

June 2, 1964

H. D. BRAILSFORD
CENTRIFUGAL SWITCH

3,135,842

Filed Feb. 1, 1960

3 Sheets-Sheet 1

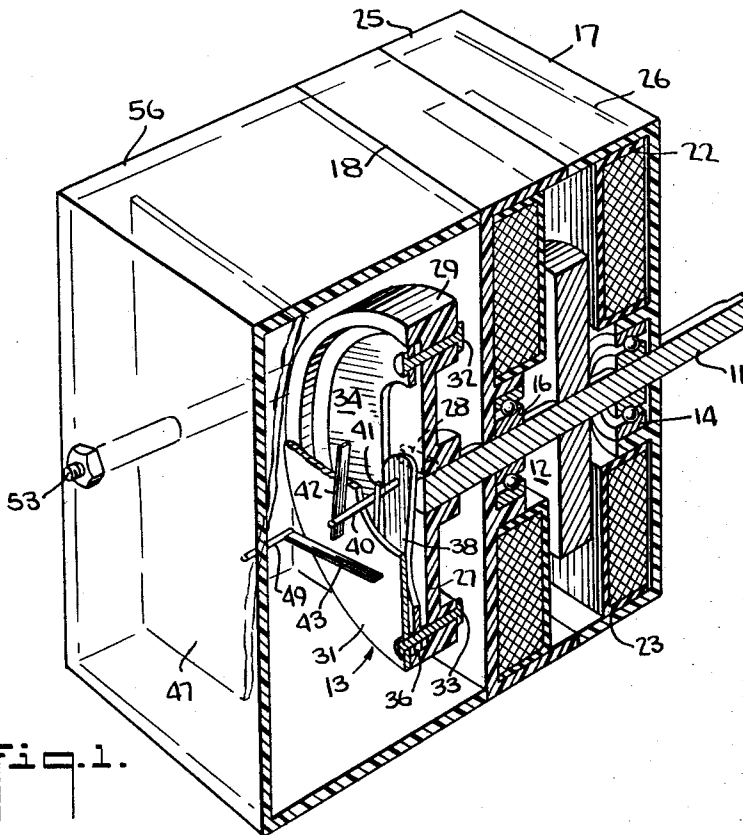


Fig. 1.

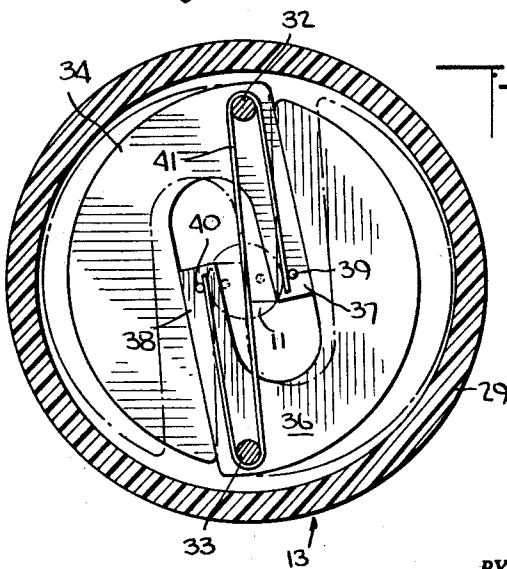


Fig. 2.

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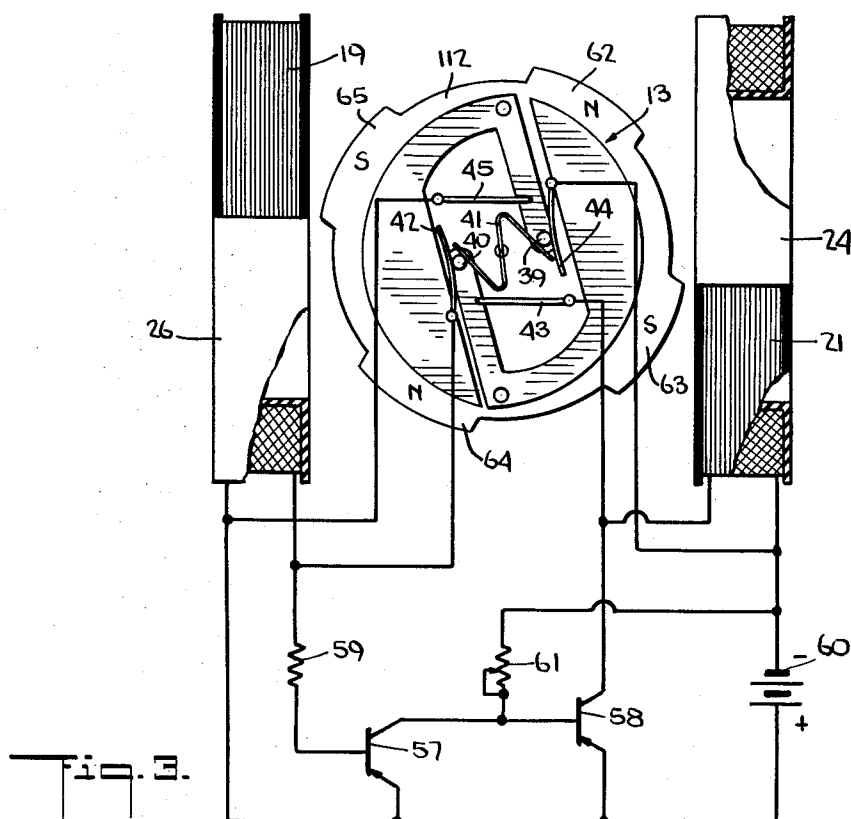
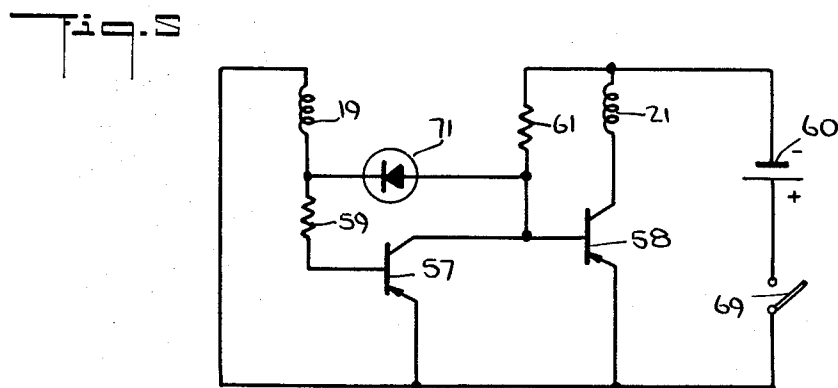
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3 Sheets-Sheet 3

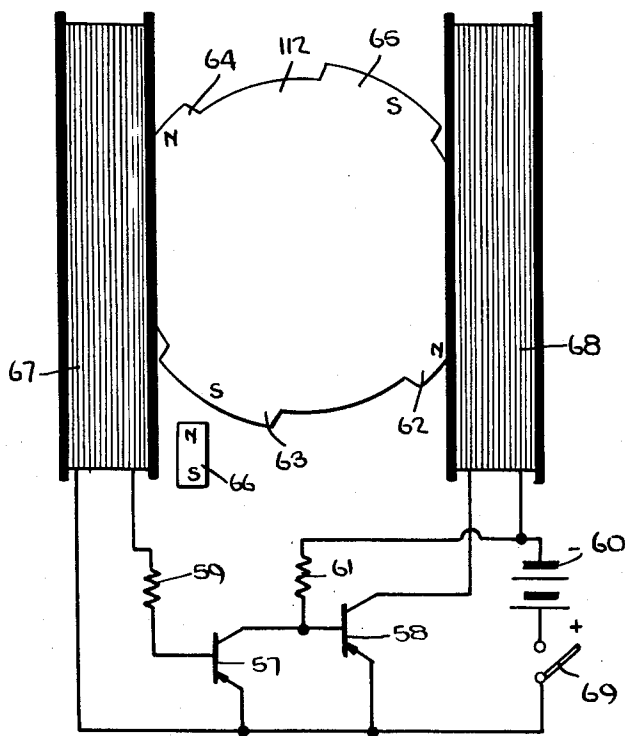


Fig. 4.

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CENTRIFUGAL SWITCH

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6 Claims. (Cl. 200—80)

This invention relates to self-starting, direct current motors, and particularly to commutatorless and constant-speed direct current motors. In particular the motor of the present invention is related to the transistor-commutated motors of my earlier Patents 2,719,944 and 2,769,946, although it differs from these prior motors in certain essential aspects that have a basic effect on the mode of operation and especially on the starting characteristics of the motor.

The features of this invention are to be found in the rotor and in the field structure as well as in the commutating arrangement. The rotor has an even number of permanently magnetized, alternately spaced north and south poles. The field structure includes a control coil, which is located adjacent to the circular path traversed by the poles as the rotor turns, and a driving coil which is located at another point adjacent to the same circular path and is connected by a commutating circuit to the control coil. The commutating circuit that connects the control and driving coils includes a pair of transistors, one of which is normally non-conductive when the motor is stopped but has an input circuit connected to the control coil to receive signal impulses generated in the control coil by the moving magnetic fields of the rotor poles when the motor is running. The other transistor has an output circuit connected to the driving coil, and this circuit is of the type that is conductive as soon as it is connected to a voltage source. As a result the driving coil becomes energized at the same time and causes the motor to start immediately. The output circuit of the first transistor is connected to the input circuit of the second to apply to the second transistor the amplified signal from the first. The polarity and amplitude of the amplified signal are such that the second transistor is momentarily rendered non-conductive, thus allowing the rotor to keep rotating.

Stationary magnetic means are located near the rotor to attract the magnetic poles of the latter to cause the rotor to come to rest with its magnetic poles in one of several limited angular positions relative to the driving coil when the motor is not running. The stationary magnetic means may be of magnetically soft material, in which case the rotor may stop in any one of several positions, the number of which is equal to the total number of north and south poles on the rotor. Alternatively, the stationary magnetic means may be one or more permanent magnets, in which case the number of possible rest positions of the rotor will be reduced by half. In the latter case the motor will not only be self-starting but will always start in one direction.

If magnetically soft material is used, the rotor may still be limited to one initial direction of rotation by attaching to it a governor, which operates during the starting period as a commutating switch that overrides the transistor circuit and connects the control coil to the voltage source as a second driving coil during starting. The commutating switch automatically disengages itself by centrifugal force after the rotor reaches a certain speed, and the transistor circuit then takes over to commute the driving coil. In a constant-speed motor the transistor circuit may be omitted, and the centrifugally-operated commutating switch may be used as a governor to permit the motor to operate at some fixed speed.

The invention will be described in greater detail in connection with the drawings in which:

FIG. 1 is a perspective cross-sectional view of the motor of the invention;

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FIG. 2 shows the commutator of the motor in FIG. 1; FIG. 3 is a schematic representation of the motor in FIG. 1 with one form of electronic circuit connecting the control coil and the driving coil;

FIG. 4 is a modification of the motor in FIG. 3; and FIG. 5 is a modified form of the circuit in FIG. 3.

In the cross-sectional view in FIG. 1 only the motor per se is shown in order to avoid the complexity of including circuit elements. The rotating parts of the motor include a rotating shaft 11 and a permanently magnetized rotor 12 and governor 13 attached to it. The governor also serves as a starting commutator if the motor is transistor-commutated. The rotor 12 is in the form of a disc or cylinder having an even number of permanently magnetized north and south poles around its periphery. In the embodiment shown in FIG. 1 there are two north poles and two south poles spaced 90° apart, and each is limited to a relatively small angular segment of the periphery of the disc. The magnetic material in the rotor must have a high coercive force to keep the poles relatively localized. The shaft 11 is supported by two ball bearings 14 and 16 which are held in place by a split cover consisting of a front section 17 and a rear section 18. These sections may be symmetrical to reduce the number of different parts in constructing the motor, and for small motors sections 17 and 18 may be molded of plastic.

The stationary field structure of the motor includes two coils 19 and 21 which are located on diametrically opposite sides of the shaft 11 adjacent to and partly enclosing the path traversed by the edge of the rotor 12. The coils are coaxial with each other and are wound on hollow rectangular forms 22 and 23, respectively, which are fitted in between the bottom and top of the half sections 17 and 18. Two pole pieces 24 and 26 of magnetically soft material, such as silicon steel, are secured in place adjacent to the coils 19 and 21. The lower pole piece 24 extends back to the side wall 25 of the section 17, while the upper piece 26 is symmetrically placed on the opposite side of the shaft 11 and extends from the other side wall (not shown) of the section 17 toward the side wall 25. Neither of the pole pieces 24 or 26 reaches completely across from one side wall to the other, as is indicated by the fact that only a small section of the upper piece 26 beyond the central plane of the motor appears in this figure.

The base of the governor 13 is a disc 27 attached to the end of the shaft 11 by means of a set screw 28. The disc has a rim 29 to which a cover 31 is attached by means of a pair of rivets 32 and 33. In the space bounded by the rim and between the disc 27 and the cover 31 are two weights 34 and 36 which are loosely attached to pivot on the rivets 32 and 33. A pair of arms 37 and 38 are attached to the weights 34 and 36, respectively, although only the weight 34 and the arm 38 appear in the cross-sectional view of FIG. 1.

The arms 37 and 38 are provided with electrical contacts 39 and 40 which extend through the central aperture 35 in the cover 31. In the present embodiment both of the contacts are alike and take the form of cylindrical rods attached near the end of the arms. The contacts 39 and 40 are connected by an S-shaped spring 41, only a small part of which appears in FIG. 1. This spring serves both as an electrical conductor between the contacts and as a means to force the contacts and, hence, the arms 37 and 38 apart when the governor 13 is at rest.

Four spring members 42-45 are evenly spaced around the path traversed by the contacts 39 and 40 so that as the governor 13 rotates the contacts will connect with these spring members in sequence and two at a time to form a direct path between diametrically opposite pairs of the spring members. The spring members are attached to a support plate 47 by means of rods 48-51 and are

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electrically connected to the windings of the coils 19—21, as will be described hereinafter. In order to insulate the four members 42—45 from each other, it is convenient to form the plate 47 of insulating material and it may then be used as a chassis for a transistor commutating circuit. The plate 47 is supported by a pair of machine screws 53 and 54 which also serve to hold a cover 56 in place.

The rotating parts of the governor 13 are shown more clearly in FIG. 2, which is an end view of the governor with the cover 31 removed. Both of the weights 34 and 36 are shown, together with their respective arms 37 and 38. The contact pin 39 extends from the arm 37 in a location symmetrical with that of the contact pin 40 on the arm 38.

The long, S-shaped spring 41 is preferably welded to both of the pins 39 and 40 and exerts a pressure on the pins that tends to hold the arms 37 and 38 apart, thus pulling the weights 34 and 36 together. As a result, each of the weights normally rests against the arm attached to the other weight, unless the diameter of the opening 37 in the cover 31 is so small that the contact pins 39 and 40 bear against it. Since the spring 51 conducts electrical current between contact pins 39 and 40, the disc 27 may be made of insulating material, such as molded plastic, although it can also be made of metal. Furthermore, conduction of electrical current from one of the contact pins to the other is not dependent upon the loose, pivotal connections of the arms 37 and 38 to the rivets 32 and 33.

When the shaft 11 rotates, carrying the disc 27 with it, the weights 34 and 36 pivot outwardly on the rivets 32 and 33 under the influence of centrifugal force. This moves the arms 37 and 38 closer together, thus lessening the distance between the contact pins 39 and 40 and compressing the spring 41. At any rotational speed of the governor 13 the distance between the pins 39 and 40 is primarily determined by an equilibrium between the force of the spring 41 on the pins and the centrifugal force on the weights. At a certain speed of the governor, inward movement of the arms 37 and 38 stops at the positions indicated in broken lines, either because the arms come together or because the outer edges of the weights strike the inner surface of the rim 29. In either case this fixes the minimum distance between the pins 39 and 40. A certain minimum speed is required to make the weights and arms assume the positions shown in broken lines but any rotational speed greater than this will keep them there.

The operation of the motor in FIG. 1 will be described with reference to FIG. 3 which shows the essential operating parts of the motor at rest and without the support structure. In addition to the motor parts, FIG. 3 also shows a transistor circuit for commutating the motor. This circuit includes two transistors, a control 57 and a power transistor 58, each operated with a grounded emitter. The base-emitter input circuit of the control transistor includes the coil 19 which, since it supplies signals to the control transistor, will be referred to as the signal, or pick-up, coil. A resistor 59 may be connected in series with the signal coil 19 to limit the current supplied to the base of the control transistor.

The output signal from the transistor 57 is derived at the collector electrode, which is connected directly to the base of the power transistor 58 to serve as an input, or control, signal for the latter. The emitter-collector circuit of the power transistor 58 is connected in series with the coil 21, and a power-supply battery 60 is connected across this series circuit. The remaining element of the transistor circuit, itself, is a biasing resistor 61 which may be made variable, as shown, to control the operation of the circuit. This resistor is connected in series between the base of the transistor 58 and one terminal of the battery 59.

The rotor 112 shown in FIG. 3 is essentially the same as the rotor 12 in FIG. 1 except for the fact that the magnetized pole areas 62—65 of the rotor 112 are salient poles.

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Two of the poles 62 and 64 are north poles and the other two poles 63 and 65 are south poles. The drawing depicts the rotor 112 at rest, with the poles 62—65 occupying the positions shown because of the magnetic attraction of the poles 62 and 63 for the magnetically soft member 24 and the corresponding attraction of the poles 64 and 65 for the symmetrically placed member 26. By placing the magnetically soft members 24 and 26 as shown, the rest position of the rotor 112 is such that none of the poles are directly aligned with the center of the coils 19 and 21 but, instead, the north poles 62 and 64 are displaced about 60° from the aligned position.

Alternatively, the rotor 112 could have stopped in three other positions that would appear the same as that shown except that the four poles 62—65 would have been displaced clockwise by 90°, 180°, or 270°. In each of the four possible rest positions of the rotor the same magnetic equilibrium would be obtained between the poles 62—65 and the stationary soft magnetic members 24 and 26.

The relative positions of the rotor 112 and the governor 13 are also shown in FIG. 3. The governor is placed so that the contact pin 39 rests against the spring member, or brush, 44, while the diametrically opposite pin 40 is against the corresponding brush 42. The latter is connected to the same terminal of the coil 19 that is connected, by means of the resistor 59, to the base of the control transistor 57. The brush 44 is connected to one pole of the battery 60.

The two remaining brushes 42 and 45 are connected, respectively, to the junction between the coil 21 and the collector of the power transistor 58 and to the common, or ground, terminal to which one pole of the battery 60 and the emitters of both transistors and one terminal of the coil 19 are also connected.

When the motor of FIG. 3 is set into operation, usually by connecting the battery 60 into the remainder of the circuit, there is an initial conductive circuit from the upper, negative terminal of the battery through the brush 44, the pin 39, the S-shaped spring 41, the pin 40, and the opposite brush 42 to the coil 19. Since the other terminal of the coil 19 is connected directly to the positive pole of the battery 60, the coil 19 is energized from the battery directly through this conductive circuit and independently of the transistor circuit.

The energizing current in the signal coil 19 sets up a magnetic field of such polarity as to attract the north pole 64 and to repel the south pole 65. The strength of the magnetic field produced by the coil 19 is in excess of the attraction of the poles 64 and 65 for the stationary iron member 26, and so the rotor 112 starts to turn in a clockwise direction.

As the rotor 112 turns, the governor 13 turns along with it and so the contact pins 39 and 40 slide across the surfaces of the brushes 44 and 42. By the time the rotor 112 is turned sufficiently to bring the north pole 64 in line with the coil 19, the contact pins 39 and 40 have moved entirely away from the brushes 44 and 42 so that the coil 19 is no longer connected in circuit with the battery 60. The magnetic field which was previously generated in the coil 19 thereupon collapses and the attraction of the magnetic poles 62—65 of the rotor for the soft iron pole pieces 24 and 26 again takes over control of the position of the rotor. However, since the rotor 112 has moved more than half way from one rest position to the next, it will not return to the previous rest position shown in FIG. 3 but will continue rotating to the next position exactly 90° removed from that of the figure. In this new position the contact pins 39 and 40 are against the spring brushes 43 and 45, respectively. This means that there is now a conductive circuit from the negative pole of battery 60 through the coil 21, the spring member 43, the contact pin 39, the S-shaped spring 41, the contact pin 40, and the spring member 45 to the positive pole of the battery. Therefore, the coil 21 is immediately energized and attracts the south pole 65 of the rotor 112 while repelling

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the north pole 62. As before, after the rotor 112 has moved something over 45°, the contact pins 39 and 40 move away from the brushes 43 and 45 and the coil 21 is disconnected from the battery 60. The rotor 112 thereupon continues to move forward until it is in a position 180° removed from that shown in FIG. 3, whereupon the coil 19 is again connected in series with the battery 16 to provide still another motor impulse. Finally a second motive impulse from the coil 21 brings the rotor 112 back into the original rest position.

There are thus four such motive impulses for each cycle of revolution of the rotor 112 while the motor is starting. This means that the starting torque is more evenly applied than would be the case for an ordinary two pole motor.

What has just been described might be considered as the static operation of the motor during one cycle. In addition to merely turning through one revolution, the rotor 112 normally accelerates, and the dynamic effect of this acceleration must also be considered. As the rotational speed of the governor 13 increases, centrifugal force on the weights 34 and 36 causes the latter to swing outward on the pivots formed by the rivets 32 and 33. As described in connection with FIG. 2, this causes the arms 37 and 38 to move closer together, thereby changing the points at which the contact pins 39 and 40 make contact with the brushes 42-45. As is indicated in FIG. 3, in the rest position the contact pins are far enough apart to cause the brushes 42 and 44 to bend backwards by a considerable amount. In the first one-fourth cycle of revolution, before centrifugal force has begun to move the weights 34 and 36, the contact pins will also strike the brushes 43 and 45 very close to their respective support rods 49 and 51, and as the governor 13 continues to turn, the contact pins 39 and 40 will slide along the brushes 43 and 45 for a considerable distance.

During the entire time that the contact pins 39 and 40 are touching the brushes 42 and 44, or 43 and 45, the coils 19, or 21, respectively, will be energized. As centrifugal force builds up, the weights 34 and 36 swing out and the arms 37 and 38 swing inward, so that the contact pins 39 and 40 make connection with the brushes 42-45 for shorter and shorter lengths of time. As a result, energizing current will be supplied alternately to the coils 19 and 21 for correspondingly shorter and shorter periods of time until, finally, the arms swing inward to the point where the contacts 39 and 40 no longer touch the brushes 42-45 at all. Thereafter the transistor circuit controls commutation.

If the losses induced by rotation are sufficient, either because of insufficient energy added to the rotational force on the rotor 112 by each of the motive impulses applied to it by alternate energization of the coils 19 and 21 or because of frictional or other losses of the load connected to the rotor, there may be a certain rotational speed at which the contact pins 39 and 40 make connection with the brushes 42-45 for just long enough to keep the rotor 112 turning at this fixed, or governed, speed. If the rotor 112 drops below the governed speed, centrifugal force on the weights 34 and 36 will be reduced and as a result the arms 37 and 38 will swing outward by a small amount thus allowing the contact pins 39 and 40 to remain connected to each of the brushes 42-45 for a slightly longer period of time. The result is that the motive impulses produced by the magnetic fields of the coils 19 and 21 will be slightly increased and will cause the rotor 112 to pick up speed slightly. On the other hand, if the rotor 112 accelerates to a greater speed than the governed speed, the arms 37 and 38 will swing still farther in toward the center, and the contact pins 39 and 40 will remain in connection with the brushes 42-45 for shorter periods of time, thus reducing the motive impulses supplied by the coils 19 and 21. Reduction of these motive impulses and the energy supplied by them to the rotor 112 results in a slight reduction in the rotational speed of the rotor, thereby bringing its rotational speed back to the governed speed.

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The effect just considered is entirely independent of the transistor circuit itself and in fact the latter may be entirely dispensed with for this type of governed speed operation. However, in that event, the contact pins 39 and 40 would be making and breaking connection with the brushes 42-45 four times during each cycle of operation, with all of the attendant disadvantages of an ordinary commutator type motor.

The criterion for the governor 13 is that as it speeds up the two arms 37 and 38 swing inward and thus change the diameter of the circle traversed by the contacts 39 and 40. By placing the contacts on the arms 37 and 38, which are on the opposite side of each of the fulcrums 32 and 33 from the respective weights 34 and 36, the circle traversed by the contacts becomes smaller as the weights move outward. The sensitivity of control of speed is greatest when the change in contact circle diameter is greatest per degree of movement of the arms 37 and 38. For a given length of lever arm this means that the contacts should move along arcuate paths that intersect at the center of rotation of the governor 13. Thus the distance from each of the rivets 32 and 33 to the respective contacts 39 and 40 is about the same as radial distance of the rivets from the center of the shaft 11. The various parts of the governor are preferably made symmetrical to their opposite members to keep the governor balanced for better high speed operation of the motor.

The operation of the transistor circuit will first be described on the assumption that the motor is running and that the contacts 39 and 40 have moved inward far enough so that the governor 13 has ceased to function as such. It will also be assumed that the rotor 112 happens, instantaneously, to be in the position shown in FIG. 3. The rotor is, of course, turning clockwise, since it would invariably start in that direction from any of its four rest positions because of the connections of the governor 13 and of the brushes 42-45.

With these assumptions, the south pole 65 of the rotor is moving away from the coil 19 and the north pole 64 is moving toward it. The changing magnetic flux linked to the coil 19 from the fields of these two poles generates in the coil a voltage of the proper polarity to cause the transistor 57 to become conductive. When this happens, the impedance of its emitter-collector circuit becomes very low and practically short circuits the base of the power transistor 58 to ground. This causes the latter transistor to become non-conductive, thus cutting off the flow of current through the coil 21. The magnetic field in the coil 21 collapses.

By virtue of its momentum the rotor 112 coasts until about the time the north pole 64 starts to leave the coil 19 and the south pole 63 approaches the coil 19. The rate of change of flux in the coil 19 and the magnetic polarity of the flux under these conditions are such as to generate a voltage of the opposite polarity, thereby biasing the transistor 57 to the non-conductive state, which means increasing greatly the impedance of its emitter-collector circuit.

The emitter-collector circuit of transistor 57 is, in effect, part of a voltage divider connected across the terminals of the battery 60. The resistor 61 is the other part of this voltage divider, and as the impedance of the emitter-collector circuit increases, the voltage level at the midpoint of the divider changes so as to approach the potential of the negative terminal of the battery 60. At a certain voltage level of this midpoint the base of the transistor 58 becomes biased to the conductive state, and the impedance of the emitter-collector circuit of the transistor 58 rapidly drops, thereby allowing current to flow through it and through the coil 21 connected in series with it. This current produces a magnetic field in the coil 21 that attracts the south magnetic pole 65 and provides a motive impulse to the rotor 112. If the coil 21 remained energized, the rotor would stop with the south pole 65 pointing toward the coil 21, but before this can happen,

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another voltage impulse, or signal, is developed in the coil 19 by the moving magnetic field of the rotor pole 63 that again renders transistor 57 conductive and reduces the voltage level at the midpoint of the base of transistor 58 by an amount sufficient to cause the emitter-collector circuit of the latter to become non-conductive. As before, this results in the collapse of the magnetic field of the coil 21, which no longer attracts the rotor pole 65.

The voltage generated in the coil 19 as the rotor 112 continues to turn is of such polarity and magnitude as to keep the coil 21 from being energized while the rotor pole 64 is approaching a position of alignment with the axis of the coil 21. However, when the pole 64 has reached a position where the coil 21 may be safely re-energized without fear of stopping the rotor 112, another voltage signal is generated in the coil 19 to render the transistor 57 non-conductive and the transistor 58 conductive. The resultant conduction of current through the coil 21 causes a renewal of the magnetic field in the latter to repel the north rotor pole 64 and attract the next south pole 63. As in the case of the preceding south pole 65, the transistor 58 is again made non-conductive in time to permit the pole 63 to pass through the coil 21. This completes the description of a complete cycle of the rotor 112. In each such cycle the coil 21 is energized only to attract the two south poles 63 and 65. It should also be mentioned that, if the rotor 112 were somehow started in the reverse direction, it would continue to run counter-clockwise about as well as it runs clockwise.

In connection with the operation of the transistors, the power transistor 58 should preferably be operated as a switch, which is either highly conductive or entirely non-conductive, rather than as an amplifier, the degree of conductivity of which would be determined by the waveform of the signal generated in the coil 19. The amplitude of the signal applied to the base of the control transistor 57 is one of the factors that determines whether the power transistor operates as a switch or as an amplifier. The signal amplitude, in turn, is dependent on the intensities of the magnetic fields of the poles 62-65, the coupling, or interaction, between these fields and the coil 19, the number of effective turns in the coil, the boundaries of the magnetized areas of the rotor poles 62-65, the non-magnetized area between adjacent poles, and the extent to which the poles enter the coil 19. It is preferable that the coil 19 be placed close enough to the center of the rotor so that the periphery of the rotor, including at least part of the magnetized areas of the poles 62-65 passes into the coil, and it is also preferable that the arcuate extent of each pole be great enough so that one pole will be partly, but not wholly, within the coil 19 before the preceding pole has entirely left the coil. By virtue of this arrangement, and a similar positioning of the coil 21, it might be expected that there would be excessive coupling between the two coils that would result in causing the transistor circuit to oscillate, but the four rotor poles 62-65 prevent any such oscillations.

In starting the motor of FIG. 3, both the transistor circuit and the governor 13 contribute. Starting from the position shown, several things happen simultaneously when the battery 60 is connected. In the first place, the coil 19 is energized, as was described previously, but in addition, the collectors of both transistors are supplied with operating potential. Also, the bias resistor 61 is connected to the battery to provide an operating bias that might be expected to render the transistor 58 instantaneously conductive. However, the same voltage that energizes the coil 19 also is applied through the resistor 59 to the base of the transistor 57 to make the latter conductive and thus bias the power transistor 58 to the non-conductive state. Thus, the effect of the governor 13 is similar, or at least complementary, to the transistor circuit, and no sharp jump in operation is required when the transistor circuit later takes over from the starting governor.

One of the advantages of the present invention is that

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the resistor 61 may serve as a speed control. The higher the value of the resistance 61, the smaller will be the conduction current through the emitter-collector circuit of the power transistor 58 and therefore the weaker will be the motive impulses supplied to the rotor 112. As a result the rotor will slow down. A reverse variation of resistance of the resistor 61 will cause the rotor 112 to speed up. This allows the speed of the rotor to be changed by variations in a resistor that carries very little current.

Another advantage of the circuit is that there is inherent temperature compensation over a wide range. The reason is that both transistors 57 and 58 react to temperature changes in the same way; the impedance of the emitter-collector circuits of both transistors increases as the temperature decreases. By making the resistor 61 relatively insensitive to temperature changes, the effect of the change in bias level on the base of the transistor 58 due to a temperature-induced change in the characteristics of the emitter-collector circuit of the transistor 57 can be cancelled out by a similar change in the emitter-collector characteristics of the transistor 58.

FIG. 4 shows a modification of the motor of FIGS. 1 and 3. In FIG. 4 the governor 13 is omitted and the motor is started on transistor circuit, which is identical with that in FIG. 3. The running characteristics of the motor in FIG. 4 are the same as those of the motor in FIG. 3. Only the starting characteristics differ and need to be explained.

A small magnet 66 is located adjacent to the path traversed by the rotor poles 62-65. The function of this magnet is basically the same as that of the magnetically soft members 23 and 26 in FIG. 3: it causes the rotor 112 to come to rest in certain limited positions. However, since the magnet 66 is polarized, only two of the rotor poles can come to rest adjacent to it. These are the south poles 63 and 65 in the embodiment shown. Use of the magnet 66 thus reduces the number of rest positions of the rotor to two, the same as the number of south poles of the rotor. It also makes the magnetically soft members 24 and 26 unnecessary, and they may, if desired, either be eliminated entirely or replaced by magnetically soft bands 67 and 68 which extend completely around the coils 19 and 21, respectively.

As before, when the switch 69 is closed to energize the transistor circuit, the power transistor 58 becomes conductive immediately, and current flows through the series circuit comprising the coil 21 and the emitter-collector circuit of the transistor 58. This current generates in the coil 21 a magnetic field of the proper polarity to repel the north rotor pole 62 and to attract the south pole 65. These poles are so oriented in the rest position that the rotor 112 must revolve through an angle of about 60° before the pole 65 becomes aligned with the coil 21. This is sufficient to impart a momentum that will carry the rotor another 90° or more, without any motive impulses. The second motive impulse is not started until the south pole 63 is approaching the coil 21. By that time, the motor may be considered to be running, rather than still in the starting phase.

It should be noted that the position of the magnet 66 is such as to cause a strong initial motive impulse to start the rotor 112. The weakest possible motive impulse would occur if the south pole 65 were directly aligned with the coil 21. With a light load on the motor, the rotor 112 would start revolving if the magnet 66 were so positioned as to cause the rotor to have a rest position not far removed from alignment, but for starting heavier loads, the south pole should be approximately 60° away from alignment. In that way there will be no ambiguity as to whether the south pole 65 or the opposite south pole 63 is to be attracted. This consideration of the rest position of the rotor in the motor of FIG. 4 is more necessary than in the motor of FIG. 3 because the latter has four motive impulses per revolution at the start, whereas

the latter has only two per revolution at the start as well as when running.

It cannot be assumed that the voltage of the battery 60 in FIG. 4 will remain constant throughout the operating period of the motor. A change in the battery voltage will normally cause a speed change in the motor, and this is frequently not desirable. FIG. 5 shows a modification that may be added to the circuits of FIGS. 3 or 4 to help govern the speed of these motors when they are operating with transistor commutation.

In FIG. 5 a Zener diode 71 is connected in series between the base of the power transistor 58 and the base of the transistor 57. This diode is polarized to be conductive as soon as the voltage level at the base of the power transistor becomes negative with the voltage on the base of the transistor 57 by more than the fixed breakdown voltage of the diode. This would occur if the voltage of the battery 60 were too high. This high voltage would cause the rotor 112 to speed up. At the same time it would cause the diode 71 to become conductive and to connect the excessively negative voltage to the base of the transistor 57, thereby making the latter conduct prematurely. This would render the power transistor 58 non-conductive and would cut short the motive impulse being applied, thus bringing the rotor speed back down.

While this invention has been described with reference to particular embodiments, those skilled in the art will recognize that the novel concept set forth in the following claims is not limited thereto.

I claim:

1. A balanced governor for an electric motor comprising a rotating shaft, at least one driving coil, and a pair of relatively fixed contacts, at least one of said contacts being connected to said coil, said governor comprising: a base member for attachment to said rotating shaft; a pair of weights pivotally attached to points of said member on opposite sides of said shaft, said pivot points being removed from the center of rotation of said member to permit said weight to pivot away from the center of said member as said member rotates; spring means biasing said weights inwardly toward the center of rotation of said member; a pair of arms, each of said arms being attached to one of said weights to pivot therewith and each of said arms extending on the opposite side of the center of rotation of said member from the weight to which it is attached, whereby, as said weights pivot in response to the centrifugal force developed during rotation of said member; each of said arms swings toward the center of rotation of said member; and a pair of moving contacts, one of said contacts being located on each of said arms, respectively, to make connection in alternation with said relatively fixed contacts to permit said driving coil to receive electric current intermittently.

2. The governor of claim 1 in which the distance between the pivot point on each of said weights and the moving contact on the arm attached to said weight, respectively, is approximately equal to the radial distance between the center of rotation of said member and the pivot points of said weights, respectively.

3. A balanced governor for an electric motor comprising a rotating shaft, at least one driving coil, and a pair of relatively fixed contacts, at least one of said contacts being connected to said coil, said governor comprising: a base member for attachment to said rotating shaft; a pair of weights pivotally attached to points of said mem-

ber on opposite sides of said shaft, said pivot points being removed from the center of rotation of said member to permit said weight to pivot away from the center of said member as said member rotates; a spring biasing said weights inwardly toward the center of rotation of said member; a pair of arms, each of said arms being attached to one of said weights to pivot therewith and each of said arms extending on the opposite side of the center of rotation of said member from the weight to which it is attached, whereby, as said weights pivot in response to the centrifugal force developed during rotation of said member, each of said arms swings toward the center of rotation of said member; and a pair of moving contacts, one of said moving contacts, being located on each of said arms, respectively, to make connection in alternation with said relatively fixed contacts to permit said driving coil to receive electric current intermittently, said spring being connected to both of said contacts to form an electrical connection therebetween.

4. A balanced governor for an electric motor comprising a rotating shaft, at least one driving coil, and a pair of relatively fixed contacts, at least one of said contacts being connected to said coil, said governor comprising: a base member for attachment to said rotating shaft; a pair of weights; a pair of pivot pins in said base member substantially equally spaced from the center of rotation of said base member and on diametrically opposite sides of said center, said weights being attached to said pivot pins to rotate freely thereon through a limited angle; a pair of arms attached to said weights, each arm being attached to one of said weights, respectively, and extending on the other side of said center from said weight; a pair of moving contact members, each of said moving contact members extending from a respective one of said arms in a direction perpendicular to the plane of rotation of said weights to make connection in alternation with said relatively fixed contacts to permit said driving coil to receive said electric current intermittently; a spring biasing said weights inwardly toward said center of rotation and biasing said moving contact members away from said center of rotation, whereby centrifugal force on said weights overcomes the force of said spring and pivots said weights about said pins and in a direction away from said center of rotation and simultaneously pivots said arms and said moving contact members toward said center of rotation, said spring being electrically connected to both of said moving contact members to form a conductive path therebetween.

5. A balanced governor as described in claim 4 in which said spring is S-shaped and is looped around each of said pivot pins.

6. A balanced governor as described in claim 4 comprising in addition a cover attached to the periphery of said base member and covering said weights and said arms and spaced therefrom, said cover having an aperture therein over said center of rotation, and said moving contact members extending through said aperture.

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