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CONTENTS.

PAGE

DYNAMOS AND MOTORS.

Introduction, - - - - - - - - 317
Electrodynamics, - - - - - - - - 322
Magnetism, - - - - - - - - 329
Electrical Units, - - - - - - - 341
Applications of Ohm's Law, - - - - - 364
Electromagnetic Induction, - - - - - 381
Physical Theory of the Dynamo, - - - - 388
Constant-Potential Dynamos, - - - - 433
Constant-Current Dynamos, - - - - - 465
Alternating-Current Dynamos, - - - - 490
Electric Motors, - - - - - - - 509
The Installation and Care of Dynamo-Electric Machinery, - - - - - - - 535
Switchboards, - - - - - - - 566

ELECTRIC LIGHTING.

Methods of Lighting, - - - - - - 589
The Electric Arc Light, - - - - - 590
Electric Lighting by Incandescence, - - - 605
Determination of Candle Power, - - - - 610
General Data for Arc and Incandescent Lamps, - 619
Conductors, - - - - - - - - 623
Electrical Distribution, - - - - - - 636
Lighting by Alternating Currents, - - - 656
Central Stations for Electric-Lighting Plants, - 659
Practical Wiring, - - - - - - - 663
Calculations for Incandescent Lighting Circuits, - 674

ELECTRIC RAILWAYS.

Motor Cars and Fittings, - - - - - 685
Electric Traction Systems, - - - - - 685
Rolling Stock, - - - - - - - 698

	PAGE
ELECTRIC RAILWAYS.—*Continued.*	
Car Equipment,	712
Overhead Line Construction,	729
Track Construction,	752
The Power Station,	757
The Testing Station,	772
Alternating Currents in Railway Work,	783
The Application of Batteries to Electric Traction,	784
Power Estimates,	788
Logarithms,	797

QUESTIONS AND EXAMPLES.

Dynamos and Motors,	Questions 1079–1138	803
Dynamos and Motors,	Questions 1139–1188	813
Dynamos and Motors,	Questions 1189–1273	823
Electric Lighting,	Questions 1274–1338	831
Electric Railways,	Questions 1339–1416	837

DYNAMOS AND MOTORS.

INTRODUCTION.

2132. Electricity is the name given to the cause of all electrical phenomena; the word being derived from a Greek word meaning *amber*, that substance having been observed by the Greeks to possess peculiar properties which we now understand to be due to electricity.

Although electrical science has advanced sufficiently far to recognize the fact that the exact nature of electricity is unknown, yet recent research tends to demonstrate that all electrical phenomena are due to a peculiar strain or stress of a medium called *ether;* that when in this condition the *ether* possesses *potential energy* or *capacity for doing work*, as is manifested by attractions and repulsions, by chemical decomposition, and by luminous, heating, and various other effects.

In all probability, electricity is not a form of matter, for it possesses only two physical properties in common with material substances, namely, **indestructibility** and **elasticity;** it does not possess *weight, extension*, or any of the other physical properties of matter.

Electrical science is founded upon the effects produced by the action of certain forces upon matter, and all knowledge of the science is deduced from these effects. The study of the fundamental principles of electricity is an analysis of a series of experiments, and the classification of the results in each particular case under general laws and rules. It is not necessary to keep in mind any hypothesis of the exact nature of electricity; its effects, and the laws which govern them, through the tube *t*. Current is conducted to the carbon by means of sixteen contact rings *d*, enclosed within a box *c*, and making flexible contact with the carbon. The inner globe *g* surrounds the carbons, and is supported by the arm or yoke *f*. The outer globe fits over the plate *h* at the bottom, and is secured at the top by a circular nut at *i*, the joint being packed by means of asbestos gaskets. The space immediately above *h* and below the inner globe is intended for the rheostat—a necessary adjunct to all enclosed arc lamps.

The enclosed arc requires carbons of exceptional purity, in order to prevent the formation of deposits upon the inner globe. The especial feature of these lamps is, however, the use of a high potential, usually about 80 volts, between the carbons, the remainder of the E. M. F. of the circuit being taken up by the resistance of the series winding and the rheostat.

ELECTRIC RAILWAYS.

MOTOR CARS AND FITTINGS.

2514. The application of the electric motor to street railway work has provided a means of car propulsion which, from its peculiar adaptability to the conditions met with, is likely to supersede all other systems. The various methods of applying electricity to street-car traction are the following: Those using storage batteries on the cars; those employing electromagnetic switching devices in connection with subsurface conductors, this being also called the closed conduit system; those having an open conduit and a trolley connection beneath the car; those using an insulated third rail, and those with an overhead conductor and trolley connection.

ELECTRIC TRACTION SYSTEMS.

STORAGE-BATTERY RAILWAYS.

2515. A **storage-battery system** presents many advantages from a theoretical point of view, which can not, unfortunately, be entirely realized in practice. The first cost of the installation need not be very great, and more battery sets could be added as the extension of the road or its traffic demanded. The station equipment could also be of minimum capacity, as it might be operated at full load continuously, and would then work at its highest efficiency. If sufficient provision be made for future enlargement, the addition of more power units at a later date would involve comparatively small expense. Another advantage possessed by this system is that no work on the roadbed is called for when it is desired to change from the use of horses, provided that the track is well laid in the first instance. There are also no overhead wires to keep in repair or present obstruction or danger, and, furthermore, every car is self-contained and independent of all others. Several disadvantages may be enumerated against this method which more than counteract these decidedly favorable points. The batteries, being composed of lead plates, are very heavy and require a large proportion of the available energy for their transportation. The weight necessary is about 100 pounds per horsepower per hour with ordinary speeds and grades; but provision must be made for cases of emergency, and, usually, for some heavy grades, so that it has been found necessary in practice to provide for each car a battery weighing 3,000 or 4,000 pounds. This dead weight is a serious objection; but worse yet is the fact that deterioration is extremely rapid, the cells having a life of only one year or less. Sudden discharging has a detrimental effect, and, in consequence, smaller motors must be used than would be installed on an ordinary car having an external source of power. It follows, as a matter of course, that high speeds with storage-battery cars, or rapid acceleration at starting, are not commercially practicable, and their use is more or less restricted to those localities where such requirements are not made.

2516. A street car operated by storage batteries is very similar in outward appearance to an ordinary car. The motors are placed beneath the car floor, and the battery under the seats. A convenient method of accomplishing the removal of the batteries, when substituting charged cells for those run down, is to have a long, swinging panel on the side of the car, which will afford ready access to the cells, or they may be placed on a long board and passed in through a hinged panel at the end. It is usually necessary to provide two or three sets of accumulators for each car, in order that there may always be one set in readiness for use, and to make allowance for any cells which may be laid aside for repair or renewal. Each cell is made up of

a number of lead plates, 12 or 14 inches square, the alternate plates being firmly joined together, thus making two sets, as shown in Fig. 977, where *N*, *N*, etc., are the negative, and *P*, *P*, etc., the positive, plates, joined, respectively, to the cross-bars *T* and *T'*, by which connection is made to the other cells, a bolt *C* being used to ensure good contact. The plates are placed in the jar *J*, resting on a wooden support consisting of two strips of wood *S*, *S* (usually boiled in paraffin) of triangular section. These support the plates at such a height that any loosened particles falling from the exposed surfaces may rest in the bottom of the jar without touching the plates and thereby short-circuiting the battery.

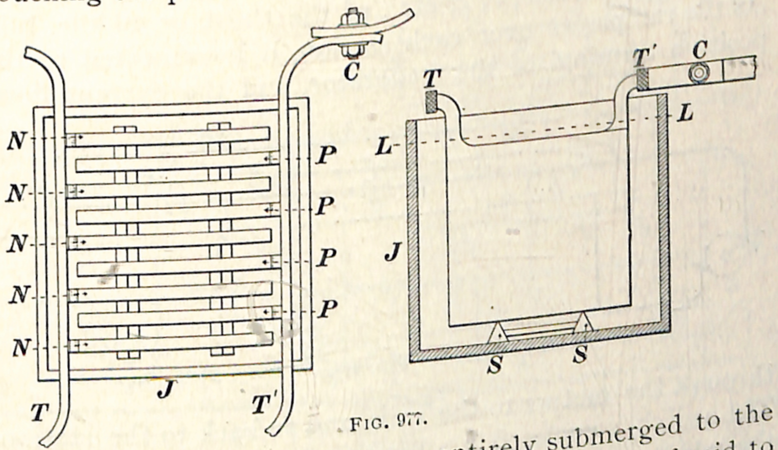

FIG. 977.

When in position, the plates are entirely submerged to the level *L L* in dilute sulphuric acid, the proportion of acid to water being about 1 to 4. To prevent the plates from touching each other, it is usually the practice to separate them by blocks or strips of insulated material, the exact arrangement varying with different manufacturers. The E. M. F. of an accumulator cell is about 1.9 volts, from which may be calculated the number of cells required to operate a given motor. Those for a street car are usually about 108 in number, giving an E. M. F. of about 205 volts. Speed regulation is affected by changing the battery connections, the changing being accomplished automatically by means of a special switch or controller on the car platform.

ELECTROMAGNETIC SYSTEMS.

2517. The **electromagnetic traction system** is one which provides an insulated conductor for the supply of current, and in which a series of automatic switches operated by the moving car make contact between successive sections of an insulated rail and the conductor. By this means only a short length of exposed conductor is at any time active, and liability to accidents is thereby much decreased, the insulation of the line being also considerably improved. A diagram of this system is given in Fig. 978, where G is the generator at the station, t t_1 the track, m the main conductor connected through the switches s, s, etc., with the insulated sections r, r, r, etc., of the third, or middle, rail. As the car passes over each section, it is connected to the positive terminal of the generator, and the current flows

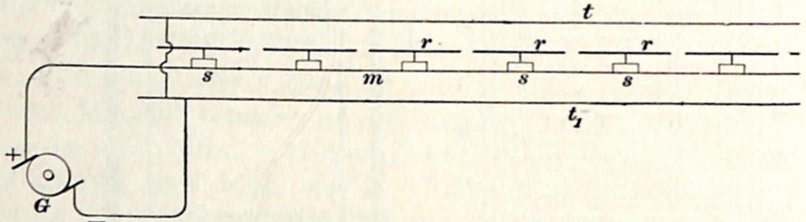

FIG. 978.

through the motors to the rails and so back to the station. The switch is enclosed in a rectangular box located between the middle rail and one of the track rails, and is provided with a non-magnetic metal cover hermetically sealed to prevent water from entering. Directly under this cover and connected to the switch lever are two armatures, which are alternately attracted by magnets on the car, one at the front and the other at the rear end, so that any section has current in it only so long as the car is passing over it. For collecting the current, a wheel or sliding shoe is used, a sweeper of stiff bristles being placed in front to clear away any obstruction. The magnets may be permanent ones of steel or electro-magnets energized by a battery carried on the car.

2518. Another electromagnetic traction system employs the so-called **button method.** The buttons are contact blocks placed between or alongside the tracks, from which the current is taken by long sliding shoes secured to the car frame. These contact blocks are normally out of circuit, and only become "alive" just before the shoe reaches them, being cut out again as soon as the car passes. The means by which this is accomplished is shown diagrammatically in Fig. 979. At the upper portion of the figure is the car carrying a battery B, from the positive terminal of which connection is made to one of the shoes S on the car frame, and from the negative terminal to the wheels

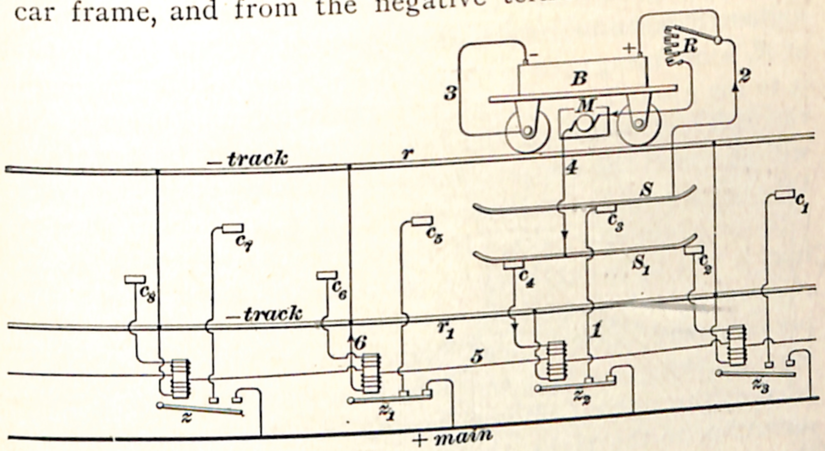

FIG. 979.

and track. The rails are marked r and r_1; but for the sake of clearness the wheels are shown as running on one rail only. On starting up the car, since all the switches z, z_1, etc., are open, an initial current must come from the battery B, which will at once close the switches nearest to the car by means of the electro-magnets in circuit. This current may pass through the motor M, as shown in the figure, in which case it may be used to propel the car over considerable distances should the line current fail or some of the contact switches refuse to work. On a down-grade track the contact blocks may be entirely omitted, as no power is required except for starting, and this the battery is able to supply.

In this case an auxiliary switch is used to connect wires *3* and *4*, and the circuit from the battery is simply through the motor and the rheostat *R*. Under the usual working conditions, current is taken from the main conductor, shown at the bottom of the figure, and the switches z_1, z_2 being already closed, the contact blocks c_3, c_5 will be connected to the main. There are, it will be seen, always two, and, for a short space of time, three, switches closed. In the position of the car shown in the figure, the current passes through the switch z_2, and wire *1* to the contact block c_3; thence through the shoe *S* and wire *2* to the rheostat *R*. The E. M. F. of the current from the mains is slightly higher than the battery E. M. F., so that the current divides at *R*, some being used to charge the battery, passing through it to the ground, but the greater amount going through the rheostat and motor to the second shoe S_1. From here it will go round the upper winding of the magnet of switch z_2 through wire *5* to the lower winding of z_1, and from there by *6* to the ground or rails. If the car is moving towards the left, it will be seen that the contact c_5 is alive before the shoe reaches it, so that there is no interruption to the supply of power; also, on leaving any contact block, as c_3, there is no sparking, because there is already another path for the current through c_5. When the car is moving in the other direction, to the right, the contact block c_1 is connected to the main as soon as the shoe S_1 touches c_2, so that the car will travel in either direction with equal facility. The contact blocks are placed in two rows at distances of eight feet, and the car body will therefore project over all those which are charged with current, and prevent possible injury to persons or horses stepping upon them.

2519. One of the chief advantages of such a system as this is the high insulation which may be obtained, owing to the fact that the whole of the active conductor is disconnected from service except at those points where a car is passing. The switch magnets z, z_1, etc., are placed in pairs in water-tight boxes alongside one of the rails on the outside of the track. The cover is in the form of a diving-bell, so that no water can possibly reach the magnets, which are raised above the bottom of the box. The effective leakage from the contact blocks, which are held on insulated supports, amounts to little, even under the worst conditions of immersion in melting snow.

THE CONDUIT SYSTEM.

2520. The open conduit system has not been put into very extensive use, because the expense of construction is very high as compared with any other system. Two bare conductors are used, which are held on insulating supports in the upper part of a channel or conduit, built in the roadway between the car rails. The general method of construction is shown in Fig. 980, the conductors *a*, *a* of circular cross-section being held at frequent intervals by the insulated clamps *b*. Two trolley wheels supported on a frame *c*, attached to the car frame, make contact with the conductors, being themselves connected with the wires leading to the motors, but insulated from each other, as the full working E. M. F. of 500 volts is maintained between the conductors. There are many ways of securing the wheels, but the principle of spring pressure is generally used. The conduit is about twenty inches deep by fourteen inches wide, and the width of the slot is five-eighths or

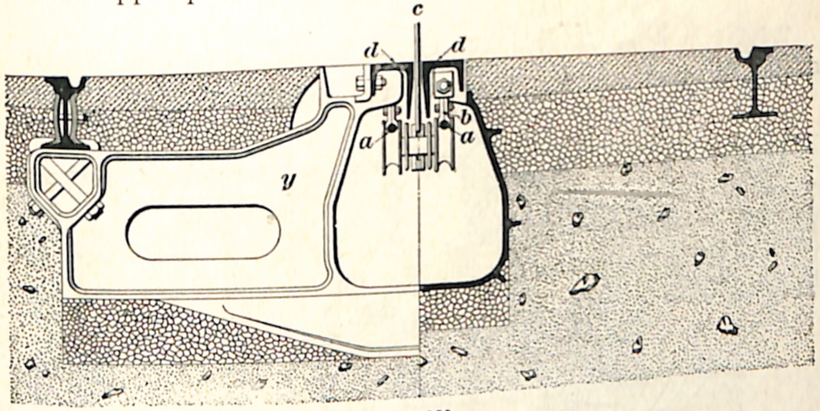

FIG. 980.

three-fourths of an inch. The yokes *y* are spaced about four feet apart, and usually extend under the rails on each side, as this tends to prevent slot closure or narrowing of the space in which the trolley frame moves. Since the conductors are intended to preserve a straight line and are of heavy section ($\frac{1}{2}$ in. or $\frac{5}{8}$ in. diameter), it is customary to provide expansion joints about every 500 feet; these may consist simply of a loop, a break in surface continuity being avoided by a bridge riveted to one side. To afford protection to the conductors from water or pieces of metal falling into the conduit, the slot rails *d*, *d* have projecting lips; the conduit is also provided with sewer connections for drainage.

2521. A successful conduit road has been established at Washington, D. C., in which the details of construction

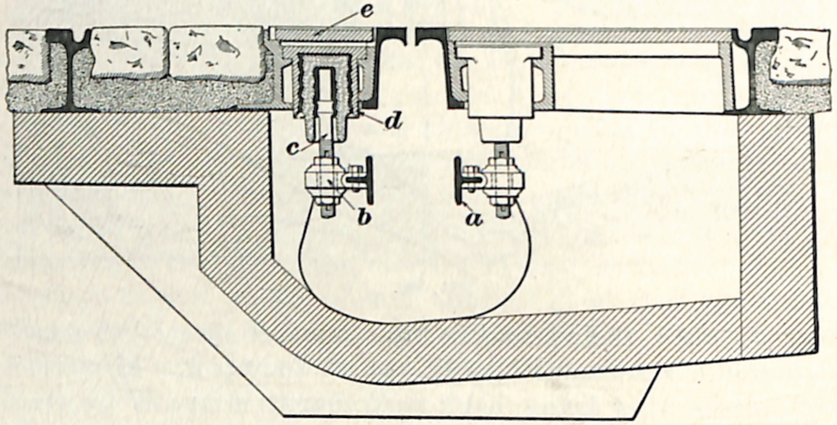

FIG. 981.

are somewhat different from the above, although the principles involved are similar. The conductor *a*, Fig. 981, is in section a **T** bar, supported by the projecting flange behind, which is bolted to an adjustable clip *b*, held on an insulating pin *c*. The shell *d*, into which the pin is cemented, is dropped into place from above and covered with the plate *e*. On the right-hand side of the figure is shown a section through a manhole. The framework carrying

the moving contact pieces is shown in Fig. 982. The insulated leads from the controller are brought down at *l*, l_1 and each of them secured to one of the shoes *s*, s_1. These

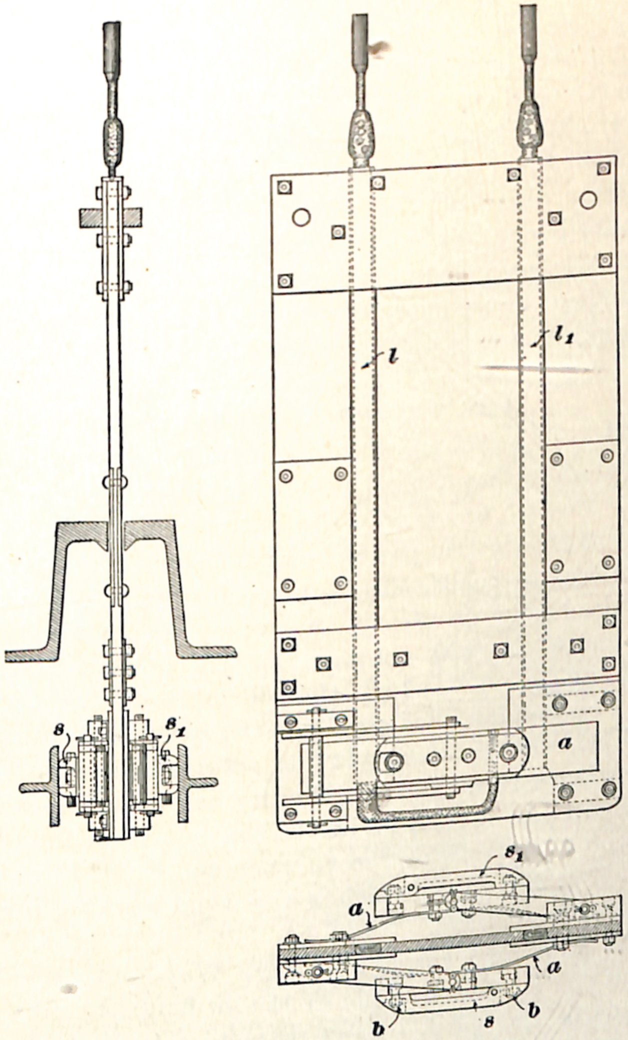

FIG. 982.

are pressed outwards against the conductor rails by leaf springs *a*, *a*. The contact shoes are renewable, being held in place by means of the bolts *b*, *b*.

2522. It is very necessary that the yokes should be well designed and strong, to resist the pressure of the earth (which is packed down by heavy traffic) and the tremendous pressure in cold climates due to the freezing of the soil, with its accompanying expansion. Wrought iron, steel, and cast iron have been employed for this purpose, the latter, perhaps, being used the most. When yokes of light weight are put in, trouble is often occasioned by breakage. The conduit may be lined with steel plates, or it may be constructed of concrete alone on the sides; in some cases the metal yokes have been replaced by concrete, but the best practice is to employ heavy castings ranging in weight from 200 to 400 pounds or more, according to the depth of conduit and the amount of wagon traffic expected.

THE THIRD-RAIL SYSTEM.

2523. This system, while not installed as yet, except in a few instances, has a most promising future before it, and seems to bid fair to become the only method which will be used to supply electric power to locomotives for interurban or long-distance roads. In high-speed work it is advisable, if not absolutely necessary, to employ as an active conductor one which will not sag, but will present a smooth, straight surface upon which the collectors on the car may slide. This conductor is usually in the form of an additional rail laid between or alongside the service rails upon which the car wheels run. Some difficulty has been experienced or anticipated in regard to insulation, but it is found that there is no trouble on this score when the E. M. F. does not exceed about 500 volts, which is the usual working pressure on all electric railways.

On the Nantasket Beach and East Weymouth Road, the third rail *r*, Fig. 983, is made in 30-foot lengths, and weighs 93 pounds to the yard. In cross-section it is in the form of a flattened **A**, the downward projecting flanges giving the requisite stiffness between supports. There are three of these supports to each rail, one at the middle and one close to each end; they are simply short, wooden posts *a* let into

the cross-ties and creosoted to prevent absorption of moisture. Creosoting consists in expelling all air from the wood in vacuum chambers and filling the pores with a tar compound; the insulation obtained is very high. Electrical continuity through the rail circuit is assured by means of copper bond wires, which are riveted to the ends of abutting rails to supplement the otherwise poor contact which would be afforded by the fish-plates. Under the head of Track Construction this subject will be fully considered. There are two contact shoes and frames to each motor car, placed

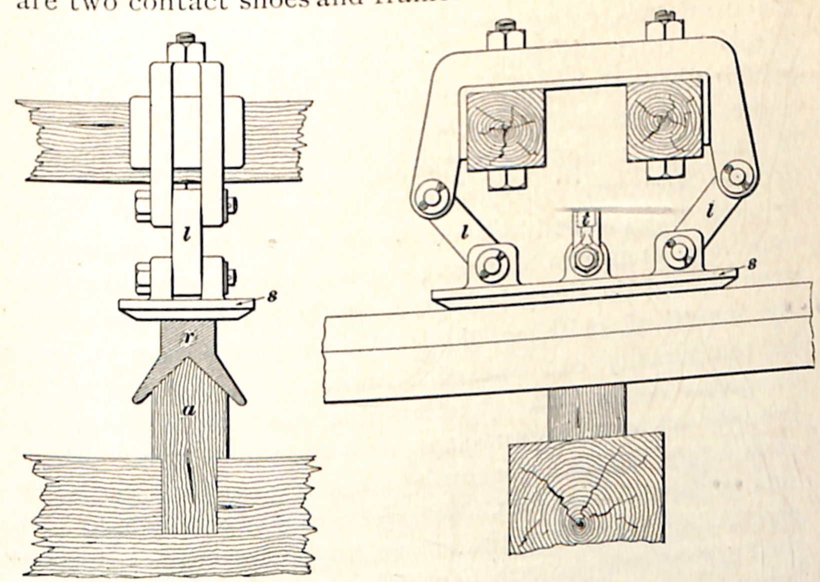

FIG. 983.

33 feet apart, so that at road crossings the third rail may be omitted and the inertia of the moving car be depended upon to carry it over. When the width of road is less than 33 feet, there will be no break at all. The shoes *s* are suspended by links *l*, *l*, allowing some vertical motion, so that there is always maintained a proper contact with the rail, and current is supplied by means of a flexible cable attached to the terminal *t*. The car is propelled by means of two motors, each of 125 horsepower, which will permit a speed of over 70 miles an hour.

2524. The advantages of the third-rail system are that the construction of the active conductor can be of a more solid and permanent character than is the case with a suspended wire, and it is at all times easy of access for inspection or repair. On long-distance roads the tracks would be fenced in to prevent accidents, so that danger to persons, due to contact with the live rail, would be minimized.

THE OVERHEAD TROLLEY SYSTEM.

2525. From its applicability to ordinary street traffic, the overhead trolley system has met with more general adoption than any other method of electric traction, due principally to the characteristic features of smaller first cost and ease of insulating the working conductors. Objection is made by some people to the use of overhead wires, on the ground that they interfere with the operations of the fire brigade when called out on service; but the feeder wires may be strung so as to be out of the way or even laid underground, and the live wires are near the middle of the street. By means of switches along the line, any section may be temporarily cut out of circuit, thus eliminating all danger of shock. The question of appearance is sometimes brought up as an argument against the use of the overhead conductors, but with the employment of center poles or single side poles with brackets, this objection will hardly hold. In crowded city streets with a large passenger traffic, the conduit system may be substituted with advantage, but in outlying districts a more reliable service may generally be obtained with the overhead construction.

2526. The standard overhead trolley system employs for an active conductor a single copper wire $m\ n$, Fig. 984, not smaller than No. 0 Brown & Sharpe gauge, and very frequently No. 00 or 000. The current passes from the positive pole of the dynamo d in the power station, along the wire to the point t, where the trolley wheel makes contact. From here it flows through the pole p on the roof of the car C, or through insulated wires within it, thence to the

controlling mechanism on the car platform, by means of which the speed of travel may be regulated within the limits of the motors. Interposed in the circuit through the car are

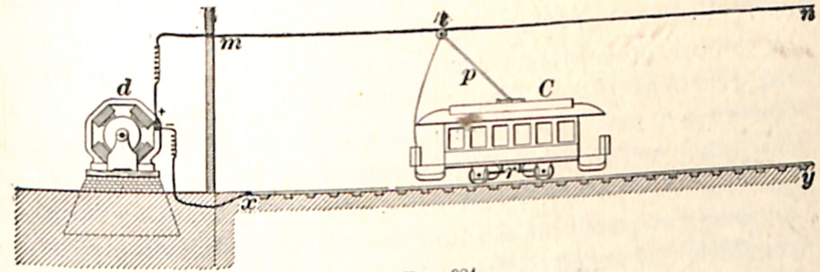

FIG. 984.

lightning arresters, fusible cut-outs, and switches. The motors r are placed beneath the car floor, and the current passes from them through the car axles and wheels to the

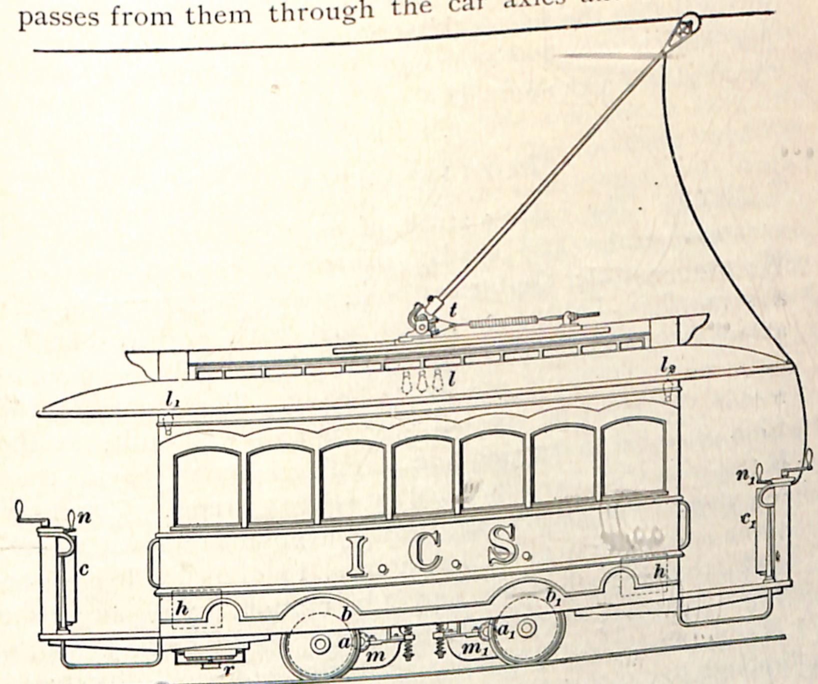

FIG. 985.

rails $x\ y$, which are connected to the minus terminal of the generator and also to ground. The car is shown more in detail in Fig. 985. The controllers c, c_1 are placed in upright iron cases on the platforms, one at each end, and are operated by the handles on the top; the shorter handles *n*, n_1 are reversing levers for changing the direction of travel of the car. Under the car are the motors *m*, m_1 in dust-proof cases; on the armature shafts are pinions *a*, a_1 which engage with the gear-wheels *b*, b_1 fixed rigidly to the wheel axles. In a convenient position is the starting rheostat *r*, containing resistance which is put in series with the armature when starting the motors, or in some cases used partly for this purpose and partly as a shunt across the field-windings for regulation of speed. Beneath the seats in the car are the heaters *h* on an independent circuit. For interior illumination there are usually five lamps *l*, which are connected in series between the trolley *t* and the wheel axles (or ground), thus utilizing the full working potential of 500 or 550 volts. One lamp is placed at each end (l_1, l_2) to illuminate a colored signal glass on the outside.

ROLLING STOCK.

2527. The rolling stock of an electric road may be arranged under two heads: **motor cars** and **trailers.** We shall consider the former only, since the trailer is merely a somewhat lighter car, provided with a draw-bar for attachment to a motor car, and is designed only as an auxiliary when traffic is unusually heavy. The frame of the motor car must be specially strong and well built, as the time occupied in starting and stopping is much shorter than is the case with cars operated on other systems. The flooring should also be arranged for convenient removal of sections immediately over the motors, to allow of inspection and attention while the car is in motion, or at any time when it is not practicable to obtain access from beneath. When an overhead trolley is used, the roof should be strong enough to support the trolley stand, as well as the weight of workmen who may occasionally be required to repair it.

2528. Cars are constructed according to many different designs, depending upon the particular uses to which

they are put. For small lines, a closed four-wheel car, sixteen feet in length, similar to that shown in Fig. 985, is most used, since it may be run all the year round. Some roads have the trucks so arranged that the body of the car may be removed and an open summer car body substituted, thus making use of the same motors. Long cars, measuring 26 feet or more along the body, are generally provided with double four-wheeled trucks, the distance between the axles of each truck being equal to about the gauge of track, or a trifle less. In countries where the winter is severe, it is customary to provide a closed platform at each end, the door being on the side; this is called a vestibule car. As a protection to the motorman in very cold weather, this style of car is to be recommended, but it is best to have the vestibule shut off from the interior of the car, and well ventilated, to prevent the condensation of moisture on the glass, which would obstruct the view. Another form of car is built with the vestibule in the side, but this is only used with long cars on double trucks. The vestibule construction is, in general, only adopted for cars stopping at rather long intervals. Double-deck cars, providing accommodation for passengers on the roof, are used in some localities. Some of the handsomest of this class have side vestibules and stairs and a covered upper deck, at one end of which is an enclosed compartment for the motorman, similar to the pilot-house on a river steamboat.

2529. The rolling stock equipment is not complete, in northern countries, without a snow-sweeper. In Fig. 986 is shown one of these, the propelling motors being omitted for the sake of clearness. A long four-wheeled car truck *a* is provided at the ends with hinged brackets *b* pivoted to the frame at *c*, and carrying at their lower ends heavy cylindrical brooms *d*, *d*, set at an angle of about 45° to the track. Each broom is independently adjustable by means of a handle *h*, and can be locked in any position. The brooms are revolved independently of the motion of the car by a motor *m* in the car body, which transmits the

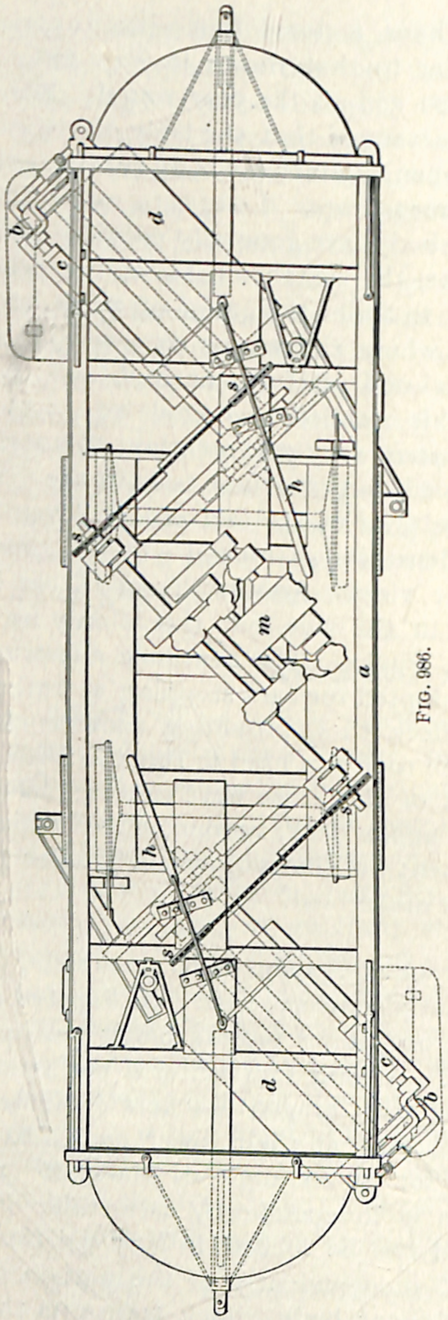

FIG. 986.

power to them by means of a chain running on the sprocket wheels *s*, *s*. It will be seen that the brooms are so placed that they follow separate paths, clearing away the snow for a short distance on each side of the rails, and throwing it far enough to clear the car.

TRUCKS.

2530. The **truck** is an exceedingly important part of the road equipment, for upon its excellence of design and building depends not only the comfort of the passengers, but the question of cost of maintenance. The trucks must be entirely self-contained; that is, the one framework must support the wheels and axles, the wheel guards, brakes, motors, and driving gear. This, in reality, constitutes the car, combining all the essential parts; for the car body above is merely a framework arranged for the convenience of passengers, having none of the more vital parts necessary to operation, except the

current-collecting apparatus in the case of the overhead trolley system, and even this is dispensed with in the conduit or third-rail system, now rapidly developing. We must not, however, overlook the fact that in all methods of electric traction the car body has a most severe duty imposed upon it, due to rapid acceleration at starting, and an equally heavy strain when the brakes are suddenly applied in stopping; so that this portion of the car requires very good design and conscientious work, as any serious fault in construction will soon become apparent after the car is put into commission. The ordinary street car truck is provided with four wheels, each pair being driven by an independent motor; this arrangement gives the highest traction efficiency, as all the wheels are drivers and take the whole weight of the car.

2531. It will be readily understood that the principle of spring suspension must be applied to the heavy motors

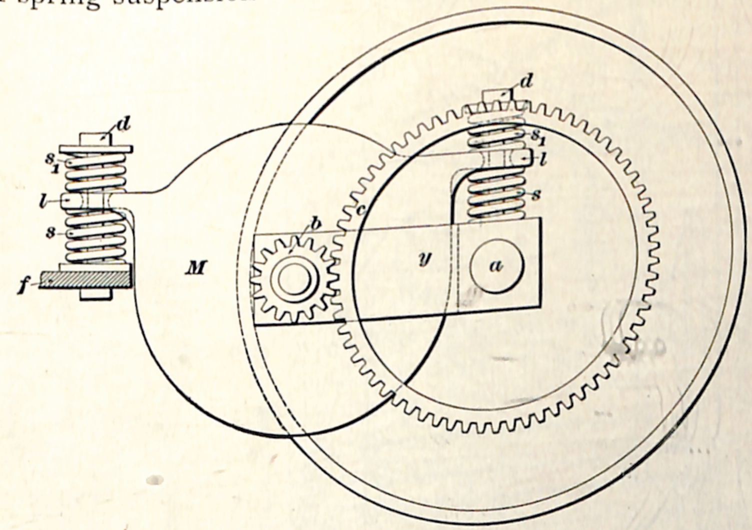

FIG. 987.

required to propel the car, as without this provision the hammer blow on the track, when passing over inequalities or bad joints, would very quickly break it up. There is always the weight due to the wheels and axles, but this can

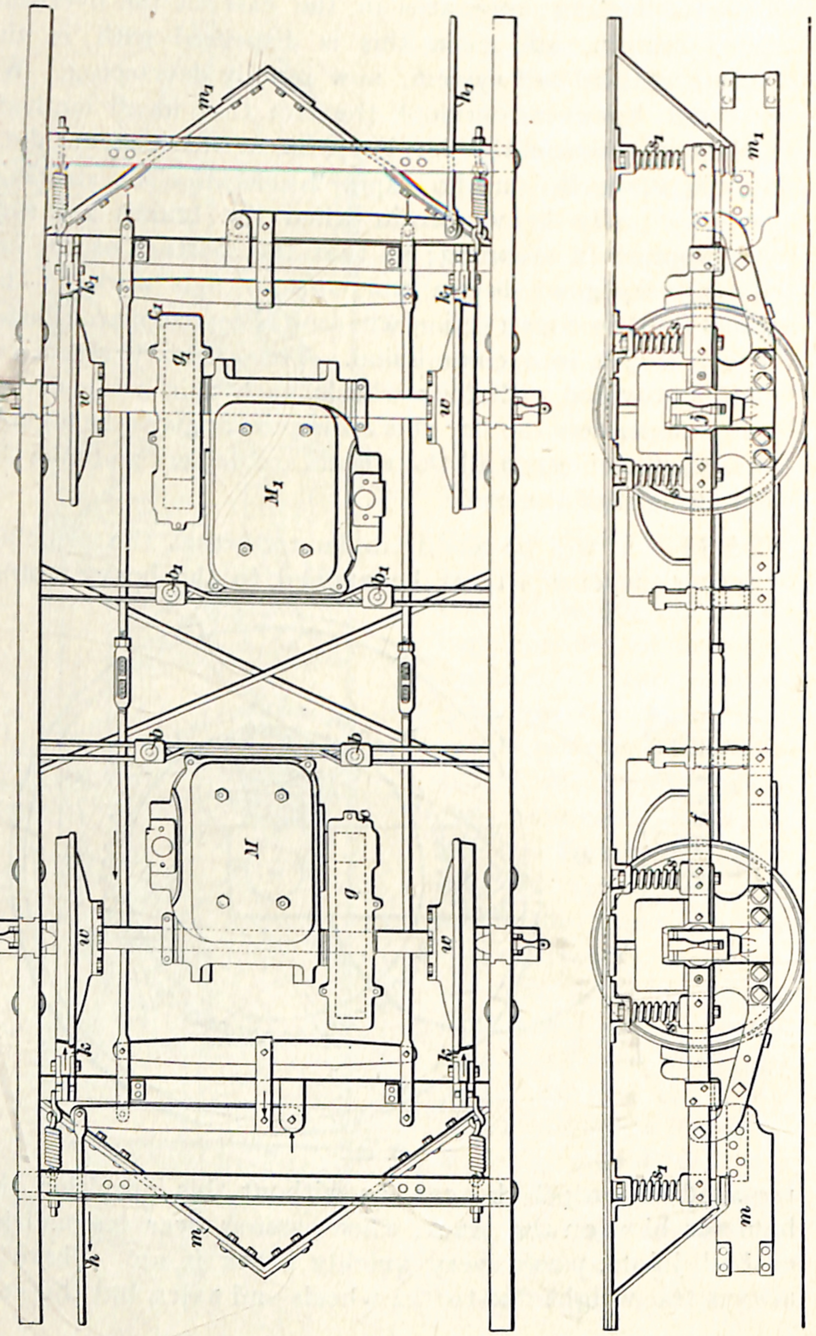

Fig. 988.

not be avoided, and it is not a very serious matter if the weight of the motor is not added. The method of suspension is shown in Fig. 987; the motor *M* is held by the lugs *l*, *l*, which rest on springs *s*, *s*, these being in turn supported, one by a stringer *f* on the car frame, and the other by the yoke *y* resting on the wheel axle. Rebounding is prevented by the upper springs s_1, s_1, bolts *d*, *d* passing through to the frame and yoke. The yoke is pivoted at one end on the wheel axle at *a*, and at the other end passes over the armature shaft carrying the pinion *b*. By this arrangement the distance between the pinion and the gear-wheel *c* is maintained constant, the motion of the motor relative to the axle being in a circular path.

2532. A complete four-wheel truck, showing the different parts in position, is illustrated in Fig. 988. The motors M, M_1 are supported by the bolts b, b, b_1, b_1 with interposed rubber cushions to give flexibility. The gears g, g_1 are covered by cases c, c_1 to exclude dust, which is very destructive to the teeth, causing them to grind each other away at the points of contact. Since it is advisable to support the motor on springs, it is, of course, equally necessary to provide flexible suspension for the truck frame and car body. For short cars the springs *s*, *s*, *s*, *s*, placed close in to the wheels, may 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 passengers, and exerts a very destructive effect on the car body. The oscillation also takes the weight off one pair of wheels momentarily, and causes them to slip, thereby diminishing their tractive power. For this reason the spring base is extended by adding extra springs at s_1, s_1. The wheels *w* are generally 33 inches in diameter, although some are made smaller; the 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. This arrangement is shown more clearly in Fig. 989. In the car frame *f* above the journal-box is a recess, into which fits a plug p, pressing up against a rubber cushion r. The plug, rounded on the bottom, rests in a hollow on the upper surface of the journal-box, which has also a recess underneath to receive a loose-fitting plug q. This is held in place by two bolts passing through the frame, rendering repair or

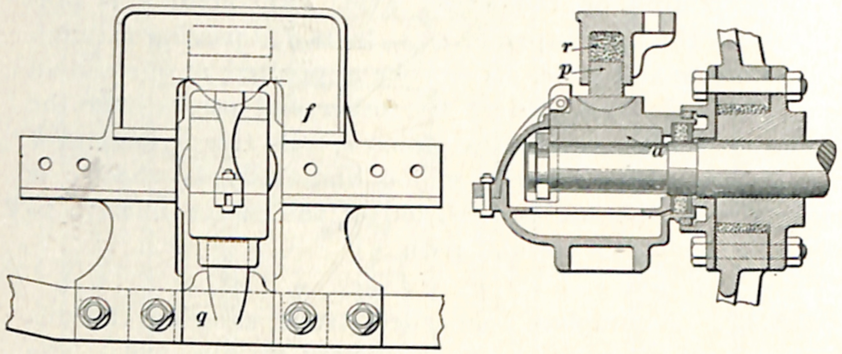

FIG. 989.

replacement of the wheels and axles a very simple matter. The bearing a extends half way round the shaft, as the pressure is in one direction only.

Referring again to Fig. 988, the brakes are operated by the rods h, h_1, the illustration showing clearly how the various levers act when tension is applied; the direction of the resulting forces, when h is drawn up by the brake chain, is indicated by arrows, showing that all the brake shoes k, k, k_1, k_1 are pressed on the wheels, whichever rod (h or h_1) is used. To guard the wheels against obstructions, the **pilots** m, m_1 are bolted securely to the frame at a sufficient height from the track to avoid touching the rails.

2533. The **wheel base,** that is, the distance between wheel centers as measured along the rail, should not exceed seven feet in a rigid truck—more frequently it is only six feet six inches—since the power required to force the car around a curve increases greatly as the length of the wheel base increases, and the wear on track and wheels becomes excessive. The following curve diagram, Fig. 990, shows the force required in pounds per ton to drag cars having wheel bases of 4 feet, 6 feet, and 7 feet around curves of

different radii. The force required in the case of each car is shown by the corresponding curve. The diagram is used as the following example shows: Suppose we have a track curve of 50 feet radius, and wish to know what tractive effort will be required to propel a car around it, the car weighing 8 tons and having a wheel base of 7 feet. To determine this, find the radius in the left-hand column; go along the horizontal line towards the right until the curve marked *7 ft.* is reached and from that point straight downwards, and read the answer in the lower line of numbers. In this case, the line from *50* on the left followed along brings us to the point a, and on carrying a line down from that

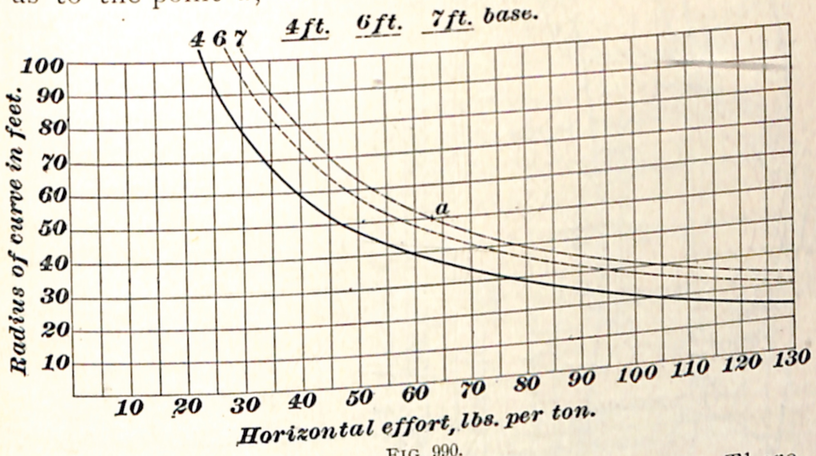

FIG. 990.

point, the value at the bottom is found to read *63*. Therefore, the force or tractive effort required will be 63 pounds per ton, and since the car weighs 8 tons, the total force will be $8 \times 63 = 504$ pounds.

It will be seen that the curves will all meet at the *20* mark on the horizontal effort line, if carried far enough upwards, which shows that for this particular track there is required for the straight portion or tangent, a force or tractive effort of about 20 pounds per ton weight of car. On curves of large radius the lines on the diagram approach each other, the length of wheel base making very little difference; but, as the radius decreases, the increased resistance, due to a

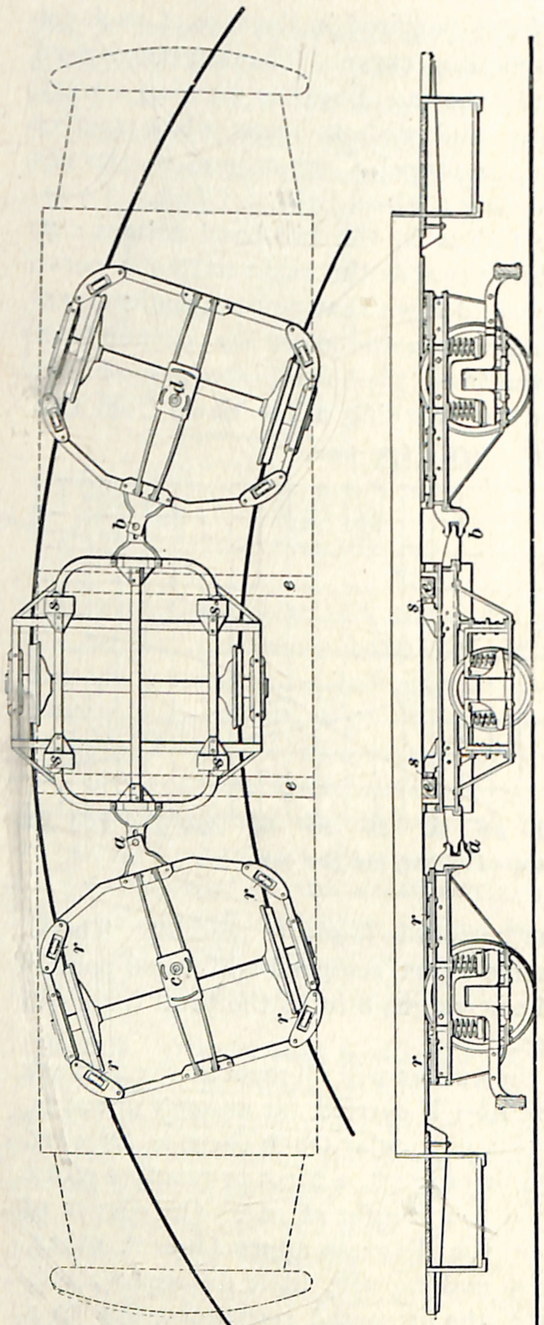

FIG. 991.

long wheel base, becomes more marked. With a forty-foot radius, there is a difference in tractive effort of twenty pounds between a four-foot and a seven-foot wheel base, and a difference of nearly thirty pounds on a thirty-foot radius. It is evident that in laying out a road, such small curves should be avoided where possible, or, if they are unavoidable and frequent, the trucks should be modeled to suit. For curves down to a forty-foot radius, a six-foot wheel base will not require an excessive amount of power to be expended; but any arrangement calculated to diminish this loss by friction is a good investment. To accomplish this object,

car trucks are built by one manufacturing concern which have three distinct sections, each supported on two wheels. This is known as the Robinson Radial Truck, Fig. 991. The three sections are pivoted at *a* and *b* to each other, and the outer ones to the car body at *c* and *d*. These latter are provided with rollers *r* at the corners, bearing upon plates on the under surface of the car frame, so that the trucks may easily, and with a minimum amount of friction, adjust themselves to any required position. The center truck is free to move transversely with respect to the car, guided by side rollers *s* pressing against cross-beams *e*. The wheel base is made 14 feet, yet the car will run around a sharp curve, even of 25 feet radius, with apparently the same ease as on the straight track. An ordinary rigid truck would be quite likely to leave the rails in such a case. This long wheel base entirely prevents oscillation of the car, and gives longer life to the wheels. The motors are carried on the end trucks, which take very nearly the whole weight of the car, as the center truck is of light construction with small wheels, and is only designed to direct the others and hold them at a tangent to the curve.

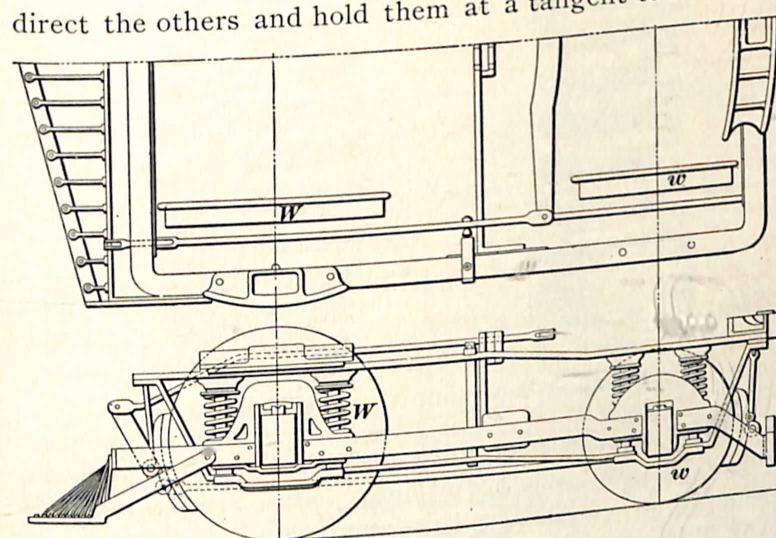

FIG. 992.

2534. Double trucks are used on long, heavy cars designed for interurban traffic, and even in large street railway systems when there is sufficient traffic to warrant the expense. One of these trucks is illustrated in Fig. 992. The motor is geared to the large wheels *W*, on which is placed as much as possible of the weight supported by this truck (there being two for each car) to increase the adhesive power, while the small wheels *w* serve to guide the truck. Double trucks having all the wheels of the same diameter are also made, but in all cases the main point is to put the weight of the motor on that pair of wheels which drives the car. Sometimes two motors are placed on each truck, by which method full adhesive power is obtained, but it is generally more convenient to have one motor, of ample capacity, on each truck.

2535. The springs used on car trucks are often made *graduated*, that is, stiffer at one part than another, so that

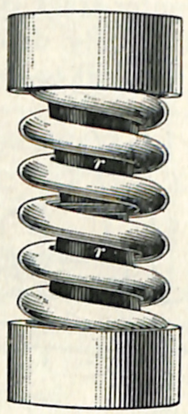

FIG. 993.

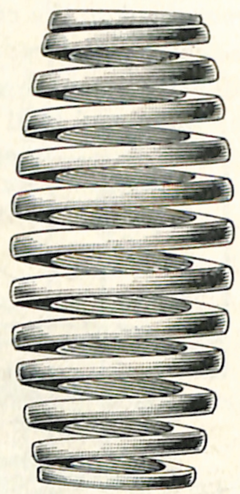

FIG. 994.

the lighter portion may move under a light load and the stronger part sustain a heavy load. There are two methods in use for accomplishing this result, one employing two rubber cones *r r*, Fig. 993, inside a helical steel spring and nearly touching each other. When a heavy load is imposed, the cones come together and assist the steel spring. One

of these cones may be of iron, when less elasticity is required.

The keg-shaped spring, Fig. 994, is another form giving rapidly increasing resistances, the large coils being more flexible than the smaller ones.

BRAKES.

2536. The question of brakes is a most important one, more so in the case of electric cars than of those propelled in other ways, because the moving weight is so much greater and the speed is higher. The kinetic energy of a moving body increases directly with the weight and as the square of the velocity, so that the retarding power necessary increases accordingly. To accomplish this by hand power requires a great and prolonged effort on the part of the motorman, who can not then use his strength to the best advantage, and is unable to accomplish an emergency stop within a very short distance. Power brakes are therefore coming into more general use. They may be arranged under five heads:

1st. Air brakes.

2d. Brakes operated by current from storage batteries on the car.

3d. Brakes operated by current from the line.

4th. Motors used as brakes.

5th. Electromagnetic brakes.

2537. Air brakes may be considered the natural outcome of the adaptation of electricity to long-distance railroads, since this system is in universal use on steam roads. In its application to electric cars, the air brake may be considered as supplementary to the hand brake, one or the other being used, as desired, and each acting on the same brake shoes. Fig. 995 shows a plan of a car thus equipped. The steam air pump of a locomotive is replaced here by an electric compressor *c*, driven by a small motor supplied with current from the line. This compressor is put in or out of action automatically by a regulator *r* consisting of a rheostat and switch, the position of which is dependent on the pressure in the reservoir *t*. When this falls below a certain limit, the motor of the compressor starts up and pumps in more air, thus keeping the pressure very nearly constant. If, in descending a steep hill, the trolley wheel were to leave the wire, there would still be sufficient air in the reservoir to stop the car, and that being accomplished, the hand brake could be set to hold it. Two main pipes are carried along the truck

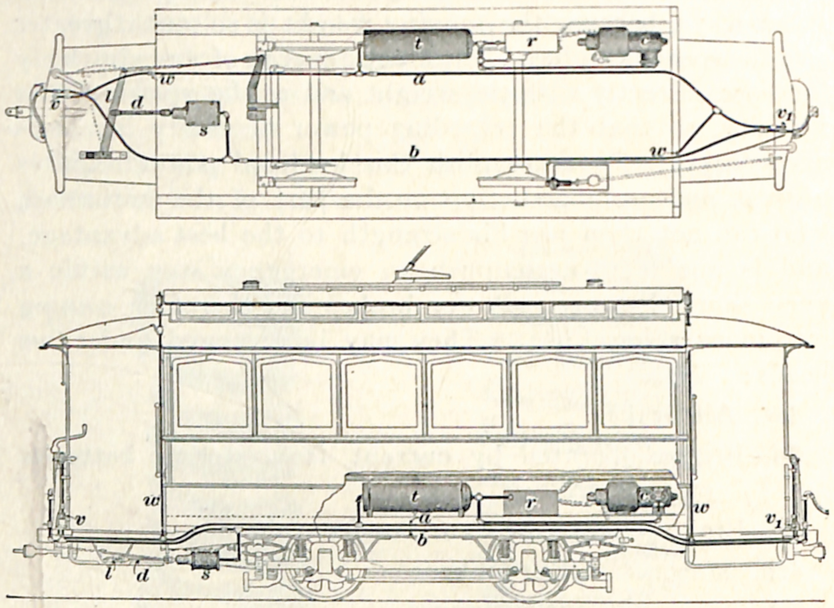

FIG. 995.

frame; the one marked *a* in the figure is the *air pipe*, affording communication between the reservoir *t* and the controlling valves v, v_1—one at each end of the car; the other pipe, marked *b*, is the *brake pipe*, running from the controlling valves to the brake cylinder *s*. Within reach on each platform are the whistles *w*, *w* connected with the air pipe, which always has the reservoir pressure. When it is necessary to stop the car, air is admitted into the brake pipe *b* by means of the valve *v*, and the pressure on the piston in the brake cylinder *s* drives forwards the

connecting-rod *d* and the lever *l*. The brake mechanism is, from this point, very similar to that shown in Fig. 988.

This system of braking is certainly a step in advance, and its practicability is, of course, well known through its universal application to steam roads, but a disadvantage is nevertheless to be found in the fact that extra power is required to stop the car, while the energy thus opposed is entirely lost, being transformed into heat at the brake shoes, and not utilized.

2538. The second system of those enumerated in Art. **2536**, i. e., the use of storage batteries, can hardly be ranked as much more than a possibility, owing to the expense of maintenance and of recharging, as well as the high first cost of the battery.

2539. The third system is not sufficiently reliable to need extended description, from the fact that the brake would become inoperative in case the line current were to fail, and should this occur when the car was running on a grade, the consequences might be serious.

2540. The fourth method, that of using the motors themselves to stop the car by short-circuiting them through a resistance, is to be recommended from the fact that such a braking system is self-contained and independent of the line. The resistance may be introduced in the armature circuit immediately on disconnecting from the supply wire, and may be cut out gradually, bringing the car to a stop within any required distance. A disadvantage is the fact that this braking method is severe on the gears, although it should be remembered that the reverse faces of the teeth are then used. A sudden short-circuiting is also liable to strip the pinion.

2541. The fifth method is one which is more likely to find general adoption than any of the others; it involves the use of the motors as generators, as already explained, but instead of practically short-circuiting them, a smaller current is taken from them, which is used to energize an electromagnetic brake mounted on the car axles, thus applying the retarding force in the most direct manner possible. The brake consists essentially of two parts, one of

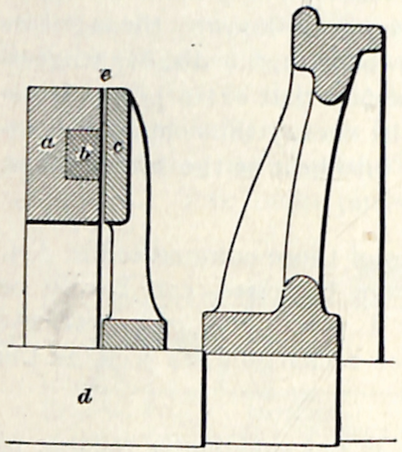

Fig. 996.

U-shaped section, annular in form, carrying a magnetizing coil, and the other a flat disk, arranged to revolve in close proximity to the face of the first. In Fig. 996, *a* is the stationary iron annular magnet, and *b* the magnetizing coil; *c* is the disk, also of iron, made fast to the axle *d*. When a current is sent through *b*, strong eddy currents are induced in the disk *c* as it revolves, their tendency being to resist the rotation and bring the disk to rest. The air gap at *e* is very small, and the brake may be used to give retardation through the induced currents thus developed, or the disk may be allowed to touch the polar surfaces, the friction thus obtained adding to the braking effect. The greater part of the retarding effect is exerted by the action of the eddy currents on the face of the disk.

CAR EQUIPMENT.

MOTORS.

2542. In the early days of electric railways, the motors used were simply an adaptation of the ordinary bipolar stationary motor to the new conditions. There was, in consequence, no protection to the armature and field winding, which were exposed to the air. The gears, forming a double reduction, were also uncovered, so that the dust from the road soon wore out the teeth by grinding on the faces. With the four-pole, low-speed motor, a single reduction in gear was obtained, and this is still adhered to. The motor, as now built, is entirely enclosed in a frame, which forms

the magnetic yoke between the pole pieces, and supports the shaft of the armature. The General Electric Company build a motor, Fig. 997, in which the wheel axle passes

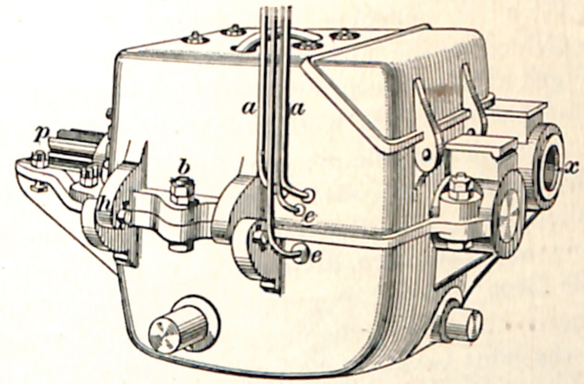

Fig. 997.

through the bearing at *x*, carrying at the other end the gear-wheel. Fig. 998 is a view of the same motor from the other side, with the cover raised, the letters of reference being the

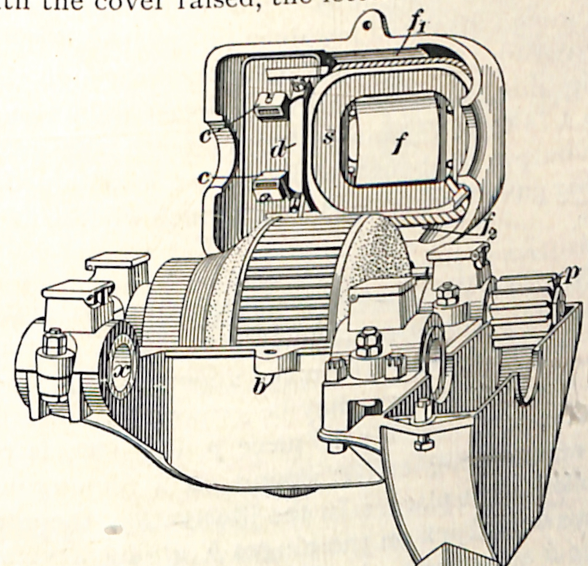

Fig. 998.

same in both figures. The gears are enclosed in a compartment distinct from that containing the armature, and are run in oil. The pinion *p* is usually made of steel, and, in the best construction, the gear-wheel is also of this metal. A cover, half of which is shown, is fitted over the gears, a small opening with a hinged lid being provided in the upper portion for purposes of inspection. The magnetic frame is divided on the horizontal center line, the two parts being hinged at *h*, and securely bolted together at *b*. In the upper frame, when swung back as in Fig. 998, may be seen the face of one of the pole pieces *f*, and the spool head *s* of one of the magnetizing coils. The motor is of the consequent-salient type, the consequent poles being on the horizontal line, and, therefore, divided; at f_1 and f_2 may be seen these pole faces. It will be noticed that this arrangement of magnetic circuits is such that no lines of force pass through the joint between the upper and lower frame castings, which would otherwise form a line of high resistance. The carbon brushes are carried in holders *c*, *c*, bolted to an insulating cross-bar *d*, which is secured to the frame, and the current is led to them by means of two cables *a*, *a*, entering through insulated bushings in the side of the frame, The current for the field coils is supplied through the wires *e*, *e*. In this motor the ratio of speed reduction by the gears is 4.78 to 1; the pinion has 14 teeth, the gear-wheel 67. An output of about 25 horsepower is obtained, giving a draw-bar pull of 800 pounds with 33-inch wheels, at 10 miles per hour.

2543. The Westinghouse single-reduction motor has a somewhat different disposition of pole pieces, all four being salient. Of these, two are in the upper casting, two in the lower, and either casting may be removed to afford access to the armature. Each pole piece *p*, Fig. 999, is provided with a magnetizing coil *c* wound on a rectangular spool which is bolted in place. In the illustration, the upper field is shown swung back on the hinges *h*, giving a view of the armature *a* and brushes *b*. The hinges for the lower field are on the right-hand side; it will be noticed that both field castings are attached to lugs on a horizontal frame *f*, carrying the armature, the gear shafts, and the box *d* which

encloses the gears. The reduction generally used is 3.44 to 1, the gear-wheel having 62 teeth, and the pinion 18.

Direct-connected or gearless motors are seldom used, as they are more expensive to construct than those having the reducing gear. Owing to the armature being connected directly to the car axle, a flexible suspension is absolutely necessary, to avoid the hammer blow on the track. This

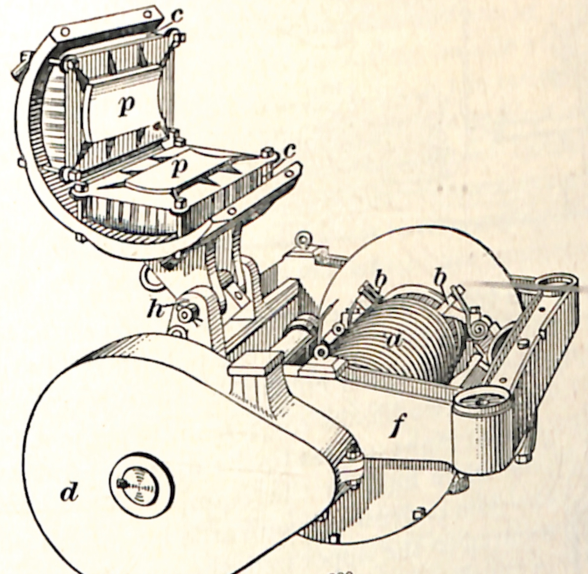

FIG. 999.

may be accomplished by mounting the armature on a hollow shaft, and connecting it, by means of springs, to the driven axle which passes through, a clearance of one inch being allowed on all of the sides.

THE TROLLEY.

2544. The device for making contact with the stationary conductor and transmitting the current to the mechanism on the car is called a **trolley**. The name is generally applied to such an apparatus placed on the roof of a car, and having, as essential parts, a pole carrying at its outer end a small wheel which is pressed up against the under side of an overhead conductor. In Fig. 1000 is shown a plan of the spring frame, and a side view of the upper end of the trolley pole. This latter is held in a clamp *p*, free to turn about an axis *a* parallel to the length of the car, thus giving lateral

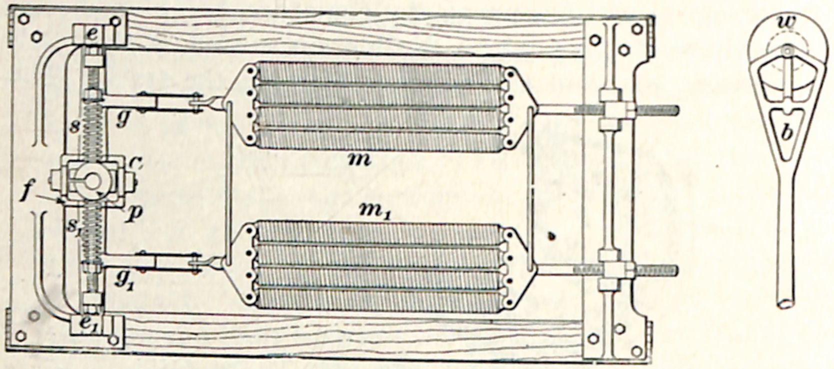

FIG. 1000

motion to the trolley. The springs s, s_1 press on each side in such a way as to tend to keep the pole in a central position. The frame f which holds the clamp is pivoted at its ends in two blocks e, e_1; from it project two arms g, g_1 at right angles to the direction taken by the pole when held in the clamp. When, therefore, the pole is drawn downwards by means of a cord secured to the upper end, the springs m, m_1 are put in tension, and tend to press the wheel against the overhead contact wire. The wheel and upper end of the trolley pole are shown in the view at the right, and are lettered *w* and *b*, respectively. An elevation of the same is given in Fig. 1001, *a* being the trolley wheel, and *b* the head of the pole, or **harp.** The wheel is bored out to a diameter greater than that of the pin *p* upon which it revolves, and a bushing is forced in, made of bronze with graphite blocks inserted to give lubrication. Oil is likely to carbonize by the action of the current and cause the wheel to stick, which results in unequal wear in the groove and continuous arcing when this surface becomes uneven, due to the wheel leaving the wire.

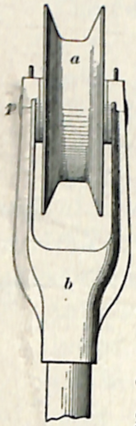

FIG. 1001.

CONTROLLERS.

2545. On the car platforms, against the dashboards, are placed the switching devices, by means of which the speed of the car is regulated. These are the **controllers;** each consists, essentially, of a vertical revolving cylinder provided with insulated metallic contact bands of different lengths, which press against stationary contact pieces at the side, and effect various combinations of rheostat, armature, and field connections, according to the position of the cylinder, which is indicated by the operating handle attached to the cylinder shaft which projects through the outside cover. In Fig. 1002 is given a developed diagram of the Westinghouse controller. The cylinder is at *C*, the contact buttons *t*, *a*, etc., are on the left, and two cut-outs are on the right, one to each motor. Above the cylinder is the reversing switch *R*, and below are the terminals to which are connected the cables leading to the motors, resistance box, trolley, and ground. The reversing switch is in the form of a disk of porcelain, upon which are mounted four brass contact pieces, indicated in the figure by double lines, as between the connection blocks f_2+ and a_2-, etc. These contact pieces may be moved around so as to take the positions shown by the curved lines ⌒, breaking the circuit at the former places and connecting the other blocks together. When this is done, the circuit through the armatures of both motors is reversed, thereby reversing their direction of rotation. At an intermediate position the circuit remains broken, and the lever, which is inserted in an opening in the side of the case, may be withdrawn. The vertical dotted lines passing across the contact bands on the cylinder represent the different working points to which, relatively speaking, the contact buttons may be moved, for the cylinder is turned by the controller handle, the buttons remaining stationary. At the lower part of the figure are the motors M_1, M_2. There are six principal working points, *1*, *2*, *3*, and *4*, *5*, *6*; the intermediate ones, lettered *a*, *b*, *c*, *d*, are passed over rapidly, and are not denoted by any marks on the brass cover-plate, being inserted to define more clearly the two divisions of

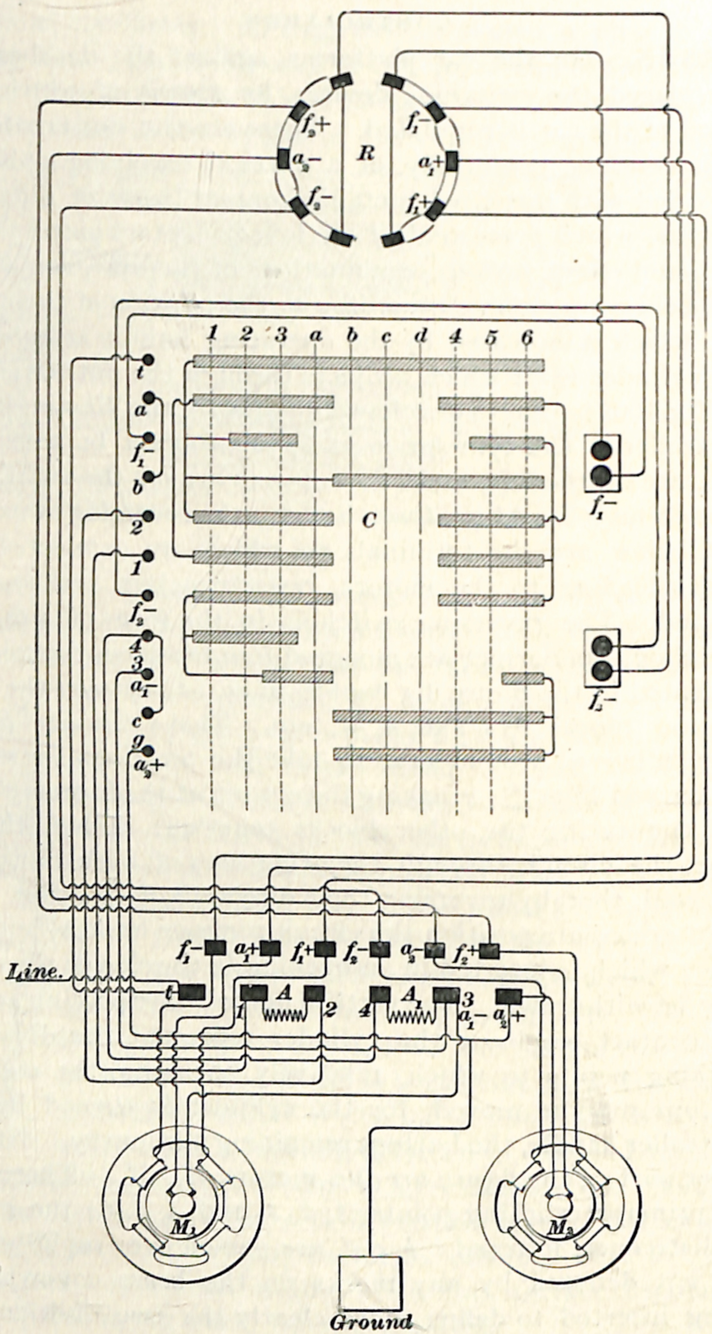

FIG. 1002.

series and parallel working. The use of this method of speed regulation has given the name of **series-parallel controller** to the compound switch employed.

2546. We may trace the path of the current when the cylinder is turned to the first, second, and third points, thus: From the line to the terminal t at the base of the controller, then for the several points as follows:

	(1)	(2)	(3)
t	button	t button	t button
2	button	Cuts out ½ rheostat.	Cuts out ½ rheostat.
2	terminal		
A	½ rheostat		
1	terminal		
1	button		
a	button		
f_1 −	button	f_1 − button	f_1 − button
f_1 −	cut-out	Same as (1).	Same as (1) and (2).
f_1 −	revers. sw.		
f_1 −	terminal		
M_1	fields		
f_1 +	terminal		
f_1 +	revers. sw.		
a_1 +	revers. sw.		
a_1 +	terminal		
M_1	armature		
a_1 −, 3	terminal		a_1 − 3 terminal
A_1	½ rheostat		a_1 − 3 button
4	terminal		Cuts out ½ rheostat.
4	button		
f_2 −	button		f_2 − button
f_2 −	cut-out		Same as (1) and (2).
f_2 −	revers. sw.		
f_2 −	terminal		
M_2	fields		
f_2 +	terminal		
f_2 +	revers. sw.		
a_2 −	revers. sw.		
a_2 −	terminal		
M_2	armature		
a_2	terminal		
	ground		

At the first point the motors are in series, with the whole of the rheostat inserted; at the second point half the resistance is cut out, and at the third it is all cut out. This point is to be used when a low speed is desired, the motors still running efficiently, as all dead resistance is out of circuit. The point marked *a* is merely one of transition; it is a return to an arrangement almost indentical with point *2*, the only difference being that the half rheostat *A* is introduced instead of A_1. The points *b*, *c*, *d* are all similar, serving as distance pieces and preparing for the parallel connection by putting M_1 between line and ground, with the half rheostat A_1 in series. To this is added the second motor M_2 at the point *4*, in series with *A*. The long space between *a* and *4* tends to lessen the sudden plunging forwards of the car which occurs when two motors are put in parallel at once, because the full E. M. F. of the line is applied to one motor alone during an appreciable interval of time.

2547. The order of connections for parallel running on the points *4*, *5*, and *6* is this:

(4)
t terminal
t button
b button

	f_1-	button	*a*	button	Short-circuited at Points *5* and *6*.
	f_1-	cut-out	*2*	button	
	f_1-	revers. sw.	*2*	terminal	
	f_1-	terminal	*A*	½ rheostat	
	M_1	fields	*1*	terminal	
	f_1+	terminal	*1*	button	
	f_1+	revers. sw.	f_2-	button	
	a_1+	revers. sw.	f_2-	cut-out	
	a_1+	terminal	f_2-	revers. sw.	
	M_1	armature	f_2-	terminal	
Short-circuited at Point *6*.	a_1-, 3	terminal	M_2	fields	
	A_1	½ rheostat	f_2+	terminal	
	4	terminal	f_2+	revers. sw.	
	4	button	a_2-	revers. sw.	
	c	button	a_2-	terminal	
	a_2+, *g*	button	M_2	armature	
			a_2+	terminal	

Ground.

2548. The General Electric Company, in their controller for series-parallel regulation, make use of the same methods as the Westinghouse Company, but, in addition, they put shunts *S*, S_1, Fig. 1003, across the field coils of the motors *M*, M_1, at the last point of the series or parallel connec-

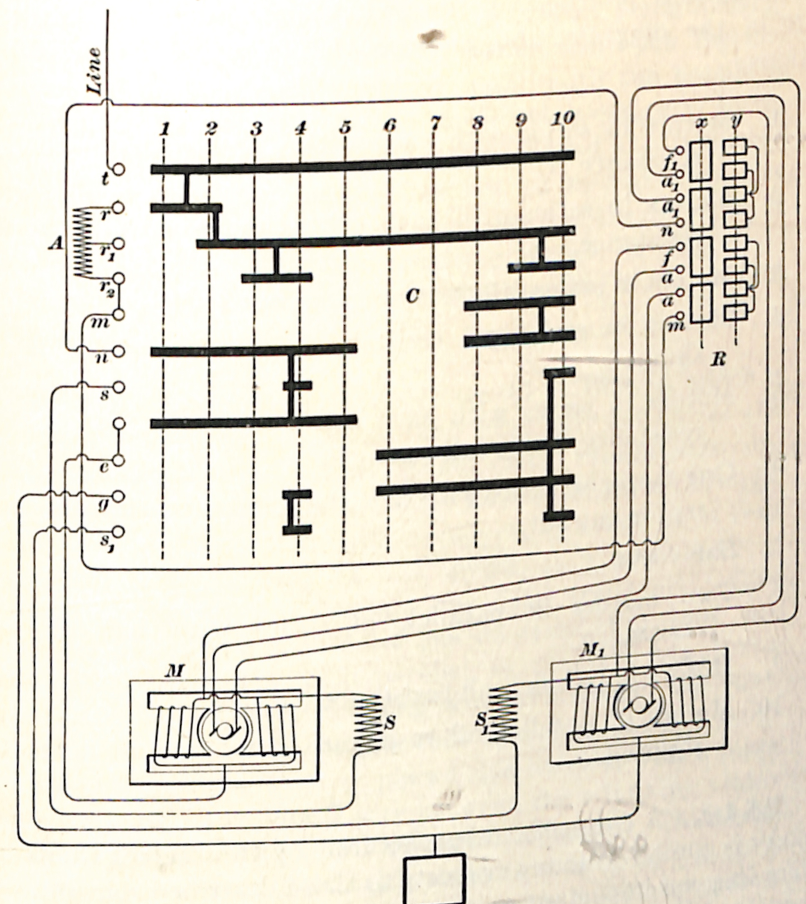

Fig. 1003.

tions. The rheostat *A* is used as a starting resistance. The controller cylinder is *C*, the contact buttons are on the left, at *t*, *r*, etc., and the reversing switch *R* is on the right. There are three positions in which this latter may be placed: first, with the contact fingers f_1, a_1, etc., on the line *x*, second, on the line y, and, third, in a central position between these two, when all connections are broken. It is in this position alone that the lever may be withdrawn, and, as only one set of levers is provided for each car, the circuit through one controller is always broken when the other is in use. The various positions of the switch are numbered *1* to *10* in the diagram, and produce the following combinations:

1. Motors in series with each other, and with all the resistance A.
2. Motors in series with each other, and with half the resistance.
3. Motors in series, all resistance cut out.
4. Motors in series, all resistance cut out, and fields shunted.
5. Motors in series with each other, and with half the resistance, fields full strength.
6. One motor in series with half the resistance, the other motor cut out.
7. Same as 6.
8. Two motors in parallel, in series with half the resistance.
9. Motors in parallel, all resistance cut out.
10. Motors in parallel, all resistance cut out, and fields shunted.

2549. A controller manufactured by the Walker Company is similar in many respects to those described, but differs in some important points. Three contact cylinders are provided. The principal one is the regular controller cylinder for regulating the speed of the car; on the right-hand side is the reversing switch, and on the left-hand a special circuit-breaker which comes into operation each time the current is cut off and distributes the arc through twenty-eight air gaps. The motor circuit has high self-induction, and when a quick break is made there is danger of the current piercing the insulation. In this case the break is relatively slow, so that time is allowed for the back E. M. F. to gradually die away. This circuit-breaking switch is fitted with a pawl on the shaft, the pawl engaging with a ratchet on the controller in such a way that a slight backward movement of the controller handle will open the circuit, and it can not be closed again until the handle is brought to the off point. An interlocking device is introduced between the controlling cylinder and the reversing switch, so that the former can not be moved from the first position unless the latter is either on the forward or backward notch; also, the reversing switch is only movable when the controlling cylinder handle is at the off position.

2550. Another method of control is that in which a starting resistance is inserted, and gradually cut out as the car attains full speed. This system, called **rheostatic control**, was the one used in the early days of electric railways, and to some extent it is still employed, although it is very wasteful when running at low speeds, as a great deal of energy is expended in heating the dead resistance. The motors, as will be seen from the diagram, Fig. 1004, are connected permanently in parallel, so that the regulation obtainable with a series coupling is not available in this case. The rheostat A, shown in side view at B, consists of a series of sheet-iron disks, as at C, placed side by side, with a piece of mica inserted in such a way between the adjoining plates that they form a long series of high resistance. These are arranged in a semicircle, with sheet-iron contact pieces r projecting, over which the lever a may be moved by means of the wheel w, to which is made fast a cord running to the controller shaft. The current from the line is brought in at p; the circuit then passes through the arm a to the rheostat, and to the terminal j at the farther end. This is insulated from a second terminal i, which is put in use only when the switch arm is carried on to that point. From j