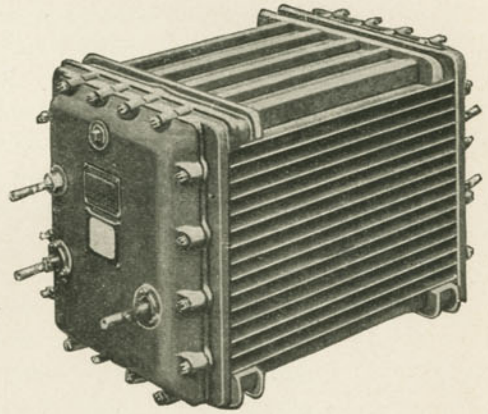
When the cars are to run on both alternating and direct current lines, a special switch is supplied to make all the necessary changes in the circuits, and suitable cast grid rheostats are provided for giving the desired direct current acceleration, which is obtained by cutting out resistance from the motor circuit step by step in an exactly similar manner to that employed on ordinary direct current equipments.

The apparatus for each alternating-direct current car equipment consists essentially of: master controllers, train cable and couplers, contactors and box, compensator, set of rheostats, commutating switch, trolleys, motor cut-out switches and the necessary protecting devices.

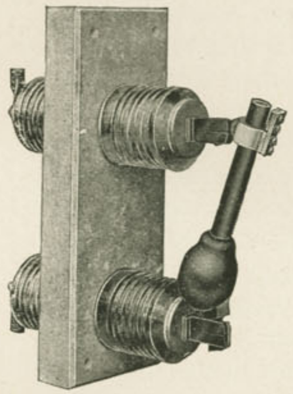
The master controller is of the standard type, being similar to the direct current master controller. It is considerably smaller than the ordinary street car controller, but is similar in appearance and operation. It is furnished with an automatic release, which cuts off the current from the entire train should the motorman remove his hand from the handle.



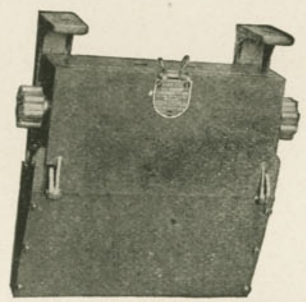
DIRECT CURRENT SWITCH



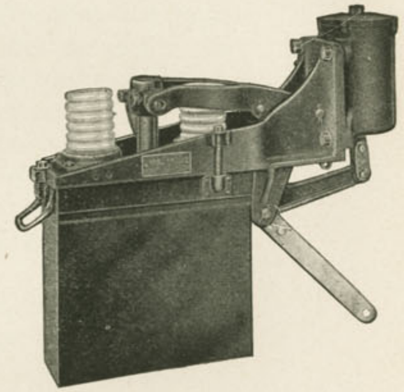
COMPENSATOR



EXPULSION FUSE HOLDERS



DIRECT CURRENT FUSE BOX



OIL SWITCH FOR LOW VOLTAGE RELEASE

Details of Sprague General Electric Multiple Unit Control

The function of the master controller is to take care of the control circuit only, and therefore it only deals with the current which energizes the coils of the contactors. It is never called upon to handle heavy currents, all the apparatus dealing with heavy current on high voltages being placed either under the car or in a specially protected compartment.

As previously stated, the multiple-unit system is a more refined development of the ordinary controller, adapted to deal with heavier currents; and each individual contactor may be considered as a segment and contact finger provided with its own magnetic blow-out.

The function of the contactors is, when energized by the master controller, to change the electrical connections in such a manner as to establish the desired motor connections for accelerating, running and reversing. Each contactor consists of an electrically operated switch, depending on a solenoid for its action. The magnetic circuit is composed of laminated iron. Each contactor is provided with a moulded insulation arc chute and powerful magnetic blow-out similar to the standard direct current contactors.

The contactor box has an iron frame work and sheet iron cover. The box is designed for use in conjunction with brass conduits, having suitable entrances for the main cables and a connection box for the control cable. No reversing switch is necessary, as some of the contactors are used for this purpose.

The compensator, which reduces the trolley potential to the proper voltage required for the motor, is of the oil-cooled type, suitably designed for suspending underneath the car body. It consists of a specially designed transformer structure entirely enclosed in a corrugated iron casing. The end castings are provided with stuffing boxes to prevent any leakage of oil where the taps enter. The coils of the compensators are specially well insulated to withstand the vibration to which such equipments are necessarily subjected. Taps giving various voltages are provided for controlling the speed of the motors.

The rheostats are of the cast grid type, and are similar in all respects to those used on the ordinary street car equipments.

The commutating switch is used to make all the necessary changes in the circuits, when the car passes from an alternating to a direct current section of the line, or *vice versa.* All such changes are accomplished by one operation.

The current may be collected by means of standard trolley wheels, poles and bases applicable for high speeds, or, when desired, a sliding or rolling contact collector of the pantograph or bow type, such as has been used in Germany for many years, may be employed. Insulation from the roof of the car is obtained by specially treated hard wood planking mounted on high-tension insulators.

The oil switch in the high-tension circuit is electrically operated and held closed by a coil energized from a small auxiliary transformer. This switch is protected by an expulsion fuse. The main direct current switch has the same characteristics as the oil switch, but is energized directly from trolley. It is insulated for the alternating current line voltage, and is protected by a copper ribbon fuse with magnetic blow-out. A single fuse of the magnetic blow-out copper ribbon type is used for protecting the motor circuit when operating either on alternating or direct current. Both the alternating and direct current circuits are protected by suitable lightning arresters.

A cut-out switch is used in connection with each pair of motors to disconnect a disabled motor when any car is operating individually as a single unit. As all the leads from each pair of motors run through their own cut-out switch, this is accomplished by simply turning the handle of the switch to the proper position.

The train line consists of a cable composed of ten conductors, and runs through the entire train, the connections being made between the individual cars by means of suitable couplers. The master controller is connected to this train line at the connection boxes on each car, from which a multiple cable is run through the control cut-out switch to the operating coils of the contactors.

The circuits for the air compressor motor and those governing the lighting and heating of the car are all protected by enclosed switches and fuses.

The air compressor motor is of the alternating direct current compensated type; its exciting fields are connected in parallel for alternating current and in series for direct current operation. The necessary changes in connections are made through the medium of the commutating switch already described. The air pressure is

regulated by a standard General Electric air compressor governor. The arrangements of the motor connections are dependent upon the service conditions required. The usual arrangement for both alternating and direct current operation is with all the motors on the car connected in series, which permits of the use of fewer pieces of controlling apparatus and of less current carrying capacity than would be necessary if the motors were connected in parallel.

During the alternating current operation the car is controlled as follows:

On the first point of the master controller the motors are connected to a compensator tap giving approximately half voltage. After this point acceleration is obtained by cutting in more sections of the compensator winding, until on the last tap the motors are connected to the full working voltage tap. A small section of cast grid rheostat is cut into the circuit during the instant of changing the motor connection from each compensator tap to the succeeding tap. This permits of an uninterrupted current supply to the motors without short-circuiting the various sections of the compensator winding. There are five steps on the master controller for alternating current operation, each constituting a running point, and seven steps for direct current operation.

The change from alternating to direct current operation is accomplished at a dead section in the trolley wire. At the instant the car enters this dead section whichever main switch is closed will open, owing to the fact that the circuit energizing its retaining coil is broken. The car can run over this dead section at full speed, and all that the motorman has to do to obtain the proper connections is to throw the commutating switch and close the main alternating current switch, as the case may be.

Current Collectors. For collecting the current from an overhead wire, either the wheel, roller or sliding bow collector is used. Which arrangement is used depends upon the size of the equipment and the conditions under which it operates.

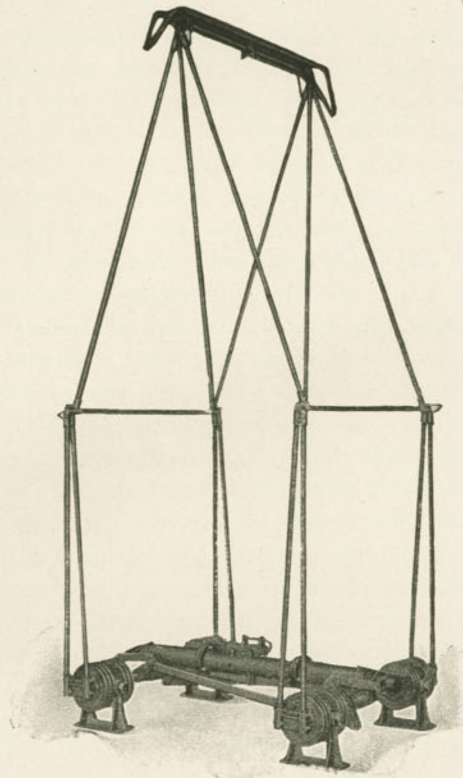
Wheel Trolleys. When a trolley wheel is used it generally consists of a grooved wheel ranging from 4 to 6 inches in diameter, depending upon the service and low or high speed. Wheels are connected upon self-lubricating bearings. The current capacity of the trolley is determined by its speed and the pressure of contact of both the wire and wheel. The higher the speed the greater the pressure necessary to maintain contact without arcing. Generally speaking, it may be said that if a wire has a current carrying capacity of 1,000 amperes when at rest, it will have only about 500 amperes when running at 30 miles per hour, and 200 amperes when running at 60 miles an hour when the pressure between the trolley and trolley wires varies between 20 and 40 pounds.

As regards its current collecting capacity, the limitation is not so much the difficulty of collecting large currents, but in the life of the wheel. With the cars of medium size, at moderate speed, an upward pressure of 15 or 20 pounds against the trolley wire is sufficient, and the life of the wheel is frequently 10,000 miles or over. At car speeds of 50 to 60 miles an hour an upward pressure of 35 or 40 pounds appears necessary to insure the wheel maintaining close contact with the wire over the irregularities of the suspension. This greater pressure, coupled with the larger amount of current commonly taken at such speeds, results in the rapid wearing of the trolley wheels, which is more especially noticeable on account of the large daily car mileage common to high-speed service.

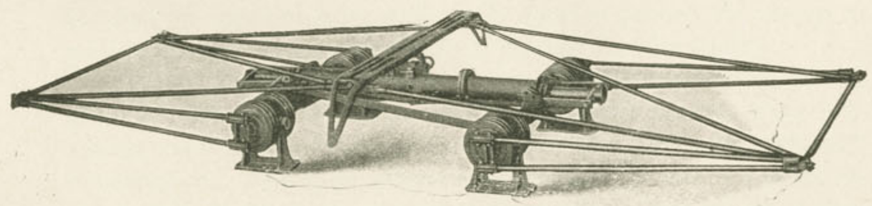
The limit of voltage for wheel trolleys has not yet been determined, but they have been used successfully on lines which have a voltage as high as 2,200 volts. When such trolleys are used with the single-phase system they are mounted on insulated bases because of the comparatively high voltage.

Roller Trolleys. Trolley wires are sometimes replaced with rollers when it is impossible to use a reversible collecting construction, or where the trolley voltage is so high as to make it desirable that all control of the trolley device shall be automatic, and not by means of a cord. Rolling contacts of this kind generally consist of a brass roller about 4 inches in diameter and 2 feet long. Such construction, however, is very heavy, and is only adapted to low-speed operation.

Sliding Bow Trolleys. For high speeds a sliding contact for current collection is generally employed. For alternating current operation the third rail and its sliding shoes are out of the question, except in very special cases, because single-phase operation almost invariably implies high voltage on the contact line,



PANTAGRAPH TROLLEY, RAISED



PANTAGRAPH TROLLEY, LOWERED
(Westinghouse Electric & Mfg. Co.)

which is not compatible with a third rail installation. To collect current from an overhead trolley line the bow and pantagraph trolleys are equally successful. The form of these trolleys is such that they will not leave the wire. Distribution of wear over the surfaces of the contact plate is effected by staggering the trolley wire. The contact plate is located in the center of the trolley, and is removable, so that it may be easily renewed. Results which have been obtained show that the sliding contacts wear at least as well as wheels for average service having a life of about 5,000 miles. Friction between the trolley and wire is reduced by the use of a lubricant placed in two longitudinal grooves in the contact surface of the bow. The wear on the trolley wire is inappreciable. With a sliding collector the car's direction of motion may be reversed without making any changes in the position of the trolley. The bow and pantagraph trolleys are not capable of collecting as heavy currents as wheel trolleys; but this cannot be classed as a disadvantage, because with high voltage the current to be collected is comparatively small, and so great a collecting capacity is not needed as with direct current. The use of such a trolley also removes one of the great objections to overhead work in yards and terminals.

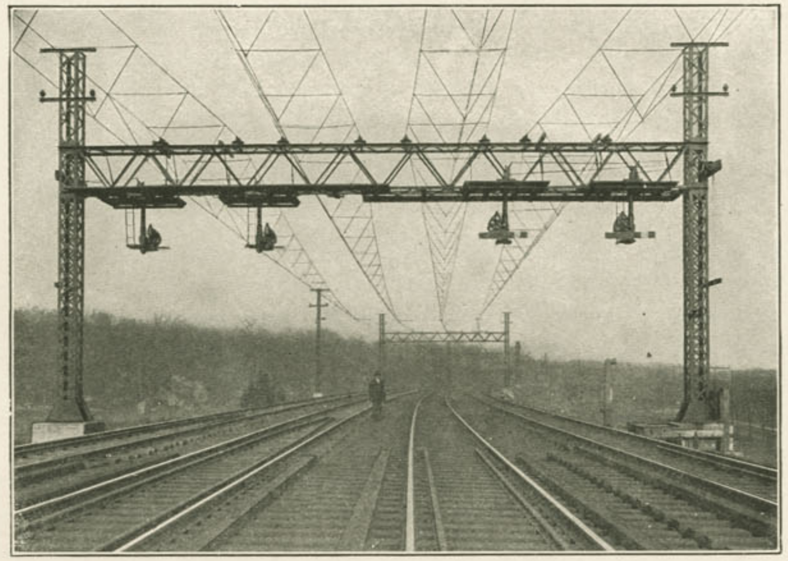
Trolley Wires. Trolley wires generally have a cross section equal to No. 000, or No. 0000, Brown & Sharpe gauge, and are made and used in three sections—round, grooved and figure 8. For high speeds the round wire is objectionable because it is difficult to secure it to the hanger without forming protection on the wire, which tends to throw the current collector off. The figure 8 wire, although it affords an easy means of fastening and leaves a clean surface for the trolley, has the objection of being difficult to handle during installation. The grooved trolley wire is considerably used in high-speed service, and consists of a round wire grooved on opposite sides sufficiently deep to permit the clamp to grip it without destroying the even surface for the trolley.

Trolley Construction. The trolley, which is generally placed about 20 feet above the track, may be supported in three ways—by a span construction, by a bracket construction, or by the catenary construction. The span construction consists of placing poles on either side of the track, connected by a cable, from which is suspended the trolley conductor. The trolley may be hung directly from the span by means of an insulated hanger, or it may be suspended from a galvanized steel wire, which is in turn supported by the span wire. The bracket construction consists of self-supporting poles having a protecting arm or bracket suspended over the track and running to the trolley wire either direct or by means of a cable. The pole is generally of wood, and should be anchored to the support of the overhung trolley. The trolley is not generally attached directly to the trolley arm or bracket, but to a flexible cable, so as to cushion the operation of the trolley wheels as it passes over it.

Catenary Construction. These ordinary methods of trolley wire suspension and insulation are not well adapted for high potential alternating trolley lines, and what is known as a catenary suspension of the trolley wire is more generally used. In the catenary suspension the supporting cable or catenary is carried over the top of high potential insulators at the point of support, and the trolley wire is attached by clips and hangers directly to the catenary without intervening insulation. The catenary thus serves as a supplemental conductor to the trolley wire, and it may be either steel or copper. As the trolley wire is supported at frequent intervals, the poles for the catenary can be spaced at longer distances than common with the ordinary type of trolley construction.

The chief requirement of the trolley line is that it shall be mechanically reliable, and this is a good requirement for direct current as well as single-phase, often justifying the extra cost of catenary construction, without taking into consideration the question of high voltage.

A typical catenary trolley construction which is being used consists of a 000 grooved trolley wire supported from a 7-16 standard steel messenger cable by rigid hangers spaced at intervals of ten feet. The messenger cable is permitted to sag, and several lengths of hangers are used, so that the trolley wire is maintained in a position parallel to the track. This construction is very rigid, permits of but small motion, gives a great degree of safety, and facilitates current collection, especially at high speed. The messenger wire is supported by clamps around insulators cemented to malleable iron sleeves, which are slipped over the bracket arms. Where wheel trolleys are used the insulators are



DOUBLE CATENARY LINE CONSTRUCTION ON FOUR TRACKS OF THE N. Y., N. H. & H. R. R.
(Westinghouse Electric & Mfg. Co.)

protected against damage due to the trolley leaving the wire by stirrups on either side. These stirrups pass under the messenger wire, and thus serve to catch the messenger wire and prevent its falling to the ground in case it becomes detached from the supporting clamp. Lightning arresters are located at intervals along the line, and section breaks are usually inserted in the trolley immediately in front of the feeding points.

For single track roads side bracket construction is found satisfactory. Where it is necessary or desirable to use cross-span construction the span wire takes the form of a catenary, with the horizontal wire above and the sagging wire below. The latter takes all the strain. In this case the insulators are placed next to the poles. Such a construction is suitable for double track roads also. On new double track roads, where the track centers may be spaced to give the proper clearances, center pole construction is good practice.

For steam road electrification, where there is extra heavy service with a large number of tracks to be electrified, a form of double catenary and latticed steel bridge supports is used. In this case two messenger wires are used for each trolley, the three wires being connected together by rigid triangles instead of single hangers.

Where steam trains are to be operated under an electrified section of road, the trolley wire should be at least 22 feet above the top of the rails. This height gives four feet clearance to a six-foot man on the top of a 12-foot car. Ordinarily the cars should be protected against danger from falling trolley wire by a grounded metal covering on the roof, sheet copper being preferable for this purpose. In Europe this protection takes the form of grounded metal guards spanning the roof at intervals.

Third Rail. When direct current is used as a motive power for heavy traction purposes, the third rail is the favorite method of distributing power to the car. As generally used, the rail is made of steel of the same composition as the track, but in some cases rails of special composition containing very small quantities of manganese are used. The rails are supported upon either standard or specially constructed insulators spaced about every 10 feet and supported by the ties. The third rails are joined together loosely by fish plates, are bonded, and are anchored at certain intervals to prevent creepage. The contact resistance of the fish plates is so great as to amount to a practically open circuit, hence the need of a bonding joint of good conductivity.

Third rail construction, as generally used, may be divided into two classes: that having over-running contact and that having under-running contact. Over-running contact third rails are in more general use. The principal objections to the over-running third rails are due to the fact that a rail of this kind, being exposed, is dangerous, and considerable trouble is encountered from sleet. These objections have been overcome in some constructions of this type by protecting the third rail by means of a wooden or metal shield, which protects it from snow and sleet or accidental contact. A protection embodying these features, when used with an over-running third rail, is shown in Fig. 18.

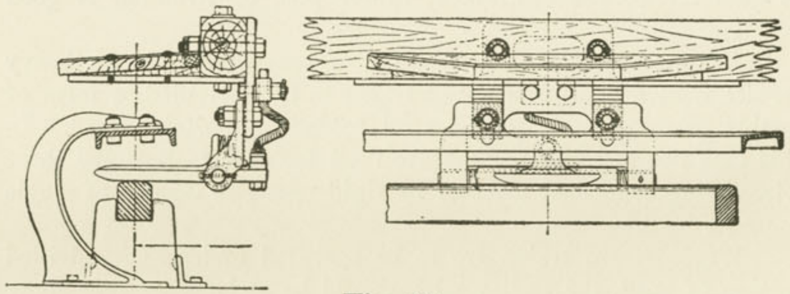


Fig. 18.

End and Side Elevation of Protected Third Rail, Showing Contact Shoe.

In the under-running contact system the rail is supported upon curved brackets, and the contact is made on the bottom side of the rail rather than on the top side. Under-running third rails of the protected type offer some advantages over the over-running type, especially in regard to better protection against accident and against sleet and snow. The contact surface, being on the under side, is self-cleaning, and this type has been run successfully through heavy snows which have completely covered the third rail.

The location of the third rail, with reference to the track, owing to local conditions, has been different in nearly every installation. Between clearing the low pressure cylinders of compound

locomotives, the hoppers on the large steel coal cars and keeping within the bridge abutments and tunnels, the location is generally a case of compromise. The average distance from the track gauge line to the center of the third rail varies from 20 inches to 28 inches, and the height above the track varies from $1\frac{1}{2}$ to $7\frac{1}{2}$ inches.

Jumpers are used to connect the third rail at crossings, and consist of copper cables bonded to the rail and extending through underground circuits. Jumpers for this purpose are generally heavily insulated and are lead-covered.

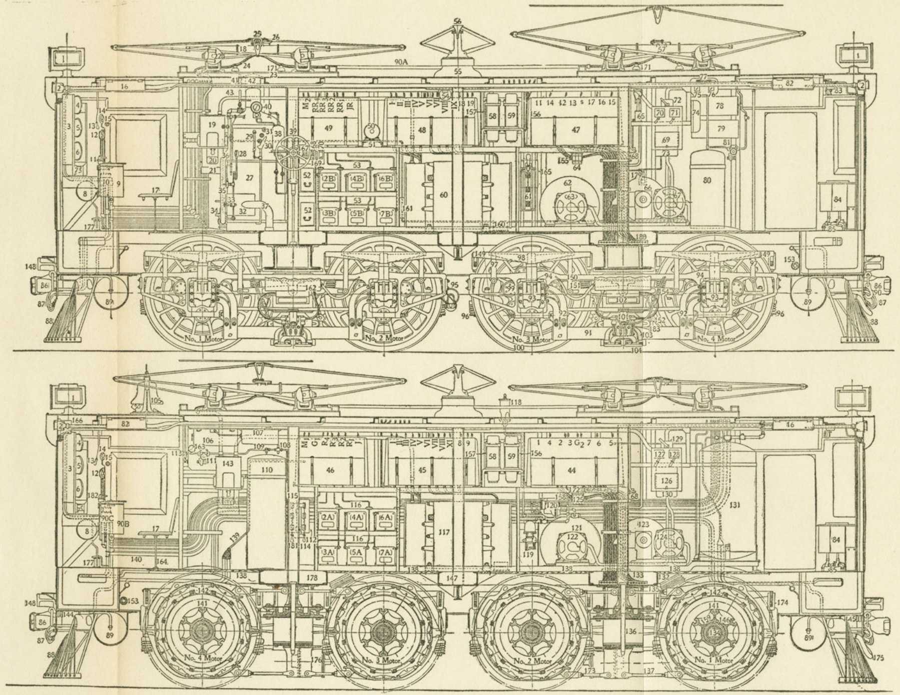
Insulators for the third rail generally consist either of wooden blocks, reconstructed granite, or porcelain. These insulators are held in chairs fastened to the ties and forming a loose support for the third rail. There is no solid fastening between the third rail and its insulating support, on account of the change in length of the third rail due to the changes in temperature. Jumpers must also be made of sufficient length to allow for this creepage.

While it might seem that the constant voltage between the shoe and the rail would cause considerable wear upon the third rail, this has not been found to be a very serious matter in practice, as tests have shown that a very soft rail will wear quite slowly. The principal care in maintaining a third rail in good condition is to keep the bonding alignment and insulators in proper condition.

Third Rail Shoes. Third rail shoes are made in two general types, those which are actuated by gravity and those which are actuated by means of springs. With the unprotected over-running third rail system the gravity shoe is in general use, but for the under-running type, or where rails are protected, it becomes necessary to use a form of shoe which is actuated by springs which give the necessary pressure. The current capacity of a third rail shoe is quite high, owing to its large surface, which also gives a cast iron shoe a considerable life, as high as from 30,000 to 40,000 miles.

Third Rail Bonds. There are a number of different methods of bonding third rails used so as to increase their conductivity, among which may be mentioned the expanded method, soldered method, cast welding method, and the electric welding method. Of these methods the soldered bond and expanded bond are the most used. The soldered bond consists of a copper conductor, which is soldered, brazed or welded to the head of the rail on the outside or to the flange of the rail. The expanded bond is one in which the copper wire is expanded through a hole in the web or flange. The cast weld bond is made by pouring metal in a mould surrounding the rail joint, which has first been thoroughly cleaned, so as to make good contact. When electric welding is used, steel straps are fastened to each rail, which gives a continuous circuit.

1. Headlight.
2. Train Line Receptacles.
3. Instrument Board.
4. Speed Indicator Meter.
5. D. C. Ammeter Motors.
6. A. C. Ammeter Motors.
7. Temperature Indicator Meter.
8. Equalizing Reservoir Air Brake.
9. No. 1 Master Controller.
10. No. 1 Automatic Motorman's Brake Valve.
11. No. 1 Independent Brake Valve.
12. Duplex Gage Main Reservoir and Train Line.
13. Whistle Handle.
14. Straight Air-brake Gage.
15. Three-way Snap Switch in Light Circuit.
16. No. 1 Junction Box.
17. Motorman's Seat.
18. No. 1 A. C. Pantograph Trolley.
19. No. 2 Oil Circuit-breaker.
20. Overload Trip.
21. Oil Tank on Circuit-breaker.
22. Insulators for Pantograph Trolley.
23. Support for A. C. Trolley.
24. High-tension Cable from A. C. Trolleys.
25. A. C. Trolley Shoe.
26. A. C. Trolley Lock Cylinder.
27. Steam-heating Boiler.
28. Gage—Air Pressure on Burner.
29. Water Gage.
30. Drain Cup.
31. Try Cocks.
32. Fire Door.
33. Burner.
34. Gold Car Co. Regulating Valve.
35. Mason Regulating Valve.
36. Steam Line from Boiler.
37. Air Inlet to Fire-box.
38. Water Feed Regulator.
39. Hand Brake Wheel.
40. Steam Gage.
41. Safety Valve.
42. Stack for Boiler.
43. H. T. Conduit from Oil Switch to Transformer.
44. Switch Group No. 1.
45. Switch Group No. 2.
46. Switch Group No. 3.
47. Switch Group No. 4.
48. Switch Group No. 5.
49. Switch Group No. 6.
50. Motor Generator Set for Battery Charging.
51. Base for Motor Generator Set.
52. Storage Battery.
53. No. 2 Set of Resistance Grids.
54. A. C. Integrating Wattmeter.
55. Base for D. C. Trolley.
56. D. C. Trolley.
57. A. C. Pantograph Trolley.
58. Preventive Coil, 100 volts, 250 amperes.
59. Preventive Coil, 50 volts, 500 amperes.
60. No. 2 Transformer.
61. Main D. C. Switch.
62. No. 2 Blower Motor Fan Casing.
63. No. 2 Blower Motor.
64. Permanent D. C. Field Shunting Grid No. 2.
65. Hand Air Pump for Unlocking A. C. Trolley.
66. No. 2 Air Compressor.
67. No. 2 Air Compressor Motor.
68. Magnet Valves.
69. No. 2 Fuse Box.
70. Canopy Switch for No. 2 Blower Motor.
71. Canopy Switch for No. 2 Compressor Motor.
72. No. 2 Motor Control Cut-out.
73. No. 2 A. C. D. C. Change-over Switch.
74. Relay Box.
75. Snap Switch for Cab Lights.
76. Snap Switch for Headlights.
77. S. P., D. T. Switch Light, Circuit.
78. Control Reservoir.
79. Cover for Resistance Grid.
80. Oil Tank.
81. Slide Valve Reducing Valve.
82. No. 2 Junction Box.
83. Signal Valve.
84. Sand Box.
85. Electro-pneumatic Sander.
86. Coupler.
87. Hose Couplings.
88. Pilot.
89. Main Air Reservoir.
90. Hook for Safety Chains.
90-A. Cable connecting A. C. Trolleys.
90-B. No. 2 Master Controller.
90-C. No. 2 Automatic Brake Valve.
91. Third-rail Shoe Beams.
92. Third-rail Shoe Bracket.
93. Journal Box.
94. Truck Frames.
95. Magneto for Speed Indicator.
96. Motor Suspension Springs.
97. Spring Hanger.



PRINCIPAL PARTS OF AN ELECTRIC LOCOMOTIVE

98. Elliptical Springs.
99. Wheel Pocket Cover.
100. Main Driving Wheel.
101. Third-rail Shoe Cylinder.
102. Third-rail Shoe Fuse Box.
103. Main Casting for Third-rail Shoe.
104. Third-rail Shoe.
105. Bell.
106. A. C., D. C. Change-over Switch Heater Circuit.
107. Fuse Box Heater Circuit.
108. Governor Valve for Emergency Control Reservoir.
109. Three-way Cock Emergency Control Reservoir.
110. Emergency Control Reservoir.
111. Slide Valve Reducing Valve.
112. Balancing Transformer (back of S. T. and D. T. Switches).
113. Combined Strainer and Drain Cup.
114. D. T. Switch No. 1 Heater Circuit.
115. S. T. Switch Heater Circuit.
116. No. 1. Set Resistance Grids.
117. No. 1 Transformer.
118. Whistle.
119. Governor—Air Brake.
120. Distributing Valve.
121. No. 1 Blower Motor Fan Casing.
122. No. 1 Blower Motor.
123. No. 1 Air Compressor.
124. No. 1 Air Compressor Motor.
125. Permanent D. C. Field Shunting Grid No. 1.
126. No. 1 Fuse Box.
127. Canopy Switch for No. 1 Blower Motor.
128. Canopy Switch for No. 1 Compressor Motor.
129. No. 1 Motor-control Cut-out.
130. No. 1 A. C., D. C. Change-over Switch.
131. Water Tank.
132. Air Connection to Motors.
133. Motor Leads for No. 1 and No. 2 Motors.
134. Axle of Main Driving Wheels.
135. Upper Torque Rod.
136. Center Pin.
137. Lower Torque Rod (long).
138. Trap Doors Over Motors.
139. Heater Circuit Leads.
140. Air-brake Piping.
141. Motor Armature.
142. Motor Field Frame.
143. No. 1 Oil Circuit Breaker.
144. Bus Line Socket Heater Circuit, No. 2 End.
145. Bus Line Socket Heater Circuit, No. 1 End.
146. Quill.
147. Tool Box.
148. Bumper Block.
149. Motor Suspension Cradle.
150. Spring Hanger.
151. Equalizer Spring.
152. Brake-shoe.
153. Steam-heating Line.
154. Equalizer Bar.
155. Series Transformer for A. C. Ammeter No. 3 and No. 4 Motors.
156. Preventive Coil, 100 Volts, 250 Amperes (Back of No. 59).
157. Field Shunting Resistance (back of No. 58).
158. Series Transformer for A. C. Ammeter, No. 1 and No. 2 Motors.
159. Armature Spider.
160. Air Inlet to Transformer.
161. Air Inlet to Resistance Grids.
162. Third-rail Shoe Leads.
163. Gage-control Line Pressure.
164. Support for Motorman's Seat.
165. D. C. Wattmeter.
166. Blind Lights.
167. D. P., D. T. Switch for Battery.
168. D. P., D. T. Switch for Battery.
169. S. P., S. T. Switch for Motor-generator Set.
170. Snap Switch for Motor Generator Set.
171. Insulators Supporting A. C. Trolley Cable.
172. Shunt for D. C. Ammeter Motors, No. 1 and No. 2.
173. Lower Torque Rod (short).
174. Motor Suspension Hanger.
175. Steam-hose Coupling.
176. Brake Cylinder.
177. Foot Push-button Switches.
178. Air Conduit.
179. Shunt for D. C. Ammeter Motors, No. 3 and No. 4.
180. Motor Leads for No. 3 and No. 4 Motors.
181. D. T. Switch No. 2 Heater Circuit.
182. Independent Brake Valve No. 2.
183. Third-rail Shoe Unlock Cylinder.

REVIEW QUESTIONS.

ELECTRIC LOCOMOTIVES AND ELECTRIC RAILROADING.

1. Give the principal fundamental differences in power conditions between the steam and electric systems of railroading.

2. What are the principal advantages derived from the electrification of steam roads?

3. How does the cost of electric locomotive maintenance compare with steam locomotive maintenance?

4. Name some of the difficulties encountered when changing a steam road to an electric one.

5. What has been the most detrimental influence which has prevented the extensive spread of the electrification of steam trunk lines?

6. Name five different types of electrification systems which may be used.

7. Describe briefly the general operation of the direct current system.

8. Describe the general method of transmitting the power from the power house to the cars when the alternating-direct current system is used.

9. Name some of the principal pieces of apparatus required in an alternating direct current sub-station.

10. What are the advantages of an alternating current substation over an alternating-direct current sub-station?

11. Name three methods which may be used for starting synchronous converters in sub-stations.

12. What is a synchronous converter, and how does it operate?

13. Describe briefly the general scheme of electrification used on the West Jersey & Seashore Railroad.

14. Describe the general arrangement of apparatus used in the power house of an alternating direct current system.

15. What is the general scheme of electrification used on the Long Island Railroad?

16. Give the general scheme of electrification used on the New York, New Haven & Hartford Railroad.

17. What are the advantages and disadvantages of the single phase system over the direct current system?

18. For what particular work is the single-phase system best adapted?

19. When single-phase systems are used, what is the frequency generally adopted?

20. What are the particular features of a single-phase transformer sub-station?

21. Give the general scheme of electrification used on a single-phase system.

22. What are the advantages and disadvantages of the three-phase system as compared with the single-phase system?

23. How are the power houses generally equipped when single-phase current is used on the cars or locomotives?

24. For what purpose were electric locomotives first used?

25. Describe briefly the Baltimore & Ohio electric locomotive.

26. Describe the general characteristics of the New York Central electric locomotive.

27. Compare the steam and electric locomotives from a general point of view, and give all the advantages and disadvantages of each which you can think of.

28. In a general way, how does the acceleration of an electric locomotive compare with the steam locomotive?

29. How does the rating of an electric locomotive differ from that of a steam locomotive?

30. Give three different types of motors available for railway service.

31. Give several reasons why the series motor is best adapted for railway work.

32. How does the single-phase motor differ from the series direct current motor?

33. What are the advantages and disadvantages of the single-phase motor as compared with a direct current motor?

34. Explain how single-phase motors operate on direct current circuits.

35. Upon what kind of roads would a three-phase induction motor be available, and when would it not be available?

36. What are the requirements which chiefly govern the choice of electric motors?

37. What is the difference between a geared and a gearless motor?

38. Explain the principal objections to a gearless motor.

39. What are the advantages of the geared motor?

40. Name two different types of trucks adapted for electric cars.

41. How is the speed of an electric locomotive controlled?

42. What is meant by concatenation?

43. Describe briefly the Westinghouse multiple control system.

44. Explain why single-phase control is more advantageous than direct current motors.

45. Explain how the change from high to low voltage is made on alternating direct current systems.

46. Of what value are preventive coils on single-phase systems?

47. Describe in detail the Sprague General Electric multiple unit control which is used so extensively in electric locomotive practice.

48. Name three ways by means of which the current may be collected from an overhead controller.

49. What are the advantages and disadvantages of the wheel trolley?

50. Why is the sliding bow trolley generally used for high speed service?

51. Describe a catenary suspension of the trolley wire.

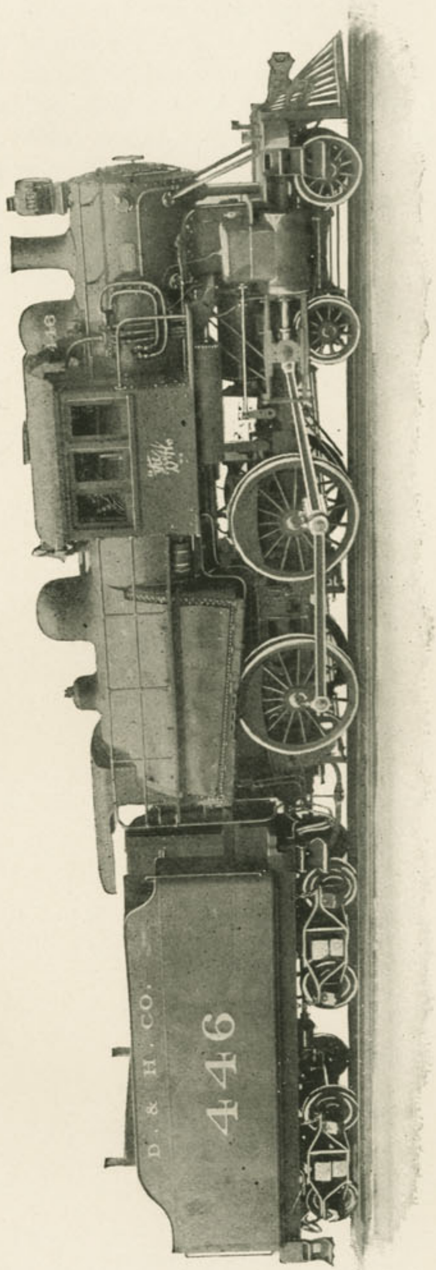
52. What are the advantages and disadvantages of the third rail over trolley wheels?

53. Explain two different kinds of third rail shoes which are used for collecting current from the third rail.

54. What are the advantages and disadvantages of the over-running type of third rail?

55. Why is it necessary to bond the third rail?

56. What is the advantage of a grooved trolley wire over a round trolley wire?



AMERICAN OR 8-WHEEL TYPE LOCOMOTIVE USED ON THE DELAWARE & HUDSON RAILROAD
(American Locomotive Company)

Block Signal Rules.

STANDARD CODE OF THE AMERICAN RAILWAY ASSOCIATION.

Definitions.

Block. A length of track of defined limits, the use of which by trains is controlled by block signals.

Block Station. A place from which block signals are operated.

Block Signal. A fixed signal controlling the use of a block.

Home Block Signal. A fixed signal at the entrance of a block to control trains in entering and using said block.

Distant Block Signal. A fixed signal used in connection with a home block signal to regulate the approach thereto.

Advance Block Signal. A fixed signal used in connection with a home block signal to sub-divide the block in advance.

Block System. A series of consecutive blocks.

Telegraph Block System. A block system in which the signals are operated manually upon information by telegraph.

Controlled Manual Block System. A block system in which the signals are operated manually, and so constructed as to require the co-operation of the signalmen at both ends of the block to display a clear signal.

Automatic Block System. A block system in which the signals are operated by electric, pneumatic or other agency actuated by a train, or by certain conditions affecting the use of a block.

1. RULES.

Home Signals.

Signal	Occasion for Use	Indication	Name
Color	The signal will be displayed when	For enginemen and trainmen	As used in rules
(a) red	Block is not clear	Stop	Stop signal
(b) ——	Block is clear	Proceed	Clear signal
(c) ——	Block is not clear	Proceed with caution	Caution signal

Where the semaphore is used, the governing arm is displayed to the right of the signal mast as seen from an approaching train, and the indications are given by positions:

Horizontal as the equivalent of (a).

Vertical or Diagonal (Angle above or below the horizontal) as equivalent of (b).

Diagonal (Angle above or below the horizontal) as the equivalent of (c).

2. Block signals control the use of the blocks, but, unless otherwise provided, do not affect the movements of trains under the time table or train rules; nor dispense with the use or the observance of other signals whenever and wherever they may be required.

SIGNALMEN.

3. The normal indication of Home Block Signals is Stop.

4. Signals must be operated carefully and with a uniform movement. If a signal fails to work properly, its operation must be discontinued and the signal secured so as to give the normal indication until repaired.

5. Signalmen must observe, as far as practicable, whether the indication of the signals corresponds with the position of the levers.

6. Signalmen must not make nor permit any unauthorized alterations or additions to the apparatus.

7. A block record must be kept at each block station. (The different times to be entered on the block record have not been prescribed in this rule, but it has been left to each road to complete the rule by adding such items as may be necessary to meet the conditions governing its traffic.)

8. The prescribed telegraph signals are as follows:

1. Display Stop-signal. Answer by S D or 5.
2. Block clear. Answer by 13.
3. Block wanted. Answer by 2 or 5.
4. Train has entered block. Answer by 13.
5. Block is not clear.
7. Train following.
8. Opening block station. Answer by Nos. of trains in the extended block, with time each train entered the block.
9. Closing block station. Answer by "13" after receiving transfer of records of trains which are in the extended block.
13. I understand.
71. Train following display Stop-signal. Answer by S D.

9. (a). To admit a train to a block the signal, is clear, will give "1 for ———" to the next block station in advance. The signalman receiving this signal, if the block is clear, must display the Stop-signal to opposing trains, and reply "S D for ———." If the block is not clear, he must reply "5 of ———." The signalman at the entrance of the block must then display the proper signal indication of the train to be admitted. This rule is for absolute block for following and opposing movements on the same track.

A train must not be admitted to a block unless it is clear, except as provided in Rule 23, or by special order.

9. (b). To admit a train to a block the signalman must examine the block record, and if the block is clear, will give "1 for ———" to the next block station in advance. The signalman receiving this signal, if the block is clear, must display the Stop-signal to opposing trains and reply "S D for ———." If the block is not clear, he must reply "5 of ———." The signalman at the entrance of the block must then display the proper signal indication to the train to be admitted.

A train must not be admitted to a block which is occupied by a passenger train, except as provided in Rule 23, or by special order.

To permit a train to follow a freight train into a block, the signalman must give "71 for ——— " to the next block station in advance, to which the reply "5 of ——— for ——— " must be made. The approaching train will then be admitted to the block under caution signal or with caution card. This rule is for absolute block for opposing movements and permissive block for following movements on the same track.

10. (a). To admit a train to a block the signalman must examine the block record, and, if the block is clear, will display the proper signal indication to the train to be admitted, reporting its movement as per Rule 11.

A train must not be admitted to a block unless it is clear, except as provided in Rule 23, or by special order.

10. (b). To admit a train to a block the signalman must examine the block record, and if the block is clear will display the proper signal indication to the train to be admitted, reporting its movement as per Rule 11.

A train must not be admitted to a block which is occupied by a passenger train, except as provided in Rule 23 or by special order.

A train may be permitted to follow a freight train into a block under caution-signal or with a caution card. This rule is for permissive block for following movements only. Where it is desired that train dispatchers shall control the display of block signals, roads may modify Rules 9 (a), 9 (b), 10 (a) and 10 (b) so as to provide for such practice.

11. When a train enters a block the signalman must give "4 ———" and the time to the next block station in advance, and when the train has passed the home block signal and the signalman has seen the markers, he must display the Stop-signal, and when the rear of the train has passed ——— feet beyond the home block signal he must give "2 of ———" and the time to the next block station in the rear. This information must be entered on the block records.

12. Unless otherwise provided, signalmen must not give "1" or "3" until they have received "4" from the block station in the rear.

13. Signalmen must observe all passing trains and note whether they are complete and in order, and the markers properly

displayed. Should there be any indication of conditions endangering the train, or a train on another track, the signalman must notify the signalman at the next block station in advance. A signalman having received this notice must display Stop-signals in both directions and answer "S D." Should a train going in the opposite direction be stopped, it may be permitted to proceed when it is known that the track on which it is running is not obstructed.

14. Should a train pass a block station without markers, the signalman must notify the signalman at the next block station in each direction, and must not report that train clear of the block until he has ascertained that the train is complete.

15. Should a train pass a block station in two or more parts, the signalman must notify the signalman at the next block station in advance. A signalman having received this notice must stop any train running in the opposite direction. The Stop-signal must not be displayed to the engineman of the divided train if the block in advance is clear, but the Train-parted signal must be given. Should a train going in the opposite direction be stopped, it may be permitted to proceed when it is known that its track is not obstructed.

16. A signalman informed of any obstruction in a block must display the Stop-signal and notify the signalman at the other end of that block. The signalman at the other end of the block must immediately display the Stop-signal. The Clear-signal for that block must not be displayed until the obstruction is removed.

17. When a train takes a siding the signalman must know that it is clear of the block before giving "2," or displaying a Clear-signal for that block.

The signalman must obtain control of the block before permitting a train on a siding to re-enter the block.

18. To permit a train to cross over or return the signalman must examine the block record, and if all the blocks affected are clear of approaching trains, he will arrange with the signalmen at the next block station on either side to protect the movement, and when the proper signals have been displayed permission may be given. Until the block is clear no train must be admitted in the direction of the cross-over switches except under Caution-signal or with Caution Card. All cross-over movements must be entered on the block records.

19. When, as provided for in Rule 36, coupled trains have been separated, the signalman must regard each portion as an independent train.

20. If necessary to stop a train for which a Clear-signal (or a Caution-signal) has been displayed and accepted, the signalman will give hand signals in addition to displaying the Stop-signal.

21. A signalman having orders for a train must display the block signal at "Stop." He may permit trains so stopped to proceed under block signal rules after complying with Rules for Movement by Train Orders.

22. If from the failure of block signal apparatus the block signal cannot be changed from the normal indication, a signalman having information from the signalman at the next block station in advance that the block is clear may admit a train to the block by the use of Clearance Card.

23. If, from the failure of telegraph line or other cause, a signalman be unable to communicate with the next block station in advance, he must stop every train approaching in that direction. Should no cause for detaining the train be known, it may then be permitted to proceed, provided ——— minutes have elapsed since the passage of the last preceding train, using Caution Card.

24. Signalmen must have the proper appliances for hand signaling (lamp, flag, torpedo and fusee signals) ready for immediate use. Hand signals must not be used when the proper indication can be displayed by the fixed signals. When hand signals are necessary they must be given from such a point and in such a way that there can be no misunderstanding on the part of the enginemen or trainmen as to the signals, or as to the train or engine for which they are given.

25. Signalmen will be held responsible for the care of the block station, lamps and supplies, and of the signal apparatus, unless provided for otherwise.

26. Lights in block stations must be placed so that they cannot be seen from approaching trains.

27. Lights must be used upon all block signals from sunset to sunrise, and whenever the signal indications cannot be clearly seen without them.

28. If a train overruns a Stop-signal, the fact, with the number of the train, must be reported to ———.

29. If a Stop-signal is disregarded, the fact, with the number of the train, must be reported to the next block station in advance, and then to ———.

30. To open a block station the signalman must give "8" to the next block station in each direction, and record the trains that are in the extended block. He must then display the normal signal indication and notify the block station in each direction that the station is open.

When trains which were in the extended block when the station was open, and which had passed his station before it was opened, clear the block in advance he must repeat the record to the block station in the rear.

He must not display the Clear-signal until all trains are clear of the block in advance.

31. A block station must not be closed except upon the authority of ———, nor when trains are approaching which are to meet or pass at that block station.

32. To close a block station the signalman must first obtain "2" for trains which he has admitted to the blocks in each direction.

He must give "9" to the next block station in each direction and transfer the records of the trains in the extended block. He must then enter on his block record "13," with the time it is received from each block station.

The block signals must then be ———, all lights extinguished and the block wires arranged to work through the closed station. The arrangement of the block signal is left for each road to determine in accordance with its local requirements.

ENGINEMEN AND TRAINMEN.

33. Block signals apply only to trains running in the established direction.

34. Trains must not pass a Stop-signal without receiving a Caution Card, a Clearance Card or a special order.

35. An engineman holding a Caution Card must deliver it to the signalman at the next block station, and personally ascertain from him that the block in advance is clear before proceeding.

36. Unless directed by special instructions, when two or

more trains have been coupled and so run past any block station, they must be uncoupled only at a block station and the signalman notified.

37. When a train takes a siding it must not again enter the block without the permission of the signalman.

38. When it is necessary for a train to cross over, the conductor, before crossing or returning, must notify the signalman and obtain permission to do so.

39. Enginemen and trainmen must not accept clear hand signals as against block signals.

40. The engineman of a train which has parted must sound the whistle signal for Train-parted on approaching a block station.

41. An engineman receiving a Train-parted signal from a signalman must answer by the whistle signal for Train-parted.

42. When a parted train has been recoupled the signalman must be notified.

43. At a block station where the signalman is absent or incapacitated, so that instructions cannot be obtained, trains must wait ——— minutes, and then proceed with caution to the next block station, where the conductor must report according to the ———.

44. If the track is obstructed between block stations, notice must be given to the nearest block signalman.

45. If a train is held by a block signal to exceed ——— minutes, the conductor must ascertain the cause.

46. Conductors must report to ——— any unusual detention at block stations.

47. A block station must not be considered as closed, except as provided on time-table or by special instructions.

CONTROLLED MANUAL BLOCK SYSTEM.

A series of consecutive blocks controlled by block signals operated manually, and so constructed as to require the co-operation of the signalman at both ends of the block to display a clear signal, consisting of:

1. Signals of prescribed form, the indications given by two positions; and, in addition, at night, by lights of prescribed color.

2. The apparatus so constructed that the failure of any part

directly controlling a signal will cause it to give the normal indication.

3. Signals, if practicable, either over or upon the right of, and adjoining, the track upon which trains are governed by them. For less than three tracks signals for trains in each direction may be on the same signal mast or upright to which the signals are directly attached.

4. Semaphore arms that govern, displayed to the right of the signal mast as seen from an approaching train.

5. The normal indication of Home Block Signals ——— Stop.

6. The apparatus so constructed that the failure of the block signal instruments or electric circuits will prevent the display of the clear signal.

7. The relative position of the home signal, and track instrument or releasing circuit, such as to make it necessary that the rear of a train shall have passed ——— feet beyond the Home Block Signal before the signal at the preceding block station can be released.

Adjuncts. The following may be used:

(A) Distant Block Signals interlocked with Home Block System; normal indication—Caution. When Distant Block Signals are used, use the rule following No. 1 for Home Signals.

(B) Advance Block Signals interlocked with Home Block Signals, and with Distant Block Signals, if used; normal indication—Stop. When Advance Block Signals are used, the name should be added to the caption of Rule 1 so as to read "Home and Advance Signals," and Rule 3 should be changed to read "The normal indication of Home and Advance Block Signals is Stop."

(C) Track circuits.

(D) Repeaters or audible signals to indicate the position of signals to the signalman operating them.

(E) The automatic release of signals to give the normal indication.

(F) The interlocking of switches with block signals.

(G) Bell circuits for signaling between a block station and outlying switches.

(H) Unlocking circuits between a block station and outlying switches.

1. RULES.

HOME SIGNALS.

Signal	Occasion for Use	Indication	Name
Color	The signal will be displayed when	For enginemen and trainmen	As used in rules
(b) Red	Block is not clear	Stop	Stop signal
(a) ——	Block is clear	Proceed	Clear signal

Where the semaphore is used, the governing arm is displayed to the right of the signal mast as seen from an approaching train, and the indications are given by positions:

Horizontal as the equivalent of (a).

Vertical or Diagonal (angle above or below the horizontal) as the equivalent of (b).

When Distant Block Signals are used, the following should be added to Rule 1:

Signal	Occasion for Use	Indication	Name
(c) ——	Home (or advance) signal at (a)	Proceed with caution to home (or advance signal)	Caution signal
(d) ——	Home (and advance) signal at (b)	Proceed	Clear signal

Where the semaphore is used, the governing arm is displayed to the right of the signal mast as seen from an approaching train, and the indications are given by positions:

Horizontal as the equivalent of (c).

Vertical or Diagonal (angle above or below the horizontal) as the equivalent of (d).

2. Block signals control the use of the blocks, but, unless otherwise provided, do not affect the movements of trains under the time table or train rules; nor dispense with the use or the observance of other signals whenever and wherever they may be required.

SIGNALMEN.

3. The normal indications of Home Block Signals is Stop.

4. Signals must be operated carefully and with a uniform movement. If a signal fails to work properly, its operation must be discontinued and the signal secured so as to give the normal indication until repaired.

5. Signalmen must observe, as far as practicable, whether the indication of the signals corresponds with the position of the levers.

6. Signalmen must not make nor permit any unauthorized alterations or additions to the apparatus.

7. If any electrical or mechanical appliance fails to work properly ——— must be notified, and only duly authorized persons permitted to make repairs.

8. A block record must be kept at each block station. The different items to be entered on the block record have not been prescribed in this rule, but it has been left to each road to complete the rule by adding such items as may be necessary to meet the conditions governing its traffic.

9. Block signal instruments and bells must be used only by signalmen and as directed by the rules.

10. Bells must not be used for any purpose other than to give the prescribed signals.

11. Bell signals must be given deliberately and distinctly and answered promptly. All signals must be repeated until answered.

12. The prescribed Bell Signals are as follows, and (-) signifies pause between beats:

1—(Long stroke.) Answer telegraph call.
2—All right. Yes.
3—Unlock my lever. Answer by unlocking, or 5, or 3-1.
4—Train has entered block.
5—Block is not clear.
6—Has a train entered this block? Answer by 2, or 2-1.
1-2—Clear. Train has cleared block.
1-4—1-4—Stop train approaching and have it examined. Answer by 1-4—1-4.
2-1—No.
2-2-2—Previous signals given in error. Answer by 2.
2-3-2—Train has passed without markers. This signal to be given to station in advance. Answer by 2-3-2.
2-4—Has train cleared block? Answer by 1-2, or 5.
2-4-2—Repeat previous signal.
3-1—Have unlocked. If levers are not released, instru-

ment must be out of order. Block is clear. This signal must be answered by 3-1, and the answer acknowledged by 2. It must not be used unless the block is known to be clear. A signalman having received 3-1 and answered it by 3-1, and received 2 in acknowledgment, may allow train to proceed under Rule 26, announcing it by 4.

3-3—Train in block will take intermediate siding. Answer by 3-3.

3-3-3—3-3-3—Train in block has broken apart. Answer by 3-3-3—3-3-3.

4-3-4—Train from intermediate siding is proceeding toward you. Answer by 4-3-4.

4-4-4—Cars running away in wrong direction and proceeding toward you. Answer by 4-4-4.

4-6-4—Cars running away in the right direction and proceeding toward you. Answer by 4-6-4.

5-2-5—Train has passed without markers. This signal to be given to station in rear. Answer by 5-2-5.

5-5-5—Obstruction in block. Stop all trains approaching this station. Answer by 5-5-5.

6-6-6—Testing. Answer by 6-6-6.

When bell circuits for signaling between a block station and outlying switches are used, Rule 12 will be amended to include the following signals, which will be given and observed by signalmen and conductors:

1-2-3—Train has gone on siding. All clear. Switch closed. Answer by 1-2-3.

3-4—Train is ready to leave siding. Answer by 3-4, or 5. Conductor when ready to go will give 3-4, and will not start his train until 3-4 has been given in reply, and this must not be given by the signalman unless the block is clear.

Additional bell signal may be used if desired. The telegraph or other equivalent may be used instead of the bell for transmitting signals.

13. To receive and forward a train, the block being clear, and signals giving the normal indication:

In answer to 3 from the next block station in the rear, the signalman must unlock by closing the circuit, and unless otherwise provided hold it closed until acknowledged.

In answer to 4 from the next block station in the rear, he must give 2, then give the block station in advance 3. If released, he must give 2 in acknowledgment, then clear the signals. When the train enters the block in advance, he must give 4 to the next block station in advance. When the rear of the train has passed ——— feet beyond the home block signal, and he has seen the markers, he must give 1-2 to the station in the rear.

14. Block signals must be restored to the normal indication as soon as the train for which they were cleared has passed ———.

15. Unless otherwise provided, signalmen must not give 3 until they have received 4 from the next block station in the rear, nor unlock the next block station in the rear before receiving 3.

16. Signalmen must observe all passing trains and note whether they are complete and in order, and the markers properly displayed. Should there be any indication of conditions endangering the train, or a train on another track, the signal 1-4—1-4 must be given to the next block station in advance, and the signalman must display Stop-signals in both directions, and then answer 1-4—1-4. Should a train going in the opposite direction be stopped, it may be permitted to proceed when it is known that the track on which it is running is not obstructed. When practicable, the signalman giving 1-4—1-4 must inform the signalman at the other end of the block why the signal was given.

17. Should a train pass a block station without markers, the signalman must give 2-3-2 to the next block station in advance, and 5-2-5 to the next block station in the rear, and must not report the block clear nor unlock the next block station in the rear until he has ascertained that the train is complete.

18. Should a train pass a block station in two or more parts, the signalman must give 3-3-3—3-3-3 to the signalman at the next block station in advance. A signalman having received this signal must stop any train running in the opposite direction. The Stop-signal must not be displayed to the engineman of the divided train if the block in advance is clear, but the Train-parted signal must be given. Should a train going in the opposite direction be stopped, it may be permitted to proceed when it is known that its track is not obstructed.

19. Should cars run away in the wrong direction, the signal 4-4-4 must be given to the next block station in the rear. Should cars run away in the right direction, the signal 4-6-4 must be given to the next block station in advance. Signalmen receiving either of these signals must take such measures for the protection of trains as may be practicable.

20. A signalman informed of any obstruction in a block must display the Stop-signal and give 5-5-5 to the signalman at the other end of that block. A signalman receiving 5-5-5 must immediately display the Stop-signal and then answer by 5-5-5. The Clear-signal for that block must not be displayed until the obstruction is removed.

21. When a train takes a siding the signalman must know that it is clear of the block before giving 1-2 or displaying a Clear-signal for that block.

A signalman, after having unlocked the next block station in the rear or given 3-1, must not permit train or switching movements that will endanger an approaching train.

22. A train must not be admitted to a block unless it is clear, except as provided in Rule 28, or by special order.

23. When, as provided for in Rule 38, coupled trains have been separated, the signalman must regard each portion as an independent train.

24. If necessary to stop a train for which a Clear-signal has been displayed and accepted, the signalman must give hand signals in addition to displaying the Stop-signal.

25. A signalman having orders for a train must display the block signal at "Stop." He may permit trains so stopped to proceed under block signal rules after complying with Rules for Movement by Train Orders.

26. If from the failure of block signal apparatus the block signal cannot be changed from the normal indication, a signalman having information from the signalman at the next block station in advance that the block is clear may admit a train to the block by the use of a Clearance Card.

27. When a train is admitted to a block, as provided in Rule 28, both signalmen must use every precaution to prevent a second train from entering the block until it is clear.

28. If from the failure of bell circuits, telegraph line or other cause a signalman be unable to communicate with the next block station in advance, he must stop every train approaching in that direction. Should no cause for detaining the train be known, it may then be permitted to proceed, provided ——— minutes have elapsed since the passage of the last preceding train using a Caution Card.

29. Signalmen must have the proper appliances for hand signailing, including the use of lamp, flag, torpedo and fusee signals, ready for immediate use. Hand signals must not be used when the proper indication can be displayed by the fixed signals. When hand signals are necessary they must be given from such a point and in such a way that there can be no misunderstanding on the part of enginemen or trainmen as to the signals, or as to the train or engine for which they are given.

30. Signalmen will be held responsible for the care of the block station, lamps and supplies; and of the signal apparatus unless provided for otherwise.

31. Lights in block stations must be so placed that they cannot be seen from approaching trains.

32. Lights must be used upon all block signals from sunset to sunrise, and whenever the signal indications cannot be clearly seen without them.

33. If a train overruns a Stop-signal, the fact, with the number of train, must be reported to ———.

34. If a Stop-signal is disregarded, the fact, with the number of train, must be reported to the block station in advance, and then to ———.

ENGINEMEN AND TRAINMEN.

35. Block signals apply only to trains running in the established direction.

36. Trains must not pass a Stop-signal without receiving a Caution Card, a Clearance Card, or a special order.

37. An engineman holding a Caution Card must deliver it to the signalman at the next block station, and personally ascertain from him that the block in advance is clear before proceeding.

38. Unless directed by special instructions, when two or more trains have been coupled and so run past any block station, they

must be uncoupled only at a block station, and the signalman notified.

39. When a train takes a siding it must not again enter the block without the permission of the signalman.

40. When it is necessary for a train to cross over, the conductor, before crossing or returning, must notify the signalman and obtain permission to do so.

41. Enginemen and trainmen must not accept clear hand signals as against block signals.

42. The engineman of a train which has parted must sound the whistle signal for Train-parted on approaching a block station.

43. An engineman receiving a Train-parted signal from a signalman must answer by the whistle signal for Train-parted.

44. When a parted train has been recoupled the signalman must be notified.

45. At a block station where the signalman is absent or incapacitated, so that instructions cannot be obtained, trains must wait ——— minutes and then proceed with caution to the next block station, where the conductor must report accordingly to the ———.

46. If the track is obstructed between block stations, notice must be given to the nearest block signalman.

47. If a train is held by a block signal to exceed ——— minutes, the conductor must ascertain the cause.

48. Conductors must report to ——— any unusual detention at block stations.

49. A block station must not be considered as closed, except as provided on time table or by special instructions.

AUTOMATIC BLOCK SYSTEM.

A series of consecutive blocks controlled by block signals operated by electric, pneumatic or other agency, actuated by a train or by certain conditions affecting the use of a block. It consists of:

1. Signals of prescribed form, the indications given by not more than three positions; and, in addition, at night by lights of prescribed color.

2. An apparatus so constructed that the failure of any part controlling the Home Block Signal will cause it to indicate—Stop.

3. Signals, if practicable, either over or upon the right of and adjoining the track upon which trains are governed by them. For less than three tracks, signals for trains in each direction may be on the same signal mast, or the upright to which the signals are directly attached.

4. Semaphore arms that govern, displayed to the right of the signal mast as seen from an approaching train.

5. Switches in the main track so connected with the block signals that the Home Block Signal in the direction of approaching trains will indicate Stop, when the switch is not set for the main track.

6. Signal connections and operating mechanism so arranged that a Home Block Signal will indicate Stop after the ——— (head or rear) of a train shall have passed it.

Adjuncts. The following may be used:

(A) Distant block signals connected with corresponding Home Block Signals and so constructed that the failure of any part controlling the signal shall cause it to indicate—Caution. When Distant Block Signals are used the rule following No. 1 should be used.

(B) Track circuits.

(C) Indicators at main track switches.

1. RULES.

Home Signals.

Signal	Occasion for Use	Indication	Name
Color	The signal will appear when	For enginemen and trainmen	As used in rules
(a) red	Block is not clear	Stop	Stop signal
(b) ——	Block is clear	Proceed	Clear signal
(c) ——	Block is clear Second block in advance is not clear	Approach next home signal prepared to stop	Caution signal.

Where the semaphore is used, the governing arm is displayed to the right of the signal mast as seen from an approaching train, and the indications are given by positions:

Horizontal as the equivalent of (a).

Vertical or Diagonal (angle above or below the horizontal) as the equivalent of (b).

Diagonal (angle above or below the horizontal) as the equivalent of (c).

Where a single disc is used for two indications, these are given by position of a (color) disc as seen from an approaching train:

Disc displayed as the equivalent of (a).

Disc withdrawn as the equivalent of (b).

When Distant Block Signals are used the following should be added to Rule 1:

Distant Signals.

Signal	Occasion for Use	Indication	Name
Color	The signal will appear when	For enginemen and trainmen	As used in rules
(d)	Home signal is at (a) or track obstructed between distant and home signal	Proceed with caution to the home signal	Caution signal
(e) —	Home signal is at (b)	Proceed	Clear signal

Where the semaphore is used, the governing arm is displayed to the right of the signal mast as seen from an approaching train, and the indications are given by positions:

Horizontal as the equivalent of (d).

Vertical or Diagonal (angle above or below the horizontal) as the equivalent of (e).

Where a single disc is used for two indications, these are given by position of a ——— (color) disc as seen from an approaching train:

Disc displayed as the equivalent of (d).

Disc withdrawn as the equivalent of (e).

2. Block signals control the use of the blocks, but, unless otherwise provided, do not affect the movements of trains under the time table or train rules; nor dispense with the use or the observance of other signals whenever and wherever they may be required.

3. Block signals apply only to trains running in the established direction.

4. When a train is stopped by a block signal it may proceed when the signal is cleared.

Or it may proceed:

(A) After waiting ——— minutes and then running under caution; or

(B) Preceded by a flagman to the next clear signal.

The Committee has provided for alternatives in this rule, considering either to be safe practice.

5. When a signal is out of service the fact will be indicated by ———.

Trains finding a signal out of service must, unless otherwise directed, proceed with caution to the next signal.

6. When a train is stopped by a signal which is evidently out of order, and not so indicated, the fact must be reported to ———.

INTERLOCKING RULES.

Standard Code of the American Railway Association.

DEFINITIONS.

Interlocking. An arrangement of switch, lock and signal appliances so interconnected that their movements must succeed each other in a pre-determined order.

Interlocking Plant. An assemblage of switch, lock and signal appliances, interlocked.

Interlocking Station. A place from which an interlocking plant is operated.

Interlocking Signals. The fixed signals of an interlocking plant.

Home Signal. A fixed signal at the point at which trains are required to stop when the route is not clear.

Distant Signal. A fixed signal used in connection with a home signal to regulate the approach thereto.

Dwarf Signal. A low fixed signal.

RULES.

Signal	Occasion for Use	Indication	Name
Color	The signal will be displayed when	For enginemen and trainmen	As used in rules
(a) red	Route is not clear	Stop	Stop signal
(b) ——	Route is clear	Proceed	Clear signal

When the semaphore is used, the governing arm is displayed to the right of the signal mast as seen from an approaching train, and the indications are given by positions:

Horizontal as the equivalent of (a).

Vertical or Diagonal (angle above or below the horizontal) as the equivalent of (b).

2. Interlocking signals, unless otherwise provided, do not affect the movements of trains under the time table or train rules; nor dispense with the use or the observance of other signals whenever and wherever they may be required.

SIGNALMEN.

3. The normal indication of Home Signals is Stop.

4. Levers, or other operating appliances, must be used only by those charged with the duty and as directed by the rules.

5. Signal levers must be kept in the position giving the normal indication, except when signals are to be cleared for an immediate train or engine movement.

6. When the route is clear the signals must be cleared sufficiently in advance of approaching trains to avoid delay.

7. Signals must be restored so as to give the normal indication as soon as the train or engine for which they were cleared has passed ————.

8. If necessary to change any route for which the signals have been cleared for an approaching train or engine, switches must not be changed or signals cleared for any conflicting route until the train or engine for which the signals were first cleared has stopped.

9. A switch or facing point lock must not be moved when any portion of a train or an engine is standing on, or closely approaching, the switch or detector bar.

10. Levers must be operated carefully and with a uniform movement. If any irregularity, indicating disarranged connections, is detected in their working, the signals must be restored so as to give the normal indication, and the connections examined.

11. During cold weather the levers must be moved as often as may be necessary to keep connections from freezing.

12. If a signal fails to work properly, its operation must be discontinued and the signal secured so as to give the normal indication until repaired.

13. Signalmen must observe, as far as practicable, whether the indication of the signals corresponds with the position of the levers.

14. Signalmen must not make nor permit any unauthorized alterations or additions to the plant.

15. If there is a derailment or if a switch is run through, or if any damage occurs to the track or interlocking plant, the signals must be restored so as to give the normal indication, and no train or switching movement permitted until all parts of the interlocking plant and track liable to consequent injury have been examined and are known to be in a safe condition.

16. If necessary to disconnect a switch from the interlocking apparatus the switch must be securely fastened.

17. During storms or drifting snow special care must be used in operating switches. If the force whose duty it is to keep the switches clear is not on hand promptly when required, the fact must be reported to ————.

18. If any electrical or mechanical appliance fails to work properly ———— must be notified, and only duly authorized persons permitted to make repairs.

19. When switches or signals are undergoing repairs, signals must not be given for any movement which may be affected by such repairs, until it has been ascertained from the repairmen that the switches are properly set for such movements.

20. Signalmen must observe all passing trains and note whether they are complete and in order; should there be any indication of conditions endangering the train, or any other train, the signalmen must take such measures for the protection of trains as may be practicable.

21. If a signalman has information that an approaching train

has parted, he must, if possible, stop trains or engines on conflicting routes, clear the route for the parted train, and give the Train-parted signal to the engineman.

22. Signalmen must have the proper appliances for hand signailing, which includes the use of lamp, flag, torpedo and fusee signals, ready for immediate use. Hand signals must not be used when the proper indication can be displayed by the fixed signals. When hand signals are necessary, they must be given from such a point and in such a way that there can be no misunderstanding on the part of the enginemen or trainmen as to the signals, or as to the train or engine for which they are given.

23. If necessary to discontinue the use of any fixed signal, hand signals must be used and ——— notified.

24. Signalmen will be held responsible for the care of the interlocking station, lamps and supplies, and of the interlocking plant, unless provided for otherwise.

25. Lights in interlocking stations must be so placed that they cannot be seen from approaching trains.

26. Lights must be used upon all fixed signals from sunset to sunrise, and whenever the signal indications cannot be clearly seen without them.

27. If a train or engine overruns a Stop-signal, the fact, with the number of train or engine, must be reported to ———.

28. Only those whose duties require it shall be permitted in the interlocking station.

ENGINEMEN AND TRAINMEN.

29. Trains or engines must be run to, but not beyond, a signal indicating stop.

30. If a clear signal, after being accepted, is changed to a stop signal before it is reached, the stop must be made at once. Such occurrence must be reported to ———.

31. Enginemen and trainmen must not accept clear hand signals as against fixed signals until they are fully informed of the situation and know that they are protected. Where fixed signals are in operation, trainmen must not give clear hand signals against them.

32. The engineman of a train which has parted must sound the whistle signal for Train-parted, on approaching an interlocking station.

33. An engineman receiving a Train-parted signal from a signalman must answer by the whistle signal for Train-parted.

34. When a parted train has been recoupled the signalman must be notified.

35. Sand must not be used over movable parts of an interlocking plant.

36. Conductors or enginemen of yard engines must report to ——— any unusual detention at interlocking plants.

37. Trains or engines stopped in making a movement through an interlocking plant must not move in either direction until they have received the proper signal from the signalman.

REPAIRMEN.

38. Repairmen are responsible for the inspection, adjustment and proper maintenance of all the interlocking plants assigned to their care.

39. Where the condition of switches or track does not admit of the proper operation or maintenance of the interlocking plant, the fact must be reported to ———.

40. When any part of an interlocking plant is to be repaired, a thorough understanding must be had with the signalman, in order to secure safe movement of trains and engines during repairs. The signalman must be notified when repairs are completed.

41. If necessary to disconnect any switch, it must be securely fastened before any train or engine is permitted to pass over it.

42. Alterations or additions to an interlocking plant must not be made unless authorized by ———.

43. Repairmen, when on duty or subject to call, must keep ——— advised as to where they can be found, and respond promptly when called.

SIGNAL RULES.

(Adopted by the American Railway Association.)

For the proper method of running trains, the American Railway Association have adopted a standard code of train rules, which give the standard method of running trains on single track, double track and three and four tracks, with and without block signals. This code should be in the hands of every engineer. From this code the following standard signal rules, both audible and visible, used on railways have been taken:

Rule 1.—Employees whose duties may require them to give signals must provide themselves with the proper appliances, keep them in good order and ready for immediate use.

Rule 2.—Flags of the prescribed color must be used by day, and lamps of the prescribed color by night.

Rule 3.—Night signals are to be displayed from sunset to sunrise. When weather or other conditions obscure day signals, night signals must be used in addition.

Rule 4.—VISIBLE SIGNALS.

COLOR SIGNALS.

Color	Indication
(a) Red.	Stop.
(b) ——	Proceed, and for other uses prescribed by the rules.
(c) ——	Proceed with caution, and for other uses prescribed by the rules.
(d) Green and white.	Flag stop. (See rule 22.)
(e) Blue	A blue flag by day and a blue light by night, displayed at one or both ends of an engine, car or train, indicates that workmen are under or about it; when thus protected it must not be coupled to or moved. Workmen will display the blue signals, and the same workmen are alone authorized to remove them. Other cars must not be placed on the same track so as to intercept the view of the blue signals without first notifying the workmen.

Rule 5.—A fusee on or near the track, burning red, must not be passed until burned out. When burning green it is a caution signal.

Rule 6.—HAND, FLAG AND LAMP SIGNALS.

Manner of Using	Indication
(a) Swung across the track.	Stop. (See Fig. 1)
(b) Raised and lowered vertically.	Proceed. (See Fig 2)

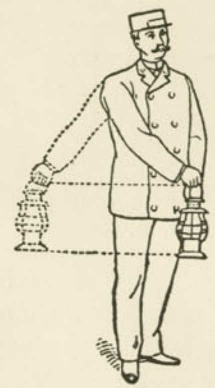


Fig. 1.

STOP—SWING ACROSS THE TRACK.

(See Rule 6).

Fig. 2.

PROCEED—RAISED AND LOWERED VERTICALLY.

(See Rule 6).

(c) Swung vertically in a circle at half arm's length across the track when the train is standing.	Back. (See Fig. 3)

(d) Swung vertically in a circle at arm's length across the track when the train is running.	Train has parted. (See Fig. 4)

Fig. 3.

BACK—SWUNG VERTICALLY IN A CIRCLE AT HALF ARM'S LENGTH ACROSS THE TRACK.
(See Rules 6 and 8).

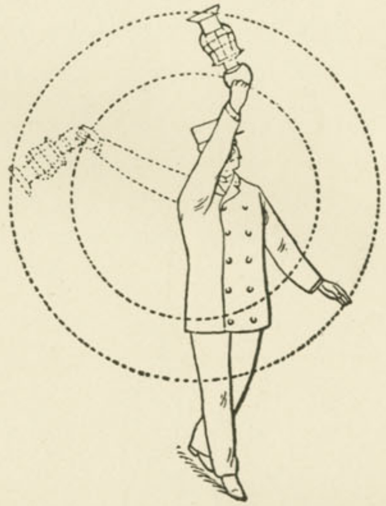


Fig. 4.

TRAIN HAS PARTED—SWUNG VERTICALLY IN A CIRCLE AT ARM'S LENGTH ACROSS THE TRACK.
(See Rules 6 and 8).

(e) Swung horizontally above the head when the train is standing.	Apply air brakes. (See Fig. 5)
(f) Held at arm's length above the head when the train is standing.	Release air brakes. (See Fig. 6)

Rule 7.—Any object waved violently by anyone on or near the track is a signal to stop.

Rule 8.—AUDIBLE SIGNALS.

ENGINE WHISTLE SIGNALS.

NOTE.—The signals prescribed are illustrated by o for short sounds; ——— for longer sounds. The sound of the whistle should be distinct, with intensity and duration proportionate to the distance signal is to be conveyed.

Fig. 5.

APPLY AIR BRAKES—SWUNG HORIZONTALLY ABOVE THE HEAD.
(See Rule 6).

Fig. 6.

RELEASE AIR BRAKES—HELD AT ARM'S LENGTH ABOVE THE HEAD.
(See Rule 6).

Sound	Indication
(a) o	Stop. Apply brakes.
(b) ——— ———	Release brakes.
(c) ——— ooo	Flagman go back and protect rear of train.
(d) ——— ——— ——— ———	Flagman return from west or south.
(e) ——— ——— ——— ——— ———	Flagman return from east or north.

(f) —— —— —— When running, train parted; to be repeated until answered by the signal prescribed by Rule 6 (d). Answer to 6 (d). See Fig. 4.

(g) oo Answer to any signal not otherwise provided for.

(h) ooo When train is standing, back. Answer to 6 (c) (see Fig. 3) and 10 (c). When train is running answer to 10 (d).

(j) oooo Call for signals.

(k) —— oo To call the attention of yard engines, extra trains or trains of the same or inferior class or inferior right to signals displayed for a following section.

(l) —— —— oo Approaching public crossings at grade.

(m) ———————— Approaching stations, junctions and railroad crossings at grade.

A succession of short sounds of the whistle is an alarm for persons or cattle on the track.

Rule 9.—The explosion of one torpedo is a signal to stop; the explosion of two, not more than 200 feet apart, is a signal to reduce speed and look out for a stop signal.

Rule 10.—COMMUNICATING SIGNALS.

Sound	Indication
(a) Two	When train is standing, start.
(b) Two	When train is running, stop at once.
(c) Three	When train is standing, back the train.
(d) Three	When train is running, stop at next station.
(e) Four	When train is standing, apply or release air brakes.
(f) Four	When train is running, reduce speed.
(g) Five	When train is standing, call in flagman.
(h) Five	When the train is running, increase speed.

Rule 11.—The headlight will be displayed to the front of

every train by night, but must be concealed when a train is standing to meet trains at the end of double track or at junctions.

Rule 12.—Yard engines will display the headlight to the front and rear by night. When not provided with a headlight at the rear, two white lights must be displayed. Yard engines will not display markers.

Rule 13.—The following signals will be displayed, one on each side of the rear of every train, as markers, to indicate the

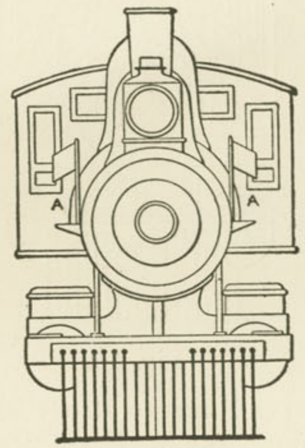


Fig. 7.

Engine Running Forward by Day as an Extra Train—White Flags at A A. (See Rule 15).

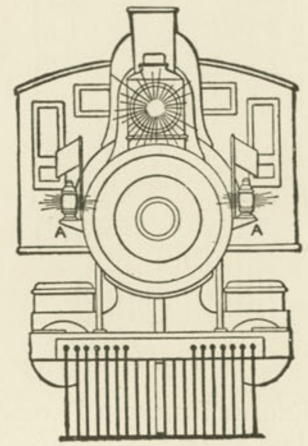


Fig. 8.

Engine Running Forward by Night as an Extra Train—White Lights and White Flags at A A. (See Rule 15).

rear of the train: By day, green flags; by night, green lights to the front and side and red lights to the rear, except when the train is clear of the main track, when green lights must be displayed to the front, side and rear, and except when a train is turned out against the current of traffic, when green lights must be displayed to the front and side, and to the rear, a green light toward the inside and a red light to the opposite side. (See Figs. 9, 10, 13, 14, 15, 16, 17, 18, 19 and 23.)

Rule 14.—All sections except the last will display two green flags, and in addition two green lights by night, in the places provided for that purpose on the front of the engine. (See Figs. 11, 12, 13 and 14.)

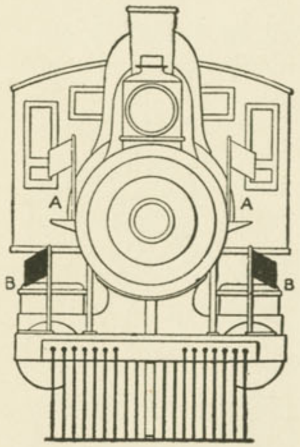


Fig. 9.

ENGINE RUNNING BACKWARD BY DAY AS AN EXTRA TRAIN, WITHOUT CARS OR AT THE REAR OF A TRAIN PUSHING CARS.—WHITE FLAGS AT A A (See Rule 15). GREEN FLAGS AT B B AS MARKERS (See Rule 13).

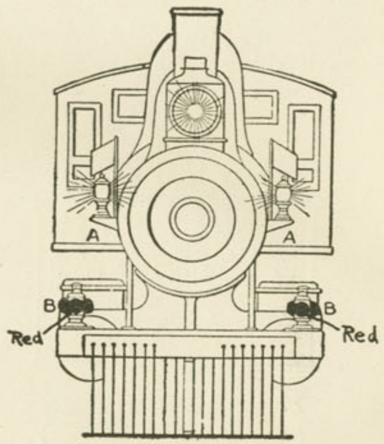


Fig. 10.

ENGINE RUNNING BACKWARD AT NIGHT AS AN EXTRA TRAIN, WITHOUT CARS OR AT THE REAR OF A TRAIN PUSHING CARS—WHITE LIGHTS AND WHITE FLAGS AT A A (See Rule 15). LIGHTS AT B B AS MARKERS, SHOWING GREEN AT SIDE AND IN THE DIRECTION ENGINE IS MOVING AND RED IN THE OPPOSITE DIRECTION (See Rule 13).

Rule 15.—Extra trains will display two white flags, and, in addition, two white lights by night, in the places provided for that purpose on the front of the engine. (See Figs. 7, 8, 9 and 10.)

Rule 16.—When two or more engines are coupled, the leading engine only shall display the signals as prescribed by Rules 14 and 15.

Rule 17.—One flag or light displayed, where in Rules 13, 14 and 15 two are prescribed, will indicate the same as two; but the proper display of all train signals is required.

Rule 18.—When cars are pushed by an engine (except when shifting or making up trains in yards) a white light must be displayed on the front of the leading car by night. (See Figs. 21 and 22.)

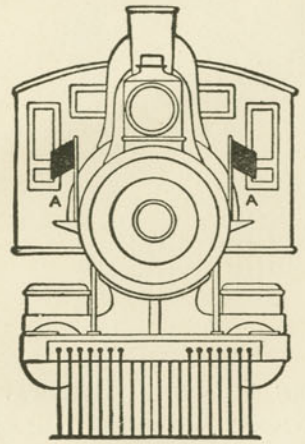


Fig. 11.

ENGINE RUNNING FORWARD BY DAY DISPLAYING SIGNALS FOR A FOLLOWING SECTION—GREEN FLAGS AT A A. (See Rule 14.)

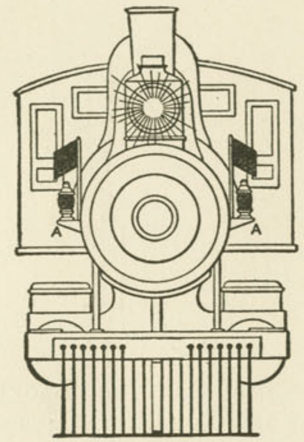


Fig. 12.

ENGINE RUNNING FORWARD AT NIGHT DISPLAYING SIGNALS FOR A FOLLOWING SECTION—GREEN LIGHTS AND GREEN FLAGS AT A A. (See Rule 14.)

Rule 19.—Each car on a passenger train must be connected with the engine by a communicating signal appliance.

Rule 20.—A blue flag by day and a blue light by night, displayed at one or both ends of an engine, car or train, indicates that workmen are under or about it; when thus protected it must not be coupled to or moved. Workmen will display the blue signals, and the same workmen are alone authorized to remove them.

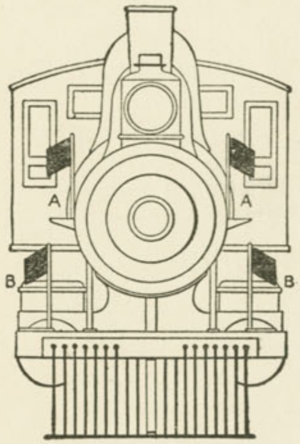


Fig. 13.

Engine Running Backward by Day, Without Cars or at the Rear of a Train Pushing Cars, and Displaying Signals for a Following Section—Green Flags at A A. (See Rule 14.) Green Flags at B B. (See Rule 13.)

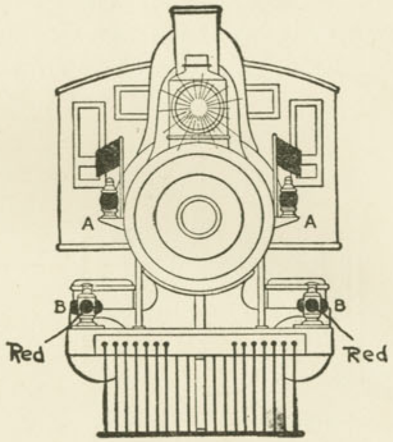


Fig. 14.

Engine Running Backward by Night, Without Cars or at the Rear of a Train Pushing Cars, and Displaying Signals for a Following Section—Green Lights and Flags at A A. (See Rule 14.) Lights at B B as Markers, Showing Green at Side and in the Direction Engine is Moving and Red in Opposite Direction. (See Rule 13.)

Other cars must not be placed on the same track so as to intercept the view of the blue signals, without first notifying the workmen.

Rule 20a. For three and four tracks a train by night running with the current on a high-speed track will display two red lights to the rear.

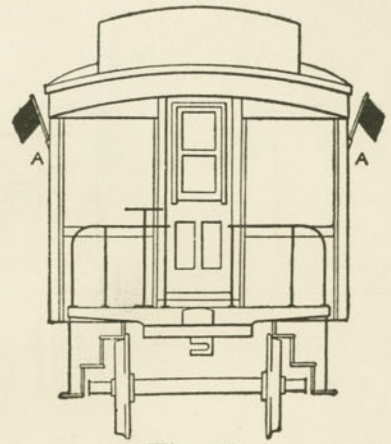


Fig. 15.

Rear of Train by Day—Green Flags as Markers. (See Rule 13.)

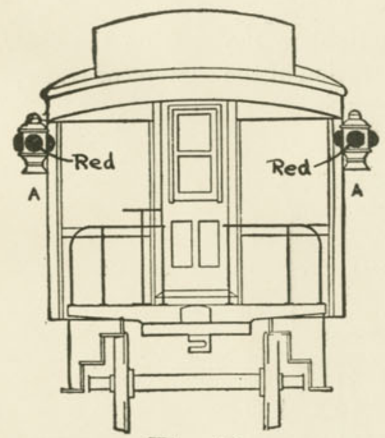


Fig. 16.

Rear of Train by Night When Running—Lights at A A as Markers, Showing Green Toward Engine and Side and Red to Rear. (See Rule 13.)

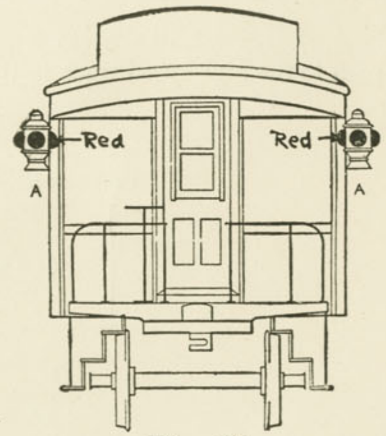


Fig. 17.

Rear of Train by Night When on Siding to be Passed by Another Train—Lights at A A as Markers, Showing Green Toward Engine, Side and to Rear. (See Rule 13.)

A train by night running with the current of traffic, on a slow speed track, or a train by night using any track against the cur-

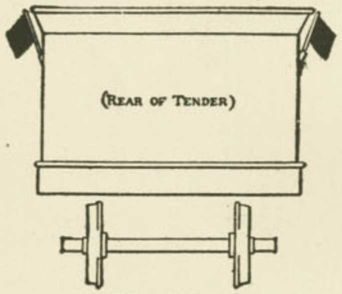


Fig. 18.

Engine Running Forward by Day Without Cars or at the Rear of a Train Pushing Cars. (See Rule 13.)

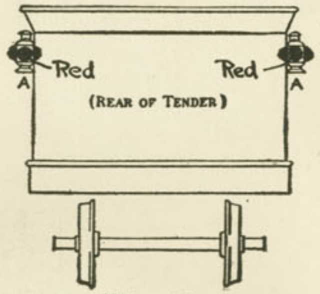


Fig. 19.

Engine Running Forward by Night Without Cars or at the Rear of a Train Pushing Cars. (See Rule 13.)

rent of traffic, will display a green light to the rear on the side next to the high-speed track in the direction of the current of traffic,

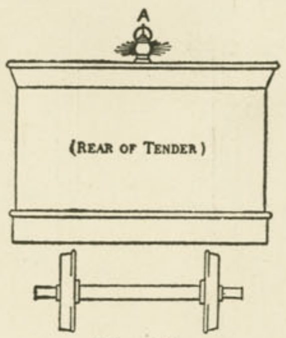


Fig. 20.

Engine Running Backward by Night Without Cars or at the Front of a Train Pulling Cars—White Light at A.

and a red light on the opposite side. (See Figs. 24, 25 and 26.)

A train by night on a siding will display two green lights to the rear.

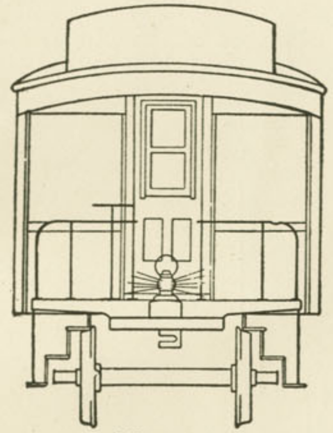


Fig. 21.

Passenger Cars Being Pushed by an Engine by Night—White Light on Front of Leading Car. (See Rule 18.)

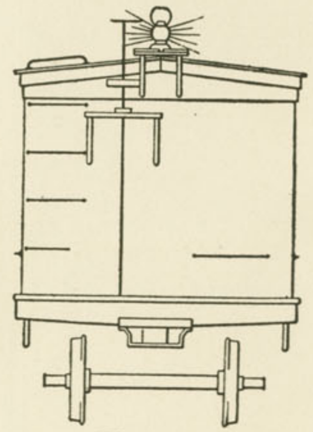


Fig. 22.

Freight Cars Being Pushed by an Engine by Night—White Light on Front of Leading Car. (See Rule 18.)

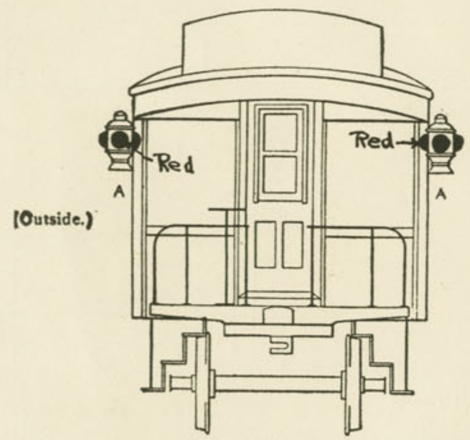


Fig. 23.

Rear of Train by Night Running Against the Current of Traffic—Lights at A A. Red to Rear on Left Lamp; Red on Inside of Right Lamp. (See Rule 13.)

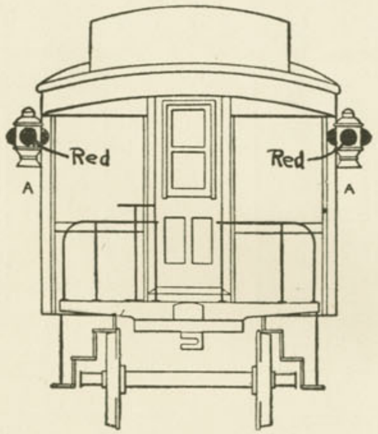
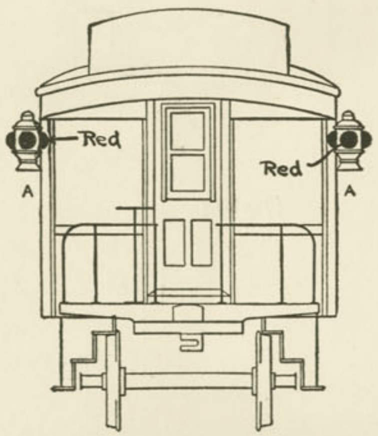


Fig. 24.

REAR OF TRAIN BY NIGHT, RUNNING WITH THE CURRENT OF TRAFFIC ON A HIGH SPEED TRACK—LIGHTS AT A A. GREEN AT SIDES; RED AT REAR. (See Rule 20A.)



(High Speed Track.)
A A

Fig. 25.

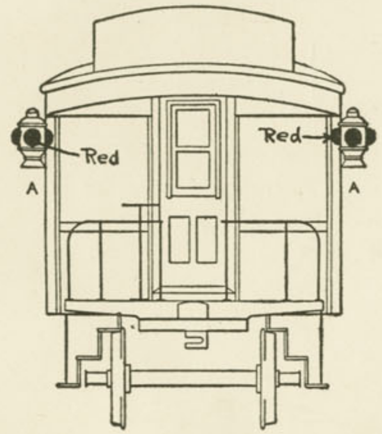
REAR OF TRAIN BY NIGHT RUNNING WITH THE CURRENT OF TRAFFIC ON A SLOW SPEED TRACK—LIGHTS AT A A AS PER RULE 20A.

USE OF SIGNALS.

Rule 21.—A signal imperfectly displayed, or the absence of a signal at a place where a signal is usually shown, must be regarded as a stop signal, and the fact reported to the ———.

Rule 22.—A combined green and white signal is to be used to stop a train only at the flag stations indicated on its schedule. When it is necessary to stop a train at a point that is not a flag station on its schedule a red signal must be used.

Rule 23.—When a signal (except a fixed signal) is given to



(High Speed Track.)
A A

Fig. 26.

REAR OF TRAIN BY NIGHT RUNNING ON ANY TRACK AGAINST THE CURRENT OF TRAFFIC—LIGHTS AT A A AS PER RULE 20A.

stop a train, it must, unless otherwise provided, be acknowledged as prescribed by Rule 8 (g) or (h).

Rule 24.—The engine bell must be rung when an engine is to move.

Rule 25.—The engine bell must be rung on approaching every public road crossing at grade and until it is passed; and the whistle must be sounded at all whistling posts.

Rule 26.—The unnecessary use of either the whistle or the bell is prohibited. They will be used only as prescribed by rule or law, or to prevent accident.

Rule 27.—Watchmen stationed at public road and street crossing must use red signals only when necessary to stop trains.