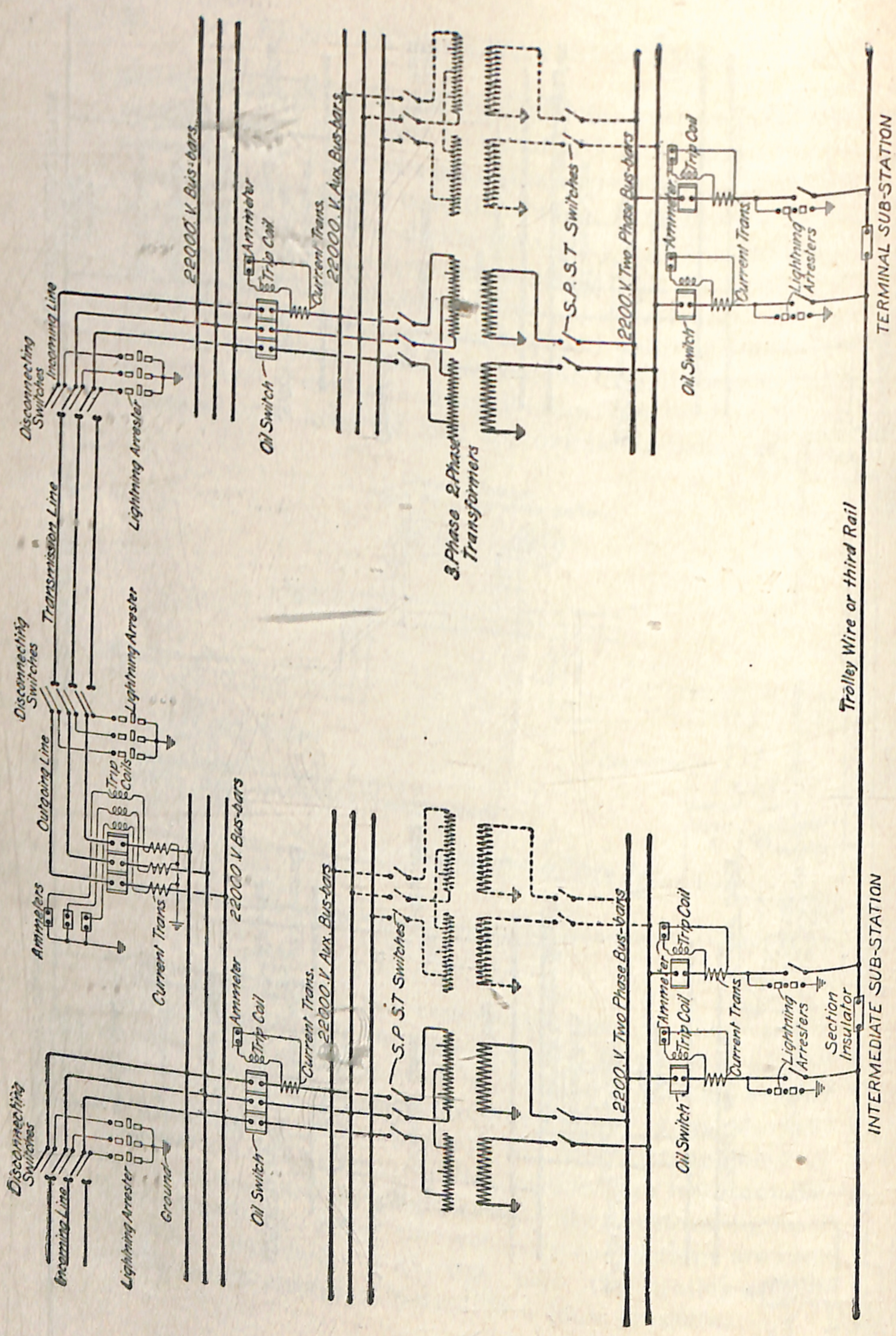


FIG. 17



**30.** Figs. 16 and 17 show substation connections for single-phase railways as proposed by the General Electric Company, Fig. 16 showing substations supplied from a single-phase transmission line and Fig. 17 from a three-phase line. The plans are the same as indicated in the elementary diagrams, Figs. 14 and 15, the three-phase current being transformed to two-phase in Fig. 17. Two substations feed into the same trolley section, thus dividing the load between the stations. The substation connections are very simple when compared with those for a station using rotary converters. All that is required in addition to the step-down transformers are the switches and protective devices. There is no moving machinery in the substations, constant attendance is unnecessary, and the use of single-phase motors makes the system as a whole nearly as simple as one using direct current. All switches used for interrupting the current are of the oil-break type; knife switches are provided for disconnecting various parts of the system, but these are not intended for opening the circuits when the current is on.

## THE POWER HOUSE

**31.** Having explained the general methods of supplying current to electric cars from the working conductor, and the different systems available for transmitting the current from the central station to the cars, it will be necessary to take up the different parts of the road and describe them in detail. For this purpose the subject may be considered under the following heads: (*a*) The *power house;* (*b*) the *line and track;* (*c*) the *car equipment.*

### LOCATION OF POWER HOUSE

**32.** The general design of power houses and the class of apparatus to be used in them has been fully covered elsewhere, so that only a few considerations affecting their location will be mentioned here. The power house, or power station, should be situated as near the center of the system as possible, assuming that it is to be a steam-power plant and that its location is not already fixed by conditions having no connection with the traffic on the road. In the case of water-power plants the site is fixed by the location of the water-power, so that the following cannot, in general, be applied to such roads. By the center of the system is meant the center of the load or traffic. Since wires must be used to convey the power from the power house to the point where it is to be used, a part of the power generated will be lost in them. If they are not of sufficient size, they will cause a loss of power that will make itself very strongly felt in its effect on the speed that the cars make and also on the amount of heat that the motors develop. This loss will

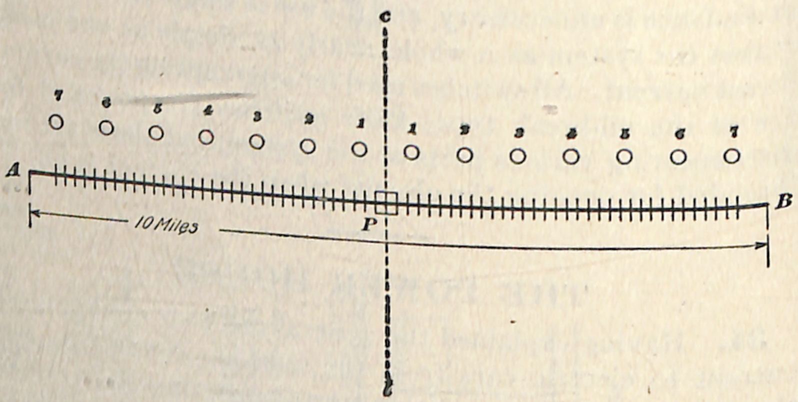


FIG. 18

depend on the resistance of the line and the amount of current that it has to carry. Hence, it follows that the center of the load may not be the geographical center of the system; in fact, these two centers very seldom fall in the same place. The true load center is located in the same way that the center of gravity of any system of bodies is located. The geographical center depends on the number of miles of track and how these are disposed; the load center depends on how the load is distributed.

In Fig. 18, *AB* represents 10 miles of track, free from grades and sharp curves, and on which a certain number of cars, *1*, *2*, *3*, *4*, etc., of about the same weight and equipped



with motors of the same size, run at regular intervals. The geographical center, or center of mileage, is in this case located at *P*, a point midway between the two ends, so that there is 5 miles of track on each side of it. Also, the load center in this case is at *P*; for, suppose that all the cars, except the two on the extreme ends, are running at full speed. Since the track is level and the cars and motors are alike, they will all take about the same power, and since the loads are evenly distributed throughout the length of track, they can be represented by circles of the same size, as shown in Fig. 18. Here there are seven loads on each side of the center line, and if each circle is supposed to represent a weight of a certain number of pounds, the center of gravity of the system will fall on the center line *c l*. So, also, if all cars, except the two end ones, are supposed to stand still or to coast along with the power off, and the two end ones start at the same time, the same load will be drawn to both ends of the line, and point *P* will still be the center of load and will therefore mark the spot where the power house should stand.

It is not implied that the load, even on such a simple layout, will always be as evenly distributed as in this ideal case, for such a condition will be the exception rather than the rule. Suppose *A* to be in the outskirts of a large city and *B* a down-town district; then, in the morning and evening, when people are going to and returning from work, the load leans a little toward the *B* end of the line, but during the rest of the day it is uniformly distributed. To alter conditions, suppose that from the middle of the line to *B* there is an up grade. Those cars that are ascending the grade will be called on to do more work than those on the level or on down grade, so that the ideal site for the station will be shifted toward *B*. In this case, the mileage center remains the same, but the load center is changed.

**33. Influence of Future Extensions.**—In locating the site for the power house, future extension and increase in traffic incidental to the development of outlying districts should be borne in mind and the site selected accordingly.

Suppose, in Fig. 19, that the full-line section $AB$ represents the track put down at the first building of the road and that, in accordance with the demand then existing, the power house was put at $P$, the center of load for $AB$, which is supposed to be level. Now, suppose that the road has been extended to a point $C$, so that $AB = AC$. If it is further assumed that the district through which $AC$ runs becomes built up, it will be only a matter of time when the travel density will be as great on the new stretch of track as on the old, in which case, assuming the different load units to be fairly evenly distributed throughout the distance $BC$, the proper place for the power house would be at point $P'$, midway between $B$ and $C$. So long as $AB$ constituted the

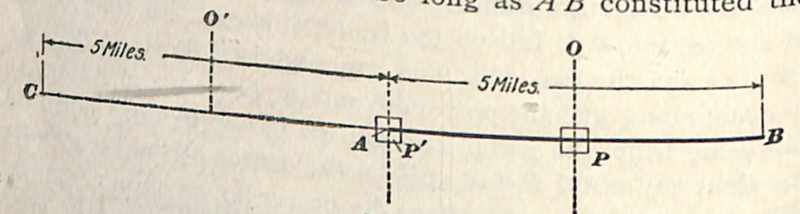

FIG. 19

whole road, the power house situated at $P$ was at the center of an evenly distributed load, and the same loss of power would attend the transmission of a given amount of power to one end of the line as to the other. As soon, however, as the extension $AC$ was started, a power house at $P$ was $2\frac{1}{2}$ miles from the $B$ end of the road and $CA + AP$ or $7\frac{1}{2}$ miles from the $C$ end. Under such a condition, should all the cars, through trouble of some sort, become congested at the far end of the line, the loss incidental to the great distance and to the large current caused by trying to start all the cars at once would seriously delay getting the cars on their time again.

If the station were put at $A$ in the first place, it would, of course, be at one end of the line as long as $AB$ was the whole road, and would not therefore be at the center of load; but if the extension $AC$ were only a matter of time, it would be far better to put up with the line loss due to want of balance on the shorter line, locate the station at $A$, and



be prepared to get the best results when the extension was in operation.

**34.** If, in deciding the best location for the power house, it were only a matter of fixing the probable center of load, the problem would be comparatively easy. But in many cases it is made very hard and almost impossible to solve, except approximately, by the fact that several other considerations enter into the question. The prospective center of the load might be located, from a purely electrical point of view, in a place so situated that every pound of coal to be burned under the boilers must be hauled to the power house. Or, it might fall in a place where it would be difficult to get water for the boilers and the condensers; such a place would, of course, be out of the question. Finally, the question of land comes in. It would be very poor engineering to build a power house in a part of a city where a city building would probably pay as good dividends as many well-managed roads. The final selection of a site for the power house must, in many cases, be a compromise between conflicting conditions. Load conditions will point to one site; good, cheap water will point to another; the coal bunkers should be arranged so that the coal may be passed directly to them from the boat, or from a coal car that can be run alongside of them by means of a siding or a spur from the main line.

## DETERMINING THE LOAD CENTER

**35.** In the following method used for obtaining the load center, it is assumed that in all cases the layout of the road is along the lines shown in the diagrams, and that there are no limitations imposed by coal, water, and property requirements, the selection of a site for the power house resolving itself to the determination of the load center. To find the load center, the engineer must have a knowledge of the traversed district. With this in hand, the problem can be treated graphically, and amounts to the same thing as finding the center of gravity of a system of bodies. As an example, in Fig. 20, $W$ and $W'$ are two bodies whose centers are

11 feet apart, and each of which, for example, weighs 20 pounds. Since, in this case, the two weights are equal, the distance of their centers from the center of gravity $P$ must also be equal, in order that $Wl$ shall equal $W'l'$. The

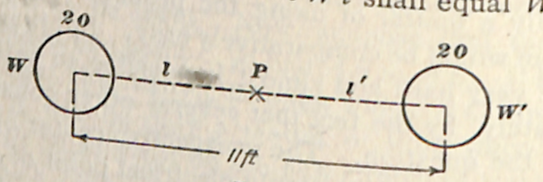


FIG. 20

center of gravity is, therefore, midway between the two bodies, and the system, as a unit, acts the same as if a weight of 40 pounds were fixed at $P$.

**36.** Where the load is supposed to be uniform over the two sections $AB$ and $AC$, Fig. 19, suppose that there are 10 cars on each section and that each car averages a load of 20 horsepower. Each section will, then, carry a load of 200 horsepower, which can be taken as concentrated at points $O$ and $O'$ in the center of the respective sections. These centers will be $\frac{1}{2}AB + \frac{1}{2}AC$, or 5 miles apart. The two loads of 200 horsepower concentrated at $O$ and $O'$ in Fig. 19 correspond to the two weights of 20 pounds in Fig. 20, and if we treat the 200 horsepower as weights and find their center of gravity, it will be the center of load or the correct location for the power house. Since the two loads or weights are equal, the center of gravity or load must be at point $A$, midway between $O$ and $O'$.

**37.** Take the case shown in Fig. 21, where $W = 40$ pounds, $W' = 50$ pounds, and $W'' = 10$ pounds; further, suppose that the distance from $W$ to $W'$ is 6 miles; from $W$ to $W''$, 7 miles; and from $W'$ to $W''$, 4 miles. Where is the center of gravity situated? First find the center of gravity between weights $W = 40$ and $W'' = 10$, where the distance between centers is 7 miles. This distance of 7 miles must be divided into two parts, such that $Wl = W''l''$, where $l$ and $l''$ are the distances of $W$ and $W''$, respectively, from the center of gravity for these two bodies.



To solve the problem graphically, lay out the plan to scale on paper; that is, represent the 7 miles by 7 inches, and so on, and let the sizes of the circles represent the weights, as shown in the diagram. Call $L$ the distance from $W$ to $W''$, and let the distance from $W$ to the center of gravity to be found, be represented by $l$; then the distance of $W''$ from

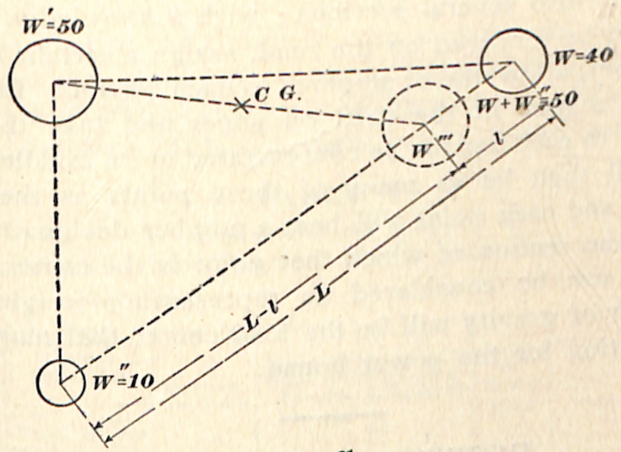


FIG. 21

the center of gravity will be represented by the difference, or $L - l$; and since $Wl = W''(L - l)$, $Wl = W''L - W''l$, or $Wl + W''l = W''L$, and $l = \frac{W''L}{W + W''}$. Substituting for the weights and for $L$ the numerical values given, $l = \frac{10 \times 7}{50} = 1\frac{2}{5}$ miles, or inches on the paper, as the distance of the weight $W$ from the required center of gravity. Since the total distance $L = 7$, the distance from the center of gravity to the center of $W''$ must be $L - l = 5\frac{3}{5}$ miles. On the line joining the centers of $W$ and $W''$ locate a point that is $1\frac{2}{5}$ inches from the center of $W$; this is the center of gravity sought. The center of gravity between the large dotted circle, representing the combined weights (50 pounds) of $W$ and $W''$, situated at their center of gravity, and $W'$, which is also 50 pounds, must now be found. Call the dotted circle $W'''$; since the weights $W'''$ and $W'$ are the same, it is evident that their center of gravity is midway between them on the line joining their centers, so that it is only necessary to bisect this line in order to find the center of gravity of $W'$ and $W'''$, and hence of the whole system.

**38. Conclusion.**—The general rule for locating the center of load is as follows: Divide the line of the proposed road into several sections; with a knowledge of the service to be rendered on the road, assign a certain load in horsepower, kilowatts, or amperes to each section. Lay out, to scale, a plan of the road on paper and take the load assigned to each section as concentrated at its middle point; there will then be as many of these points as there are sections, and each point will bear a number designating the load on the section of which that point is the center. The numbers can be considered as representing weights and the center of gravity will be the load center that marks the best location for the power house.

## POWER ESTIMATES

**39.** The problem of deciding what capacity the station generators must have in order to operate a given number of cars on a given road is a complex one, in that it involves conditions peculiar to each case and calls for the use of quantities that must, to a great degree, be determined from data relating to roads of a similar character. Among the factors that must be considered are: Weight of equipment; number of cars; speed of cars; topography of the road (grades, curves, etc.); character of traffic; condition of line and rail return; manner of handling the equipment.

The speed at which the cars run is determined largely by the character of the road; cars in cities may not average more than 8 to 12 miles per hour while on interurban roads the average speed might be as high as 40 or 45 miles per hour. The number of cars to be operated depends on the frequency of the service, the length of the line, and the schedule speed. The best schedule speed and frequency of



service for any given road require a close preliminary study of the district to be served, probable traffic and the returns therefrom, competition that must be met, etc.

**40. Weights of Cars.**—The size and weight of cars are determined by the traffic. On interurban lines, cars are much heavier than in cities and frequently they approach, in size and weight, those used on steam roads. A modern 40-foot body interurban car complete with motors and controlling apparatus may weigh as much as 65,000 pounds, whereas a city car with 28-foot body will weigh in the neighborhood of 30,000 pounds. Table I gives approximate weights of

TABLE I

WEIGHTS OF CARS

| Open Cars | | | | | Closed Cars | | | |
|---|---|---|---|---|---|---|---|---|
| Number of Benches | Length Over All | | Seating Capacity | Weight of Body and Trucks Pounds | Seating Capacity | Length of Body Feet | Length Over All Feet | Weight of Body and Trucks Pounds |
| | Feet | Inches | | | | | | |
| 10 | 28 | 8 | 50 | 12,000 | 24 | 18 | 26 | 10,400 |
| 12 | 34 | 0 | 60 | 16,000 | 34 | 25 | 35 | 18,000 |
| 15 | 40 | 4 | 75 | 25,000 | 40 | 28 | 37 | 20,000 |
| | | | | | 44 | 32 | 40 | 28,000 |

ordinary cars of standard size. In designating the length of closed cars, it is customary to measure between outsides of the bulkheads (end walls) and not over the bumpers. The weights given in Table I do not include the motors, controllers, air-brake equipment, etc. The motors will weigh from 45 to 75 pounds per horsepower (railway-motor rating), the weight per horsepower being smaller for large motors than for small ones. An ordinary controller for a 25-horsepower motor will weigh about 200 pounds, and a complete equipment of two such controllers with the starting resistance, about 500 pounds. This is a light equipment, such as is used for a small 18- or 20-foot car. For a large car equipped with two 65-horsepower motors, the complete electrical equipment will weigh about 8,300 pounds, of which the two motors constitute over 7,000 pounds. The auxiliary devices, such as controllers, brakes, etc., vary so much in design that it is difficult to give general figures as to the weight of cars complete with equipment. Ordinary closed cars intended for city service will weigh, roughly, .4 ton per foot of over-all length when fully equipped with motors and all auxiliary appliances. For example, a car with 28-foot body, 37 feet long over all, will weigh, fully equipped, 37 × .4 = 14.8 tons. Cars intended for interurban traffic, where the speeds are high, will weigh, fully equipped, from .6 to .7 ton per foot of over-all length. In making power estimates, the weight of passengers that should be added to the weight of the car, will not, as a rule, average more than 10 to 15 per cent. of the dead weight of the car.

**41. Formulas for Power Estimates.**—A number of formulas have been devised for calculating the power required by cars under given conditions, but all of them are only approximate, because several elements modify the power taken. For example, the running gear or roadbed may be in bad condition or there may be excessive friction on some of the curves. Again, the state of the weather may have a marked influence on the power required—a strong head-wind may have a very great effect on the resistance offered to the motion of a car; while it is a well-known fact that cars do not run as easily in cold weather as in warm, because of the increased friction at the journals. As a consequence of all these influences, the effects of which cannot be accurately determined, formulas in which the resistance offered to the motion of a car or train is used must not be expected to give results other than approximate.

**42. Force Required to Move Car on Level Track.** The force or horizontal effort at the rail head, per ton weight, required to move a trolley car on a level track at a uniform speed is considerably higher than required for cars operated on steam roads, where the track is cleaner and in better condition generally. Steam cars are also much



heavier than ordinary street cars and the effort per ton is less for heavy cars than for light ones.

The effort that must be applied to keep a car in uniform motion on a level track depends on the train resistance at uniform speed and this, in turn, is made up of a number of factors that are more or less difficult to determine and which vary, to a certain extent, with the speed. For example, the train resistance includes the track friction, or the resistance that the wheels encounter in rolling over the slight irregularities in the surface of the track, the friction in the journals, friction of wheel flanges against the rails, air resistance, etc.

If $f$ = resistance, in pounds, per ton on a level track, i. e., horizontal effort at rail head for each ton that the car weighs;
$W_t$ = weight of car, in tons;
$F$ = total pull required;

then,
$$F = f\,W_t \qquad (1)$$

The case of cars operating at moderate speeds in cities, where the effort per ton may be taken as constant for all speeds at which the cars usually run, will first be considered. For ordinary cases, with cars and track in good condition, a fair average value for $f$ on a level track is 20 pounds.

**43. Effect of Grades.**—Grades are always expressed as a percentage, but there seems to be considerable confusion as to what this percentage refers. In some cases it relates to the distance actually traveled by the car in ascending the grade; in others, to the horizontal distance. The more general method in dealing with electric railways is to consider the percentage as referring to the actual distance traveled by the car, and it will be so taken in the following calculations. Thus, if a grade is said to be 3 per cent. it means that for every 100 feet traveled along the grade the car rises 3 feet. This simplifies calculations and, as a matter of fact, unless grades are much steeper than those usually met with in practice it makes very little difference, so far as numerical results are concerned, which is taken because the distance traveled along the grade is practically the same as the horizontal distance.

When a car ascends a grade, the force exerted, in addition to overcoming the various resistances, must be sufficient to lift the weight of the car. Thus, on a 1-per-cent. grade, the car rises 1 foot for every 100 feet traveled. This is equivalent to lifting the weight of the car one one-hundredth of the distance or lifting one one-hundredth of the weight the whole distance. In other words, for each ton (2,000 pounds) that the car weighs, each per cent. grade is equivalent to the addition of $\frac{2000}{100} = 20$ pounds to the effort required on the level, and

$$f_g = f + 20G \qquad (2)$$

where $f_g$ = pounds per ton on the grade;
$f$ = pounds per ton on the level;
$G$ = per cent. grade.

EXAMPLE.—If 20 pounds per ton is required to maintain uniform motion of a 10-ton car on a level track, what effort, per ton, will be required on a 5-per-cent. grade?

SOLUTION.—For each per cent. of grade, the force must be increased 20 lb. per ton over the amount required on the level; hence, $f_g = 20 + 20 \times 5 = 120$ lb. per ton. Ans.

**44. Horsepower.**—When the total force $F$, in pounds, and the speed $S$, in miles per hour, are known the horsepower can at once be calculated as follows:

$$\text{Speed, in feet per minute} = \frac{5{,}280\,S}{60}$$

$$\text{horsepower} = \frac{\text{foot-pounds per minute}}{33{,}000} = \frac{5{,}280\,SF}{60 \times 33{,}000}$$

or,

$$\text{horsepower} = \frac{SF}{375} \qquad (3)$$

If the car is moving up a grade, $F$ must, of course, include the effort necessary to lift the car. This formula gives the horsepower actually used in moving the car; the electrical power supplied will be somewhat greater on account of the electrical losses in the motors and controlling apparatus.

**45.** The curves shown in Fig. 22 are useful in making approximate determinations of the tractive effort and



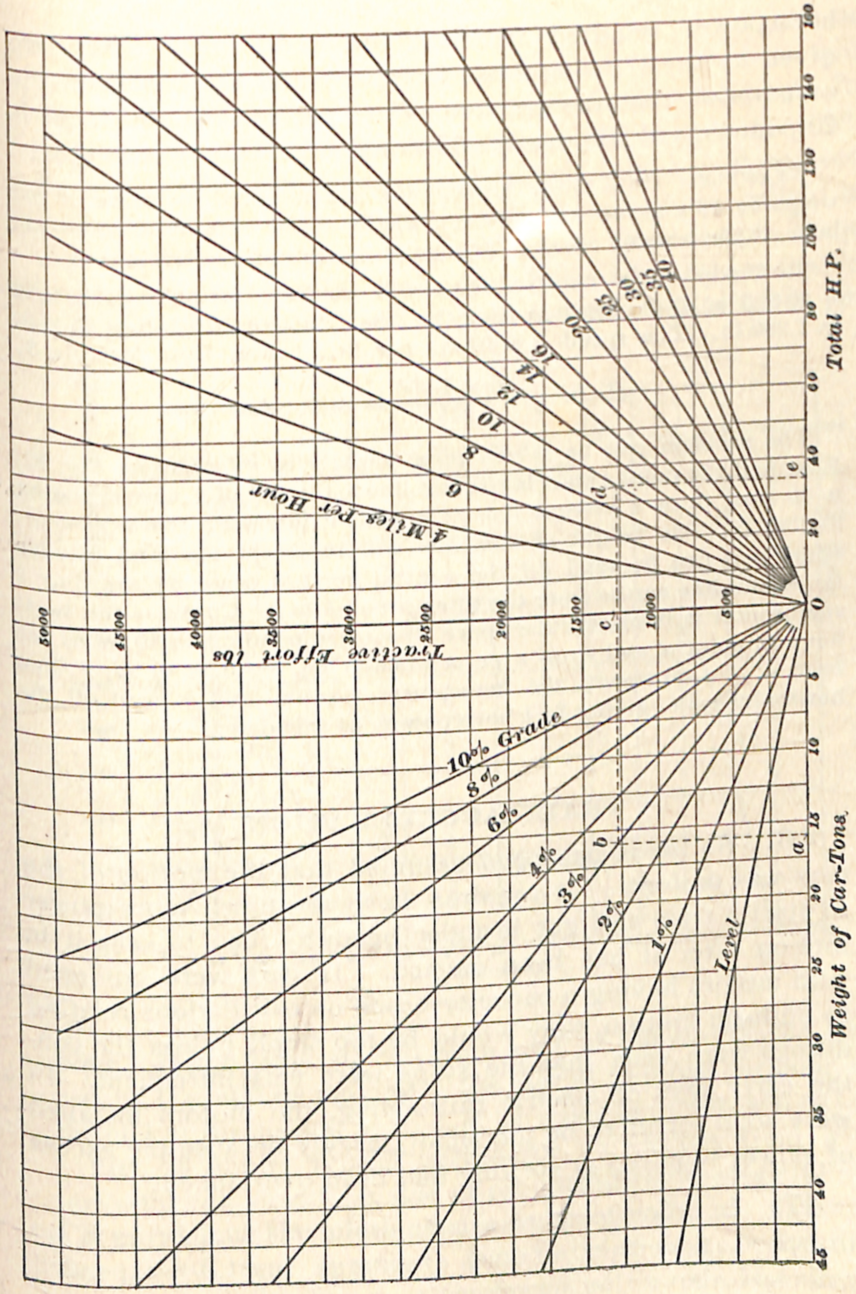


FIG. 22

horsepower required under given conditions. They are given by the Westinghouse Company and are based on the assumption that the tractive effort per ton on the level is 20 pounds, and 20 pounds additional for each per cent. grade.

EXAMPLE.—How many horsepower are required to move a car weighing 16 tons up a 3-per-cent. grade at the rate of 10 miles per hour, if the tractive effort is 20 pounds per ton on the level?

SOLUTION.—The tractive effort will be from formula **2**, $f_g = 20 + 20 \times 3 = 80$ lb. per ton and the total tractive effort $F = 16 \times 80 = 1,280$ lb. The speed $S$ is 10 mi. per hr., hence, from formula **3**,

$$\text{H. P.} = \frac{10 \times 1,280}{375} = 34.1. \quad \text{Ans.}$$

The problem can be solved more rapidly by referring to Fig. 22. First find the point $a$ on a horizontal line to the left of $0$, corresponding to 16 tons; draw a vertical line at $a$ until it intersects the 3-per-cent. line at $b$. The height of this line will represent the total tractive effort that can be read off the central vertical scale by drawing a horizontal line across from the intersection $b$ to $c$. Continue this horizontal until it intersects the speed line corresponding to 10 miles per hour at point $d$ and drop a perpendicular on the base or $H. P.$ line from $d$; $Oe$ represents the horsepower required and is read off the horizontal scale, giving 34.1 horsepower, as calculated.

## TRAIN ACCELERATION

**46.** So far it has been assumed that the motion of the cars was uniform. It requires, however, much more power to start a train and get it under headway than to keep it in motion after it has been started. If cars were equipped with motors having a capacity based on calculations relating to uniform motion, they would be too small unless the conditions were such that the stops were very infrequent. In the early days of electric railroading, the motors installed were soon found to be too small, largely because the excess of power required at starting had been overlooked.

**47.** In order to start a train from rest and bring it up to speed, a certain amount of energy must be expended over and above that necessary to overcome the train resistance. The energy so expended is stored in the train as



kinetic energy. A powerful effort is necessary to accelerate the train, and the effort required in any given case will depend on the weight of the train and the acceleration. In problems connected with train operation, the rate at which the speed of a train is increased (acceleration) or decreased (retardation, or deceleration, as it is sometimes called) is expressed in miles per hour per second. For example, if the acceleration is $1\frac{1}{4}$ miles per hour per second, it means that in each second the speed of the train is increased $1\frac{1}{4}$ miles per

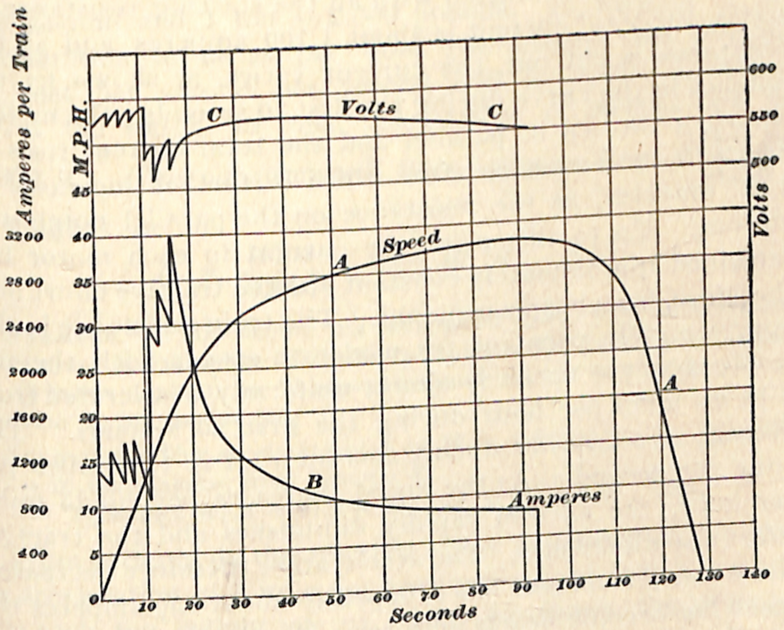


FIG. 23

hour. If the train started from rest, at the end of the first second it would be moving at the rate of $1\frac{1}{4}$ miles per hour, at the end of the second second, at $2\frac{1}{2}$ miles per hour, and so on.

Fig. 23 shows typical curves for an electric train with powerful equipment capable of producing rapid acceleration. Curve $A$ shows the relation between speed and time; $B$, shows the total current supplied; and $C$, the voltage. Starting from a standstill, the speed increases at an almost uniform rate up to 25 miles per hour; the curve then bends over and the increase in speed during a given interval of time, i. e., the acceleration, becomes less until at 37½ miles per hour the curve has become nearly horizontal; the speed is then nearly uniform and the acceleration has become practically zero. After 93 seconds the current is shut off and the train coasts along, by virtue of the energy stored in it, with gradually decreasing speed. The brakes are applied at the latter end of the run and the train is retarded and finally brought to a stop, as indicated by the straight sloping line at the right. When the train is started with all the starting resistance in series, the total current is about 1,100 amperes, and as the resistance is cut out, the current varies, as shown by the notches in the curve during the first 10 seconds; the motors are then thrown in parallel and the total current rises to nearly 2,400 amperes, after which it further increases to 3,200 amperes, as the resistance on the parallel notches is cut out. Up to this point the current in each motor has remained approximately constant and the tractive effort has, therefore, been nearly constant. The train resistance is also approximately constant for moderate speeds with the net result that the speed is almost uniformly accelerated from 0 to 25 miles per hour during the first 20 seconds. The average acceleration during this interval is 1.25 miles per hour per second. As the speed increases beyond 25 miles per hour, the current rapidly diminishes and the tractive effort also diminishes. The acceleration therefore decreases, and when the current has dropped to about 650 amperes the speed has become nearly uniform. The tractive effort is then wholly utilized in overcoming the train resistance; during the acceleration period a large part of the total effort was used in increasing the speed and thereby storing energy in the train, and the remainder went to overcome the train resistance.

**48. Force Required for Acceleration.**—The total force $F_a$ required to make a car or train increase its rate of speed is easily calculated; it is $F_a = m\,a$, where $m$ is the mass of the train and $a$ the acceleration. $m = \frac{w}{g}$, where $w$



is the weight of the train and $g$ the acceleration due to gravity; hence, $F_a = \frac{w}{g}\,a$. If $w$ is expressed in pounds, $g$ in feet per second per second, and $a$ in feet per second per second, then $F_a$ will be in pounds and $F_a = \frac{w}{32.16}\,a$, since $g$ is equal to 32.16 feet per second per second. Usually, in train calculations, the weight is expressed in tons and the acceleration in miles per hour per second instead of feet per second per second. One mile per hour = 1.467 feet per second and 1 ton = 2,000 pounds. If, then, $A$ is the acceleration in miles per hour per second, the number of feet per second per second will be 1.467 $A$, and if $W_t$ is the weight in tons, the number of pounds will be 2,000 $W_t$. The equation will then become $F_a = \frac{2{,}000\,W_t}{32.16} \times 1.467\,A$, or

$$F_a = \frac{W_t\,A}{.01097} = 91.2\,W_t\,A \qquad (4)$$

EXAMPLE.—If an electric car weighs 20 tons, what accelerating force must be exerted to bring the car from a standstill up to a speed of 18 miles an hour in 15 seconds, assuming the acceleration to be uniform during this period?

SOLUTION.—The acceleration $A$ is $\frac{18}{15} = 1.2$ mi. per hr. per sec. $W_t = 20$ tons; hence, from formula 4,

$F_a = 91.2\,W_t\,A = 91.2 \times 20 \times 1.2 = 2{,}188.8$ lb. Ans.

From formula 4, the tractive effort necessary to produce an acceleration of 1 mile per hour per second is 91.2 pounds for each ton weight of car. Fig. 24 shows the relation between the acceleration, in miles per hour per second, and the accelerating force, in pounds per ton. It must be remembered that this is in addition to the force required to overcome the train resistance. Again, whenever a train is started there are two kinds of inertia to be overcome: The train must be made to move horizontally and the force required for this acceleration is given by formula 4; also, a certain amount of energy is required to overcome the inertia of the rotating parts, such as armatures, wheels, gears, and axles, and this may amount to 8 or 10 per cent. of the force given by the formula. The force required to overcome train resistance may be taken as 20 pounds per ton for moderate speeds on a good track, and if the force required to produce acceleration both rotational and linear is 100 pounds per ton for an acceleration of 1 mile per hour per second, the total tractive effort required to speed up the car at this rate will not be far from 120 pounds per ton.

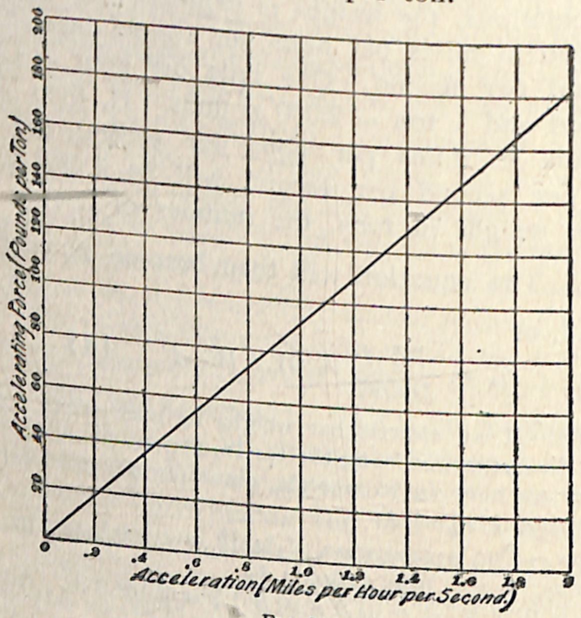


FIG. 24

In city streets, where the speed is limited, it is not necessary or even desirable to accelerate the cars rapidly, but in elevated or underground service, where a large number of trains must be operated at close intervals, they must be started quickly, and the size of the motors will be determined very largely by the energy required for acceleration.

**49. Limit of Adhesion.**—The maximum effort at the rail head that can be applied to a car is limited by the slippage of the wheels on the track; as is also the possible acceleration and the grade that a car can ascend. The adhesion between wheels and track depends on the weight on the drivers and the coefficient of friction between the



wheels and track. The latter varies greatly with the condition of the rails, being considerably lower for street-car lines where the tracks are liable to be dirty and slippery than for elevated, undergound, or interurban roads where the tracks are cleaner. It also depends on the kind of car wheels, being considerably less for wheels with chilled-iron treads than for those with steel tires. As safe limiting values, the adhesive force may be taken as about 15 per cent. of the weight on the drivers for elevated or interurban roads, and 12 per cent. for street-car roads. Thus, on street-car lines, the maximum tractive effort that can be exerted without causing wheel slippage may be taken as $2{,}000 \times .12 = 240$ pounds per ton weight on the driving wheels and $2{,}000 \times .15 = 300$ pounds for elevated or interurban roads. It should be particularly noted that these limiting tractive efforts are per ton weight on the driving wheels. With a small single-truck street car having two motors, all wheels are drivers and the whole weight rests on driving wheels; hence, this style of car is well adapted for hill climbing and running on slippery tracks. With interurban or elevated cars having double trucks and two motors, the weight resting on the drivers will not be more than 55 to 70 per cent. of the total weight, thus making the limiting tractive effort from 165 to 210 pounds per ton weight of car. With cars having double trucks with four motors, one on each axle, the whole of the weight is on drivers; hence, four-motor equipments are desirable for roads operating double-truck cars in hilly localities. For interurban roads, the grades are usually quite moderate and two-motor equipments give sufficient adhesion.

Let $f' =$ force, in pounds per ton weight of car to start car on level;
$G =$ grade expressed as percentage;
$W_t =$ weight of car, in tons;
$a =$ percentage of weight on drivers, expressed as a decimal;
$b =$ ratio of adhesive force to weight on drivers expressed as a decimal.

Then,

Total weight on drivers, in pounds . . . $= 2{,}000\, a\, W_t$

Total adhesive force . . . . . . . . . . $= 2{,}000\, a\, W_t b$

Total force required for starting on grade $G = f' W_t + 20\, G\, W_t$

Each per cent. grade requires 20 pounds per ton additional effort. When the grade is such that the tractive effort required to start on it is just sufficient to produce wheel slippage, we must have $2{,}000\, a\, W_t b = f' W_t + 20\, G\, W_t$, and

$$G = \frac{2{,}000\, a\, W_t b - f' W_t}{20\, W_t} = \frac{2{,}000\, a\, b - f'}{20} \qquad (5)$$

About 70 pounds per ton is a fair value for the effort $f'$ required to start a car on the level under ordinary conditions; if, however, the acceleration is very rapid, the effort during the time that the car is gaining headway may be much higher than this and the acceleration obtainable may therefore be limited by the wheel slippage.

Example.—If 65 per cent. of the weight of a car rests on the drivers and if the ratio of the adhesive force to the weight on the drivers is 15 per cent. what is the maximum grade that the car can start on without wheel slippage, assuming that it requires an effort of 70 pounds per ton weight of car to start the car on the level?

Solution.—Using formula **5**, we have $a = .65$, $b = .15$, and $f' = 70$; hence, $G = \frac{2{,}000 \times .65 \times .15 - 70}{20} = 6.25$; i. e., slippage will occur if the grade exceeds 6.25 per cent. Ans.

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## TRAIN RESISTANCE

**50.** In all that has so far been said regarding power calculations, the tractive effort has been taken as 20 pounds per ton regardless of the speed, weight, or shape of the cars. This gives fairly close results for light single cars operated at moderate speeds, under the conditions usually met in city streets, but for heavy single cars or trains operated at high speeds, as used in the heavier kinds of electric traction, it is not safe to assume a fixed value for the train resistance. At low speeds and with heavy cars the effort per ton may be considerably under 20 pounds, and at high speeds it will be greater.



The subject of **train resistance** is a complicated one, because the resistance depends on a number of quantities, which vary more or less with the speed. The air friction increases approximately as the square of the speed and is dependent in a large measure on the shape of the front of the cars and on the area of the exposed surface. On account of the difficulty of determining the amount of the different resistances and their relation to the speed of the train, no formula has yet been established for calculating the tractive effort that must be exerted to move electric trains under widely varying conditions; and from the nature of the case, it is doubtful if any generally applicable formula can be obtained. A number of formulas have been devised that are reasonably accurate, provided that their use is limited to cases where the conditions correspond to those existing during the tests on which the formulas are based. The object here is simply to point out two or three formulas that have been proposed and to show, to some extent, the quantities on which the resistance depends and the amount of resistance due to each. Formula **6**, given below, is due to Mr. W. N. Smith,* and has been found to give results that agree quite closely with tests made on cars weighing from 28 to 32 tons operating at schedule speeds varying from 16 to 35 miles per hour, the maximum speeds during the runs varying from about 27 to 44 miles per hour. The formula is

$$f = 3 + .167\, S + .0025\, \frac{A S^2}{W_t} \qquad (6)$$

where $f$ = train resistance, in pounds per ton;
$S$ = speed, in miles per hour;
$A$ = cross-section of car, in square feet;
$W_t$ = weight of car, in tons.

For example, the resistance offered to a 40-ton train moving at the rate of 30 miles per hour and having a cross-sectional area of 100 square feet would be $f = 3 + .167 \times 30$

*Transactions American Institute of Electrical Engineers, Vol XXI, No. 10.

$+ .0025 \times \frac{100 \times 30^2}{40} = 13.64$ pounds per ton. With heavy trains, the train resistance per ton weight of train is less than with light trains.

**51.** As an example of the resistance of electric trains obtained from actual tests, the experiments of Wm. W. J. Davis* may be cited. These were made with a 37-ton electric locomotive hauling passenger cars of standard type weighing 25, 35, and 45 tons. The number of cars per train was varied from 1 to 5, and the influence of the size of the cars and the weight of the train on the resistance per ton could thus be noted. The curves in Fig. 25 give the results obtained with 25-ton cars; those in Fig. 26 the results obtained with 45-ton cars; these show that the resistance per ton weight is much greater with light than with heavy trains. In Fig. 25, a single-car train at 60 miles per hour offers a resistance of about $58\frac{3}{4}$ pounds per ton, whereas, with a two-car train at the same speed, the resistance is but 39 pounds per ton. The journal friction in case of the 25-ton cars is 8 pounds per ton for all speeds; with the 45-ton cars, the journal friction is 5 pounds per ton. In Figs. 25 and 26, the constant journal friction is represented by the vertical dotted line. The friction due to unevenness in the track is taken proportional to the speed, and in these tests was found to be

$$f' = .13\,S \qquad (7)$$

where $f'$ = track friction;

$S$ = speed, in miles per hour.

The track friction is represented by the slanting dotted lines. That is, the distance between the vertical dotted line and the track-friction line at any given speed represents the track friction at that speed, and the distance between the track-friction line and the vertical passing through $0$ represents the journal friction and track friction combined.

*Street Railway Journal, Vol. XIX, No. 18.



At a speed of 35 miles per hour, the track friction would be $f' = .13 \times 35 = 4.55$ pounds per ton. Hence, the distance between the two dotted lines at the point corresponding to a speed of 35 miles per hour is equivalent to

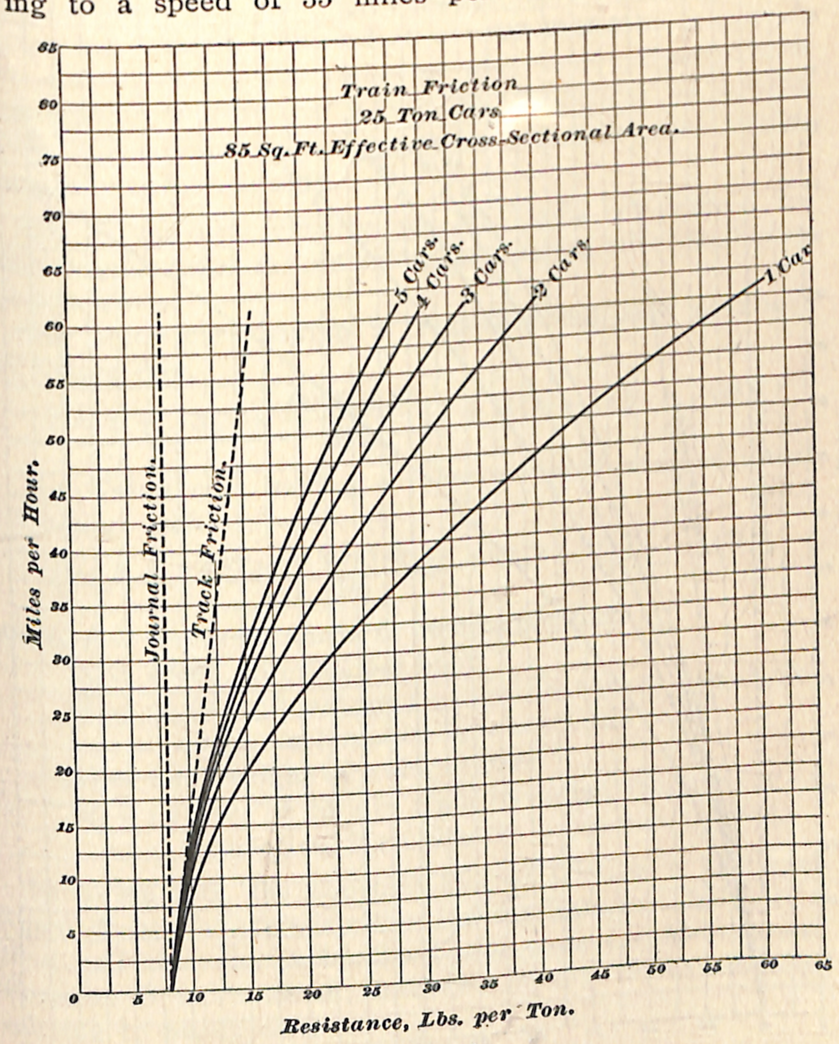


FIG. 25

4.55 pounds per ton. The full-line curves represent the total resistance per ton for trains of 1, 2, 3, 4, and 5 cars. The horizontal distance between the dotted slanting line and

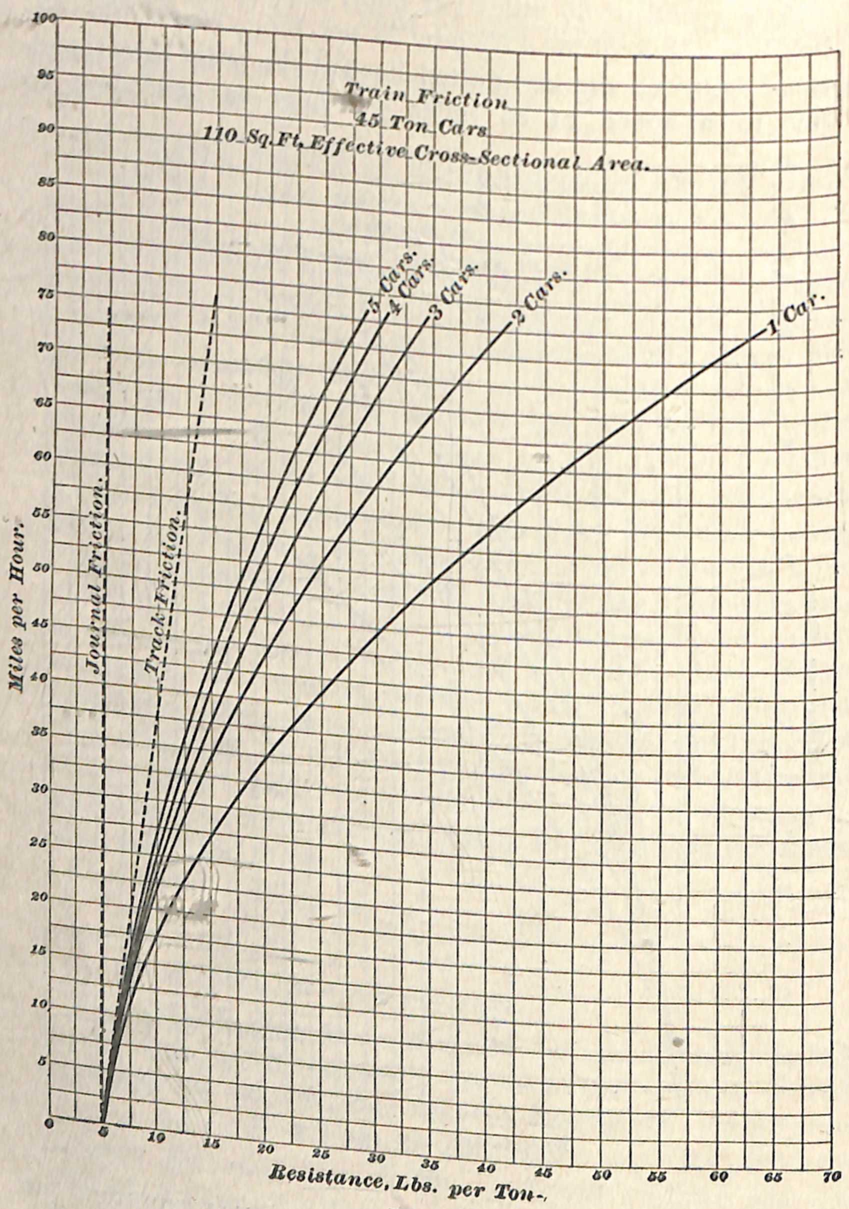


FIG. 26



the curved lines represents the air resistance for trains made up of different numbers of cars. With a single-car train at a speed of 35 miles per hour, the air friction is nearly 16 pounds per ton, and the resistance increases rapidly with increasing speeds. The effect of air resistance is not as pronounced with heavy trains as with light trains. These experiments indicate that it is more economical, as regards power consumption, to operate the cars in trains than singly, especially at high speeds.

**52.** From these experiments Mr. Davis has derived the following formulas for obtaining the tractive effort for heavy electric trains:

For 25-ton cars having a cross-sectional area of about 85 square feet,

$$f = 8 + .13\, S + \frac{.0035\, A\, S^2}{W_t}[1 + .1(n - 1)] \qquad (8)$$

For 45-ton cars having a cross-sectional area of about 110 square feet,

$$f = 5 + .13\, S + \frac{.0035\, A\, S^2}{W_t}[1 + .1(n - 1)] \qquad (9)$$

where $f$ = train resistance, in pounds per ton;
$S$ = speed, in miles per hour;
$A$ = cross-sectional area of car, in square feet, including area bounded by wheels and truck;
$W_t$ = total weight of train, in tons;
$n$ = number of cars in train including leading car or locomotive, if an electric locomotive is used.

In formula **6**, the constant journal friction is taken at 3 pounds per ton; this is rather low for light cars, being less than half that shown by the Davis tests for 25-ton cars. Formula **6** is, however, intended chiefly for calculations relating to heavy cars.

## POWER CONSUMPTION TESTS

### INTERURBAN ROADS

**53.** Tests made on cars in every-day operation afford the most reliable means of estimating the probable amount of power required for a given service. Such tests include observations of the power, speed, time, voltage, current, grades, curves, etc.; in fact, everything that is liable to influence the power consumption. Some very elaborate tests of this character have been made and with regard to interurban roads one of the most complete is that conducted by Mr. Clarence Renshaw on the system of the Union Traction Company, of Indiana.* The figures here given relate to tests made on this road with cars having 40-foot bodies, weighing 63,000 pounds, and equipped with two 150-horsepower motors mounted on the forward truck. The power consumption was measured for both limited and local service so that the effect of stops could be determined. In local service, the average speed for the whole run, 56.5 miles, was 22.6 miles per hour, but part of the run was through cities where the speed had to be reduced. Outside the cities, the speed on local service averaged 26.6 miles per hour. In limited service, the cars averaged 28.3 miles per hour for the whole run and 35.3 miles per hour leaving out the slow running in the cities. The speed between stations frequently rose to 40 and 45 miles per hour, and on one part of the road reached 60 miles per hour. Most of the grades were less than 2 per cent., but a few short ones were as high as 3 per cent. The weight of the car with passengers varied on the different trips, but was usually from 34 to 34.5 tons. The power consumption, as indicated by the average of a large number of wattmeter readings, is given in Table II.

From these figures, it would be safe, in making a preliminary estimate on a road of the same general character as this, to allow from 70 to 75 watt-hours per ton-mile for

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



limited service and 85 to 90 watt-hours per ton-mile for local service.

It is interesting to note that very complete tests made with 25-ton cars on a different interurban road—the Dayton and Northern Traction Company—give results that agree quite closely with those in Table II. The average power consumption for a number of regular trips with the speed varying from 8 to 29 miles per hour, was 2.16 kilowatt-hours per car mile or 86.4 watt-hours per ton-mile. The average consumption for a number of test runs, with speeds varying from 19 to 27.5 miles per hour, was 1.96 kilowatt-hours per car mile or 78.4 watt-hours per ton-mile. The greatest power consumption was for a short run of 1.46 miles at the slow speed of 8 miles per hour, when the consumption was 148 watt-hours per ton-mile.

TABLE II

POWER CONSUMPTION OF CARS

*(Interurban Road)*

| Class of Service | Kilowatt-Hours per Car Mile | Watt-Hours per Ton-Mile |
|---|---|---|
| Local service, outgoing trips | 2.24 to 2.78 | 66.7 to 81 |
| Local service, return trips | 2.62 to 2.31 | 77 to 89.5 |
| Local service, average for six round trips | 2.62 | 76.6 |
| Limited service, outgoing trips | 2.1 | 58.7 |
| Limited service, return trips | 2.31 | 71.6 |

**54. Influence of Stops.**—It seems strange at first glance that the slow-speed local service (Table II) should show a power consumption greater than that of the high-speed limited service, but the explanation is found in the relatively large number of stops necessitated by the local service. Every time a car is started, a certain amount of energy is wasted in the starting resistance and energy is also required for acceleration. The greater part of the latter is usually wasted at the brake shoes when the car is brought to a stop. Thus, if the stops are very numerous the power consumption per ton-mile is considerably increased. Tests on the Union Traction Company's road showed that, on the average, the local service required 15 per cent. more power per trip than the limited service.

The following comparison of a number of runs shows clearly the increased power consumption due to stops.

| Service | Stops | Watt-Hours per Ton-Mile | Time for Trip | |
|---|---|---|---|---|
| | | | Hours | Minutes |
| Limited . . . | 4 | 71.6 | 2 | |
| Local . . . . | 31 | 83.3 | 2 | 36 |
| Local . . . . | 44 | 89.5 | 2 | 53 |

It must not be inferred that in all cases local service with numerous stops requires more power than high-speed service with few stops; in fact, the contrary is often the case. In this instance the schedule speed on limited service is not very high (35.3 miles per hour), but with higher schedule speed the energy per ton-mile for limited service would be greater than that for local service and might easily be from 90 to 110 watt-hours. When the average speed is over 35 miles per hour a comparatively slight increase in speed involves a large increase in power because of the great increase in air resistance.

**55. Current.**—In the above tests, the cars took at starting from 200 to 250 amperes and when the motors were placed in parallel the current rose as high as 250 to 330 amperes. These large currents, however, only lasted for short intervals.

**56. Voltage.**—The average line voltage, when the car was running, was 454 volts, but the average voltage at the terminals of the motors was very much lower because sometimes the motors were in series, with resistance, sometimes in series without resistance, or in some cases no voltage at all was applied to them, as, for example, when the car was



coasting or when the brakes were applied. The average voltage per motor was thus about 237 volts.

**57. Conclusion.**—The application of the data here given can best be illustrated by working an example.

EXAMPLE.—An interurban electric road is to operate ten cars weighing 30 tons each when loaded. Six of these are to run on local service and four on limited service, the average speed on local service being 20 miles per hour and on limited service 32 miles per hour. Estimate the approximate capacity of the generating plant, assuming that the total loss between generators and cars is 18 per cent. of the delivered power.

SOLUTION.—Referring to the figures given in Art. **53**, the average power consumption, in watt-hours per ton-mile, may be taken at, say, 72.5, taking the average of 75 and 80 for the limited cars, and 87.5 for the local service. In 1 hr., therefore, the total number of watt-hours supplied would be:

For local service, $6 \times 30 \times 20 \times 87.5 = 315{,}000$ watt-hours
For limited service, $4 \times 30 \times 32 \times 72.5 = 278{,}400$ watt-hours
Total, $593{,}400$ watt-hours.

Since the energy supplied to the cars in 1 hr. is 593,400 watt-hours it follows that the power is 593,400 watts, or 593.4 K. W. The loss between the generating station and the cars is $593.4 \times .18 = 106.8$ K. W. This represents the loss in lines, third rail, rotary converters, and transformers. The average output of the station will therefore be $593.4 + 106.8 = 700.2$ K. W. On an interurban system, where comparatively few cars are operated, the fluctuations in load are very great and the maximum load is usually from 1.5 to 2 times the average load. Also, considerable power is required for lighting and heating cars and lighting stations. In this case, therefore, the machinery should be capable of furnishing at least 1,000 K. W., and in order to insure against shut-downs it would be advisable to install two generating units of 1,000 K. W. each, or at least three generators of 500 K. W. each, two being operated in parallel under ordinary conditions and the third kept as a reserve. Ans.

## CITY ROADS

**58.** The power consumption per ton-mile is greater for city roads than for interurban lines. The cars are lighter and the tractive effort per ton greater, the stops are much more frequent, and in most cases the track is not as clean or in as good condition. Also on account of the slow speed and numerous stops, considerable power is wasted in the

## TABLE III

### POWER CONSUMPTION OF CARS

*(City Road)*

| Type of Motor | Horsepower of Each Motor (Railway Rating) | Number of Motors per Car | Average Current Amperes | Maximum Current Amperes | Average Pressure Volts | Average Watts | Watt-Hours per Car Mile |
|---|---|---|---|---|---|---|---|
| Westinghouse, No. 3 . . | 30 | 1 | 13.3 | 60 | 538 | 7,155 | 812 |
| Westinghouse, No. 3 . . | 30 | 1 | 26.0 | 60 | 519 | 13,494 | 1,180 |
| Westinghouse, No. 3 . . | 30 | 2 | 37.7 | 160 | 470 | 17,719 | 1,690 |
| Westinghouse, No. 3 . . | 30 | 2 | 30.6 | 125 | 470 | 14,382 | 1,249 |
| Westinghouse, No. 3 . . | 30 | 2 | 20.3 | 80 | 470 | 9,541 | 864 |
| Westinghouse, No. 3 . . | 30 | 2 | 17.0 | 72 | 474 | 8,058 | 690 |
| Westinghouse, No. 3 . . | 30 | 2 | 17.8 | 65 | 488 | 8,686 | 781 |
| Westinghouse, No. 3 . . | 30 | 2 | 18.0 | 88 | 494 | 8,892 | 804 |
| Westinghouse, No. 3 . . | 30 | 2 | 20.1 | 75 | 498 | 10,010 | 1,062 |
| Westinghouse, No. 3 . . | 30 | 2 | 17.3 | 70 | 519 | 8,979 | 814 |
| Westinghouse, No. 3 . . | 30 | 4 | 38.9 | 175 | 486 | 18,905 | 1,636 |
| Westinghouse, No. 3 . . | 30 | 4 | 41.2 | 150 | 446 | 18,375 | 1,895 |
| Westinghouse, No. 49 . . | 35 | 2 | 34.0 | 125 | 452 | 15,368 | 1,479 |
| Westinghouse, No. 49 . . | 35 | 2 | 27.0 | 118 | 444 | 11,988 | 1,034 |
| Westinghouse, No. 49 . . | 35 | 2 | 10.6 | 75 | 494 | 5,236 | 539 |
| Westinghouse, No. 49 . . | 35 | 2 | 18.7 | 70 | 492 | 9,200 | 798 |
| Westinghouse, No. 49 . . | 35 | 4 | 43.5 | 170 | 471 | 20,489 | 1,924 |
| Westinghouse, No. 49 . . | 35 | 4 | 44.8 | 170 | 536 | 24,013 | 2,128 |
| Westinghouse, No. 38 B . | 50 | 2 | 50.8 | 185 | 435 | 24,638 | 1,845 |
| Westinghouse, No. 38 B . | 50 | 2 | 47.4 | 200 | 478 | 22,657 | 1,845 |
| Westinghouse, No. 56 . . | 60 | 4 | 110.4 | 420 | 471 | 51,998 | 3,778 |

## TABLE IV

## EQUIPMENT OF ELECTRIC RAILWAYS

| Road | Kind of Road | Miles of Single Track | Number of Cars | Number of Open Cars | Number of Closed Cars | Size of Open Cars | Length of Closed Cars Over All | Length of Closed Cars Between Bulkheads | Other Rolling Stock in Regular Operation | Motors: Number per Car | Motors: Type or Horsepower (Railway Rating) | Average Speed of Cars Miles per Hour |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Inter-urban | 28.25 | 13 | | 6 | | 42 ft. 3 in. | | 1 double-truck work car; 6 single-truck flat cars | 4 | * W. H. No. 56 | |
| B | Inter-urban | 90 | 20 | | 20 | | 60 ft. | 50 ft. | | 4 | † G. E. 73 75 H. P. | 30 |
| C | Small city | 9.16 | 40 | 24 | 15 | | 18 ft. | | 1 combined sprinkler and snow plow | 2 | 30 | 8 to 20 |
| D | City | 116.8 | 268 | | | 9 and 10 bench | | 20 and 21 ft. | | 2 | G. E. 67 38 H. P. | 8 to 18 |
| E | Inter-urban | 39.5 | 8 | | 8 | | 44 ft. 6 in. | | 1 freight car, 42 ft. long | 4 | 50 H. P. | 25 |
| F | City | 83 | 122 | 39 | 70 | 8 and 10 bench | | 18 ft.<br>20 ft.<br>28 ft. | | 18 ft. 20 ft. and open cars, 2 motors; 28-ft. cars, 4 motors | W. H. No. 3<br>W. H. No. 49<br>W. H. No. 38 B<br>W. H. No. 56 | |
| G | Inter-urban | 34 | 10 | | 10 | | 45 ft. | | | 4 | G. E. 67 | |
| H | City and sub-urban | 34 | 9 | | 9 | | 6 suburban, 49 ft. 5 in. | 3 city cars, 18 ft. body | | Suburban 4<br>City 2 | 75 H. P.<br>25 H. P. | |
| I | City | 63.37 | 57 | | 57 | | 40 ft. | | 1 electric locomotive | 4 | | |
| J | Inter-urban | 66.6 | 15 | 3 | 12 | 15 bench | 50 ft. | | 1 35-ton electric locomotive for freight | 4 | 50 H. P. | 25 to 30 |
| K | Inter-urban | 26.2 | 6 | | 6 | | 51 ft. | 43 ft. | | 4 | G. E. 66 | 30 |
| L | Inter-urban | 40 | 13 | | 13 | | 52 ft. | 42 ft. | | 2 | 150 H. P. | express 35, local 25 |

| Road | Generators: Number of Generators | Output per Generator Kilowatts | Engines: Number of Engines | Indicated Horsepower per Engine | Type of Engine | Boilers: Number of Boilers | Horsepower per Boiler (Boiler Rating) | Type of Boiler | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| A | 2 | 400 | 2 | 500 | Horizontal cross-compound, direct-connected | 3 | 300 | Horizontal water-tube | Flat cars not equipped with motors. A. C. distribution from sub-stations |
| B | 2 | 800 | 2 | | Horizontal cross-compound, direct-connected | 6 | 500 | Horizontal water-tube | A. C. distribution to four substations each containing two 300-kilowatt rotary converters |
| C | 2<br>2 | 150<br>200 | 2<br>2 | 175<br>300 | Tandem compound, belted: tandem compound, direct-connected | 2<br>2 | 150<br>300 | Horizontal return tubular; horizontal water-tube | D. C. distribution used throughout |
| D | 6 | 700 | 6 | 750 | Tandem compound, vertical | 8 | 500 | Horizontal water-tube | Combined water-power and steam plant. Each generator driven either by engine or water wheels giving 1,200 horsepower under 25-foot head |
| E | 2 | 250 | 2 | 400 | Horizontal compound, direct-connected | 3 | 260 | Horizontal water-tube | A. C. distribution. Freight car has same motor equipment as passenger cars |
| F | 1<br>1<br>2 | 200<br>225<br>800 | 1<br>1<br>2 | 300<br>300<br>1,200 | Vertical cross-compound, belted; horizontal cross-compound, direct-connected | 6 | 300 | Vertical water-tube | D. C. transmission. Boosters used on long feeders. Three storage-battery sub-stations |
| G | 2 | 350 | 2 | 500 | Direct-connected | 4 | 175 | Return tubular | D. C. transmission. Power house located near center of road |
| H | 2 | 400 | 2 | 625 | Horizontal cross-compound, direct-connected | 4 | 310 | Horizontal water-tube | D. C. transmission Distant parts of line supplied through booster feeders |
| I | 2 | 1,000 | 2 | | Horizontal cross-compound | 6 | 450 | Horizontal water-tube | D. C. transmission |
| J | 2<br>1 | 540<br>360 | 2<br>1 | 750<br>500 | Tandem compound, direct-connected | 4 | 300 | Vertical water-tube | A. C. transmission |
| K | 3 | 400 | 3 | 600 | Cross-connected simple engines | 6 | 300 | Horizontal water-tube | Cars equipped with multiple-unit control. Each generator driven by a pair of 300-horse-power cross-connected simple engines |
| L | 2 | 1,250 | 2 | 2,000 | Vertical cross-compound, direct-connected | 5 | 400 | Horizontal water-tube | Double-current generators are used (600-volt, direct current, 360-volt alternating current) |

* W. H (Westinghouse). † G. E. (General Electric).

starting resistance. The average power consumption per ton-mile will seldom be less than 90 watt-hours and in most cases will exceed this amount; 110 to 120 watt-hours may be taken as a fair approximation. The watt-hours per car mile will usually lie between 750 and 1,500 for single-truck cars with two motors of 30 or 35 horsepower, and between 1,500 and 2,500 for double-truck cars with four motors of 30 or 35 horsepower. Table III shows the results of tests on a number of different runs with motors of the sizes ordinarily used for operation in cities. The first two cars are equipped with a single motor with rheostatic control; all the others have series-parallel control.

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### EXAMPLES FOR PRACTICE

1. If 25 pounds per ton is required to propel a 30-ton car on a level track, what total force must be applied to propel the car up a 2-per-cent. grade? Ans. 1,950 lb.

2. If a total force of 500 pounds is required to propel a car at the rate of 15 miles per hour, how many horsepower are expended in moving the car? Ans. 20 H. P.

3. (*a*) If a car weighs 25 tons, what force must be applied to produce an acceleration of 1.25 miles per hour per second? (*b*) What must be the total force applied to produce the acceleration and overcome the train resistance as well, assuming that the latter amounts to 20 pounds per ton weight of car? Ans. { (*a*) 2,850 lb. (*b*) 3,350 lb.

4. A certain car has 60 per cent. of its weight resting on the driving wheels and the adhesive force between track and rail is 15 per cent. of the weight on the drivers. A force of 75 pounds per ton weight of car is necessary to start the car from rest. What is the steepest grade on which the car can be started without slippage of the wheels on the tracks? Ans. 5.25 per cent.

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## EXAMPLES OF RAILWAY EQUIPMENT

**59.** In order to show the character of station equipment used for the operation of a number of typical railways, Table IV is here inserted. In all cases, except *K*, compound condensing engines are used; road *K* is situated in a coal-mining region where fuel is cheap and water suitable for condensing purposes scarce; hence, simple non-condensing engines are used. On all the roads except *G*, water-tube boilers are used; this type of boiler is almost essential in railway work because the demand for power fluctuates greatly and the steaming of the boilers must respond quickly to the changes in load. Also, they must admit of forcing beyond their regular capacity in cases of emergency.

## COST OF POWER

**60.** The cost of generating power in electric-railway plants varies greatly, as one would naturally expect, because it includes many items that are subject to wide fluctuation. In fact, in even the same station the cost will be higher during some months than others. Table V, from the Street Railway Review, gives figures relating to the cost of generating power in some stations of considerable size. It should be noted that the total cost covers only the items of fuel, labor, supplies, water, and repairs. It does not allow for interest on the investment, or depreciation of the plant. The cost per kilowatt-hour, not including interest and depreciation, will lie between .65 cent and 1 cent for many steam-power stations. In a large number of plants the total cost, including interest, etc., will lie between 1 and 2 cents per kilowatt-hour and in some of the largest plants it may be somewhat below 1 cent per kilowatt-hour. When power is sold from one railway company to another a common charge is 3 cents per kilowatt-hour. Every station switchboard should be equipped with at least one recording meter for measuring the station output, and it is a good plan to provide two meters so that one can operate while the other is being calibrated. In case only one instrument is used, it should be checked at frequent intervals to see that its indications are correct.

**61. Station Record.**—In order that the cost of generating power in a station may be accurately known, it is necessary to keep a complete record of the various elements



### TABLE V

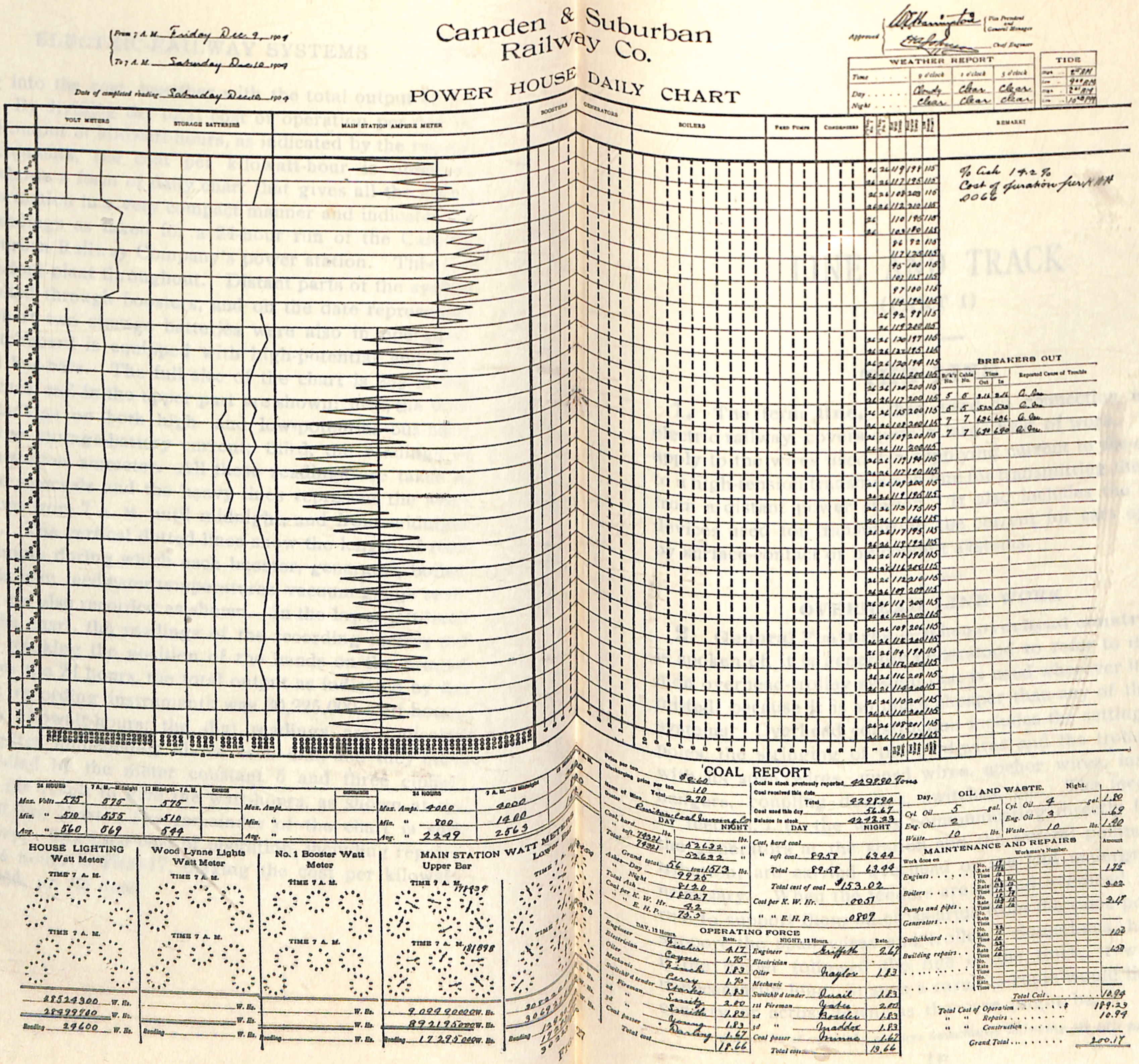
### COST OF POWER FOR ELECTRIC RAILWAYS

*(Output Measured by Wattmeter in Each Case)*

| Station | Month | Monthly Output Kilowatt-Hours | Cost of Electrical Output per Kilowatt-Hour. Cents | | | | | | Gallons of Cylinder Oil per 10,000 Kilowatt-Hours | Gallons of Lubricating Oil per 10,000 Kilowatt-Hours | Pounds of Water per Pound of Coal | Pounds of Fuel per Kilowatt-Hour | Price of Fuel per Ton of 2,000 Pounds | Kind of Fuel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fuel | Labor | Supplies—Oil, Waste, Etc. | Water | Repairs | Total | | | | | | |
| 1 | Jan. | 2,455,060 | .322 | .111 | .029 | .029 | .044 | .535 | 2.62 | .848 | 10.83 | 2.45 | $2.63 | Bituminous |
| 1 | Feb. | 2,511,280 | .334 | .114 | .036 | .027 | .025 | .536 | 2.64 | .829 | 10.05 | 2.54 | 2.63 | Bituminous |
| 1 | Mar. | 2,097,160 | .337 | .123 | .037 | .030 | .040 | .567 | 2.84 | .987 | 11.21 | 2.55 | 2.64 | Bituminous |
| 1 | Apr. | 2,158,660 | .344 | .129 | .039 | .032 | .043 | .587 | 2.98 | .722 | 11.37 | 2.61 | 2.64 | Bituminous |
| 5 | Jan. | 2,445,161 | .408 | .110 | .013 | .011 | .016 | .558 | 2.18 | 1.31 | 5.51 | 4.10 | 1.99 | Bituminous |
| 5 | Feb. | 2,512,125 | .389 | .116 | .014 | .008 | .011 | .538 | 2.50 | 1.08 | 5.32 | 3.89 | 2.00 | Bituminous |
| 5 | Mar. | 2,352,698 | .405 | .126 | .018 | .011 | .016 | .576 | 2.52 | 1.70 | 5.15 | 4.33 | 1.87 | Bituminous |
| 5 | Apr. | 1,887,029 | .347 | .149 | .020 | .011 | .036 | .563 | 3.91 | 1.14 | 5.22 | 4.22 | 1.65 | Bituminous |
| 6 | Nov. | 827,008 | .712 | .198 | .033 | | .067 | 1.010 | | | | 2.35 | .943* | Oil |
| 6 | Dec. | 810,728 | .709 | .198 | .024 | | .070 | 1.001 | | | | 2.36 | .937* | Oil |
| 6 | Jan. | 643,482 | .680 | .251 | .038 | | .185 | 1.154 | | | | 2.24 | .945* | Oil |
| 6 | Feb. | 494,000 | .655 | .282 | .037 | | .181 | 1.155 | | | | 2.25 | .905* | Oil |
| 6 | Mar. | 562,574 | .761 | .266 | .031 | | .059 | 1.117 | | | | 2.42 | .976* | Oil |
| 6 | Apr. | 616,634 | .628 | .236 | .030 | | .095 | .989 | | | | 2.31 | .843* | Oil |

*Price of oil per barrel.

entering into the cost, together with the total output of the station. By dividing the total cost of operation per day by the total output in kilowatt-hours, as indicated by the recording instruments, the cost per kilowatt-hour is obtained. Fig. 27 shows a form of daily chart that gives all the necessary information in a very compact manner and indicates the actual readings as taken for a 24-hour run of the Camden and Suburban Railway Company's power station. This is a direct-current plant throughout. Distant parts of the system are supplied through boosters, and on the date represented by the chart two storage batteries were also in operation. The switchboard is equipped with high-potential and low-potential bus-bars. The full size of the chart is 23½ inches by 25 inches, and in the upper part are shown: first, the voltmeter readings on both high- and low-potential bus-bars; second, the storage-battery current; third, the readings of the main-station ammeter. All these readings are taken at 15-minute intervals and the heavy lines represent the average current from 7 A. M. until midnight, and from midnight to 7 A. M. The vertical dotted lines show the length of time and the hours during which each booster, generator, boiler, etc. was in use; feedwater temperatures, vacuum-gauge readings, etc. are also recorded as shown. In the lower left-hand part of the chart, the readings of the recording meters are given by marking the position of the hands on the printed dials. For the 24 hours, the total output as indicated by the two main recording instruments was 30,225,000 watt-hours, or 30,225 kilowatt-hours; the dial readings are indicated by the figures immediately above each dial, and they must be multiplied by the meter constant 5 and three ciphers added to the result to give the watt-hours, as shown at the bottom of the chart. The remainder of the chart is self-explanatory. The total cost of operation, including repairs, for the 24 hours is $200.17, making the cost per kilowatt-hour $.0066, or .66 cent.


Camden & Suburban Railway Co.
POWER HOUSE DAILY CHART
From 7 A.M. Friday Dec 9, 1904
To 7 A.M. Saturday Dec 10, 1904
Date of completed reading Saturday Dec 10 1904
VOLT METERS
STORAGE BATTERIES
MAIN STATION AMPERE METER
BOOSTERS
GENERATORS
BOILERS
FEED PUMPS
CONDENSERS
REMARKS
WEATHER REPORT
TIDE
BREAKERS OUT
COAL REPORT
OIL AND WASTE
MAINTENANCE AND REPAIRS
OPERATING FORCE
HOUSE LIGHTING Watt Meter
Wood Lynne Lights Watt Meter
No. 1 Booster Watt Meter
MAIN STATION WATT METERS
Upper Bar
Lower Bar
Total Cost of Operation
Grand Total
Fig. 27