LINE CALCULATIONS

ECONOMICAL USE OF FEEDERS

1. There is no problem involving as little prospect of ever having general rules laid down to cover all cases and all conditions as the problem of calculating the most economical amount of copper to install and the best method of disposing that copper to meet the requirements of a given street-railway service. It is true that the present practice of dividing the line into insulated sections has, to a certain extent, simplified the work of calculation, because each section can be considered as an independent line governed by its own local conditions of load. If these conditions of load could in any case be laid down with certainty, the problem for any particular case would be solved; but once solved for that case, the solution would be of little use to the engineer for application to other cases, because it is almost impossible to find any two roads or even any two sections of the same road that call for the same conditions of load, and therefore for the same distribution of copper. During one part of the day the heaviest load might be on one part of the line and later in the day it might be on a section several miles away. Again, there may take place gradually a general shifting of the load more serious than a daily or weekly shift, due, possibly, to changes of attractions from one end of the line to the other, by a shift in the field of suburban improvements. Though overhead work may be installed under a design that meets satisfactorily almost every requirement of the present service, subsequent changes, such as the development of suburban property, may throw the system completely out of balance. The only thing to do then is

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to go over the work again and put copper where it is needed. But it is now a well-known fact that in promiscuously putting up copper, although it may be placed with good judgment from an electrical point of view and successfully fulfil its mission of raising the voltage to its normal value at the desired point, it can be put at a net loss to the company. Copper is expensive, and in the effort to lessen the loss in the line, it is an easy matter to get so much copper strung that a condition arises where the money invested in copper might be more profitably invested in other ways, as, for example, in the installation of boosters or storage batteries.

2. The conditions that confront the engineer, then, when he proposes to improve the service by stringing more feeders are as follows: By thus raising the voltage, a certain amount of energy is saved by reducing the line loss, and the saving in watts or horsepower can be approximately calculated. By knowing what it costs to produce a unit of energy at the power house, the direct saving effected by the increase of copper can be at once obtained, and by knowing the cost of the additional copper installed, including the cost of construction, the interest on the cost of the copper may be computed. The rule that it pays to install more copper to raise the voltage, if the cost of the watts saved in a year exceeds a year's interest on the cost of the additional copper put up, is one that should always be kept in mind. It must not be forgotten, however, that the above limiting condition expressed in the form of an equation (interest on the cost = value of energy saved) does not include all the elements that modify the equation. When the feeding system is improved, it brings about a saving in a direct way; it makes the loss in the line less, and effects a saving in an indirect way that is just as important; for, by keeping up the voltage and thereby increasing the efficiency and speed at which the cars run, it not only decreases the number of cars necessary to conform to the conditions of a certain time table, but by improving the service it attracts travel, especially in cases where there is a competing road. Even in cases where there

is no competing road, an improvement in the service draws travel. Calling Q the interest on the cost, W the value of the energy saved, and S the money returned per year as a result of the raising of the E. M. F. by the additional copper, the modified equation will read (the present one reads $Q = W$) $Q = S + W$. This equation is more in favor of the added copper and conforms more to the true state of affairs.

EXAMPLES OF FEEDER CALCULATION

3. In the transmission of current for electric railways, as in other cases of electric transmission, the loss or drop in the line is usually limited. If the loss is large, a comparatively high-resistance line with a corresponding small amount of copper can be used, but a large line drop means a low voltage at the cars unless the voltage at the station is automatically increased as the load increases. Low line voltage makes it hard for the cars to maintain their schedule and always gives rise to trouble with the motors, to say nothing of the actual cost of the power wasted in the line. It is seldom that the average drop is less than 10 per cent. (50 volts), and in a great many cases it runs much higher than this; if feeding is accomplished through boosters, the line drop may be as great as 200 volts. These figures are for the average drop, and the maximum drop may at certain instants be as high as three or four times the average if the load is of a very fluctuating character.

4. The weight of the rail is fixed by traffic considerations, so that an approximate estimate of what the drop in the return circuit will be can be formed at the outset. The balance of the drop will then give that allowed for the feeders, and they should be designed to conform to this as nearly as possible. Feeders designed under this condition seldom fail to fulfil the requirements of the average drop. There is a great difference between the maximum and average loads in the stations, and the smaller the station, the greater is the difference liable to be. For this reason, the

average drop and maximum drop may be widely different. Take a case where the road operates only two or three cars and the load fluctuates between zero and the maximum several times in a minute. Before the size can be assigned to the feeders, the average load that each feeder has to look after must be approximately known or ascertained. In doing this, it is very convenient to divide the line into sections, assign to each section the load that probably will be on it, and proportion the feeders accordingly.

5. When the size, number, weight of cars, speed, type of equipment, etc. are known, the average current required for any given section of the road can be determined approximately, as described in a previous section and, knowing the current and allowable drop, the size of the feeders can be calculated. For purposes of illustration in the following examples, a current of 25 amperes per car is taken. This is a fair average for a 24-foot body car. Of course the current taken at starting is very much greater than this, but on the other hand when the car is standing still it is taking no current at all, so that 25 amperes may be safely taken. Also, in all examples, the trolley wire is No. 00 and its cross-section is taken as 133,000 circular mils, this being close enough for line calculations; its resistance per mil-foot is also taken the same as that of ordinary soft copper. This is not strictly accurate, because the resistance of hard-drawn copper is slightly higher than that of annealed copper, but it simplifies the calculations to consider them the same, and since the other quantities used in the calculations are necessarily approximate, there is no advantage in considering the slight difference in the conductivities of the two kinds of copper. Single track laid with 80-pound rail is assumed in all cases; the resistance per mile of track (two rails in parallel) will therefore be .028 ohm, assuming that the resistance across joints is no greater than that of an equal length of solid rail. In order to make some allowance for imperfect joints we will add 25 per cent. and take the resistance per mile of track as .035 ohm.

ROAD FED FROM ONE END

6. Fig. 1 shows the layout of a road 5 miles long. The system is fed from a power station at one end of the line and operates ten cars using on an average 25 amperes each, making a total of 250 amperes. It is specified that the total load concentrated at the end of the line shall not produce an average drop of over 100 volts. If the trolley wire is No. 00, what must be the size of the feeder BA?

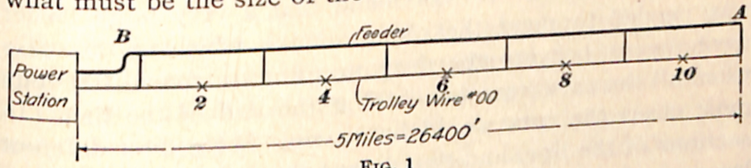


FIG. 1

The road is single track, so that the resistance of the 5 miles will be $.035 \times 5 = .175$ ohm, which resistance, carrying a current of 250 amperes, will cause a drop of $250 \times .175 = 43.75$ volts, leaving a drop of $100 - 43.75 = 56.25$ volts in the trolley wire and feeder. If it is assumed that the conductivity of the copper in the trolley wire is the same as that in the feed-wire, we may use the formula

$$\text{circular mils} = \frac{10.8\,L\,I}{e} \qquad (1)$$

where L = length of wire, in feet, through which the current I is delivered;
I = current supplied;
e = drop in volts.

The number of circular mils given by this formula will be the combined cross-section of the trolley and feeder, because these two wires are tied together in parallel throughout their length. In this case, $L = 26{,}400$ feet, $I = 250$ amperes, $e = 56.25$ volts; hence,

$$\text{circular mils} = \frac{10.8 \times 26{,}400 \times 250}{56.25} = 1{,}267{,}200$$

The trolley wire is No. 00, has an area of cross-section of 133,000 circular mils, and, deducting this from the total cross-section as calculated, leaves $1{,}267{,}200 - 133{,}000 = 1{,}134{,}200$

circular mils as the cross-section required in the feeder; two 500,000-circular-mil cables could be used and the system worked with a drop slightly larger than that calculated.

7. It should be noted that in working this example a fair value for the track resistance was assumed and the drop in the track circuit estimated. This was subtracted from the total drop, thus giving the value e used in formula **1**. Formula **1** does not, therefore, in itself take the track resistance into account. It was found that a very large feeder was needed to meet the requirements, which in this case were severe, because the drop was not to exceed 100 volts when all the cars were bunched at the end of the line. In most cases the cars would be moving along over different sections of the line, and thus lessen the drop on the system, because some of the cars would be comparatively near the station. At the same time, conditions arise where the cars may all be bunched at the end. In this case, therefore, it would be well to raise the voltage to 600 at full load at the station, either by using a heavily overcompounded generator, or by means of a booster.

POWER HOUSE IN MIDDLE OF LINE

8. If the power house were situated at the middle of the line, the amount of copper required would be very much less, as will be easily seen by referring to Fig. 2. The limiting condition is the same as before; that is, the drop

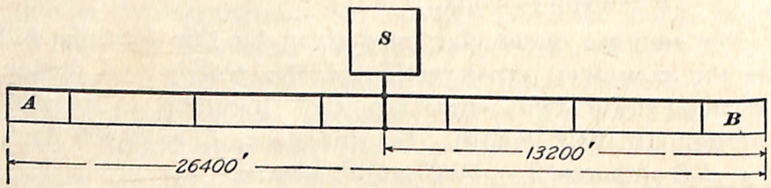


FIG. 2

from S to A or B must not exceed 100 volts when all the cars are concentrated at either A or B. If the cars are bunched at either A or B, 250 amperes must be transmitted through $2\frac{1}{2}$ miles of track and feeder. Taking the track

resistance as .035 ohm per mile, the resistance of $2\frac{1}{2}$ miles of track will be $.035 \times 2.5 = .0875$ ohm. The drop in the track part of the circuit will, therefore, be $.0875 \times 250 = 21.875$ volts. This leaves a drop of $100 - 21.875 = 78.125$ volts in the feeder and trolley wire. The length of feeder and trolley wire is $2\frac{1}{2}$ miles; hence, by applying formula **1**, the combined cross-section of the two is

$$\text{circular mils} = \frac{10.8 \times 13{,}200 \times 250}{78.125} = 456{,}190$$

The trolley wire supplies 133,000 circular mils of this cross-section; hence, the cross-section of feeder required is $456{,}190 - 133{,}000 = 323{,}190$. Placing the power house near the middle of the line results in a very large reduction in the amount of copper required, and a single 300,000-circular-mil cable would supply the current with as little drop as two 500,000-circular-mil cables in the first example.

EFFECT OF DISTRIBUTED LOAD

9. So far the feeder problems have been worked out on the assumption that the load was bunched at one end. This is a condition that sometimes arises in practice, but it can hardly be looked on as the ordinary operating condition. In most cases, a number of cars are spaced at fairly regular intervals along the line, each car moving at an approximately

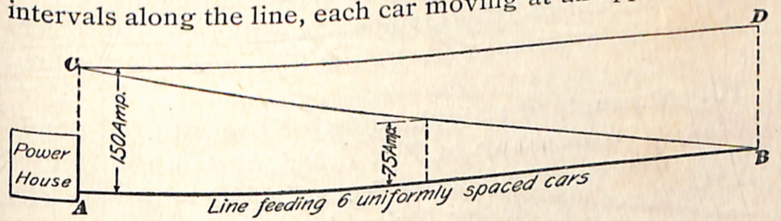


FIG. 3

uniform rate with the result that current is taken off at a number of points that are continually shifting. The load is nearly uniformly distributed and there is a gradual falling off in current from the station to the end of the line. For example, suppose that AB, Fig. 3, represents a stretch of line that supplies six uniformly spaced cars moving at a

uniform speed and taking 25 amperes per car. On account of the uniform movement and even spacing, the current will decrease gradually from 150 amperes at the station to zero at the end B. We may represent the falling off in the current by the line CB. The drop between A and B will, therefore, be found by multiplying the average current in AB by the resistance. The average current is evidently one-half the station current, or 75 amperes; hence, if the resistance of AB is, say, $\frac{1}{2}$ ohm, the drop between A and B will be 37.5 volts. If the whole load is bunched at B, the current will be 150 amperes throughout the whole length, as represented by the line CD, and the average current throughout the length will be the same as the current at the station; hence, the drop will be $150 \times \frac{1}{2} = 75$ volts. Hence, for a given line wire and a given amount of current transmitted, the drop with a uniformly distributed load is one-half that with a concentrated end load. In other words, if calculations are made relating to a distributed load and the whole length of line is considered in the calculations, the current must be taken as one-half the actual current supplied to all the cars, because it falls off from the station, or feeding point, to the end of the line.

Another and perhaps a better way of considering a distributed load is to look on it as if the whole load were concentrated at the middle of the line and work out the problem as if the whole current were transmitted over half the line.

10. Example of Calculations for Distributed Load. Taking the road shown in Fig. 1, find what size of feeder will be required when the load is distributed and the average drop to the end of the line limited to, say, 50 volts.

There are ten cars, each taking 25 amperes and uniformly spaced; the whole load of 250 amperes may be considered as concentrated at the middle of the line, or that an average current of 125 amperes is transmitted over the whole line. In order to be definite, we will work the problem as if 250 amperes had to be transmitted through $2\frac{1}{2}$ miles of feeder and $2\frac{1}{2}$ miles of track with a drop of 50 volts. The

track resistance is .035 ohm per mile and the resistance of $2\frac{1}{2}$ miles of track is .0875 ohm; the drop in the track is $.0875 \times 250 = 21.875$ volts. This leaves $50 - 21.875 = 28.125$ volts drop for the feeder and trolley. Then the combined cross-section of the feeder and trolley will be

$$\text{circular mils} = \frac{10.8 \times 13{,}200 \times 250}{28.125} = 1{,}267{,}200.$$

This combined cross-section is the same as that necessary to supply an end load with a drop of 100 volts. In other words, with the same amount of line copper, a uniformly distributed load will produce only one-half the drop that a bunched end load will cause, or if the drop is kept the same in both cases, the amount of copper required for the distributed load will be only one-half that called for by the concentrated load.

The method of working out the case shown in Fig. 2, for a distributed load, will be the same as the above except that the current supplied on each side of the station will be only 125 amperes, because the load is uniformly distributed and one-half the cars will be on each side. Also, this 125 amperes will be considered as concentrated at the middle of the 13,200 feet. This will require much less copper than when the load is concentrated at either end. In the above, it must not be forgotten that while the load is considered as bunched at the middle of the line, the feeder runs the whole length, as indicated in the figures.

CALCULATIONS FOR A LOOP LINE

11. Fig. 4 represents a so-called **loop line** that runs down one street and comes up at the next street parallel to it. It is a modified form of the **belt line** that is supposed to encircle the business part of the city, but it differs from a belt line in that, since the parallel lines are in neighboring parallel streets, the power house can, without great sacrifice of economy, be placed to one side of the area enclosed by the system, instead of being placed within this area.

In Fig. 4, AC is the street that the cars go up, DB the street on which they return. The area enclosed by the two tracks is very long in comparison to its width, but the width

between the streets is exaggerated in Fig. 4 in order to make the arrangement clearer. The track is represented by the parallel dotted lines, and the two trolley wires are tied together at intervals. Two feeders, represented by the heavy lines, are connected to the trolley wires at points l, m, and the trolley wire is divided into two sections by means of section insulators x, x', each feeding-in point being at the middle of a section. Since the two sections are independent and each is supplied by its own feeder, it will be sufficient to calculate one of the feeders; the other will be the same, because the road is symmetrical. Since the cars are uniformly distributed, the load on each section may be considered as

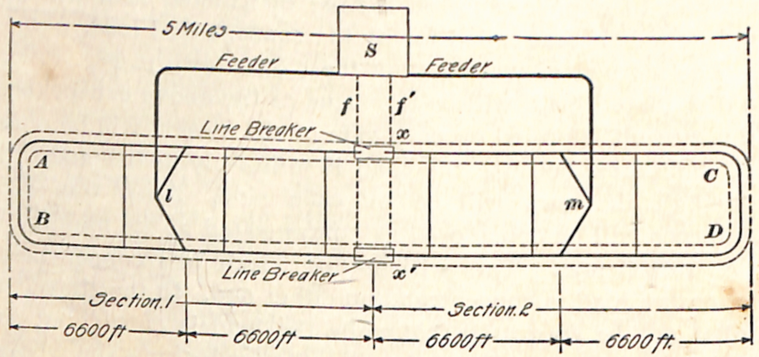


FIG. 4

concentrated at the middle of that section, that is, where the feeders are attached. The drop from the station to the feeding-in points l, m must not exceed 50 volts, and a total of ten cars is operated, each taking 25 amperes. The number of cars on each of the two sections will, therefore, be five, and each feeder will have to supply 125 amperes. Since the trolley wire is fed from the middle point of each section and there are no feeders on the end of the section, there will always be more or less drop in the trolley wire itself, but this will not be very great because there will not be more than two cars on any trolley section, and if the drop to the feeding-in points is limited to 50 volts the service will be satisfactory. The length of a section is $2\frac{1}{2}$ miles, or

13,200 feet; a half section is 6,600 feet. The resistance through which the drop of 50 volts is to take place is that of four lines of single rail well bonded together, each line being $2\frac{1}{2}$ miles long. However, the load is uniformly distributed and the total current of 125 amperes can be considered as flowing through $1\frac{1}{4}$ miles of double track. The resistance of 1 mile of single track is .035 ohm and of double track $\frac{.035}{2}$; hence, $1\frac{1}{4}$ miles of double track has a resistance of $\frac{.035}{2} \times \frac{5}{4}$ = .0219 ohm. The drop in the rail return is $.0219 \times 125$ = 2.74 volts, and the allowable drop in the feeders 50 − 2.74 = 47.26 volts. So far as the feeders are concerned, the load is not distributed because they each connect to the trolley wire only at the end, and 125 amperes is carried over the whole length of the feeder. The length of the feeder is 6,600 feet; hence, circular mils $= \frac{10.8 \times 6{,}600 \times 125}{47.26}$ = 188,530, approximately.

No. 000 B. & S. is too small (167,805 circular mils) and No. 0000 (211,600 circular mils) is larger than the calculated size; however, it would be advisable to use No. 0000 and thus allow for a future increase in load. The drop in the feeder can be calculated from formula 1 transposed to read

$$e = \frac{10.8\, L\, I}{\text{circular mils}} \qquad (2)$$

which for a No. 0000 feeder (211,600 circular mils), gives

$$e = \frac{10.8 \times 6{,}600 \times 125}{211{,}600} = 42.1 \text{ volts, nearly}$$

12. In the layout shown in Fig. 4, the trolley wires are not fed on the ends, and if the five cars on one-half of the road became bunched at the end of a trolley section the drop would be considerable. Under these conditions, 125 amperes would be carried 6,600 feet by two No. 00 wires in parallel and the drop in the trolley wire would be, from formula 2,

$$e = \frac{10.8 \times 6{,}600 \times 125}{2 \times 133{,}000} = 33.5 \text{ volts}$$

13. In Fig. 4, suppose that two feeders f, f', indicated by the dotted lines, are connected, one to each section, directly from the power house. In practice, it will cost but little to do this, because these feeders are very short and, as shown by the following, the effect on the voltage is beneficial. Consider one of the sections, say, section *1*; it is fed by the regular feeder previously calculated, and, in addition, the feeder f runs out directly from the power house and is tapped on the trolley wire at the line breaker. We will find what the drop would be under the most unfavorable conditions, that is, with the five cars on the section bunched at A. The whole current, 125 amperes, will have to return to the station through $2\frac{1}{2}$ miles of double track. In the overhead work there will be $1\frac{1}{4}$ miles of feed-wire, and in parallel with this will be the two trolley wires extending back to the station, because the connection of the feeder f places the trolley wires in parallel with the regular feeder. Up to the point l, therefore, the feeder and the two trolley wires, in parallel, carry the current; beyond l, to the end of the line, the current is carried by the two trolley wires alone. It will be assumed that No. 0000 wire is used for the feeder.

The resistance of $2\frac{1}{2}$ miles of double track will be $\frac{.035}{2} \times \frac{5}{2}$ = .0438 ohm, approximately. The drop in the track will, therefore, be $.0438 \times 125 = 5.475$ volts, or say, 5.5 volts. From l to A, the drop in the two trolley wires will be 33.5 volts. From the station to point l, there is a No. 0000 feeder in parallel with two No. 00 trolley wires; hence, the total cross-section of copper is $211{,}600 + 2 \times 133{,}000 = 477{,}600$ circular mils. The drop from the station to point l is therefore

$$e = \frac{10.8 \times 6{,}600 \times 125}{477{,}600} = 18.7 \text{ volts, nearly.}$$

The total drop from station to cars is the sum of the drops in the different portions of the circuit, or $5.5 + 33.5 + 18.7 = 57.7$ volts.

If feeders f, f' were not provided, the drop with five cars bunched at A would be $5.5 + 33.5 + 42.1 = 81.1$ volts. Adding feeders f, f', therefore, effects a reduction of 23.4 volts in the drop under the most unfavorable conditions. If the load were concentrated at the power-station end of the section, there would be little or no resistance in the circuit, save that of the tap wire and the ground-connection wire, so that it is safe to say that the loss caused by a current of 125 amperes would not at this point be more than 5 volts. The power-house taps, as well as the line feeder, should be provided with feeder switches, so that the current can be cut off at any section desired.

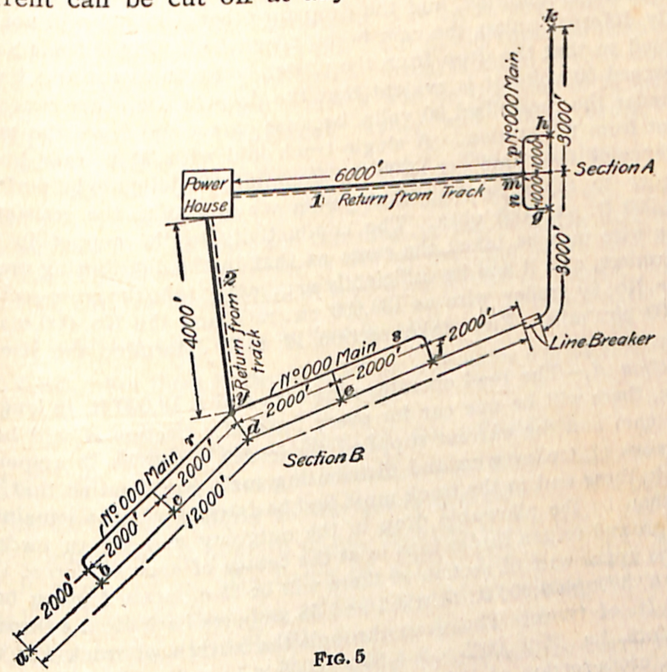


FIG. 5

SMALL ROAD WITH RETURN FEEDERS

14. To illustrate the calculations for a road where the power house is not situated alongside the track and where return feeders must be run, the following example will be taken:

EXAMPLE.—Fig. 5 shows the layout of a single-track road operating nine cars, which are spaced fairly evenly along a line divided into two sections by means of a line breaker. The sections are provided with

No. 000 mains, fed by two feeders *1* and *2* running from the power station. Return feeders, represented by the dotted lines, are run alongside the outgoing feeders and the drop under average conditions is to be limited to 50 volts. Each car takes an average current of 25 amperes, the track is laid with 80-pound rails, and the trolley wire is No. 00.

SOLUTION.—Since the cars are equally spaced and constantly shifting in position, the drop will vary somewhat, depending on the position of the cars. In order to make things definite, we will assume that the cars are located as shown by the crosses. This will represent a fair average condition, and the drop for other positions will not be greatly different unless the cars become bunched. If the feeders are designed so that the drop from the power house to cars *a* and *k* will not exceed 50 volts, it is evident that the drop to the other cars will fall under the prescribed 50 volts, because cars *a* and *k* are the most distant from the station. A single track laid with 80-lb. rails has a resistance of .0053 ohm per 1,000 ft., assuming the joints to be perfect; in order to allow for imperfect joints we will take the resistance per 1,000 ft. as .0065 ohm. The conductivity of the copper in the trolley wire may be taken the same as that in the distributing mains and feeders, and it will be sufficiently accurate to take the cross-section of the No. 00 trolley wire as 133,000 cir. mils and the No. 000 mains 167,800 cir. mils. First take section *A* and determine the size of feeder *1*.

Section A.—The road operates nine cars and is 18,000 ft. in length; hence, there will be one car for every 2,000 ft. Section *A* will have three cars and the current supplied by feeder *1* will be 75 amperes. The sizes of trolley wire and distributing main are fixed so that the drop in these and in the track must first be determined; the remainder will then be the allowable drop in the outgoing and return feeders. The ground-return feeder taps in at the center of each section so that for the upper half of section *A* there will be 25 amperes flowing back from *k* through 2,000 ft. of track and 50 amperes back from *h* through 1,000 ft. of track. The drop through the stretch of track *k m* will therefore be $25 \times .0065 \times 2 + 50 \times .0065 \times 1 = .65$ volt. The wire has a cross-section of 133,000 cir. mils, is 2,000 ft. long, and carries 25 amperes; hence, drop $e = \frac{10.8 \times 2{,}000 \times 25}{133{,}000} = 4.06$ volts.

From *m* to *h*, the trolley wire is in parallel with a No. 000 main; hence, the total copper cross-section is 133,000 + 167,800 = 300,800 cir. mils; the current is 50 amperes, and drop $e = \frac{10.8 \times 1{,}000 \times 50}{300{,}800} = 1.79$ volts. The total drop between *m* and *k* and in the track-return circuit will be $.65 + 4.06 + 1.79 = 6.50$ volts, thus leaving $50 - 6.50 = 43.5$ volts for the drop in the outgoing and return feeders.

The current in feeders *1* is 75 amperes, and the total length (outgoing and return) 12,000 feet; hence, circular mils of feeders for section $A = \frac{10.8 \times 12{,}000 \times 75}{43.5} = 223{,}450$, approximately. Either No. 0000 B. & S. wire (211,600 cir. mils) or a 300,000-cir.-mil cable can be used for these feeders, the latter being preferable.

Section B.—The drop in the track from *a* to *d* will be $25 \times .0065 \times 2 + 50 \times .0065 \times 2 + 75 \times .0065 \times 2 = 1.95$ volts. In the overhead work, the drop between *a* and *b* in the trolley wire will be the same as from *k* to *h* in section *A*; i. e., 4.06 volts. The drop between *b* and *c* will be twice that between *h* and *m* in section *A* because the current and sizes of wires are the same but the distance is twice as long; hence, the drop from *b* to *c* is $1.79 \times 2 = 3.58$ volts. Car *d* will cause no drop in the track or overhead work because its current is taken directly from the feeder. The drop between *c* and *d* will be that due to 75 amperes through 2,000 ft. of combined trolley and main; hence, drop $e = \frac{10.8 \times 2{,}000 \times 75}{300{,}800} = 5.4$ volts, nearly. The total drop between *a* and *y* is therefore $1.95 + 4.06 + 3.58 + 5.4 = 14.99$, or say, 15 volts, leaving $50 - 15 = 35$ volts for the drop in the outgoing and return feeders. The current in feeders *2* will be that due to six cars, or 150 amperes, and the total length of feed-wire is 8,000 ft.; hence, circular mils of outgoing and return feeders for section $B = \frac{10.8 \times 8{,}000 \times 150}{35}$ = 370 286. For these feeders 350,000-cir.-mil cable will be suitable.

CARRYING CAPACITY OF FEEDERS

15. In making these calculations, no attention was paid to the carrying capacity of the wires and cables. Of course, this point must be kept in mind, because if the lines are simply figured out on the basis of giving the allowable drop, it might happen that the current would overheat the wires. Table I, due to Mr. H. W. Fisher, gives the approximate amount of current that wires may be allowed to carry without causing the temperature to increase much over 25° F. above that of the surrounding air.

In most cases, however, it will be found that the size of wire needed to keep the drop within the specified limits will be considerably larger than that necessary to carry the current without overheating. Only in cases where the distances are short is there likelihood of the wire not being large enough. It is always well, however, to compare the

TABLE I

CURRENT-CARRYING CAPACITY OF FEEDERS

No. B. & S. Gauge	Circular Mils	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately Amperes	No. B. & S. Gauge	Circular Mils	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately Amperes
Stranded Cables	500,000	509	2	66,370	124
	400,000	426	3	52,630	107
	350,000	388	4	41,740	91
	300,000	355	5	33,100	74
	250,000	319	6	26,250	63
0000	211,600	275	7	20,820	52
000	167,800	237	8	16,510	44
00	133,100	195	9	13,090	36
0	105,500	168	10	10,380	30
1	83,690	143			

sizes obtained and the current that the wires must carry with the values given in the table. If the wires should prove to be too small, the only thing to do is to use a wire that will carry the current safely or else run the risk of the wire overheating. If the larger wire is used, it will result in a somewhat smaller drop, but this will be an advantage, although the first cost of the wire will be a little higher.

16. Effects of Low Voltage.—If the drop becomes excessive, either on account of the feeding system being too light or the load too heavy, it will produce a low voltage at the cars, and this in turn means low speed. It is a well-known fact that just as soon as the voltage on a system becomes low, troubles with the motors and car equipment begin to multiply. There are many cases on record where controller and brush-holder troubles have been very much decreased and where the roasting of field coils, controller blow-out coils, and the throwing of solder out of the commutator

connections have been entirely stopped simply by raising the voltage on the line.

Suppose that a road having a certain number of cars is operated at, say, 550 volts and on a certain schedule; also, suppose that owing to an extension of the road, the addition of more cars, the deterioration of the track-return circuit, or any other reason, the voltage gradually comes down to 400. This will make a maximum decrease of about 20 per cent. in the running speed of the cars. If the time table is rearranged so that the motormen can run the cars on time with the same ease that they could with the higher voltage, the troubles with the rolling stock will not only not increase, but they will actually decrease, because the lower voltage is not as hard on the insulation and arc-breaking devices and the lower speed is not as hard on the car bodies and trucks.

If, on the other hand, no notice is taken of the gradual decrease in the average line voltage and the same time table is kept in force, the following will be the result: Since the maximum running speed of the cars has been cut down, the motorman must make up time wherever he can. Most of this will be made up at starting and getting the car under headway; part of it will also be made up on curves, crossings, and other places where, under ordinary conditions, slow running would be the rule. At starting, the controller is moved around rapidly and the car takes far more current than it should and the excessive current injures the controller, the commutator, and the brushes. The insulation on the fields becomes roasted and troubles of all kinds are liable to occur simply because the equipment has to be abused to make the car run on time.

As a practical instance of the result of low voltage, the following actual case that occurred where two abutting roads used each other's tracks for about ¾ mile may be cited. Their trolley wires were separated by a line breaker and each road had its own feeder system. On one side of the breaker the voltage was 425 volts; on the other side, 525 volts. As long as each road used only its own trolley wire the

high-voltage road had no trouble to speak of. As soon as its cars began to run over the low-voltage road, controller and brush-holder breakdowns set in and continued until two extra feeders were run to the low-voltage side.

The above effects have been noted here simply to show that the question of proper voltage is an important one. It is true that there are many roads operating under an excessive drop, and this in itself is not so bad if the pressure at the station is increased so that the proper voltage at the cars is maintained. At the same time, a large drop means a large waste of power, and the question as to whether it will pay better to lose a considerable amount of power or buy more feed-wire is something that must be determined by the relative cost of power and copper.

ELECTROLYSIS

17. Introductory Remarks.—The subject of **electrolysis**, by which is here meant the eating away of the rails, underground pipes, or other buried metallic conductors by stray currents from the street-railway system, is closely connected with the feeding system, especially with the track-return part of it. When electrolysis was first noticed, a great outcry was raised against the trolley roads by gas and water companies, telephone companies, and other corporations owning underground pipes or lead-covered cables. The many lawsuits brought against electric-railway companies led to an investigation of the subject, with the result that electrolysis is not feared nearly as much as it once was, because means have been devised for avoiding it largely or for limiting it to sections where it can be watched or provision made to prevent it.

18. Elementary Principles.—In Fig. 6, *A* and *B* are two iron plates buried a short distance apart in damp earth. If the terminals of *A* and *B* are connected to a dynamo and a current made to flow from *A* to *B* through the earth, plate *A* will be eaten away or pitted while plate *B* will not

be damaged. This is practically the same electrochemical effect that takes place in electroplating, where metal is taken from a plate, or anode, and deposited on the article to be plated. The point to notice is that wherever current flows *from* a metal conductor into damp earth, the conductor is eaten away, provided that the difference of potential between the conductor and the adjacent earth is sufficient to effect the chemical decompositions; but where current flows from the earth *into* the conductor, the latter is not damaged. The rate at which the metal will be eaten depends on the strength of the current.

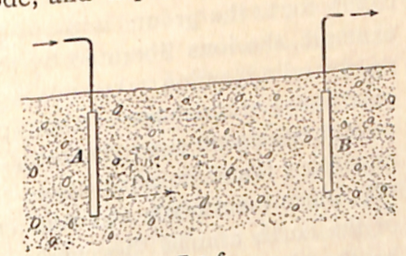


FIG. 6

19. Table II shows the weight of metal that will, theoretically, be eaten away by 1 ampere flowing steadily for 1 year, for metals likely to be affected by stray underground currents.

TABLE II

ELECTROLYTIC EFFECT OF CURRENT ON VARIOUS METALS

Metal	Grams per Ampere-Hour	Pounds per Ampere per Year
Aluminum	.327	6.31
Copper	1.190	22.97
Iron	1.044	20.15
Lead	3.852	74.34
Tin	2.218	42.71
Zinc	1.216	23.47

This table is of interest chiefly because it shows the relative effect of a current on the different metals. It does not follow that in practice, whenever a current of 1 ampere flows

for 1 year from a conductor into the ground, the amounts of metal indicated by the table will be eaten away. In fact, under some circumstances current may flow from a buried conductor to the ground without eating the metal at all. For example, the ions liberated by the current may be such that no corroding action takes place on the pipe, or the energy expended per unit area of the pipe surface may not be great enough to decompose the salts in the damp earth. It has also been found in many cases that electrolytic action may take place for a while and then cease owing to the character of the earth around the conductor having become changed by the decomposition of the salts contained therein and rendered incapable of acting as an electrolyte for further electrolytic action. It should also be remembered that underground pipes and conductors may become corroded by the simple chemical action of the salts contained in the earth, and whenever a conductor or pipe shows signs of pitting it by no means follows that the corrosion is due to electrolysis; in fact, there is no sure way of telling simply from the appearance of the pipe to which source the corrosion is due.

Mr. Albert B. Herrick* suggests the following method for determining definitely whether or not corrosion is due to simple chemical action or to electrolytic action. The pipe in question is uncovered for about 8 feet of its length. Half-round test shields made of material as nearly like the pipe as possible and of inside diameter corresponding with the outside diameter of the pipe, are provided; the length of these is usually about three times the diameter of the pipe to be tested. A length of the pipe corresponding to the length of shield is carefully cleaned and amalgamated, and the inside surfaces of a pair of shields are similarly treated. The shields are then firmly fastened to the pipe by bolting the semicircular halves together by means of bolts passing through projecting flanges. Another pair of plates is also bolted to the pipe, alongside of but not touching the first

*Street Railway Journal, Vol. XXIII, No. 14.

pair, and before bolting them in place the pipe is covered with a $\frac{1}{8}$-inch sheet of rubber. The second sheath is thus insulated from the pipe while the first is in good metallic contact with it and before being placed in position both shields are carefully weighed and notes made as to the character of their surfaces. The pipe and sheaths are then covered with earth and allowed to stand undisturbed for 6 months. At the end of that time they are examined, carefully cleaned, and weighed. If the insulated shield has been corroded it must have been on account of ordinary chemical action and the difference in weights will indicate the amount of corrosion. If the uninsulated sheath is corroded it may be due to electrolytic action, to ordinary chemical action, or to a combination of the two. By thus noting the difference in the effects on the two shields, the effects of corrosion from the two sources can be determined.

In Table II, it is interesting to note that lead is eaten away more rapidly than any of the other metals there given. Underground lead pipe, and the lead sheaths of underground cables are, under like conditions, eaten away much more rapidly than iron pipe. Also, wrought-iron pipe is much more susceptible to electrolytic corrosion than cast-iron; with cast iron the impurities in the iron appear to form a kind of scale that protects the pipe.

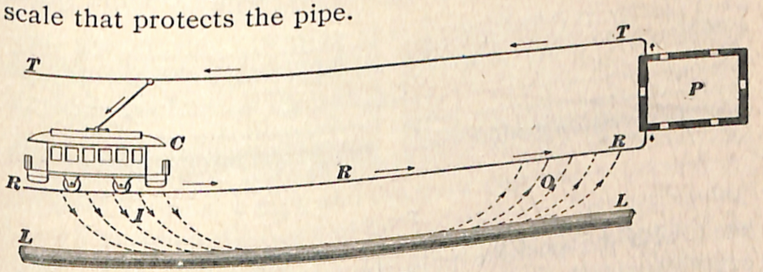


FIG. 7

20. Electrolysis Due to Railway Currents.—Fig. 7 gives a simple illustration as to how electrolysis may occur in connection with an overhead-trolley system. $T\,T$ is the trolley wire and $R\,R$ the track; under ordinary conditions, the current returns by way of the rail, as indicated by the

arrows. If, however, there happens to be a pipe $L\,L$, in the neighborhood of the track, that offers a ready path for the current, part of the current will leave the rails, as at I, enter the pipe, and flow out again at O to return to the power station. At O, where the current leaves the pipe, electrolytic action will be set up, if the conditions are favorable, and in the course of time will eat holes in the pipe. At I, the current leaves the

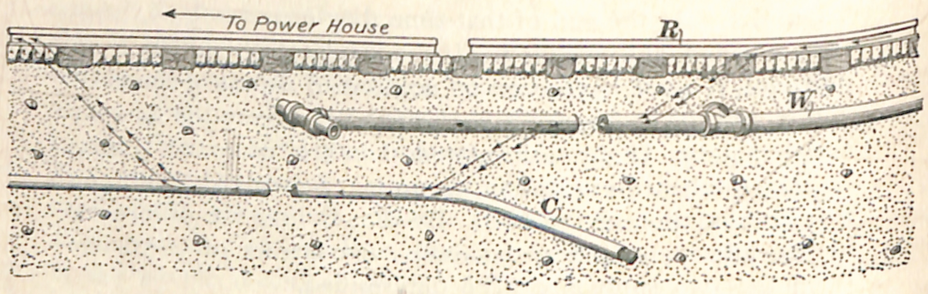


FIG. 8

rails; hence they will be eaten away to some extent. If the trolley wire were connected to the negative pole of the dynamo instead of the positive, the current would flow out through the track, and whatever corrosion occurred on the pipes would take place at points removed from the station and would be scattered over a wide area. On the other

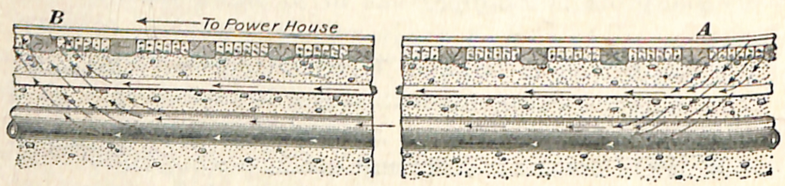


FIG. 9

hand, with the positive pole connected to the trolley, whatever action takes place on the pipes is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them. This is the principal reason why the positive pole of the dynamo should be connected to the trolley side of the line. Figs. 8 and 9 show modifications of the simple case shown in Fig. 7.

In Fig. 8 the current leaves the rail R, enters the pipe W, and flows through W until a better path presents itself in the shape of the lead-sheathed cable C. It flows along C until the track presents a better path, when it flows back to the rail again, as indicated by the arrows. Electrolytic action may occur where the current leaves the rail, the iron pipe, and the lead sheath of the cable. Fig. 9 shows a case where a cable and pipe run parallel to the iron rail $A\,B$, the arrows indicating the path of the stray current. Lead-covered underground cables are particularly liable to damage, because lead is eaten away much more rapidly than iron; moreover, the corrosion never takes place evenly, but in spots, so that the pipe or sheath becomes pitted and is soon destroyed. However, the general practice now is to run underground cables in tile ducts which form an insulating medium between the cable sheath and ground, thus preventing electrolysis to a large degree. Wrought-iron pipes are more quickly eaten than cast-iron; in fact, the harder grades of cast iron, such as chilled iron, seem to be very little affected.

It is seen, by referring to Fig. 7, that if the track return is in good condition, there will be little inducement for the current to leave the track and pass through the intervening earth to come back on the pipes. One of the most effective precautions against electrolysis is thorough rail bonding. With the greater attention that is paid to rail bonding on modern roads, there has been a corresponding reduction in the damage due to electrolysis.

21. Testing for Electrolysis. — The difference of potential between a pipe and the track depends on the current flowing between the two and the resistance of the intervening earth. The difference of potential that is effective in producing electrolytic action is that which exists between a pipe and the earth immediately surrounding the pipe. A very small E. M. F. may be sufficient to cause electrolysis while the E. M. F. measured between pipe and track might be quite high because of the intervening resistance. In order for electrolysis to take place, the pipe must be positive to

the surrounding earth so that current will flow from the pipe to the earth. If a test shows that the earth is positive to the pipe there is no danger at that point so far as the pipe is concerned. The old method of testing between the pipe and rail with a millivoltmeter does not give reliable information as to the potential between the pipe and adjacent earth, and

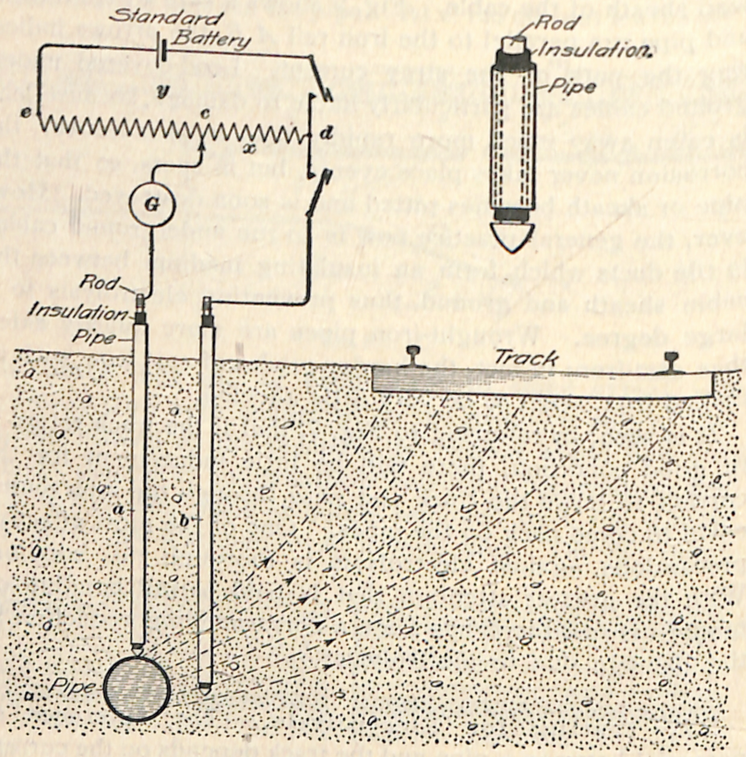


FIG. 10

the following test is recommended by Mr. Herrick as being much more reliable. An insulated pointed rod *a*, Fig. 10, is driven through the soil until the point comes in contact with the pipe. A second insulated rod *b* is driven in so that its point will come close to the pipe but will not touch it. Both rods are insulated and protected by running them through a piece of iron pipe lined with insulating material, as, for

example, a piece of lined conduit such as is used for wiring buildings. The earth potential point is covered with cadmium so that there will not be a local E. M. F. set up, which will disturb the difference of potential due to the earth currents. Also, the E. M. F. existing between the pipe and the test point is measured not by means of a voltmeter, which would disturb the normal current flowing between pipe and ground, but by balancing the unknown E. M. F. against a known E. M. F. from a standard battery. The resistance *c* is adjusted until the galvanometer indicates zero current, and the E. M. F. between pipe and ground then bears the same relation to the known E. M. F. of the standard battery that resistance x between *c* and *d* bears to the total resistance y included between *e* and *d*; or,

$$E_1 = E\frac{x}{y} \qquad (3)$$

where E_1 = E. M. F. between pipe and ground;
E = E. M. F. of standard battery;
x = resistance *c d*;
y = total resistance.

It is not necessary to know the values of x and y, in ohms; if the ratio of their resistances is known it is sufficient. Resistance y can be in the form of a bare high-resistance wire wound on a cylinder and provided with a sliding contact and scale, so that the divisions read off for any position of the contact will be proportional to the resistance x.

EXAMPLE.—A test was made, as shown in Fig. 10, with a standard battery giving 5 volts and a sliding contact resistance divided into 100 equal parts. When the galvanometer gave no deflection, resistance x was represented by 30 divisions on the scale. What was the E. M. F. between the pipe and ground?

SOLUTION.—In formula 3, since the resistances are proportional to the lengths of wire,

$$\frac{x}{y} = \frac{30}{100} \text{ and } E_1 = 5 \times \frac{30}{100} = 1.5 \text{ volts. Ans.}$$

22. Prevention of Electrolysis.—A large system of piping forms a conducting network of very low resistance in

parallel with the track, hence it is a very difficult matter to prevent part of the current from leaving the track. However, if proper steps are taken, the bad effects of electrolysis can be largely avoided; the following are the main points that experience has shown should be observed:

(*a*) The trolley wire should be made the positive side of the system.

(*b*) The track should be thoroughly bonded and the bonds maintained in good condition.

(*c*) Any metallic connections that may exist between piping or cable systems and the track should be located and removed.

(*d*) Return feeders should be run out from the station and connected to those pipes that carry the greater part of the current. Thus, the current in the pipes will be "drained" off without passing from the pipes to ground.

(*e*) Where service pipes, cables, or underground conductors pass under tracks or through other regions where they are exposed to electrolytic action, they can often be protected by covering them with glazed tile or by placing them in a trough filled with asphalt.

(*f*) If in any part of a system the rail return carries an excessive current, return feeders should be run so as to relieve the rail of part of the current and prevent an excessive fall of potential along the rail. The greater the fall of potential in the rails the greater is the tendency for the current to pass off to neighboring pipes.

The remedy given under (*c*) is important. Very often accidental connections exist between the rails and pipe so that current can pass directly to the piping system. This is specially the case where pipes run across iron bridges that also carry railway tracks. Before attempting to "drain off" the current from a piping system it is needless to say that all metallic connections between track and pipe must be removed. Where pipes pass across iron bridges the best plan is to insulate the pipe from the bridge, or if this is impossible, insulate the pipe by the insertion of insulating joints at either end of the bridge.

Remedy (*d*) is very commonly practiced and gives good results if properly applied. The return feeders should be attached to the pipes that carry the most current and, as a rule, the current so returned to the power house will not be more than 5 or 6 per cent. of the total current; if it exceeds this amount it is probable that there is a metallic connection somewhere between the track and pipes.

Service pipes crossing under street-car tracks are particularly subject to electrolytic action, and when they are being laid or repaired it costs but little to cover them with tile or to run them in a box, as explained in (*e*).

23. Method of Measuring Current in Pipe.—Fig. 11 shows a convenient method for measuring the current flowing in a pipe. Clamp terminals *a*, *b* are attached from 4 to 6 feet apart, and low-resistance connections made to an ammeter *c* through a switch *d*. A millivoltmeter *e* is also connected across terminals *f*, *g*, and readings taken from it with the switch *d* open and readings taken from *e* and *c* with *d* closed. The reading of *e* will be less when *d* is closed, as then part of the total current flows through the ammeter circuit. The current flowing in the pipe is then obtained from the formula

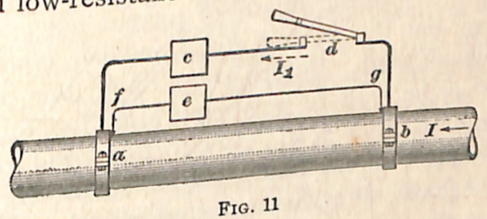


FIG. 11

$$I = \frac{I_1 E}{E - E_1} \qquad (4)$$

where I = amperes in main pipe;
I_1 = amperes indicated by ammeter *c* when switch *d* is closed;
E = volts indicated with switch *d* open;
E_1 = volts indicated with switch *d* closed.

EXAMPLE.—In Fig. 11, the current indicated by *c* with *d* closed is 20 amperes and the reading of *e* is 300 millivolts. With *d* open, *e* reads 400 millivolts. How many amperes are flowing in the pipe?

SOLUTION.—In formula 4, $I_1 = 20$, $E = 400$ millivolts $= .4$ volt, $E_1 = 300$ millivolts $= .3$ volt; hence,

$$I = \frac{20 \times .4}{.4 - .3} = 80 \text{ amperes.} \quad \text{Ans.}$$

24. Systems Free From Electrolysis. — Systems using the double overhead-trolley or conduit system where the rails do not form the return circuit, are, of course, free from trouble due to electrolysis. Also roads where alternating current is supplied to the cars are exempt because alternating current, even if it does return by way of pipes, is incapable of producing any electrolytic effect.

AUXILIARY EQUIPMENT

25. The part of an electric-railway system that pertains directly to the supply of current for the cars has been taken up, but the rolling stock and car equipment remain to be considered. Before going on to this part of the subject, it may be well to pay some attention to the auxiliary departments of a road. Under this head may be included car houses or car barns, repair shops, etc. These, while not, perhaps, directly connected with the running of the cars, are at the same time an essential part of the road. Their equipment varies greatly on different roads, so that the descriptions can only be very general in character.

THE CAR HOUSE

26. The **car house** or **car barn** is a building used for storing cars that are not in use. It is now customary to provide storage under cover only for those cars that are not in regular commission. Cars that are running regularly are stored outdoors; there is no good reason why a car that is in fit condition to be out all day in all kinds of weather should be put under cover over night, especially when such storage room is expensive and when there is always more or less danger from fire.

Where practicable, the tracks in car barns should be far enough apart to admit of easy passage between them, and the more uniformly the daylight is diffused throughout the building, the better. In some car houses, the storage room is all on one floor; this may be the first or second floor, according as the cars to be stored are out of season or are just temporarily out of use. In other storage houses, two or more floors are used, in which case an elevator must be provided for handling the cars on the upper floors.

Where the cars must be transmitted to and from an upper story by means of an elevator, it is almost always the case that the stripped or out-of-season cars are stored there. As there is no possible chance of saving the cars in time of fire, there is no objection to setting them on horses or barrels; but where the storage tracks are on a level with a street track, the cars should be set on temporary trucks, so that at an alarm of fire they can be run out. Where practicable, every storage track should lead to the street at one end or the other of the car house. In some houses it is the practice to grade the rails down to the street, so that in case of fire it is only necessary to let off the brakes and the cars will run out.

27. For inspection of trucks and motors there should be **pits** about 4 feet 8 inches deep directly under the tracks, no pit to be shorter than any car that may be placed over it. As to the total amount of pit room required per car, it is a very hard matter to fix between narrow limits, as it depends a great deal on how much trouble the equipments give. A safe value, however, based on long experience with almost all conditions of working with several types of motors and trucks, is 1 linear foot of pit room for each car that runs into the depot; though in some modern car barns the allowance is much less than this for the reason that it is now considered best to remove the car bodies from the trucks and work on the motors from above when thorough overhauling is required. Pits are used for ordinary inspection or for light repairs, but when an equipment has to be thoroughly gone

over a much better job can be done by dispensing with pit work altogether. The pits should have cement bottoms and be properly drained. The space between the tracks on the floor level should be boarded, but the underneath space between the pits should be left open.

A couple of shelves and a row of small bins to hold a few of the most commonly used sizes of bolts, nuts, and washers save time and should be placed in each pit.

28. **Wiring of Car House.**—The wiring of the car house is a simple matter, but its plan depends on the track layout of the house. Every track should have a trolley wire over it. The house trolley wiring, as a whole, should be separated from the main line outside by means of a line circuit-breaker; it must then be connected to the street wires by means of a jumper that passes through a switch placed outside of the building, so that in case of fire the whole house wiring can be disconnected. The wires in the house are supported on barn hangers (see Fig. 12). The hanger is fastened to the house beam by means of lugs *b*, *b*, the trolley wire being fastened to ear *c*; in barns with steel roof trusses, the hanger must be screwed to wooden blocks supported from the iron girders. In some barns, the trolley wire is run in an inverted wooden trough, the hangers being screwed to the bottom of the trough. In such a case, the trough generally catches the wheel if for any reason it leaves the wire; it also serves as an insulated support for the wheel at night and obviates the necessity of tying down the pole where such a rule is in force. Sometimes at short curves under very low structures it is the practice to do away with the trolley wire altogether and replace it with an inverted brass or copper trough, in which the trolley wheel rolls along on its flanges.

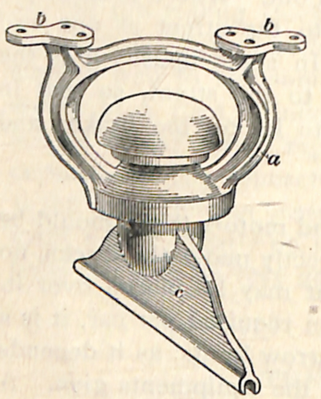


FIG. 12

THE REPAIR SHOP

29. The **repair shop** is the place where all heavy repairs and alterations are made. A well-appointed repair shop should include a machine shop, carpenter shop, mill, blacksmith shop, paint shop, winding room, commutator room, controller room, and a wheel-grinding annex. In the machine shop, all general machine work is done, such as fitting bearings, turning down commutators on the shaft, recutting bolts, etc. In the winding room, fields, armatures, armature coils, etc. are wound, insulated, and baked. In the commutator room, the parts of the commutator are assembled and the finished article tested. In the controller room, controllers, switches, resistances, etc. are repaired, and in the mill, the repair parts for car bodies are made. The shop building should be a substantial fireproof structure and every effort should be made to have good light throughout.

30. **The Pit Room and Machine Shop.**—The number and length of the pits depend on the nature of the work to be done and the number of cars to be handled. The pit rails should be laid on stringers supported by brick piers, and the space underneath between pits should be left open, so that a man can go from one pit to another without going up on the floor. There should be means provided for raising the car bodies off the trucks quickly and with as little labor as possible. It is common practice to provide car shops with an air compressor and reservoir, the air to be used in blowing the dust out of motors, controllers, etc.; in such a case, the compressor, or air pump, is driven by a motor. The air pump stores the air in a main reservoir that is piped to auxiliary reservoirs situated at the points where the air is to be used. Air has proved to be the best thing for cleaning purposes, and in the several instances where it has been used as a means of operating lifts to raise cars and to handle heavy work around the lathe and boring machines, it has scored an equal success.

31. **The Machine Shop.**—In laying out a machine shop, two important points must be kept in mind: the machines

must be so disposed as to admit of having a good light thrown on the work and at the same time must take up as little floor space as possible. The number and kind of machines to be installed depend on the class of work to be done. There should be enough machines so that the work may not be held back for want of them, but at the same time there should be no more of the same or similar kinds than can be kept busy.

The machines necessary are about as follows: One lathe to take an axle with the wheels on it; one smaller one to take armatures and bearings; one speed lathe; one metal saw; one large and one small drill press; one boring mill; one planer and shaper; one bolt-cutting machine, with right- and left-hand dies; one milling machine; one wheel press; one axle straightener; emery wheels; one grindstone; one power hack saw; one ratchet drill; one punch press; and one power hammer, usually in the blacksmith shop. On a small road, some of the above might be omitted.

32. The Winding Room.—As good a place as any for a winding room is in a gallery built around the wall above the machine shop, but a great many object to this plan on the ground that all cores to be wound and wires for winding must be elevated to the gallery. This is true; and where there is plenty of room on the ground floor, it is best to do the winding there; but where space is limited, the above location is a good one. The size of the armature room required for a given number of cars depends, of course, on many local conditions. For a road operating 100 cars or over, from 6 to 8 square feet of floor space per car should be sufficient. For a small road, the space required per car would be much larger. Every winding room in which all the processes of winding are carried out and where coils are not bought ready-made, should be equipped with about the following: One machine for putting bands on armatures; one field-winding machine; one armature-coil winding machine with a coil former for each type of armature; one gasoline stove, brick-enclosed, with the tank well removed and

enclosed (gas is better and safer when it can be had) for heating soldering irons; a device for pulling off commutators (the pinions should be removed before the armatures are sent in); racks for holding rolls of insulation; stands for holding armatures in course of winding; one machine for cutting insulation; one machine for pressing coil papers; one coil press for each kind of coil; ample facilities for dipping the coils in varnish or some other compound; racks for holding completed armatures; an oven or its equivalent for baking armatures (it can be either steam-heated or heated with street-car heaters). If the armature coils are dipped in an air-drying compound, no oven is needed, because the armatures themselves and the fields and other coils can be baked by sending a current through them; but if the armature coils are to be dipped in varnish—a much better practice—an oven must be provided, and it might just as well be large enough to bake everything.

The winding room should be provided with substantial patterns of every standard piece of insulation used in the place; one set of these should be hung in a convenient place; a duplicate set should be kept under lock and key, preferably in a fireproof place.

33. The Commutator Room.—The commutator room should be in charge of a good mechanic, and should contain a lathe, a drill press, a milling machine, and an oven for baking commutators. It should be provided with a full line of gauges for the several kinds of mica bodies used and plug gauges for the shaft hole bored in the shell. There should be provided a device for tightening up the nuts without twisting the commutator bars out of line. There must be an adequate supply of assembling rings and the proper wrenches for adjusting them; no emery wheel should be allowed in the commutator room. The most natural and convenient location for the room is next the winding room; it should be enclosed, but should have the best possible light and ventilation.

34. The Controller Room.—There is no particular condition to be fulfilled in selecting a site for the controller

room. A location just off the machine shop, where it will be convenient to the machines, is as good as any.

35. The Mill and Carpenter Shop.—The mill is the room in which the wood-working machines are placed and the carpenter shop is where the cars are run in for general body repairs. There is no reason why they should not both be within the same enclosure—the mill at one end and the carpenter shop at the other. The best place for them is between the machine shop, pit room, and paint shop, a line of single or double track running through, so that a car can come in at one end of the building and go out at the other. In the mill there should be a planer, boring machine, lathe, band saw, circular saw, and grindstone.

36. The Paint Shop.—The paint shop should be at the extreme rear of the main shop and should have free access to the street; it should be provided with as many doors on the street side as there are tracks, so that in case of fire the cars can be run out without any shifting or transferring. The paint shop should receive only cars that have been repaired and are ready to run on the road except for the painting. This being the case, each track in the shop should have a trolley wire over it, the whole system of trolley wires being kept cut out by means of a switch except when they are to be used. Under no circumstances should the car bodies be set on horses or barrels in the paint shop; the risk of fire is too great. They should always be on temporary trucks, and where possible, at the head of each line of cars should be a car fully equipped, so that in case of fire they can be coupled together and towed out of danger. Another good plan is to have the tracks down grade out of the house, so that when the brakes are released or the chocks removed from the wheels, the cars will run out by gravity. On account of the great fire risk incidental to the storage of so many inflammable materials, oils, varnishes, etc., there should be an absolutely fireproof wall between the paint room and the rest of the shop, communication between the two shops being only through self-closing fireproof

doors. As a prime precaution against fire, the building should be of brick, with a fireproof roof and a cement floor. The floor should be graded to gratings that lead to the sewer or to a cesspool and the roof should be designed to give the best possible light and ventilation. All inflammable materials should be kept in a small, absolutely fireproof room that will admit barrels, etc., without trucking them the entire length of the paint shop. The question of fire risk in a paint shop is a serious one, for the reason that the shop is generally full of cars that will burn quickly if once started.

37. The Blacksmith Shop.—The blacksmith shop must be located where the coal dust and gases from the forges cannot reach the paint shop. It should contain at least two forges, anvils, and a blower. One forge should be provided with an ordinary bellows all ready to be connected on, in case anything should happen to the blower or to the motor from which it is run. Besides the usual complement of forge tools, there should be a machine hammer, shears, and a drill press.

38. The Grinding Room.—If the brakes on a trolley car are applied too hard or if for any other reason the car skids along the track, flat spots, or **flats**, as they are called, are found on the tread of the wheel. These make the wheels pound on the rails, and unless they are removed by grinding or a new wheel put on, the trouble is liable to go from bad to worse. Most car wheels are of chilled cast iron. In the molding, the tread of the wheel is chilled so that the iron is very hard for a depth of $\frac{3}{8}$ or $\frac{1}{2}$ inch. If the wheel is worn down so that the chilled portion is ground through, there is no use in doing anything further with it, as the iron under the chilled part is too soft to last any length of time. If small flats develop, they can often be removed before they get any worse by taking off the regular brake shoe and putting on a special wheel-truing shoe provided with emery, carborundum, or similar abrasive. Fig. 13 shows one of these shoes; it simply replaces the

regular brake shoe and in the course of a few hours' run the abrasive blocks *a* grind the wheel true. When the flat is a bad one, it is removed by a regular grinder, which is a device for holding a revolving emery wheel against the tread of the wheel to be ground. The wheels may be ground either in place on the car or separate from the car. The car-wheel grinder can, as a rule, be used to greater advantage out at one of the depots, if the wheels are to be ground on the car; this is undoubtedly the best practice, but it is not always followed. Where the wheels are taken out to be ground, there must be extra means provided for driving the axle, whereas, if ground on the car, one of the car motors can do the work. In either case, the car wheels should make from 20 to 40 revolutions per minute, and the speed of the rim of the emery wheels should be about 5,000 feet per minute. Steel-tired wheels are trued up by turning in a lathe.

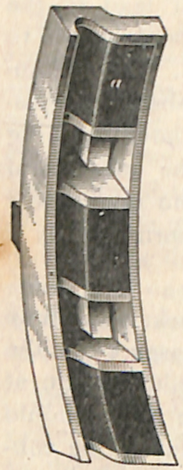


FIG. 13

CAR BODIES AND TRUCKS

CAR BODIES

39. The **car body** constitutes the main part of the car and is mounted either on one or two trucks, depending on its length. Car bodies are made in a large variety of styles, some being open for summer use, others closed, and others a combination of the two. They are made in lengths ranging from 18 or 20 feet to 40 or 50 feet; the larger cars usually have two rows of seats arranged crosswise as in an ordinary steam railway coach.

40. Selection of Car Body.—The selection of the cars for any given road is a matter that requires careful attention. No fixed rules can be laid down to govern the selection of the car body in all cases, because conditions vary and a body

adapted to one place and condition of service might fail entirely to meet the requirements elsewhere. In some places, open cars can be used the year round, while in other sections there are only a few days in the year when closed cars are uncomfortable. The average conditions call for both open and closed cars, and much attention has been paid to the question of devising a car that can be made open in warm weather and closed in cold weather. One result of this has been the so-called *semiconvertible* car, a type which all car manufacturers now make. The nearest approach to a solution of the problem of producing a combination car that is as good in hot as in cold weather is found in the car that is partly open and partly closed. This car has the advantage that it is not only adapted to hot and cold weather, but to rainy weather as well. It has the disadvantage that in no kind of weather does it, as a rule, carry a full load, except during the rush hours, so the power house must carry just so much dead weight over the road. Semiconvertible cars are made in a number of different ways, but the windows are made larger than ordinary. In one style of car both upper and lower window sash can be pushed up into pockets in the roof and held there, thus leaving practically the whole side of the car open. In another type no window sashes are provided at all; the windows are of large heavy glass panes fixed in place but arranged so that they can be removed in summer, thus leaving the side of the car open. Of course, in both cases, entrance must be from the ends, hence these cars cannot load or unload as quickly as a regular open car; at the same time they avoid the necessity of keeping two kinds of cars on hand and have come into very extensive use.

The single-truck four-wheel car is giving way to double-truck eight-wheelers, because a single truck, on account of the limited wheel base, cannot well accommodate a car body over 20 or 22 feet long. The most economical practice from the energy point of view, is to run **trailers**, which are cars similar to motor cars, but lighter and not equipped with motors. On account of the trailer being so light, the ratio

of live weight to total weight carried is very much increased; also, the trailers can be left off when they are not needed. But unfortunately the use of trailers increases the number of accidents and consequent damage suits, and these more than offset the value of the power saved.

The point must often be decided as to whether single-truck or double-truck cars should be purchased for a road. It can be safely said that if there is the least doubt as to which to buy, give the preference to the double-truck car. There is nothing so attractive as a well-built and well-appointed double-truck car. This type of car is easier on the car body, easier on the line work, easier on the track, and last but not least, it is easier on the passengers. Actual statistics show that the introduction of the double-truck car will create travel. Being higher from the rail and longer than the single-truck car, it takes longer to load and to unload passengers, and for this reason is not adapted to local runs, where the travel is heavy and the stops frequent. This, of course, does not apply to open cars, where ingress and egress are just as free as on a single-truck car.

TRUCKS

41. The main requirements of a good truck are that it be easy riding, durable, have few parts, wearing parts easily replaced, and wheels easily changed. The trucks must be entirely self-contained; that is, one framework must include the wheels and axles, the brakes, motors, and driving gear. This in reality constitutes the car, for the car body above is merely a framework to hold and shelter passengers, having none of the vital parts necessary to operation. The fact must not be overlooked, however, that the car body has to stand severe strains on account of the rapid acceleration at starting and an equally heavy strain when the brakes are suddenly applied in stopping; so that this portion of the car must be carefully designed or it will not last long.

42. Classes of Trucks.—Trucks are of two kinds: **single trucks** and **double trucks;** the latter may be

further subdivided into *ordinary double trucks* and *maximum-traction trucks*. A single truck has four wheels, takes a single motor on each axle, and there is one truck to a car; an ordinary double truck has four wheels, all the same size, can take a motor on each axle, and there are two trucks to a car; a maximum-traction truck has two large wheels and two small ones, the idea being to throw most of the weight on the large wheels, which are driven by the motor. The weight on the small wheels is regulated by means of a compression bolt and spring, just enough compression being put on to keep the small wheels on the rail when rounding curves. As a rule, the large wheels take about 70 per cent. and the small ones 30 per cent. of the total weight. Experiment has shown that for a given weight of car, the maximum-traction trucks do not require as large an expenditure of energy as a single truck with a 7-foot wheel base. The single truck, being more rigid, binds more in curves and does not equalize as readily as the maximum-traction truck, with its shorter wheel base. Nevertheless, the maximum-traction truck does not ride as easily as the ordinary truck and is now used comparatively little. The ordinary double truck equipped with a single motor has the disadvantage that the driving power is all on one axle, while the weight is divided between two. The result is a tendency for the driving wheels to spin when called on to do heavy duty, because the traction between the wheel and rail is not great enough. By putting a motor on each axle, making four motors to the car, conditions are much improved.

For large interurban cars, ordinary double trucks are always used, but they must be of heavier construction than for the lighter cars used for city traffic. In many cases, one of the trucks is made especially heavy and both motors placed on it, the other truck being without motors. In some cases, however, where the cars must have a very powerful motor equipment, it has been found advisable to use four motors, one on each axle, because the space is so limited that it is sometimes difficult to develop the necessary power in two motors without overheating.

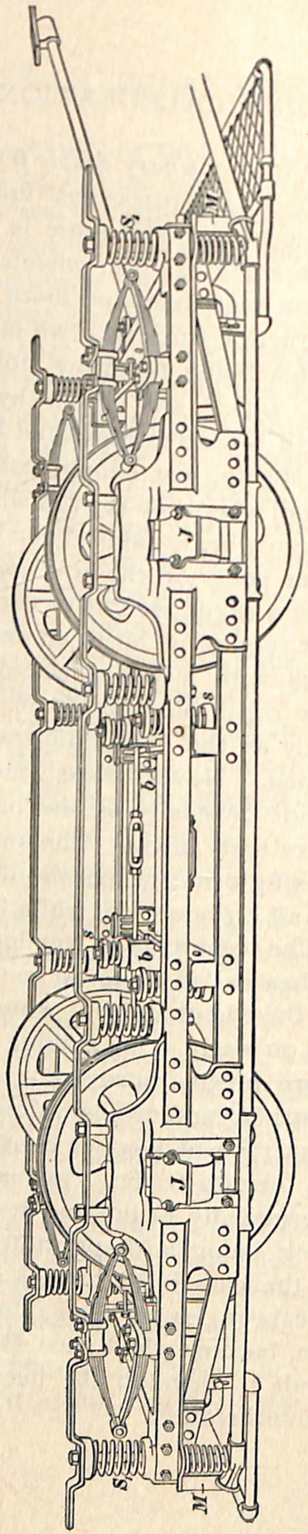


FIG. 14

The car body is rigidly bolted to a single truck by body bolts passing through the car sills and the top rail of the truck's side frame. Double trucks are attached to the car body by means of center bearings and pins, around which the truck turns as a center. Part of the weight is sustained and the car body kept balanced by the **rub plates**, which are circular pieces that engage mates attached to the car body; they should be kept well greased. Cars mounted on double trucks sit higher from the rail than single-truck cars, because the body of the car has to clear the wheels and motors. In open cars the truck wheels have to clear the side steps, so that in some cases two steps must be used.

43. Types of Trucks.—Fig. 14 shows a type of single truck; Fig. 15, an ordinary double truck; Fig. 16, a maximum-traction truck. In Fig. 14, the motors are supported by the suspension bars b, b, which are in turn carried by the springs s, s resting on the side frame of the truck. Since it is advisable to support the motor on springs, it is, of course, equally necessary to provide a flexible support for

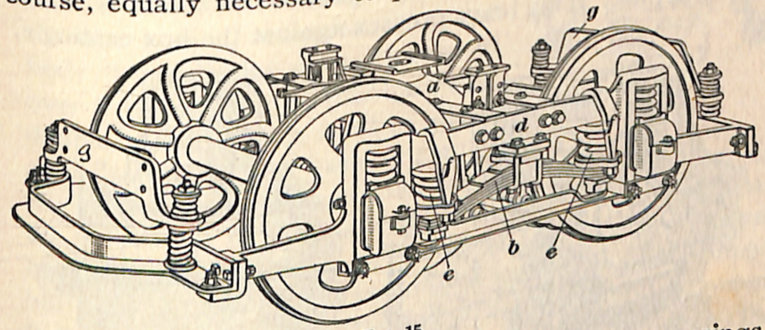


FIG. 15

the truck frame and car body. For short cars, springs placed close to the wheels would be sufficient, although such a construction would have little merit. The reason for providing a longer spring base is to prevent oscillation, which is unpleasant for the passengers and hard on the car body. The oscillation when excessive diminishes the traction on the rising end of the car and causes the wheels to slip. For these reasons, the spring base is extended by

adding extra springs at S_1, S_1. The axle bearings are outside the wheels, to give stability to the car body, the journal-boxes J being free to move vertically through a short distance controlled by a heavy coil spring.

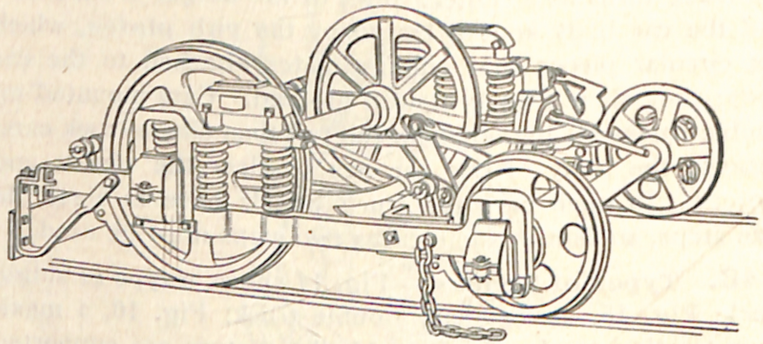


FIG. 16

Fig. 17 shows a larger view of the bearings used on a single-truck car; a is the journal and b the bearing brass, which is on the upper half only, because the thrust is all in one direction. This brass presses against the box casting c,

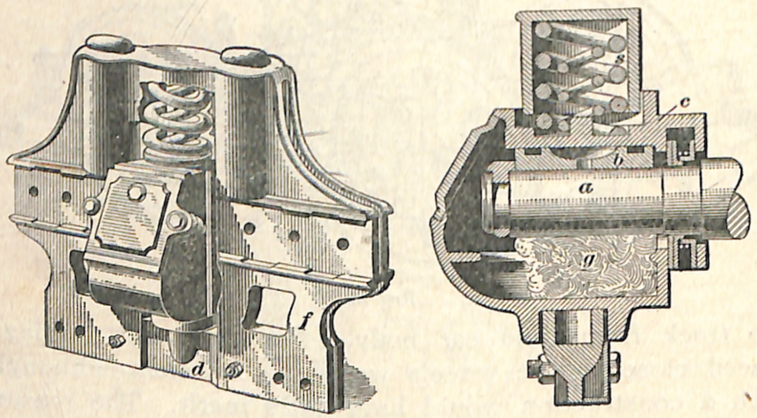


FIG. 17

which in turn bears up against the spiral springs s, that are held in a socket in the frame f. By removing the piece d, the frame can be lifted clear of the axles. The journal is lubricated by means of waste g in the lower part of the casing.

This waste is kept soaked with oil and effects the lubrication in the same manner as on ordinary railway cars. To guard the wheels against obstructions, the **pilots** M, M, Fig. 14, are bolted securely to the frame at a sufficient height from the track to avoid touching the rails.

In Fig. 15, the car body rests on the bolster a, carried by elliptical springs b. The weight resting on springs b is transmitted to the side frame d through equalizing coil springs e and links f. Fig. 18 shows, in detail, the relative arrangement of elliptical spring, equalizing bolt, equalizing spring, equalizing-spring link, and side frame.

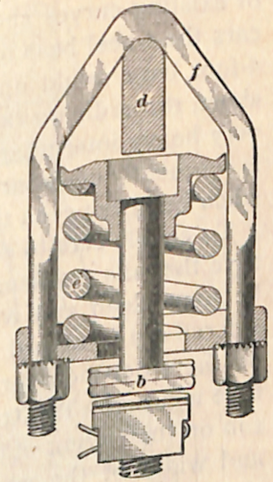


FIG. 18

44. The **wheel base**, that is, the distance between centers of axles on a truck, should be long enough to support the car body without excessive oscillation, but not so long as to make the wheels bind on curves. Any car body that calls for a wheel base of over 8 feet should be provided with double trucks; 7 feet is often given as the limiting wheel base for single-truck cars, but it is practicable to use an 8-foot base unless the curves are of unusually short radius. An 8-foot wheel base will require a much larger power expenditure on curves, but a car is rounding curves only a small part of the time it is in operation, and the increased power consumption is more than made up for by the increase in the size of the car that the longer wheel base makes possible. Excessive length of wheel base not only wears out the rails and wheels, but increases the power required to pull the car around a curve. If it takes a pulling force of 500 pounds to pull an 8-ton car with a 7-foot wheel base around a curve having a radius of 50 feet, it will take a pulling force of only 350 pounds to pull the same car around the same curve on a 4-foot base. To pull the car around a curve of 100 feet radius on a 7-foot

wheel base would require a pull of 255 pounds, and on a 4-foot base, 185 pounds. The difference in the pull required on the two bases on the 100-foot curve is much less than on the 50-foot curve, which goes to show that the greater the radius of the curve, the less difference does it make what the wheel base is. It is evident, then, that in laying out a road, all the curves should be made of as great a radius as possible; and in buying trucks for a road already installed, the radii of existing curves should be considered. With double-truck cars the wheel base may be anywhere from 4 to 7 feet. The 4-foot base would only be used where the curves are very short, the ordinary base for such trucks being 6 feet. For very heavy interurban traffic, a 6½-foot or 7-foot wheel base is frequently necessary to allow room enough for the motors when hung between the axles.

To enable cars to round curves with the least effort and to save the rails and flanges, guard-rail flanges at curves should be kept clean and well greased. Other points to be considered are in regard to the treads and flanges of the wheels; on them depends very much the ease with which a car will take a curve. The treads should not be so wide that they run on the paving outside of the track, and the shape, depth, and width of the wheel flange should be governed by the shape, depth, and width of the rail groove.

45. Wheels used on electric cars vary from 30 inches to 36 inches in diameter; on ordinary street cars, the diameters are usually from 30 to 33 inches. For heavy work it is necessary to use wheels somewhat larger so as to give more clearance for the motors; therefore, diameters of 33 to 36 inches are quite common.

For light cars operating at low speed, cast-iron wheels with chilled treads are used. However, the ordinary chilled wheel is not strong enough for high-speed interurban work, and even for heavy city traffic at low speed it is giving place to the steel-tired wheel, which is provided with a tire made of rolled open-hearth steel. This type of wheel has long been used on steam roads for locomotives and passenger

coaches, but until the advent of heavy electric traction its use on electric roads was limited, owing chiefly to the high cost. The tire can be fastened to the cast-iron center by bolts, or retaining rings, but the usual method in wheels for electric cars is to fuse or cast-weld the tire to the center. The tire is heated, placed in the mold, and the iron center poured; the melted iron fuses the tire and a perfect joint

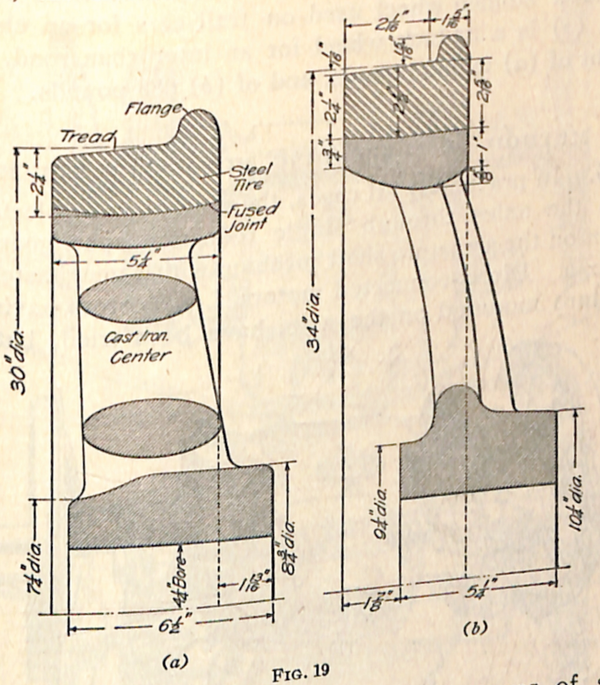


FIG. 19

between the two results. The main advantages of steel-tired wheels that compensate for their high cost as compared with chilled cast-iron wheels are: (*a*) Greater strength and security; these wheels are not likely to fly to pieces no matter how high the speed may be or how severe the strains due to rough track or very cold weather. (*b*) They are not nearly so liable to develop flat spots. (*c*) They are not so liable to slip, since the wrought steel tire has, with the steel rail, a much higher coefficient of friction than a chilled

cast-iron wheel; this reduces slippage and trouble due to flat spots; the action of the brakes is also much more effective. (*d*) They avoid trouble due to chipped or broken flanges. (*e*) The rim can be made thick, so that the wheel will wear a long time before becoming useless; with chilled wheels, the depth of chilled iron is limited.

Fig. 19 shows sections of two fused steel-tired wheels; (*a*) is a 30-inch wheel used on trail cars for an elevated road; (*b*) is a 34-inch wheel for an interurban road. The weight of (*a*) is 650 pounds, and of (*b*) 688 pounds.

METHOD OF SUSPENDING MOTORS ON TRUCK

46. In practically all cases, the motors on an electric car drive the axles through single reduction spur gearing, a pinion on the armature shaft meshing with a gear fastened to the axle. Direct-connected motors, i. e., motors having the armature mounted on the axle, have been tried, but have

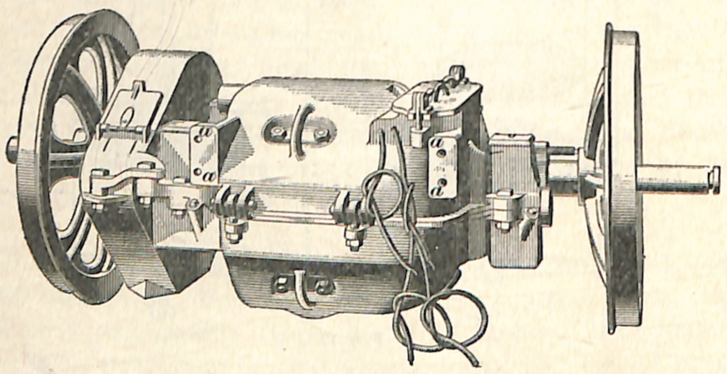


FIG. 20

never proved a success except in some special types of electric locomotive where the motors are of such large size that they can be designed to operate satisfactorily at the low speed necessitated by direct connection.

47. Figs. 20 and 21 show the ordinary *nose suspension*, which is by far the most common method of suspending railway motors. Fig. 20 shows a G. E. (General Electric) 52

motor mounted on the wheels; the axle passes through the axle bearings at the rear of the motor and the front is supported by a suspension bar bolted to the motor at *a a*, *a a* and resting on springs carried by the side frames of the truck. In Fig. 21, the axle *a* passes through the axle bearings *b*, *b* and the motor is prevented from shifting along the

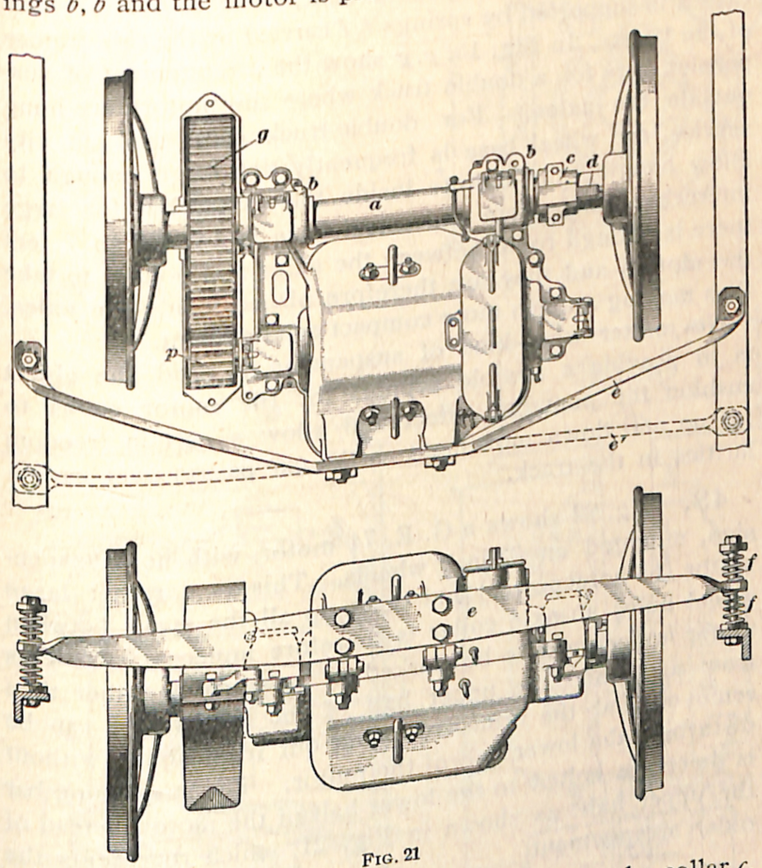


FIG. 21

axle on the one hand by gear *g* and on the other by collar *c*, the location of which can be adjusted by screw *d*. This is a comparatively small motor, and it does not take up all the space between the wheel hubs; with large motors, the space between hubs is often completely filled and no collar is

necessary. Instead of a split collar c with a screw adjustment, it is now common practice to use a plain solid collar pressed on to the shaft in the same way as the wheels; it is cheaper than the collar shown in Fig. 21 and there is no possibility of its working loose. The suspension bar may be straight, as shown at e', or bent, as at e, but in either case it is supported by springs f, f carried on the side frames of the truck. In Fig. 15, g, g show the arrangement of suspension bars for a double truck where the motors are hung outside the axles. For double-truck cars used in city service, the wheel base is frequently not large enough to allow hanging the motors inside the axles, but for large interurban cars where the wheel base is from 6 to 7 feet there is enough room between the axles and bolster to take the motors and they are therefore placed inside the axles, thus making a much more compact arrangement.

No matter what kind of suspension is used, the object is to provide a flexible support for the motor so as to cushion the pounding effect and allow a certain freedom for up and down movement as the car passes over irregularities in the track.

48. Fig. 22 shows a G. E. 74 motor, with nose suspension, mounted on 33-inch wheels. This is a rather large motor (65 horsepower) and takes up all the space between wheel hubs; an axle collar is therefore unnecessary. This motor is designed to be worked on from above rather than from a pit and the upper half of the field frame can be removed and the armature taken out from above without disturbing the lower half of the motor. The suspension bar is therefore bolted to the lower half of the motor instead of the upper half, as shown in Fig. 21, which represents the older arrangement.

49. Westinghouse Cradle Suspension. — Fig. 23 shows a method of suspension used considerably with Westinghouse motors in which the motor is supported by a cradle or frame AA. The front of the cradle is supported by a cross-bar that rests on the truck side frames, and the back

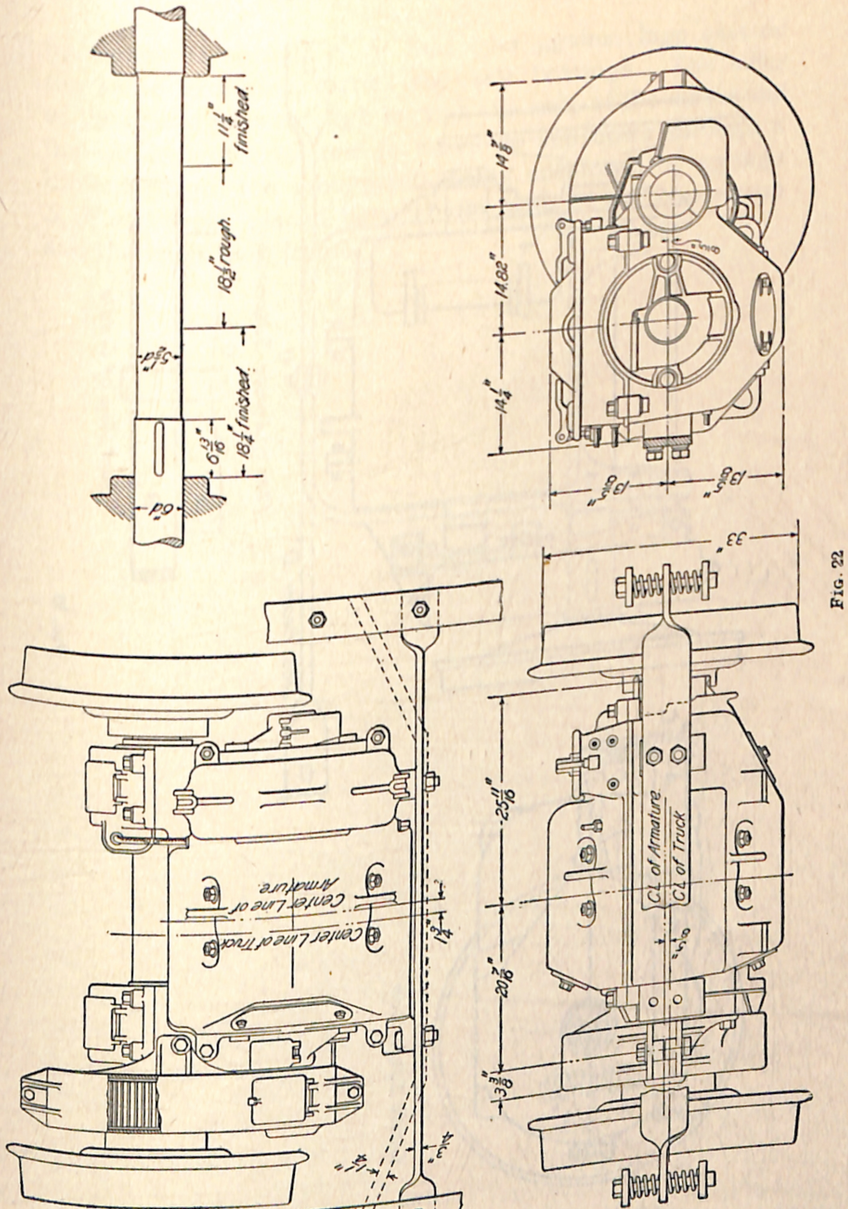


Fig. 22

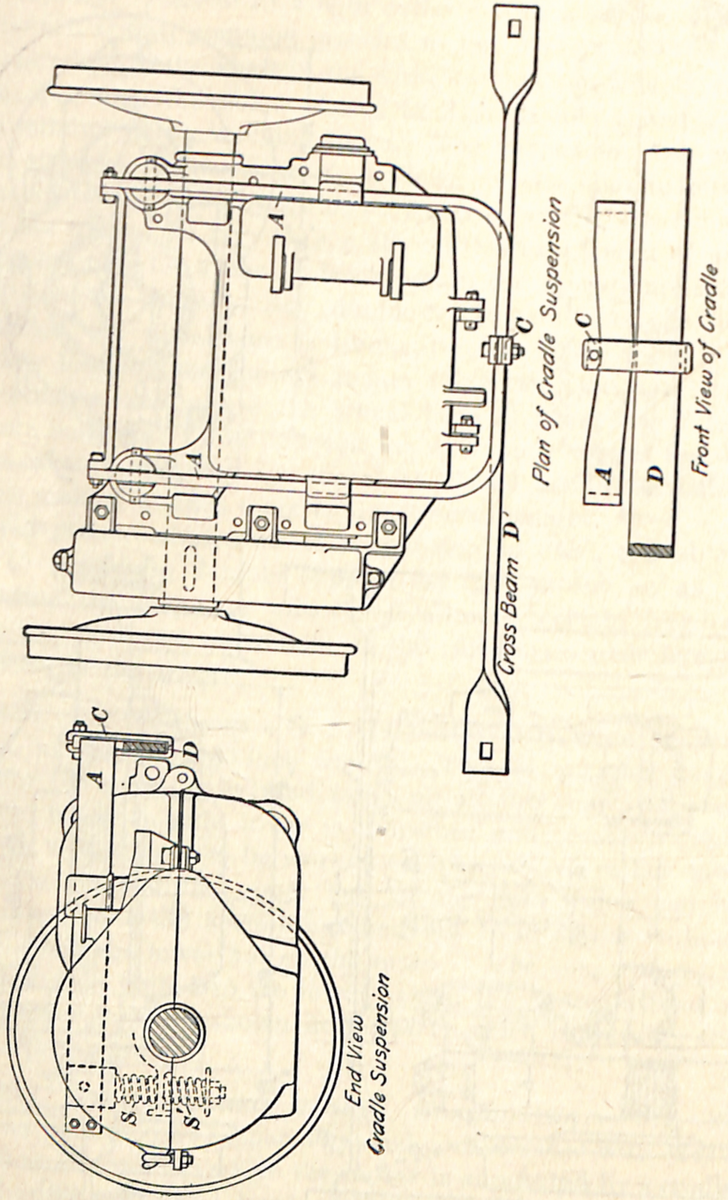


FIG. 23

by means of springs S, S' that bear against lugs cast on the same arm that carries the axle bearings. The sides of the cradle pass through lugs on the ends of the motor and the whole motor is free to move up and down through a limited range, the movements being cushioned by springs S, S' and those placed between the ends of the cross-beam and the truck side frame.