notice in Figs. 40 and 42 that the two circuit-breakers are connected in parallel, whereas the hood switches shown on the other diagrams are connected in series. This is the usual practice when circuit-breakers are used. The breaker on the front end is in while the car is running and the one on the rear end is left out, so that only one breaker is in use at the same time. If both breakers were in series, they would both trip in case a short circuit occurred, and the tripping of the one on the rear platform, in close proximity to the passengers standing there, would be undesirable; besides, it might not be convenient to reset the breaker on the back end, because the conductor would very likely be engaged in collecting fares. For these reasons, the breakers are connected in parallel instead of in series.

STREET-RAILWAY MOTORS.

64. A street-railway motor has to meet several conditions not imposed on motors that are used for stationary work. Its design is limited to a large extent by the space in which it is to be placed. It must go wholly beneath the car floor, and its width is limited by the gauge of the track. It must be dust-proof and waterproof, because it may have to run through all kinds of dirt and water. It must be arranged so that it can be readily suspended from the car axle. A railway motor must be substantial in every particular, because it is called on to stand harder usage than almost any other kind of electrical machinery.

As mentioned before, nearly all motors used for railway work are operated by direct current at 500 volts. The fields are connected in series with the armature, because the series-wound motor is capable of giving a strong starting effort and also gives a wide range of speed under varying loads. Moreover, the series-field coils, being wound with a few turns of coarse wire, are substantial and comparatively easy to repair. Alternating-current motors will, no doubt, be used much more in the future for railway work than heretofore, but at present their application to this line of work is limited. The general construction of a street-railway motor is the same as that of any other direct-current motor. In other words, it must have a field magnet, armature, commutator brushes, etc. The field frame is made so that it will enclose the motor as much as possible. The earlier motors were only partly enclosed, but the later types are wholly enclosed. Access is allowed to the commutator and brushes by means of a hinged or removable lid.

65. Fig. 43 illustrates sections of some of the styles of field that have been used on street-railway motors. (*a*) is the style used on the old Thomson-Houston W. P. 50 (waterproof) motor. It is a two-pole field with a single magnetizing coil. (*b*) is the field used on the old Edison No. 14. It is a

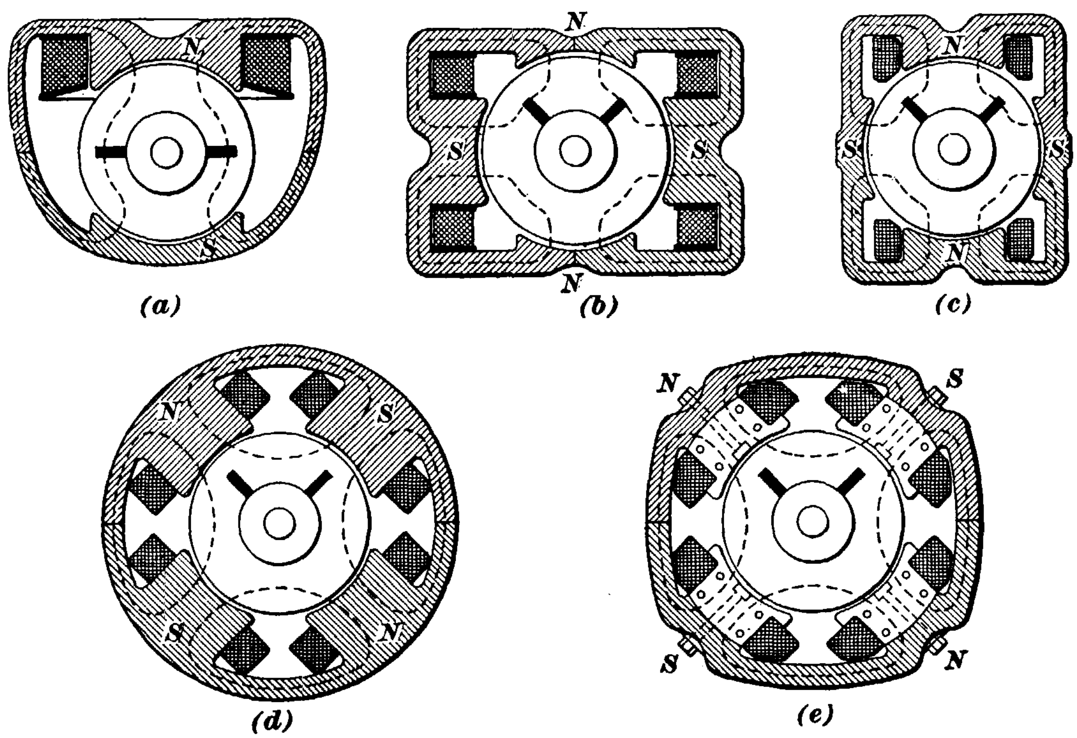

FIG. 43.

four-pole field with two field coils. (*c*) is the General Electric 800 (G. E. 800) motor field. It is similar to the Edison No. 14, but is turned up the other way. (*d*) shows the four-pole magnet frame introduced about 1891 by the Westinghouse Company in their No. 3 motor. It has four poles set on the diagonal and each pole is provided with a field coil. This style of field has been used on nearly all street-car motors since, and practically all motors are now of the four-pole type, with their pole pieces set on the diagonal. Of course, the frame has been modified so as to enclose the motor and modifications have been made in the construction of the pole pieces. Cast steel has replaced cast iron for the magnet frame, allowing it to be made much lighter and stronger, but the fact remains that the frame and general construction of the Westinghouse No. 3 motor contain the main features of the motors as constructed at present. (*e*) shows a field about as used on a modern motor. Here the frame is of cast steel and can be made comparatively light. The pole pieces, instead of being cast with the frame, are built up of sheet-iron stampings and are bolted to the frame. This laminated pole construction reduces heating in the pole pieces and also tends to keep down sparking at the commutator.

Railway-motor armatures are of the slotted type. The coils are wound on forms and are then placed in slots on the core. In the earlier slotted armatures, a large number of slots were used, generally anywhere from 87 to 105. This was necessary because if the slots were made coarse, it was found that they caused the magnetism in the pole pieces to vary to such an extent that the solid poles would heat considerably. By laminating the poles, it has been found possible to reduce the number of slots to about one-third the number formerly used, thus making the slots very much larger, cheapening the cost of production, and making the motor operate better generally.

66. Speed Reduction.—It has not been found practicable or economical to drive ordinary street cars by means of direct-connected motors, i. e., by means of motors the armatures of which drive the axle directly without the use of any gearing. Such motors may be used where the motors are of large capacity, as on some electric locomotives, but in practically all cases geared motors are used. If the motor drives the axle directly, the speed of the armature must, of course, be the same as that of the axle. This means that the motors must be designed for very low speed, and hence are heavy and bulky for their output. The heavy weight on the axles is hard on the track and the track joints are soon pounded out. For these reasons, the general practice is to use geared motors, so that the armature may be allowed to run four or five times as fast as the axle, thus keeping the size and weight of the motor for a given output within reasonable bounds. Direct-connected motors have been brought out and tried in connection with ordinary trolley cars, but they have not proved a success. They may, however, be used more in the future for the heaviest kinds of electric traction.

67. Speed Reduction.—When electric railways were first put into operation the motors ran at a much higher speed than those built at present, and it was necessary to transmit the power to the axle through an intermediate shaft. The small gear or pinion on the end of the armature meshed with a large gear on one end of the intermediate shaft, and a small gear on the other end of the intermediate shaft meshed with the axle gear. Motors of this kind were known as **double-reduction** motors, because of the double reduction in speed between the armature and the axle.

As the design of railway motors was improved, it was found possible to make efficient motors that would run slow enough to admit gearing direct to the axle, thus dispensing with the intermediate shaft. This is the kind of motor now almost universally used, and is known as the **single-reduction** type, because there is but one reduction in speed between the armature and the car axle. The ratio of the number of teeth in the gear to the number of teeth in the pinion gives the amount by which the speed of the axle is reduced as compared with the speed of the armature.

For example, suppose an axle gear has 65 teeth and the armature pinion 14 teeth; then the armature runs

$\frac{65}{14} = 4.64$ times as fast as the axle, because the armature has to make 4.64 turns for every turn that the axle makes. The **gear ratio** is, therefore, 4.64 : 1, the axle gear having 4.64 times as many teeth as the pinion. Various gear ratios are used in practice, depending on the size of the motors and on the speed at which the cars are to be run. If the cars are to run at a slow speed, the number of teeth in the axle gear will be large compared with the number in the pinion, and *vice versa*. The most common values of the gear reduction lie between 4 and 5. It will not be necessary to go into details regarding double-reduction motors, as they are no longer used. The number of different types and sizes of single-reduction motors in use is very large, and it would be an endless task to take up all of them. We will, however, take up two or three representative types, and the student will note that there is comparatively little difference between them so far as their general design is concerned. Motors are, of course, being improved all the time, but they have now reached a point where the changes are more in the line of improvements in details rather than radical changes in design.

GENERAL ELECTRIC MOTORS.

68. The General Electric Company have made a great variety of motors, some of the more common of which are the G. E. 800, G. E. 1,000, G. E. 1,200, G. E. 52, G. E. 54, etc. The numbers 800, 1,000, 1,200, etc. were given to these motors to denote the number of pounds drawbar pull that the motor could exert when taking full-load current and when mounted on 33-inch wheels. This method of rating the motors has now been dropped, and the machines are designated by arbitrary numbers, such as 52, 54, etc. The field used on the G. E. 800 and G. E. 1,200 is of the type shown at (*c*), Fig. 43. The G. E. 1,000 has four poles arranged on the diagonal, as shown in Fig. 43 (*e*). The poles are, however, not laminated, but consist of steel castings bolted to the frame, and the armature is therefore provided with a large number of small slots. The G. E. 1,000, G. E. 52, and G. E. 54 are much the same in general appearance. We will select the G. E. 52 motor for illustration.

G. E. 52 MOTOR.

69. Motor Frame.—Fig. 44 shows the general appearance of the G. E. 52 motor. The general shape of the field frame is hexagonal; it is made in halves, which are held together by bolts. The two arms *b*, *b* extending from the back of the motor receive one-half the axle bearing, which is in the shape of a split bushing. The axle-bearing caps *c*, *c*

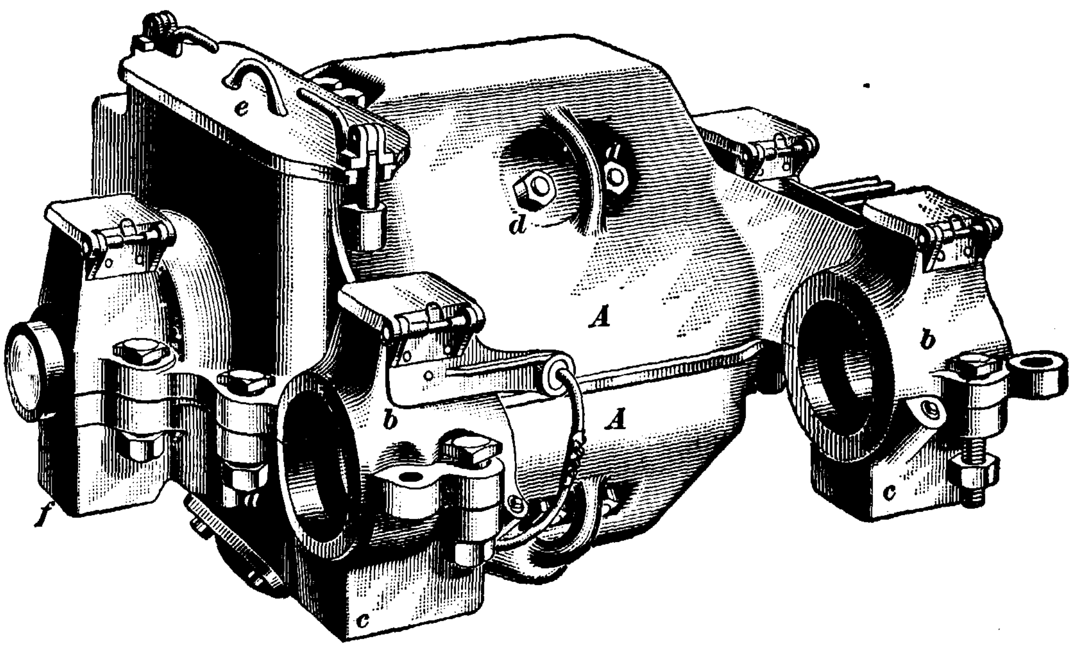

FIG. 44.

are provided with grease boxes, and the grease or oil is fed on the axle by means of pieces of felt from underneath as well as from the grease cups on top. The bolts *d*, *d* hold the pole pieces and field coils in place. The removable cover *e* allows access to the commutator and brush holders. The lower armature-bearing caps *f* are separate from the lower half field *A*, and by leaving these caps in position, the lower half field *A* may be swung down, leaving the armature in the upper half, as shown in Fig. 45. The lower half field is here swung down and the two lower pole pieces are exposed for repair or inspection. By removing the bearing

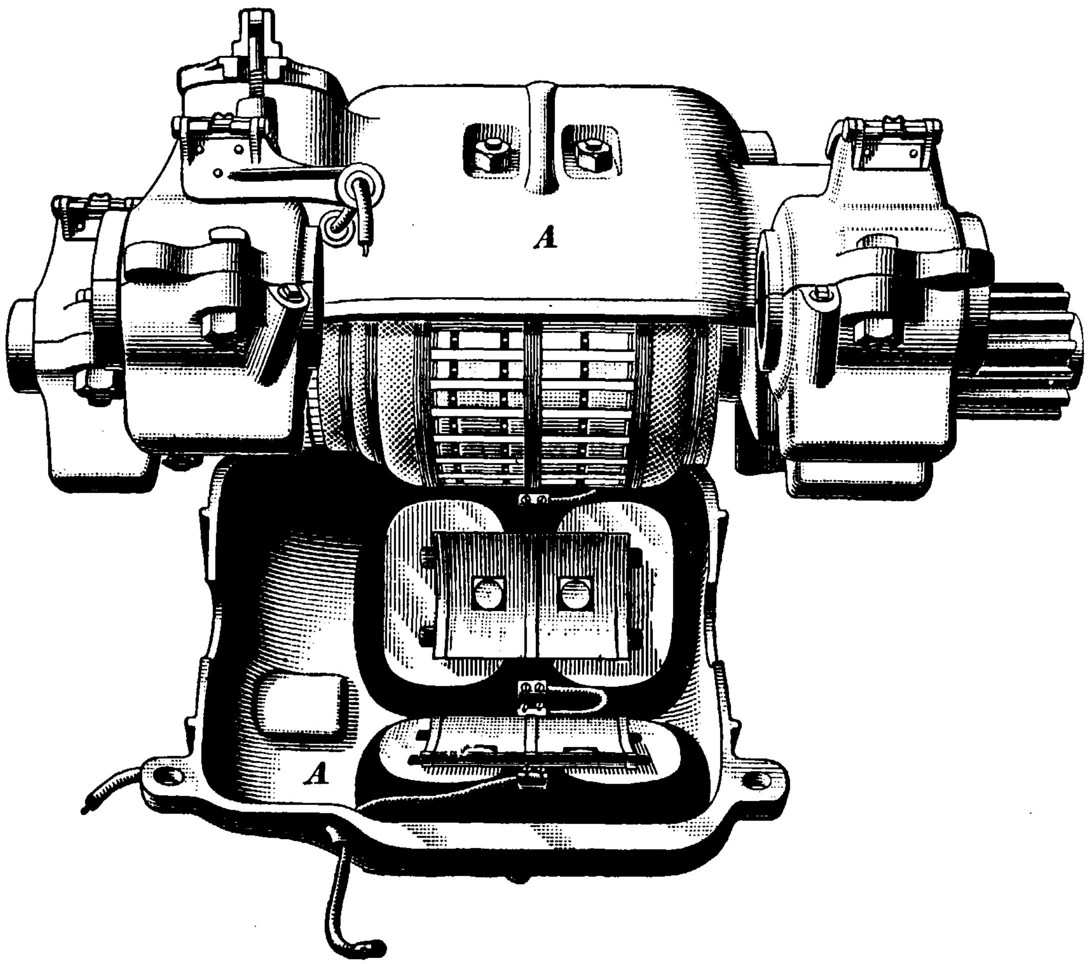

FIG. 45.

caps, the armature can be lowered with the field, thus leaving the upper field coils and pole pieces exposed, as shown in Fig. 46. Most modern motors are constructed in this way, because it is a great convenience in inspecting and repairing the motors.

70. Capacity of G. E. 52 Motor.—The G. E. 52 motor has an output of 27 horsepower. This means that it will develop 27 horsepower continuously for 1 hour, and at the end of the hour the temperature of the windings will not be more than 75° C. above the temperature of the surrounding air. The motor is intended for ordinary street-railway work and is not recommended for the heavier kinds of traffic.

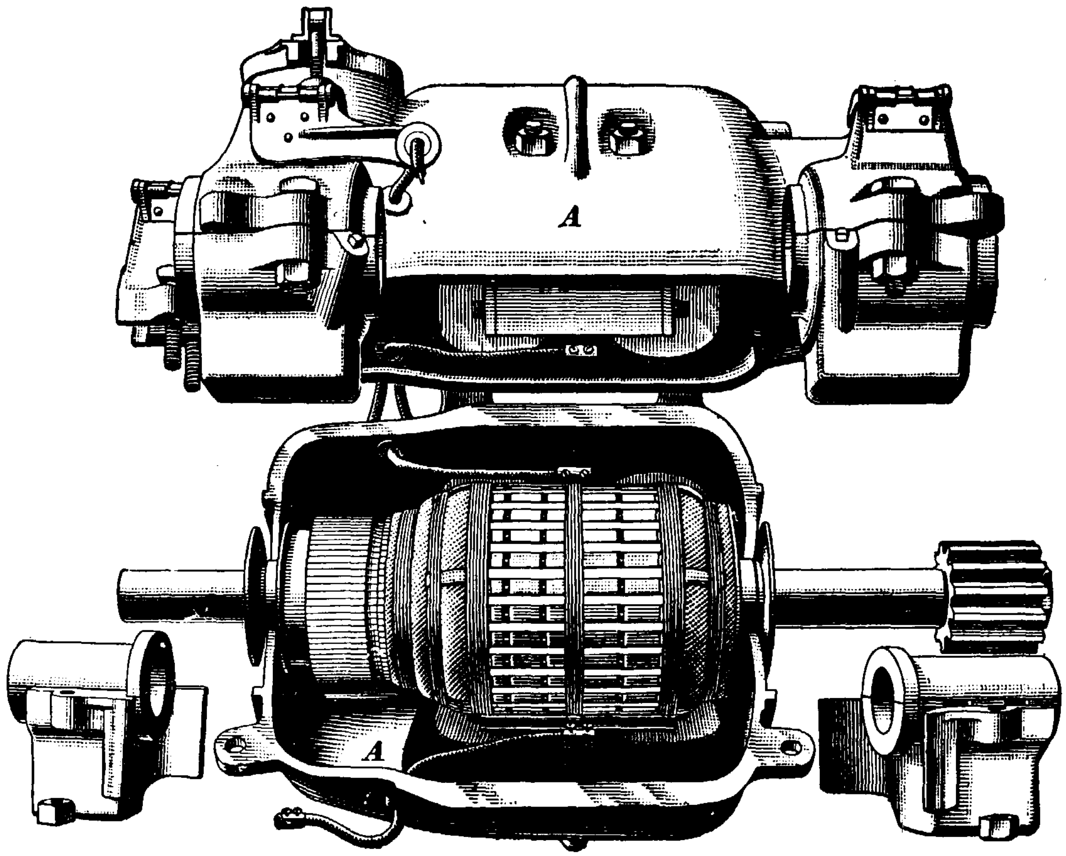

FIG. 46.

71. Pole Pieces.—The motor has four poles provided with flanged pole pieces that are laminated; the flanges serve to hold the field coils in place, and the laminations not only do away with a great deal of heat in the pole piece, but from the way in which they are built up, they produce a magnetic field that does away with much of the sparking at the brushes. The pole pieces are made of iron plates shaped

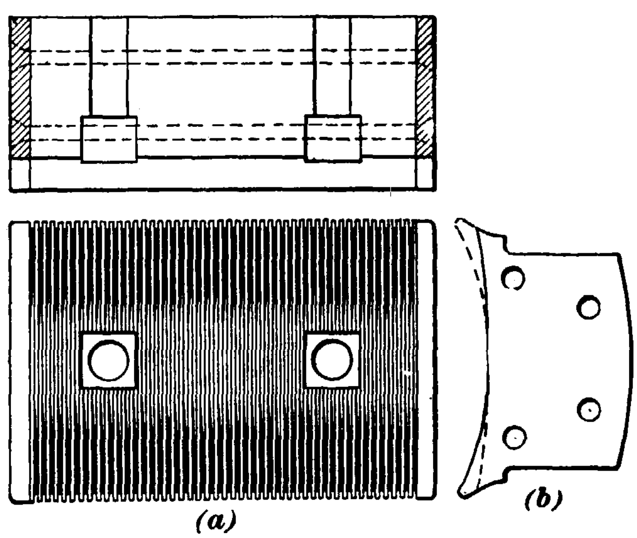

FIG. 47.

something like the full-line part of Fig. 47 (*b*). The pole pieces are built up of these plates, every other one of which is turned end for end. The result of this manner of construction is shown in Fig. 47 (*a*), where, along the horizontal center part of the pole piece, the plates are close together, but on the horns only half of the plates come out on each side. This plate construction, to a great degree, does away with sparking at the brushes, because the thinning out of the metal on the horns of the pole pieces produces what is called a *shaded field* or *fringe*. This means that the pole-piece horns are so made that the lines of force are distributed in such a way that they gradually become thinner and thinner at the proper rate and in the right place. This shaded field provides a fringe that reverses the current in the coil passing under the brush, and hence brings about the change in the direction of the current with but little sparking.

72. Field Coils.—The field coils are wound on forms, and while the asbestos-covered wire is being wound it is treated with a mixture of chalk and japan and afterwards baked. The coils are heavily insulated with tape and insulating varnish and are given a glazed surface that will readily turn off water and prevent moisture getting in.

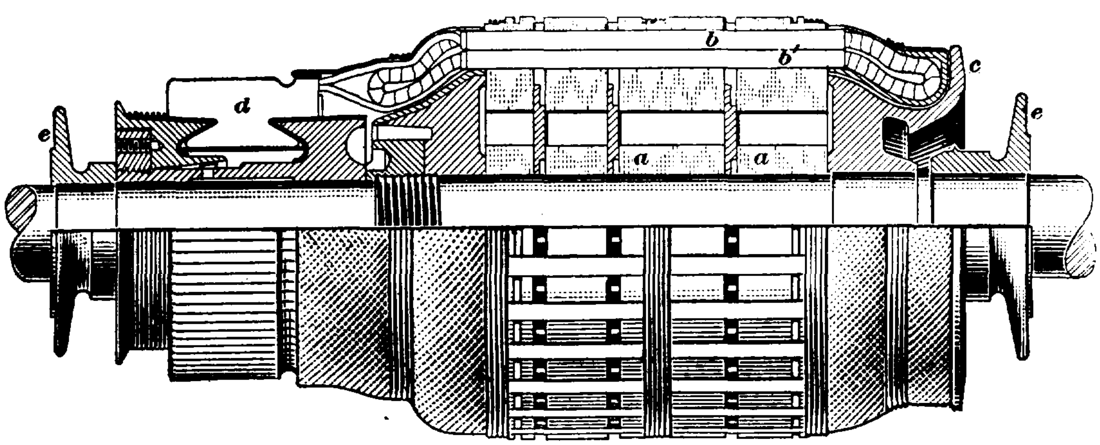

FIG. 48.

73. Armature.—Fig. 48 shows a half section of the G. E. 52 armature, and its construction is typical of many of the railway-motor armatures now in use. The core is provided with 29 slots. One side of 6 coils goes into each slot, so that there are 87 coils altogether, and the commutator has 87 bars. The coils are bunched in groups of three, and one side of one bunch goes into the bottom of a slot, one side of another into the top of the same slot. In Fig. 48, *a a* is the laminated armature core and *b*, *b'* the upper and lower halves of two different coils lying in the same slot. The ends of the coils, where they project from the core, are supported and protected by the end shield *c*. The leads from the coils are connected to the commutator bars *d*, which are mounted as shown. The flanges *e*, *e* are for preventing grease and oil working their way into the armature. The bearings are so arranged that any oil getting on *e*, *e* drops through an opening to the street.

74. Brush Holders.—Railway-motor brush holders are fixed permanently at the neutral point and are not arranged so that they can be shifted, as is the case with many other direct-current machines. The reason for this is twofold. In the first place, the motor has to run in either direction, and in the second place, the variations in load are so sudden that any brush-shifting arrangement is out of the question. The brushes are, however, mounted so that they can be moved radially towards the center of the commutator as the latter wears away.

Fig. 49 shows the brush holders and brush-holder yoke of the G. E. 52 motor. The yoke *a*, which is made of well-seasoned hard wood treated with insulating material, is bolted to the upper field frame by means of bolts *b*, *b*. The brush holders *h*, *h* are bolted to brass slides on *a* by means of bolts *c*, *c*. All railway motors use carbon brushes, and in this case, two brushes $2\frac{1}{4}$ in. × $1\frac{1}{4}$ in. × $\frac{1}{2}$ in. are used in each

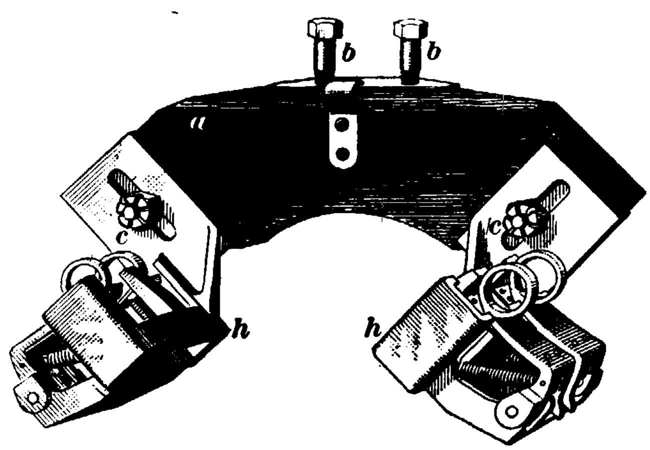

FIG. 49.

holder. The brushes are radial, i. e., they point towards the center of the commutator, so as to work equally well for either direction of rotation of the armature.

75. Gears.—The standard gear for the G. E. 52 motor has 67 teeth and the pinion 14 teeth, making a gear reduction of $\frac{67}{14} = 4.78$ to 1. Fig. 50 shows the motor mounted on the axle complete with its gear case shown at the left. All modern motors are provided with gear cases that are

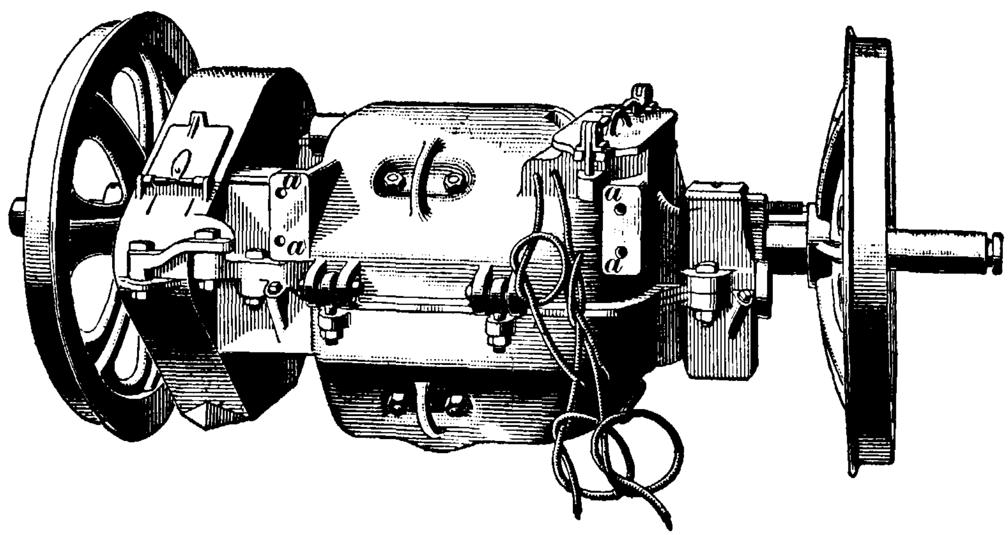

FIG. 50.

kept partly filled with soft grease or oil. This greatly prolongs the life of the gears by keeping them well lubricated and by shutting out dirt and gritty material. The holes *a*, *a* receive the bolts for attaching the suspension bar that is used to hold the motor in place.

76. Nose Suspension.—Fig. 51 shows another view of the suspension. This is the ordinary **nose suspension** so widely used. *P* is the small gear or pinion, *G* the axle gear, and *W* the car wheels. The back of the motor is supported by the axle and the front is held up by means of a cross-bar or yoke bolted to the front of the motor and resting on springs supported by the side frames of the truck. The arms cast on the motor frame hold the gears at the proper distance from center to center, while the outer part of the motor is free to rise up and down. The motor is thus supported flexibly, and there is not nearly as much pounding

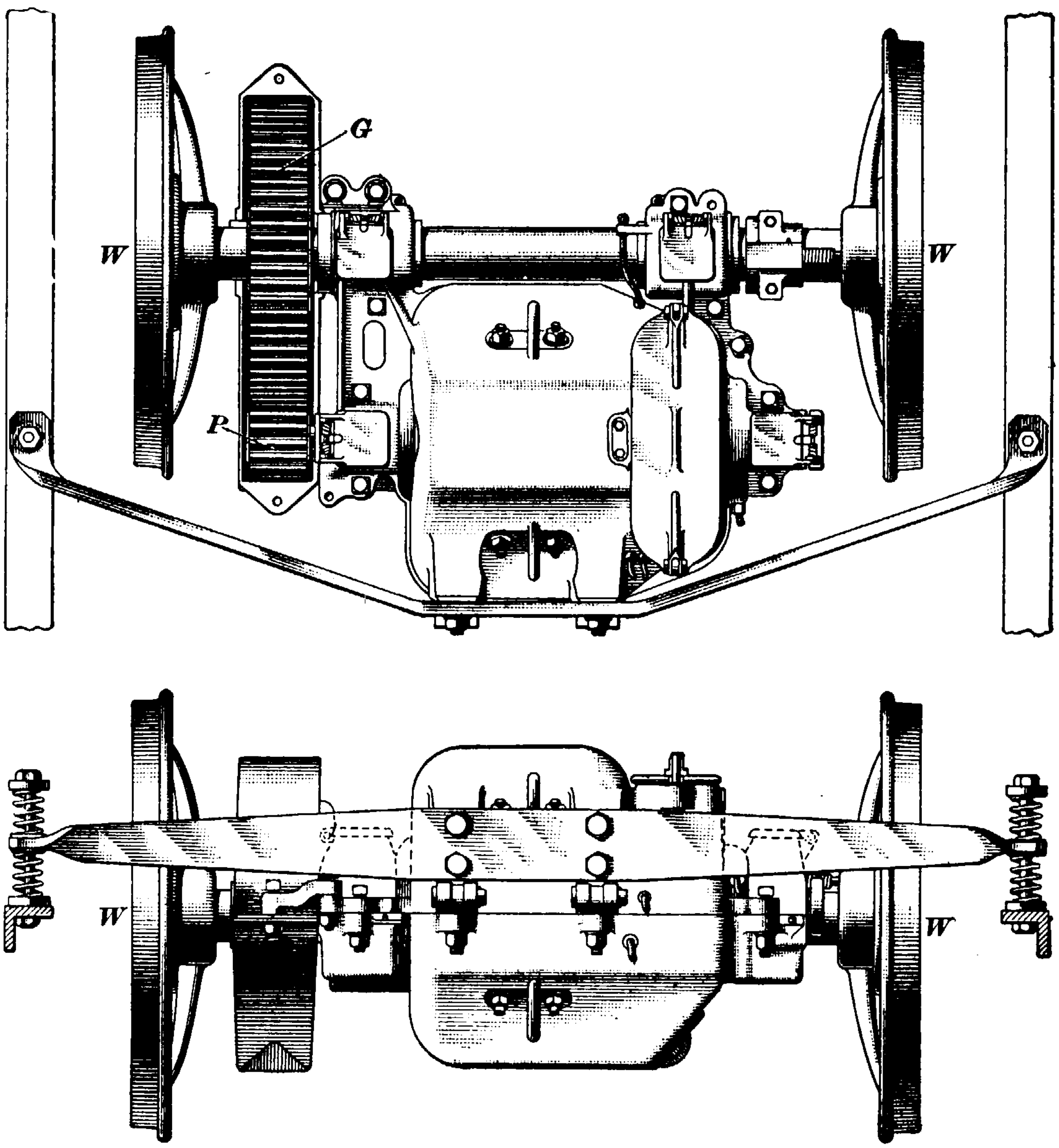

FIG. 51.

action as if it were mounted directly on the axle. The weight of the G. E. 52 motor without axle gear and case is 1,460 pounds.

WESTINGHOUSE NO. 56 MOTOR.

77. The Westinghouse No. 56 motor is intended for the heavier kinds of street-railway work. It is intended for interurban or cross-country traffic or for any service where heavy cars are operated at high speed. Fig. 52 shows the motor closed, and it will be seen that its construction is much the same as the motor previously described. *A*, *A'* are the top and lower halves of the field frame, which is made of mild cast steel. The lid *C* may be thrown back to get at the commutator and brushes. The armature leads are shown at *a*, *a'* and the field leads at *f*, *f'*. Post *g* is used for making the connection to the ground. The lug *l* is used to hang the motor when the nose suspension is used. Sometimes the motor is supported by side bars or by a cradle that passes through the rectangular openings *r* at

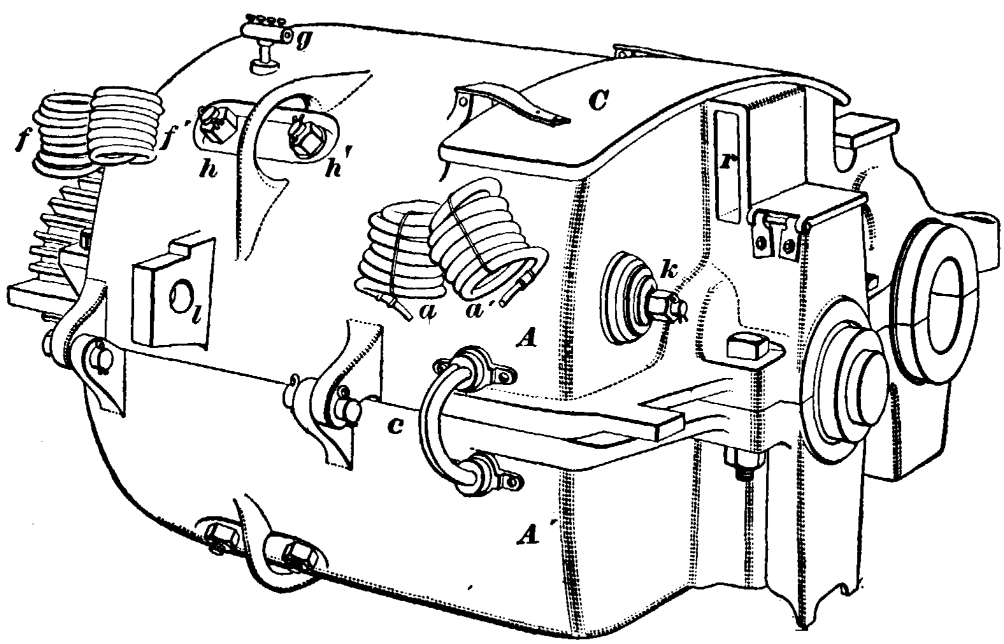

FIG. 52.

each end of the motor. The wires shown at *c* connect the top and bottom field coils together. The pole pieces are laminated and held in position by the bolts *h*, *h'*, and the armature bearings are so arranged that the armature may be either swung down with the lower half or retained in the upper half. The bearings are provided with grease cups on the top and wick lubrication below. In this motor the brush holders are bolted to the frame, but, of course, are thoroughly insulated from it. One of the bolts for attaching a holder is shown at *k*. The total weight of the motor, not including the axle gear and gear case, is 2,680 pounds.

78. Cradle Suspension.—Fig. 53 shows the **cradle suspension** as applied to the Westinghouse No. 56 motor. The front of the cradle *A A* is supported at *C* by the cross-beam *D*, which is supported by the side frames of the truck. The back end of the cradle is supported by springs *S*, *S'*, which bear on lugs cast on the same arm that carries the axle bearing. The cradle passes through the lugs on the ends of the motor, and the use of the springs insures a flexible suspension.

79. Capacity of No. 56 Motor.—Different makers have different ways of rating the capacity of their motors. Some rate them at the power they are capable of developing for a run of one hour without their temperature rising more than 75° C. above that of the surrounding air. Of course, the current taken by a motor in actual service is very variable, and the voltage at the terminals of the motor is also variable. For example, when the two motors are in series, each motor will get about 250 volts if the line voltage is 500. When the car is coasting or standing still, the voltage applied to the motors is zero. The average voltage applied to a motor throughout the day will not likely be more than 250 or 300 volts, and the No. 56 motor will carry a load of 50 amperes *continuously* at a pressure of 300 volts with a rise in temperature of 75° C. Of course, much larger currents than this can be carried for short intervals, as, for example, when a car is starting up and getting under headway. The motor can carry a current of 100 amperes for over an hour without increasing the temperature over 100° C., provided it starts at 25° C. With 100 amperes, a tractive effort of over 1,600 pounds would be exerted with the motor mounted on 33-inch wheels. The continuous output of a railway motor, like any other electric motor, is limited by the heating. Railway motors are generally worked at a fairly high temperature, because they must be enclosed to such an extent that free ventilation is difficult.

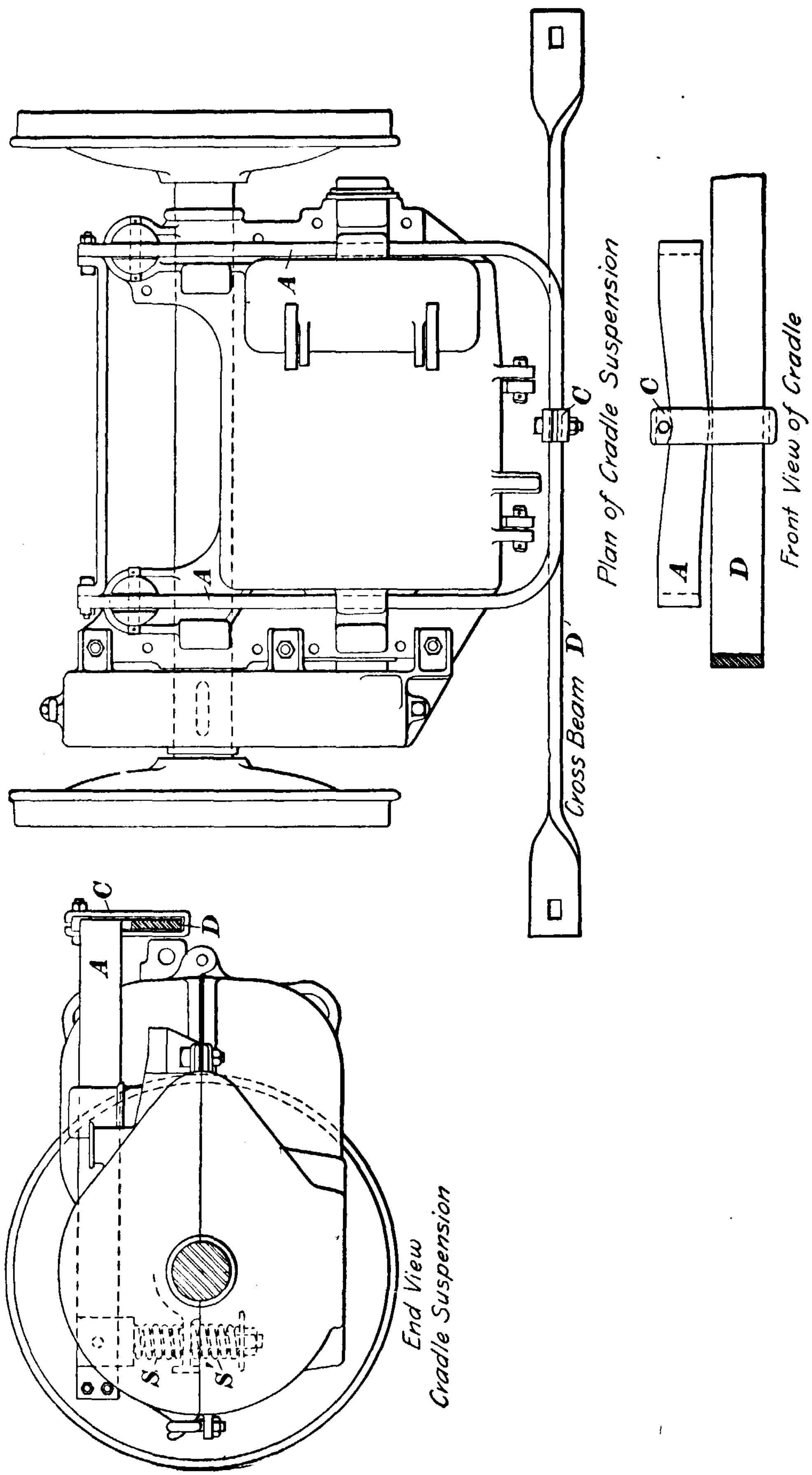
Plan of Cradle Suspension
Front View of Cradle
Cross Beam D'
End View
Cradle Suspension
A
C
D
S

FIG. 53.

RAILWAY-MOTOR ARMATURE CONNECTIONS.

80. There are so many different styles of railway-motor armatures that it will not be possible to take up the methods of connecting the different kinds in detail. The following will, however, give some general directions relating to these connections. These all relate to four-pole machines and the coils span over about one-quarter of the armature. They also refer to drum-wound armatures exclusively, as ring armatures are not used to any extent on modern railway motors. In former times, the cores were separately insulated and the wire was wound on from a reel ; these armatures were known as *hand-wound armatures*. At present, the core insulation is confined to insulating disks on the ends, a strip of insulation in the bottom of each slot, and pieces of insulation, in some cases, on the sides of the slot. The coils are wound first on coil machines and then insulated and pressed to a shape to fit the slot. By using form-wound coils, much less skill is required to repair or rewind armatures. The first step was to have a slot for each coil; the next step was to bunch two coils together in one insulating casing or armor, so that the armature core had but one-half as many slots as there were coils. This practice left two empty half slots that had to be filled with a dummy coil (i. e., a coil whose ends were insulated instead of going into the commutator), so the scheme of using 2 coils in a case was abandoned in favor of grouping 3 coils in a case, so that a core need have but one-third as many slots as coils.

81. Modern street-railway armatures are of the series-connected type; that is, although a machine may have four poles, the armature is so connected that it has but two paths through it, and therefore requires but two brush holders. On an enclosed motor, four brush holders would be out of the question, because the bottom ones could not be inspected and it would be almost impossible to replace a brush if the motor were hot. Another point to bear in mind is that some motors have their pole pieces on the diagonal, while others have them on the vertical and horizontal, with the result that on the former type, the brushes are set on the commutator at points opposite the centers of the pole pieces instead of being set at points midway between them corresponding to the position of the neutral line. This is necessary from the fact that if the brushes were set at the neutral line, one would be on top and the other would be down on one side, where it would be hard to get at.

82. Connections for a 99-Coil Armature.—Fig. 54 shows an armature having 99 coils and slots, its pole pieces being horizontal. The coil for this armature would have one short lead and one long one, and would be of such a width that one side could drop into slot *1* and the other side into slot *26*; the short lead would then go straight down to

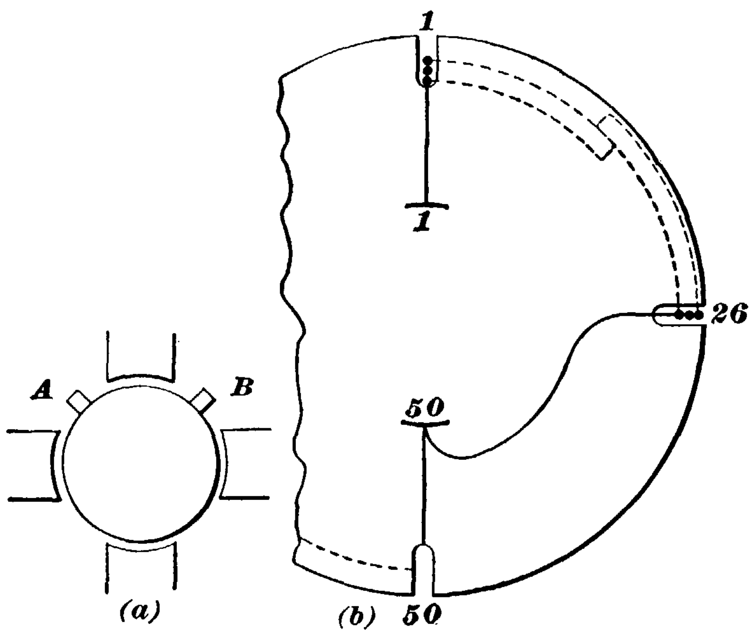

FIG. 54.

the commutator bar immediately in line with it and the long lead would go to the bar as nearly diametrically opposite as possible. This would be bar *50*. The next coil would drop into slots *2* and *27* and its leads would go to bars *2* and *51*. This is a rule that holds good on any armature having 99 slots and 99 coils where the four poles are on the horizontal and vertical, as, for example, on the G. E. 800 or 1,200 motors. To make it hold good on armatures having 99 coils, 99 bars, but only 33 slots, it is only necessary to count off as if each coil had its own slot or as if there were no slots at all. For instance, suppose there are only 33 slots; then, one side of coils *1*, *2*, and *3* will be in slot *1*; *4*, *5*, and *6* in slot *2*; *7*, *8*, and *9* in slot *3*; and so on, so that the other sides of coils *1*, *2*, and *3*, which formerly fell into slots *26*, *27*, and *28*, when there was a slot for each coil, must now drop into slot *9*; the other sides of coils *4*, *5*,

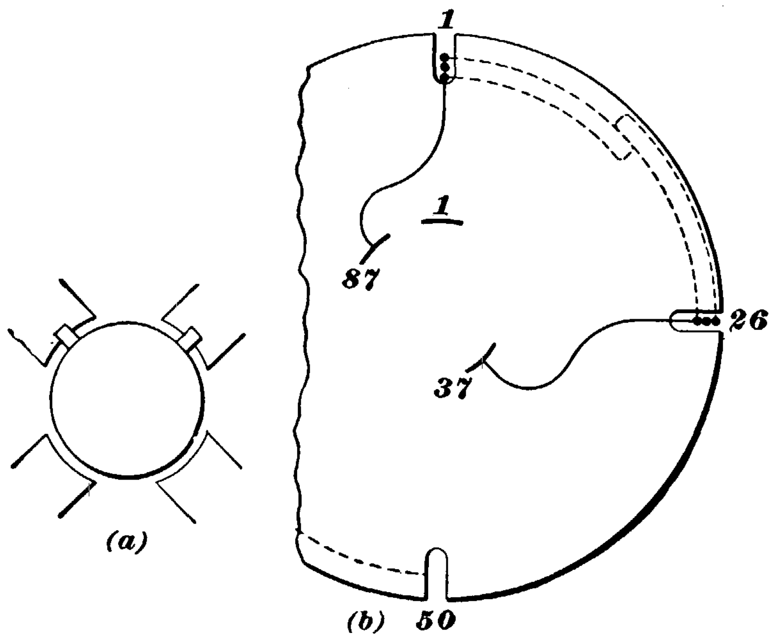

FIG. 55.

and *6* in slot *10*; and so on. The short lead of coil *1* goes to bar *1* and the long lead to bar *50*, as before. After one coil is installed, the others follow the same course.

Fig. 55 shows the connections for an armature having 99 slots and 99 coils, with the pole pieces on the diagonal. It will be noticed that in both cases, the brushes fall in the same place. In Fig. 55, however, the lead out of slot *1*, instead of going to bar *1*, directly opposite, goes to bar *87*, obtained by counting to the left 14 bars, including bar *1*; 99 is not divisible by 8, so that this is as nearly one-eighth a circumference as it is possible to get. Since the lead coming out of slot *1* is shifted $\frac{1}{8} \times 99$ bars to the left, so must the lead out of slot *26* be shifted the same amount, so that instead of going into bar *50*, it goes into bar *37*, which is 14 bars to the left, counting bar *50*. In practice, the two bars are located as follows: The coil is dropped into slots *1* and *26*; begin with bar *1*, opposite coil *1*, and count 14 to the left, including *1*; this fixes one end of the coil in bar *87*; then, including bar *87*, count 50 bars to the right, which fixes the other end of the coil in bar *37*. After one coil is in, the others are easily placed. This scheme of bringing the connections around one-eighth a circumference to the left is called *giving the connections a lead.** It is nothing but a mechanical trick for bringing the brushes into the right place, and is used on all street-railway motor armatures whose pole pieces are on the diagonal. In Fig. 54, one lead is longer than the other, so that they are readily distinguished by their length; in Fig. 55, the leads are about the same length, so that to distinguish them, it is the practice to slip a piece of black hose on one, the other being white. Fig. 55 can be followed in assembling and connecting any armature that has 99 coils and either 99 slots or 33 slots, if the pole pieces are on the diagonal.

83. Connections for a 95-Coil Armature.—Figs. 56 and 57 give the general scheme for winding and connecting any armature having 95 slots and 95 coils for vertical and diagonal pole pieces, respectively. In Fig. 56, the coils drop into slots *1* and *25*, as before, but the lead out of slot *1* goes straight down to bar *1* and the other end of the coil in slot *25* goes half way around the commutator to bar *48*. In Fig. 57, one side of the coil goes into slot *1* and the other side into slot *25*; the bar in front of slot *1* is bar *1*. Including bar *1*, count off 13 to the left; this fixes the lead coming out of slot *1* in bar *84*. Including bar *84*, count off 49 bars to the

*The term "lead" as applied here should not be confused with the term "lead" as applied to a wire or terminal. In connection with armatures, dynamos, etc., the term "lead" (pronounced "leed") is commonly used to denote a terminal wire—such as the terminal of an armature coil—a wire running from a dynamo to the switchboard, etc.

right; this brings us to bar *37*, which takes the other end of the coil coming out of slot *25*.

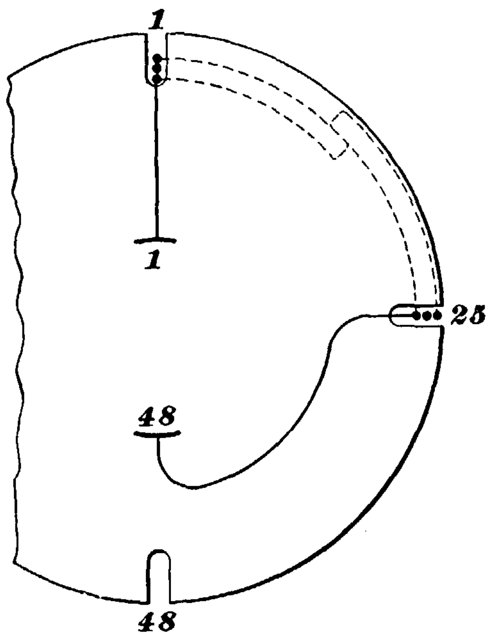

FIG. 56.

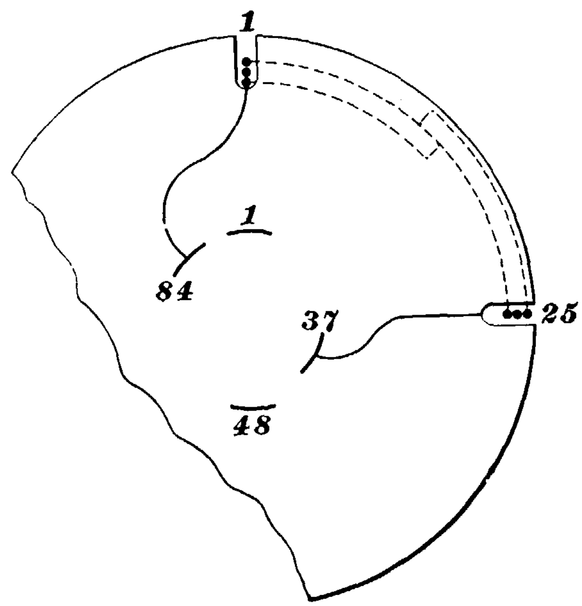

FIG. 57.

84. Connections for a 93-Coil Armature.—Figs. 58 and 59 show the scheme for winding and connecting any armature having 93 coils and bars and 93 or 31 slots for vertical and diagonal pole pieces, respectively. In both cases,

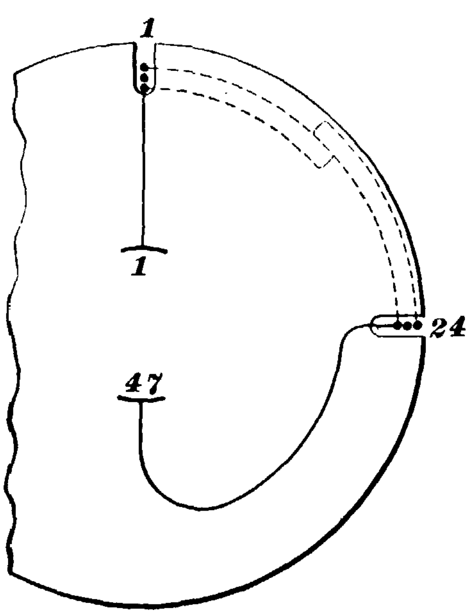

FIG. 58.

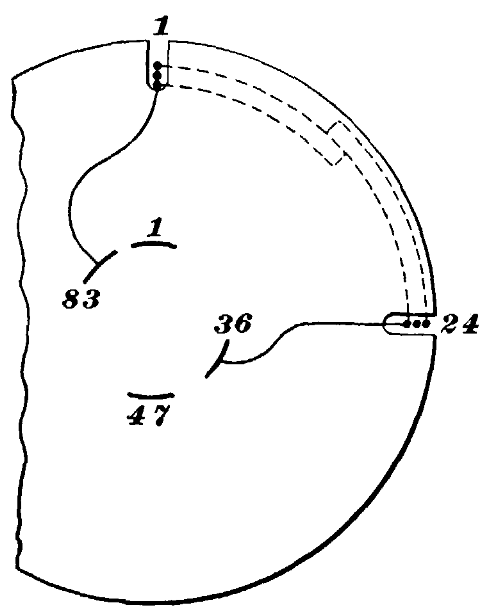

FIG. 59.

the coil drops into slots *1* and *24*. In the first case, the lead out of slot *1* goes straight down to bar *1* and the lead from the same coil in slot *24* goes half way around and connects to bar *47*. In the second case, the lead from slot *1* goes into bar *83*, which is found by counting off 12 to the left of bar *1* and including it; the other end of the same coil in slot *24* connects to bar *36*, obtained either by going half way around the commutator from bar *83* to the right or by counting off a throw of 12 back from bar *47*.

85. Connections for a 105-Coil Armature.—Figs. 60 and 61 show, respectively, the vertical and diagonal methods of winding and connecting an armature having 105 slots, bars, and coils. In both cases, the first coil drops into slots *1* and *27*. In the first case, the lead out of slot *1* goes straight down to bar *1* and the other end of the same coil

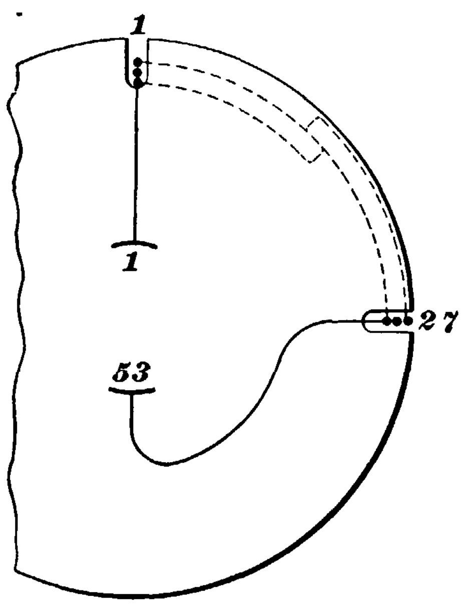

FIG. 60.

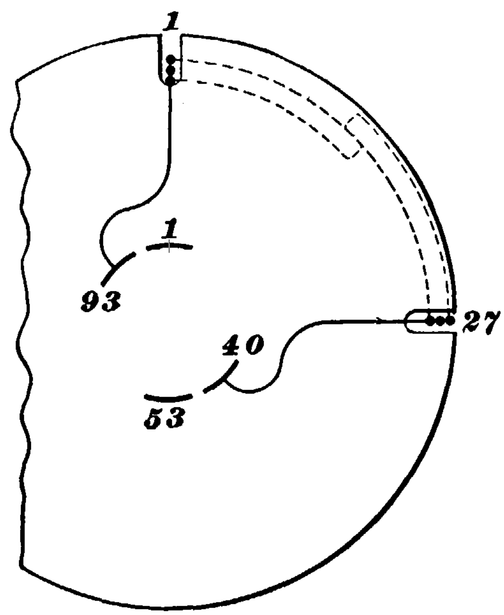

FIG. 61.

coming out of slot *27* goes half way around to bar *53*. In the second case, count off a throw of 14 bars to the left from and including bar *1*, which gives bar *93*, the bar for the lead out of slot *1*. To get the bar for the lead of the same coil out of slot *27*, count off 53 to the right from bar *93*, which gives *40*.

86. Connections for Armature With 93 Coils and 47 Slots.—Fig. 62 shows the scheme for connecting up for diagonal pole pieces an armature having 93 bars and coils but only 47 slots; the single coils are done up into cells or cases, two coils to a cell; there are 47 of these cells, so there will be 1 coil (2 ends) more than there are places in the commutator. This extra coil might just as well be left out, so far as doing any work is concerned, for its ends are taped up so that they cannot come in contact with any other parts of the winding, but it is put in to preserve the mechanical balance of the armature. As shown in the figure, the coil drops into slots *1* and *13*. To connect the armature, pick out any coil and find both ends of it with a magneto or lamp circuit. Standing at the commutator end, call the end on the left *1*. With a straightedge, find the bar immediately in front of it; call this bar *1*, and count off 13 to the left; this fixes the left-hand lead at bar *82*. The other lead goes into the bar half way around the commutator or bar *35* to the right.

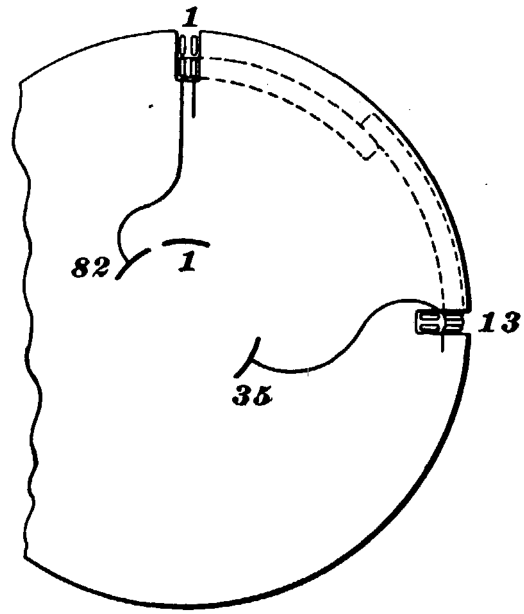

FIG. 62.

87. In all these winding diagrams, the student will note that one side of the coil occupies the bottom of a slot, while the other side of the same coil is in the top of a slot about one-fourth of the distance around the armature. By arranging the coils in this way, the crossings at the ends of the armature are easily disposed of, and in nearly all modern railway motors this arrangement is adopted.

There are many different styles of armature windings for railway motors, and for this reason it has been thought best to take up general principles that may be applied to any of them rather than particular cases. Practically all railway motors use windings that are, in general, similar to those described, although the exact grouping of the coils in the slots may be somewhat different.

RAILWAY-MOTOR FIELD CONNECTIONS.

88. One of the most common sources of trouble in connection with street-railway motors is wrongly placed or connected field coils. Few have any idea of the great amount of trouble a wrongly connected field coil may cause. Its effect is felt long after the trouble has been found and removed. A wrongly connected field not only injures itself, but it injures the other field coils and the armature. The armature probably heats to such an extent that it throws solder and the fields gradually bake inside, with the result that the car is soon turned in for blowing fuses. The chances are that before the trouble is discovered and removed, there may be two or three grounded brush holders, armatures, or fields, due to the current jumping across to the frame of the motor, because the weak fields in the first place cause poor commutation, and in the second place reduce the counter E. M. F. and allow more current to flow than the brushes can stand. It is safe to say that one-half of the trouble on cars turned in for blowing fuses can be traced directly or indirectly to defects in the field coils.

89. General Remarks on Field Coils.—Fig. 63 shows a section through the middle of a four-pole motor having top and bottom field coils. The halves of the shell come

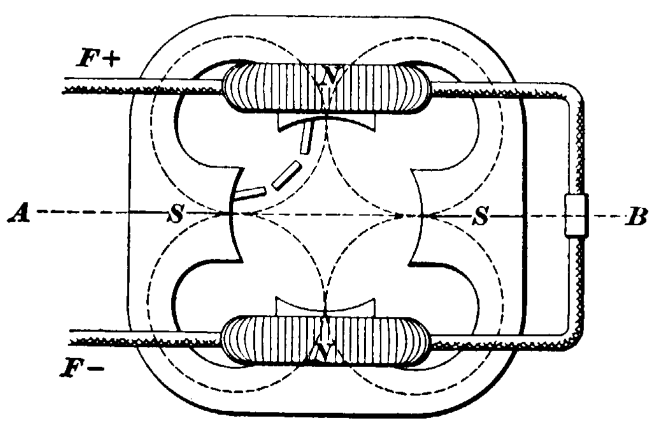

FIG. 63.

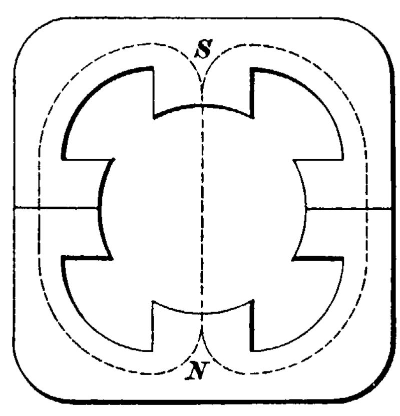

FIG. 64.

apart along the line *A B*. In Fig. 63, the two coils are connected correctly, and the general path of the lines of force forms the curved four-sided figure at the center. In Fig. 64, the two field coils have been left off to simplify the drawing, but the figure is supposed to be the same as Fig. 63, except that the two coils are connected incorrectly, so that opposite poles are of opposite polarity and the side pole pieces cease to be poles at all. The lines of force pass across the armature core just as they would in a regular two-pole machine, with the result that the neutral point falls midway between the brushes, which are in an active part of the field, and therefore spark a great deal even when the car is run with the two motors in series.

Fig. 65 shows a section through a four-pole motor that has a coil on each of its poles. The coils are so connected that the pole pieces alternate in polarity. Fig. 66 is the same as Fig. 65, but the field coils are not shown. The top left-hand field coil is supposed to be connected incorrectly, with the result that the motor has three south poles and only one north pole, and the lines of force are very much twisted out of their path. However, it will be noticed that two sides of the four-sided figure made by the path of the lines of force can still be seen. Part of the armature is, therefore, effective, and, as a matter of fact, if one coil out of four is wrongly connected, the car will continue to start and run on the faulty motor, but the brushes will spark badly. One wrong field coil out of four amounts to about the same thing as lifting off the top half of the motor and running the

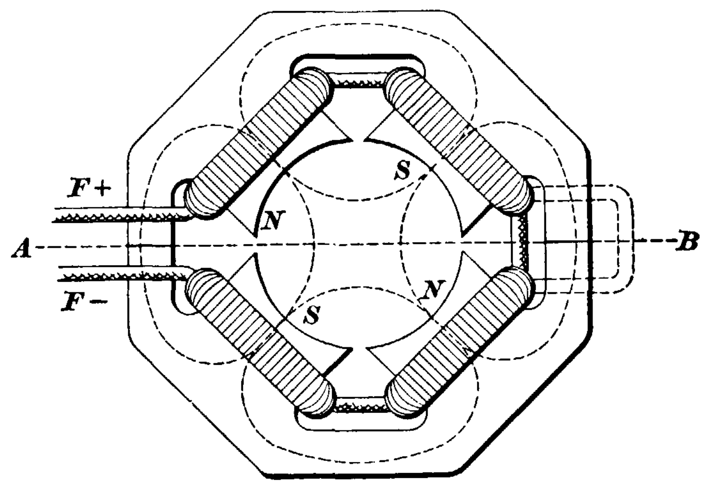

FIG. 65.

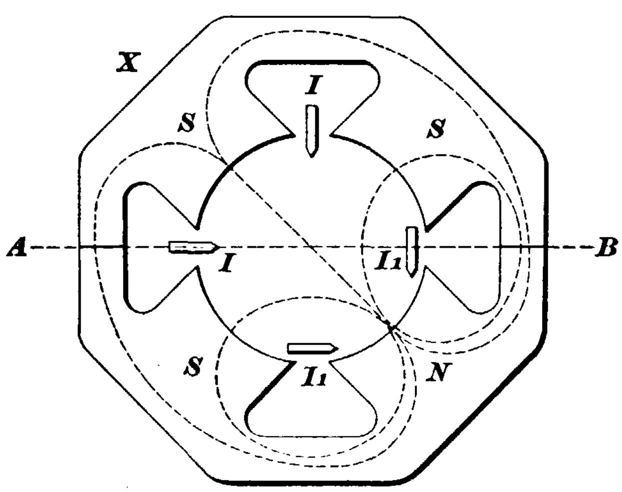

FIG. 66.

armature on the field coils in the lower half. The armature would run, but there would be great consumption of current.

90. Test for Field Connections.—If there is any doubt as to whether a set of field coils is connected properly or not, the matter can be decided by a very simple test with a piece of soft-iron rod about 3 or 4 inches long. It is well known that if a piece of iron is placed near a magnet of any kind, it will, if free to move round a center, take up a position parallel to the general direction of the lines of force that run through the place where it rests. If the person making the

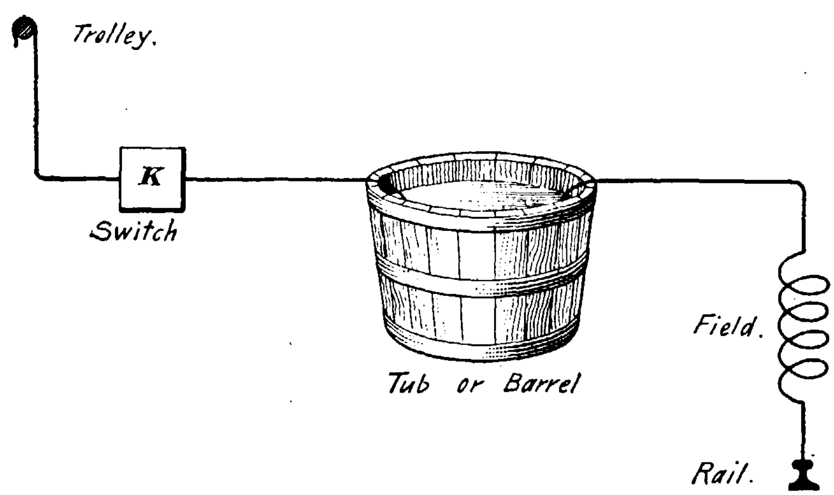

FIG. 67.

polarity test is inexperienced, it is a safe plan to take the armature out of the motor, because when a current is sent through the field coils and the pole pieces become magnetized, they induce poles of the opposite polarity in the armature core opposite them, so that unless great care is taken, the tester will not always be certain whether he is getting the effect of the pole piece or that of the induced pole in the armature core.

Procure a piece of $\frac{1}{4}$-inch iron rod and point it on one end, so that the two ends may be distinguished by feeling them. Next send a current through the fields; this can be done by using a tub or barrel of water as a resistance, connected as shown in Fig. 67. The wires going into the tub have each a fish-plate or an old bearing attached to their submerged ends. The current can be varied by varying the distance between these pieces of metal. Sometimes it is necessary to drop a handful of common salt into the water, in order to bring down its resistance and pass a current strong enough for the test. As soon as the current is adjusted (it should not be more than the full-load current of the motor), reach into the motor and rest the blunt end of the piece of iron on the horn of one of the pole pieces and let the sharp end point towards the pole piece next to it; then pass the piece of iron on over towards the pole piece that it points at, as shown in Fig. 63. The piece of iron is held loosely at the center between the thumb and forefinger, so that it is free between certain limits to turn and follow the path of the lines of force. If the iron rod in its passage from one pole to the other tends to remain in the same general direction in which it was started, i. e., starts from one pole on its blunt end and reaches the other pole on its sharp end, showing no tendency to turn or straighten up, the path of the lines of force is correct.

Fig. 68 shows the action of the piece of iron if one of the coils is connected incorrectly. If the motor has only two coils, as shown in Fig. 63, the lines of force, when one of the coils is incorrectly connected, will take the path straight across, shown by the dotted line in Fig. 64, and the piece of iron, instead of being willing to go in the most natural way from one pole to the one next to it, will try to follow the direction shown at I_1, I_1 in Fig. 68. Of course, if the motor has only two coils, matters can be set right by reversing either of them. It does not matter whether the motor has two coils or four coils; if they are all connected properly, the path of the lines of force from one pole to another will be regular, and the piece of iron will persevere in taking up between each pair of adjacent poles the position shown at *I*, *I*, Fig. 68.

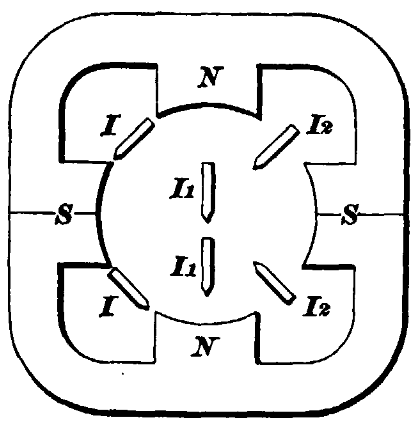

FIG. 68.

Now, suppose the motor to be of the four-coil, four-pole type, such as shown in Fig. 65, and suppose the left-hand top field coil to be wrongly connected, so that the path of the lines of force becomes that shown by the dotted lines in Fig. 66. In this case, the test iron will rest in positions *I*, *I* on both sides of the faulty coil, because the general direction of the lines of force is at right angles to what it should be. Between the right-hand bottom coil and the two adjacent coils, the path of the lines is correct and the test iron takes up the correct position, as shown at I_1 and I_1. If, then, one of the four coils on any four-coil motor is wrongly connected, the action of the test iron will be irregular on both sides of that coil. Further than this, the pole piece coming out of the faulty coil will be weaker than any other pole piece in the motor; also, the removed corners of neighboring pole pieces will be considerably stronger than the corners adjacent to the faulty pole piece.

91. Field Connecting.—In the practical work of connecting up a set of field coils, one does not care whether the coil is connected so that it makes the pole piece a north pole or a south pole; what one must see to is that if any given pole is a north pole, the pole next to it on either side must be a south pole, and *vice versa*. Now, whether a pole will be north or south depends on the direction in which the current flows around it. This in turn depends on how the coil is wound, how the leads are brought out after it is wound, and, lastly, on how the coil is connected when it is in the motor. As we have to do only with the completed coil in the motor, we will assume that all the coils are wound alike and that in every case the inside and outside ends of the winding go to the same lugs or leads, respectively. If the current enters a coil by way of the inside end, the coil will give the pole piece one polarity, and if it enters at the outside end of a similarly placed coil, the polarity of that pole piece would be reversed. In order to make adjacent pole pieces have opposite polarity, the current must enter the coil of one at its inside end and the coil of the other at its outside end.

Fig. 69 shows four coils laid out in the same order in which they would go into a motor and connected so that

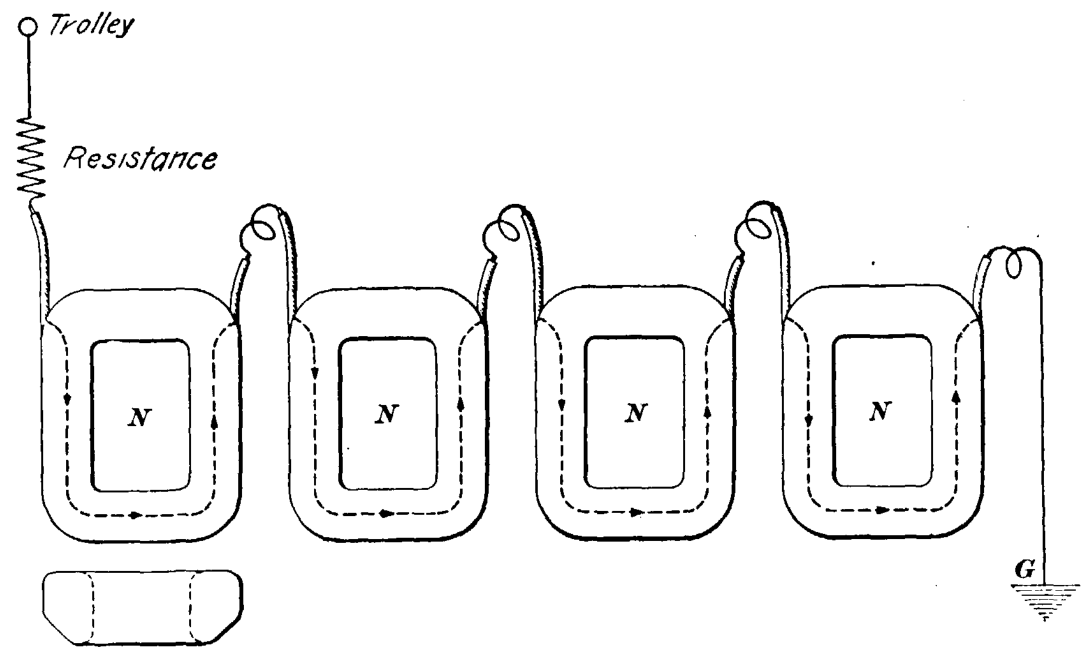

FIG. 69.

the current flows through all of them in the same direction. Fig. 70 shows them connected as they should be. In Fig. 69, it will be noticed that each of the four coils has

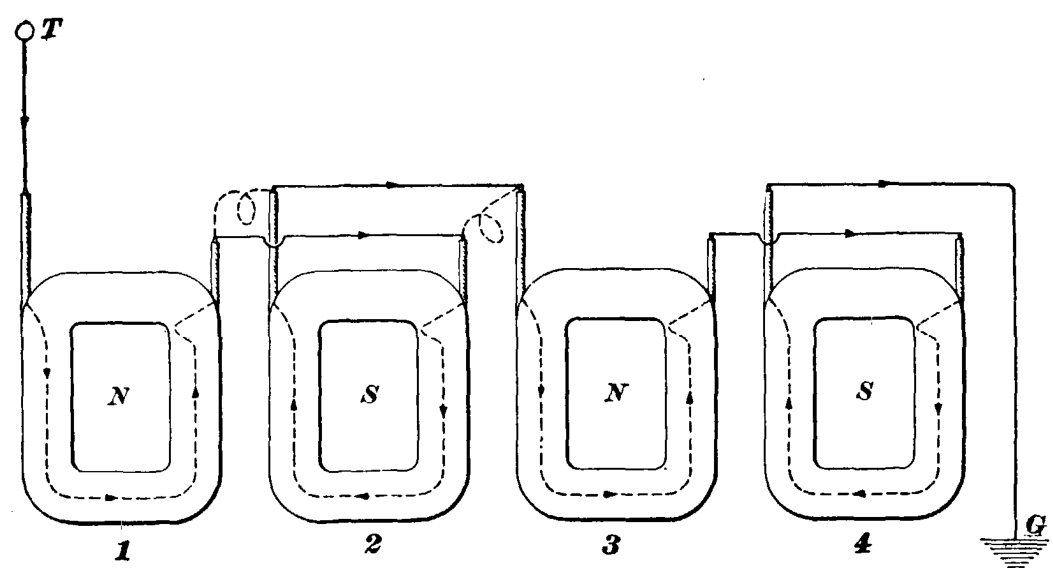

FIG. 70.

one long lead and one short one; so that if connected as shown in Fig. 69, the coils will all have the same polarity, because in each case the current goes into the coil by way of the long lead and comes out by way of the short one, circulating through all the coils in a counter-clockwise direction.

There are two points that must be especially noted about the four field coils and their connections in Fig. 70; one is that the difference in the length of the leads enables one to tell readily which are the like ends of several coils. The next point to note is that the like ends of coils that are next to each other join together; a short lead always connects to a short lead and a long lead to a long lead. One more point to be noticed is that, after all the internal motor-field connections are made, the two field leads that are left unconnected to go to the field car wires should be alike; in Fig. 70, two long leads are left open, so that the connections must be correct. In Fig. 69, one long lead and one short lead are left open, so that the connections are not correct. It is, however, possible to get the coils connected improperly and still have two like ends left open; Fig. 70 shows one way in which this might be done if the second coil were connected as indicated by the dotted lines instead of by the full lines. The connections should be carefully made and well taped up, because they are in very close quarters and are liable to chafe.

92. Coils With Leads on Opposite Ends.—Fig. 71 shows a type of coil that is very easily placed incorrectly. Fig. 72 is the same style of coil except that it has leads instead of lugs. It does not make any difference which way the coil is turned; it looks just the same. To add to the possibility of confusion, the coil has the same shape on the bottom as on the top, as shown in Fig. 71 (*b*), so that it is an easy matter to get the coil into the motor top side down. The effect of getting such a coil in end for end, or top side down, can be seen by the aid of Fig. 72. In this figure, $T\,T$ is supposed to be the wire that takes the current to the coil; if this wire is connected to the coil as it stands in the figure, the current goes into the coil by way of the $F+$ lead, which we will call the *inside end;* if the coil be now turned over so that the *a* side comes where the *b* side is, and *vice versa*, the *F*— lead is brought nearest the

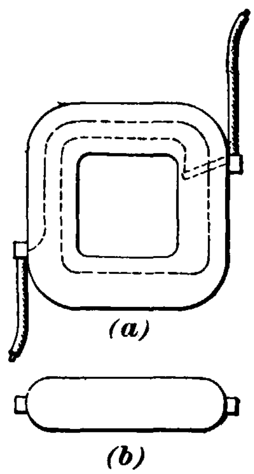

FIG. 71.

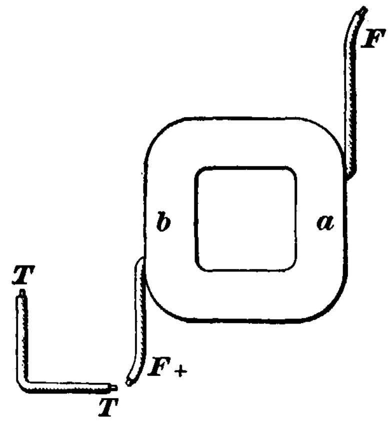

FIG. 72.

wire *T T*, and if it is connected to it, the current enters the coil by way of the outside end and reverses its polarity.

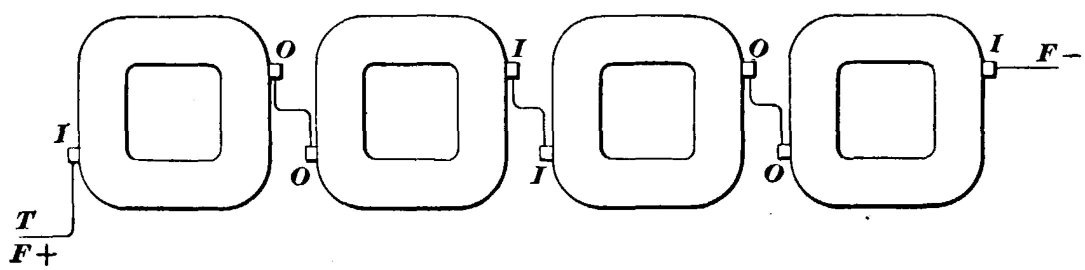

FIG. 73.

Fig. 73 shows how such a set of coils appear if they are connected correctly, and Fig. 74 shows the effect of having one coil in top side down. Observe that in Fig. 73 the *I*'s

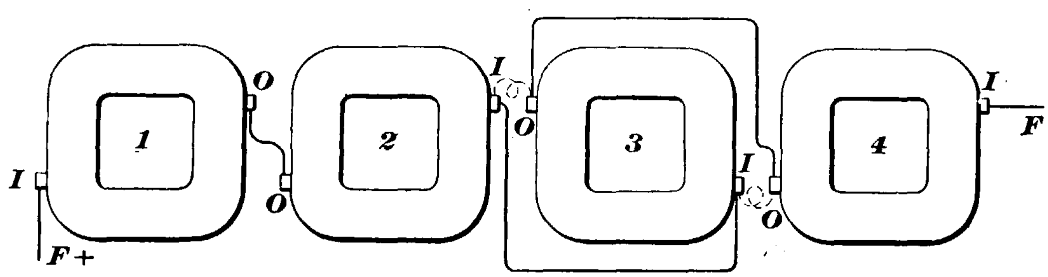

FIG. 74.

connect to *I*'s and the *O*'s to *O*'s; also, that every other coil is turned end for end; this is done in order to bring together those lugs that connect together, thus avoiding a long connecting wire, which would have to be cleated up to keep it away from the armature. If coil *3* were connected as indicated by the dotted lines in Fig. 74, the polarity of the coil would be reversed.

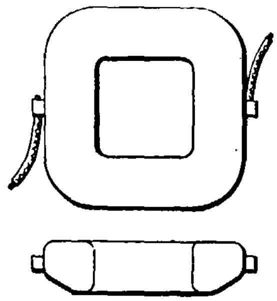

FIG. 75.

Fig. 75 shows a type of coil with the lugs on the side and midway between the two ends. This coil is convex on the bottom and cannot be put in top side down. As the lugs are midway between the ends of the coil, it is an easy matter to get the coil in end for end. The correct connections for coils of this kind are shown in Fig. 76. The connection between coils is

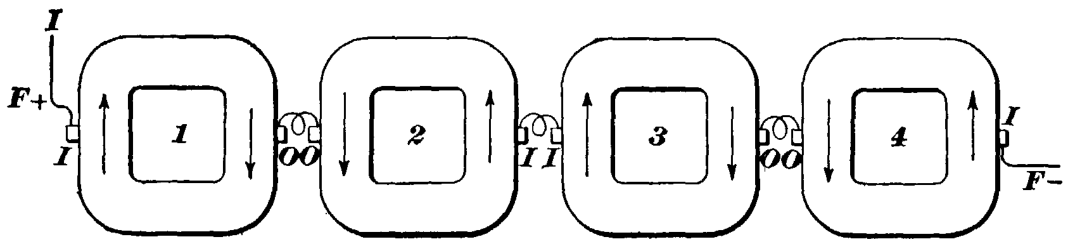

FIG. 76.

short and is not very apt to give trouble from getting loose.