(12) UK Patent Application (19) GB (11) 2 324 956 (13) A

(43) Date of A Publication 11.11.1998

(21) Application No 9709179.7

(22) Date of Filing 06.05.1997

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(51) INT CL^6
A47L 9/04 9/00, H02K 7/116 7/14 16/02 // B03C 3/66, H02K 9/06 17/00 19/00 29/00

(52) UK CL (Edition P)
A4F FD12 FSDM
H1T T1C T12
H2A AKJ9B AKQ1 AKRR AKX1 AK100 AK111 AK112 AK116 AK121 AK201 AK208 AK215U AK218S AK220B AK807 AK814 AK820
H2H HAMF HAMJ HB8 HEP
H2J JCSS

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(58) continued overleaf

(54) Abstract Title
Motor for domestic appliance

(57) A domestic appliance incorporates a brushless motor (such as a switched reluctance motor or a stepper motor), which is used to power a plurality of separate features of the appliance. The appliance can be a vacuum cleaner in which the brushless motor acts as a transformer to supply power to a secondary motor in a vacuum cleaning head or to an electrostatic filter. The motor can comprise a stator and at least one winding and at least two rotors.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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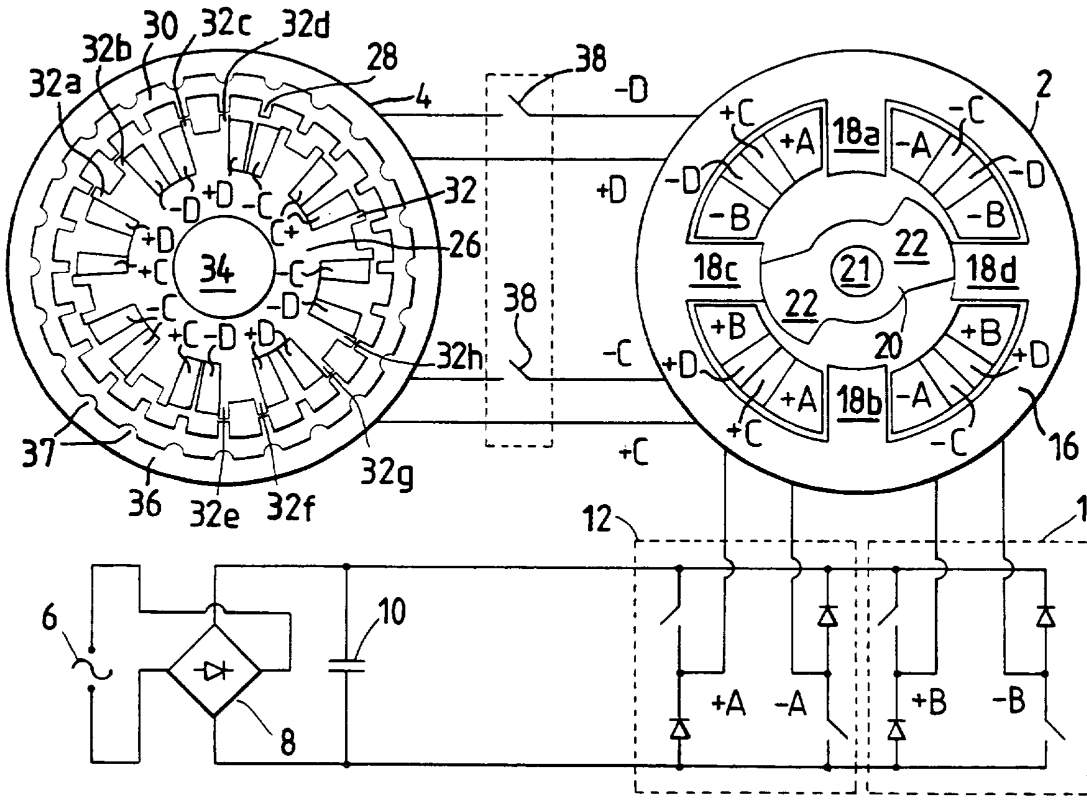
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FIG.1

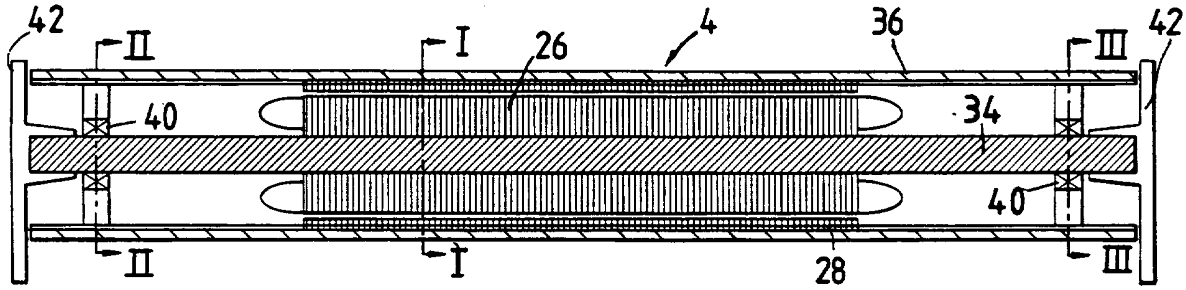


FIG.2a

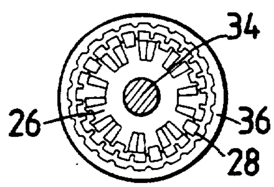


FIG.2b

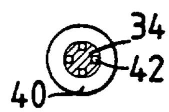


FIG.2c

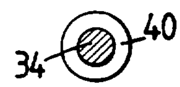


FIG.2d

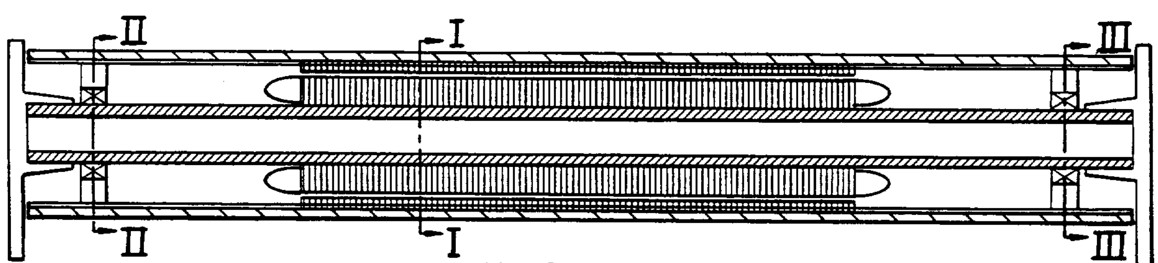


FIG.3a

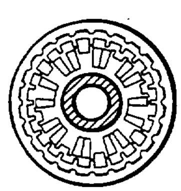


FIG.3b

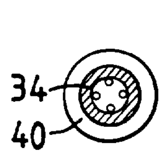


FIG.3c

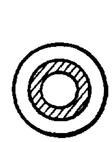


FIG.3d

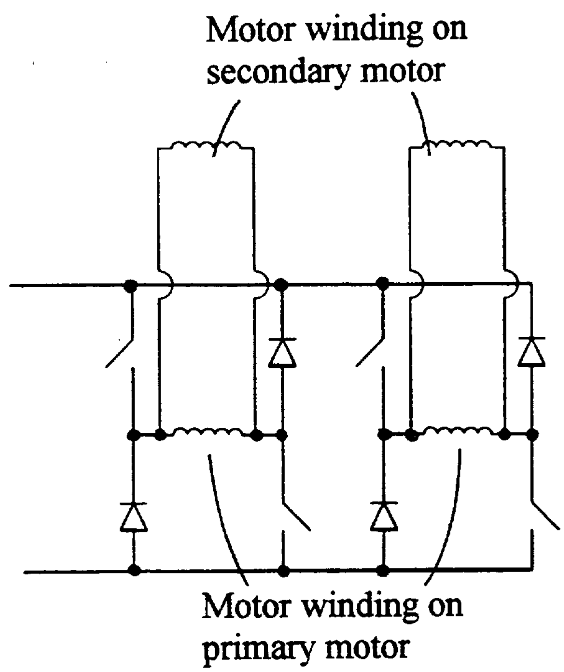

Motor winding on
secondary motor
Motor winding on
primary motor

FIG. 4a

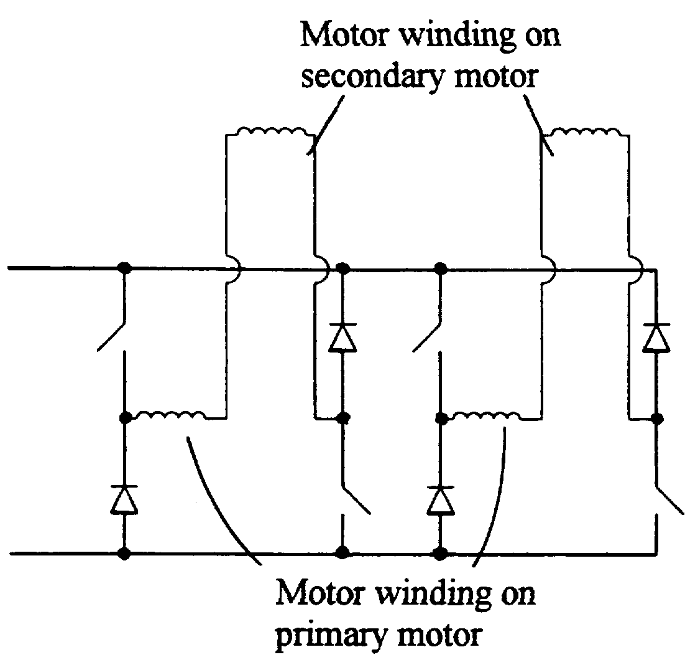

Motor winding on
secondary motor
Motor winding on
primary motor

FIG. 4b

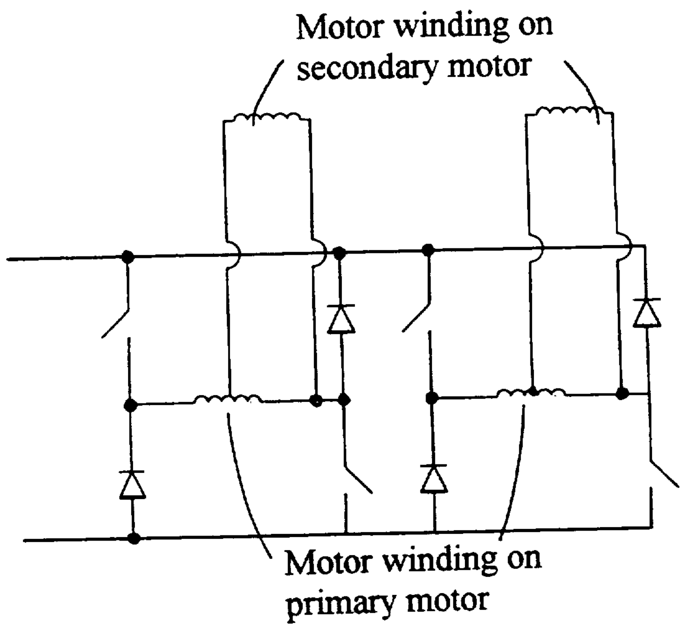
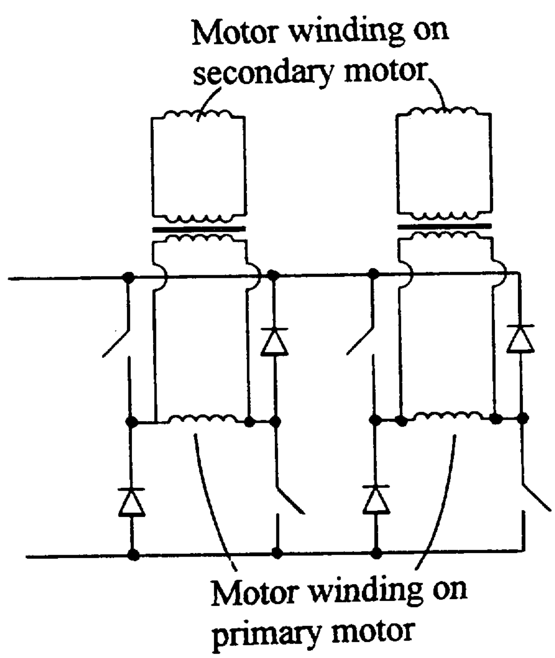

Motor winding on
secondary motor
Motor winding on
primary motor

FIG.4c


Motor winding on
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Motor winding on
primary motor

FIG.4d

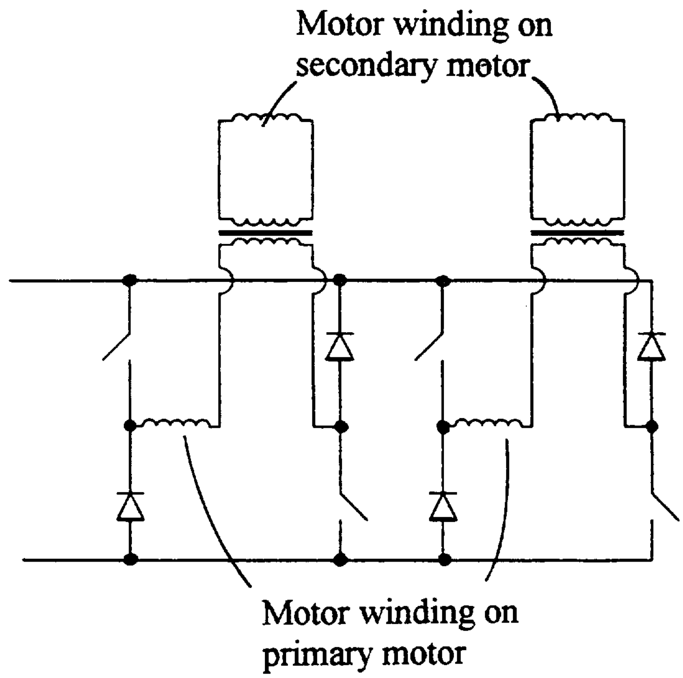
Motor winding on
secondary motor
Motor winding on
primary motor

FIG. 4e

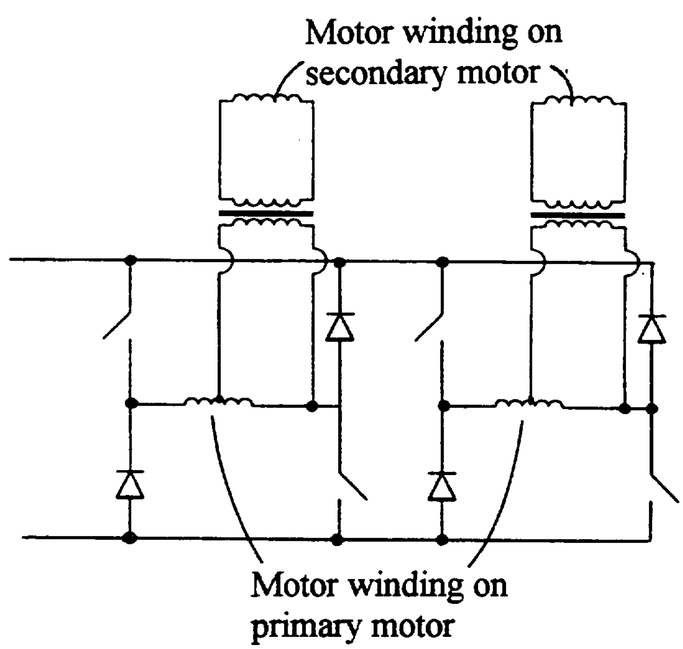
Motor winding on
secondary motor
Motor winding on
primary motor

FIG. 4f

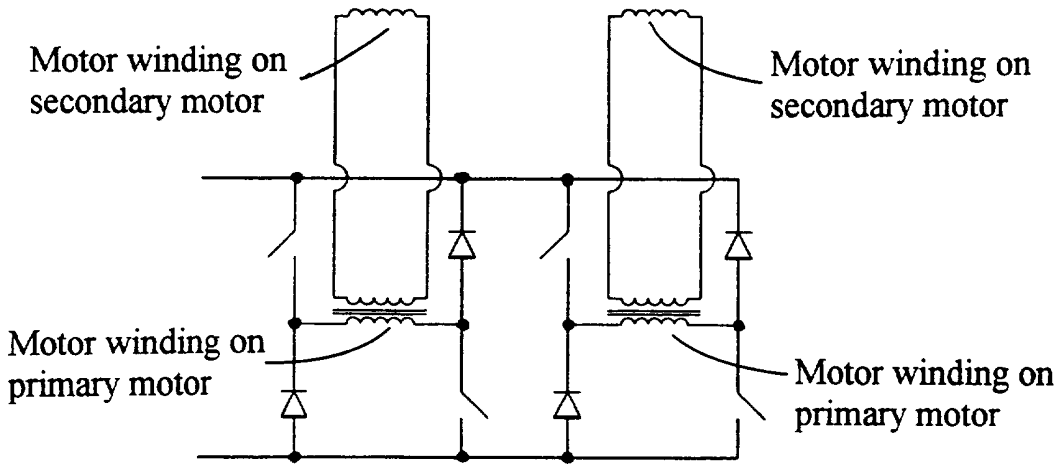

FIG. 4g

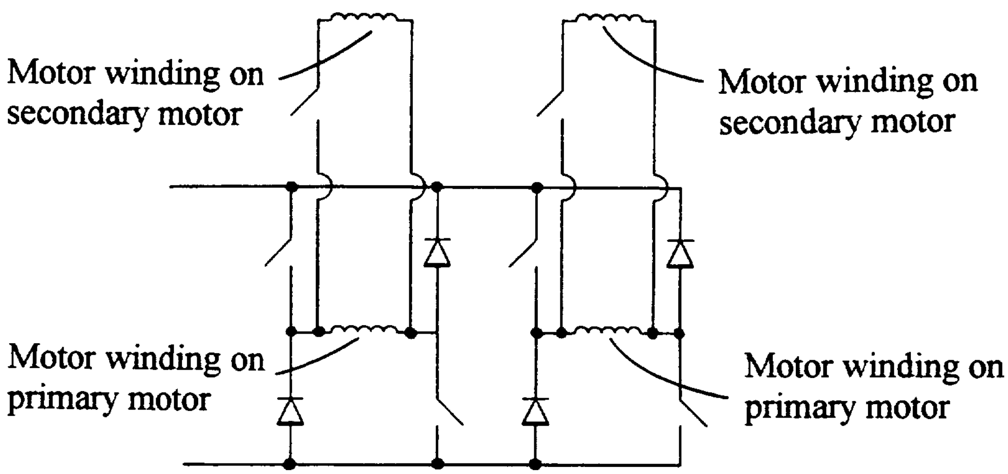

FIG. 4h

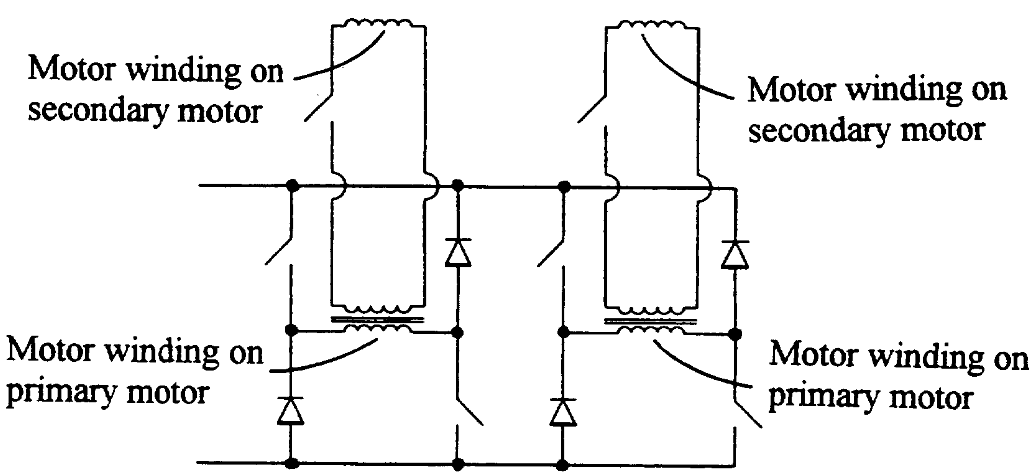

FIG. 4i

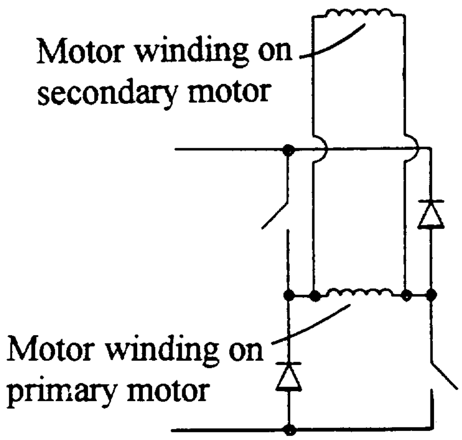

FIG.5a

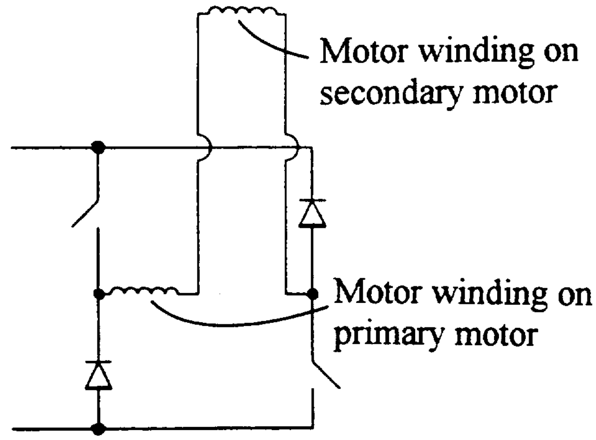

FIG.5b

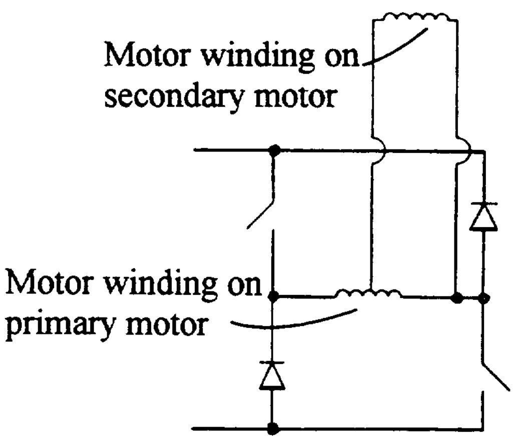

FIG.5c

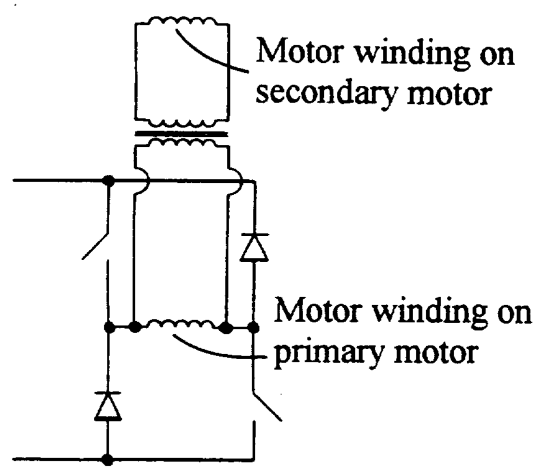

FIG.5d

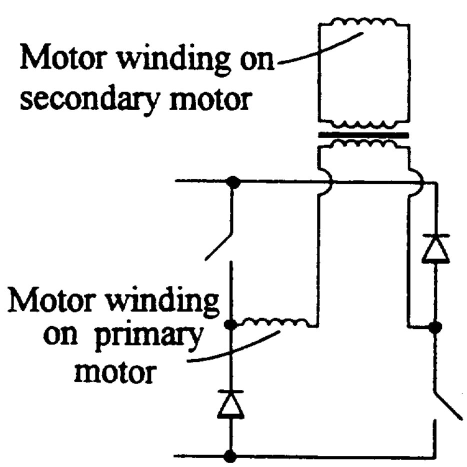

FIG 5e

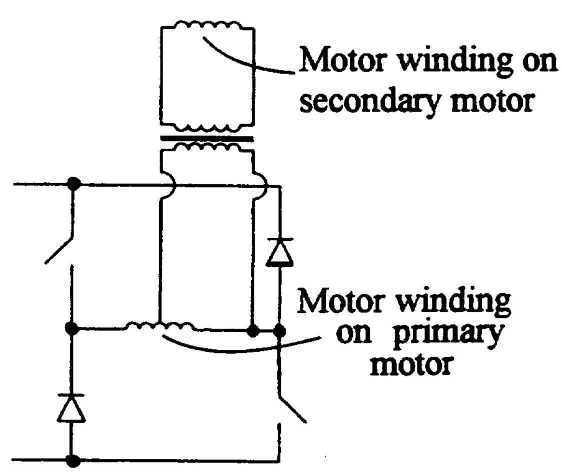

FIG 5f

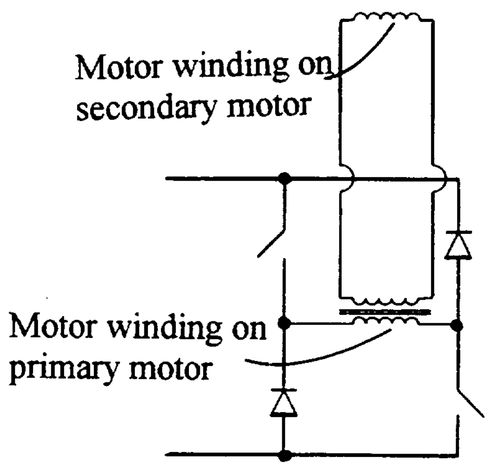

FIG.5g

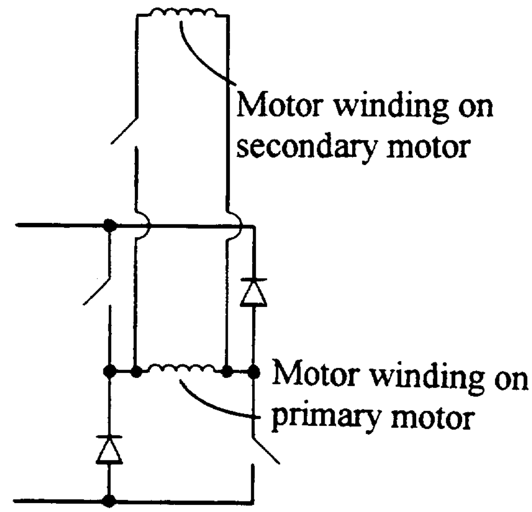

FIG.5h

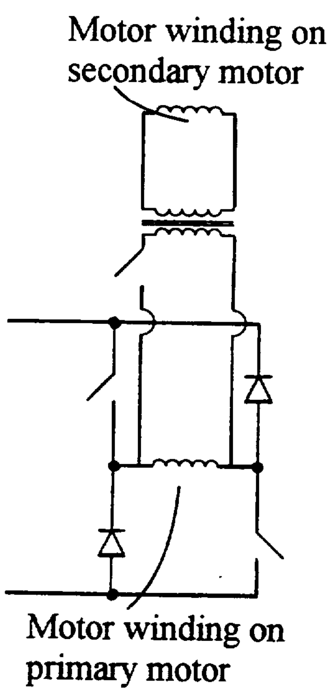

FIG.5i

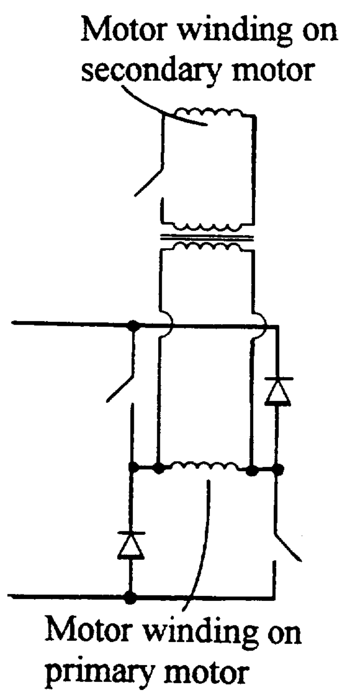

FIG.5j

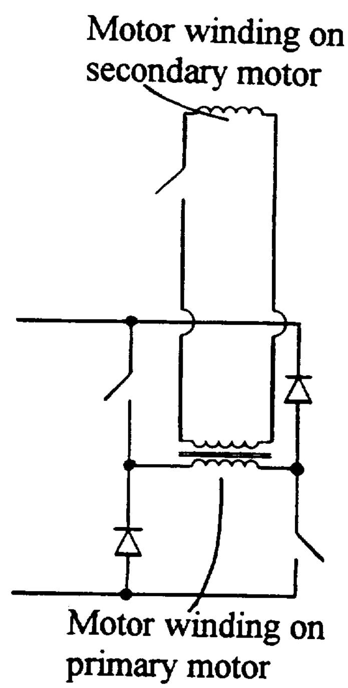

FIG.5k

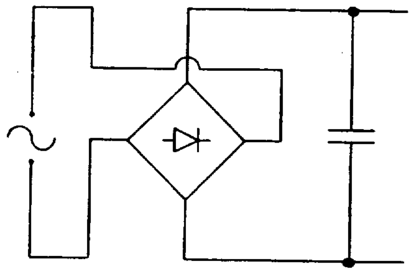

FIG.6a

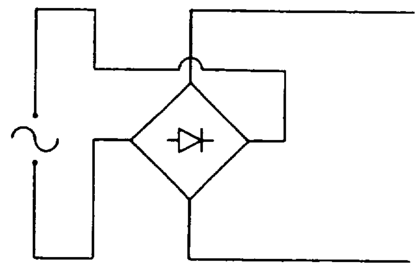

FIG.6b

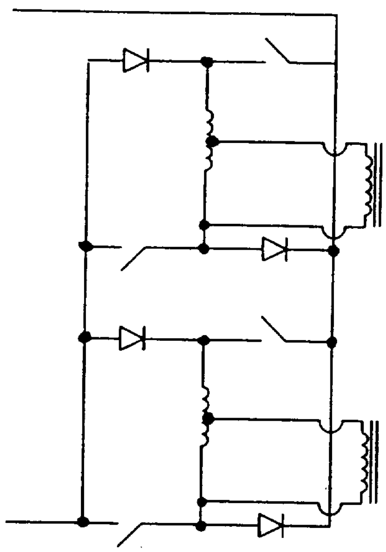

FIG.6c

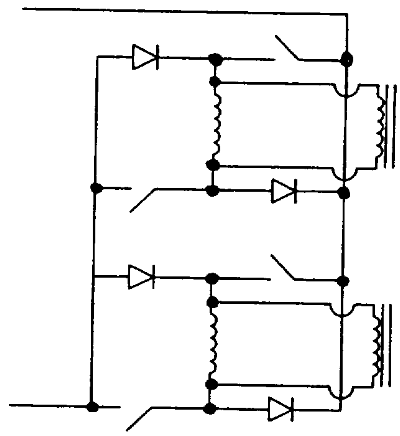

FIG.6d

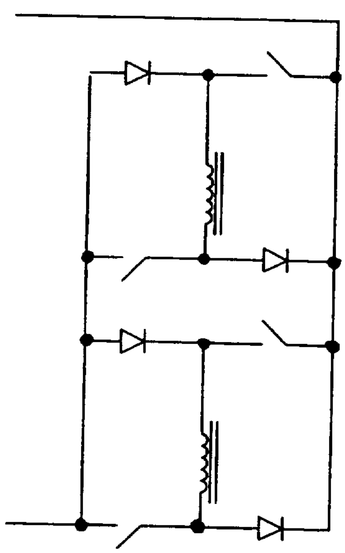

FIG.6e

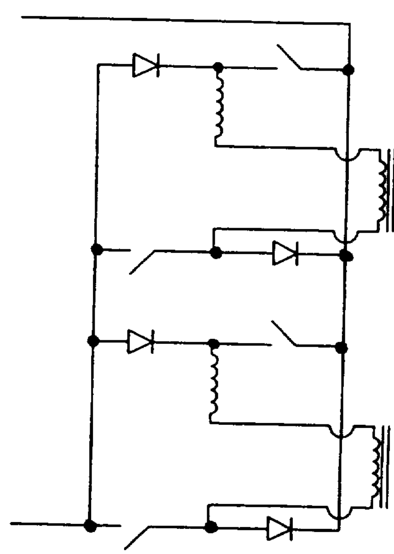

FIG.6f

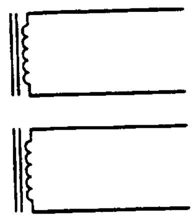
FIG.6g

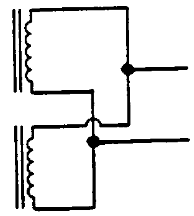
FIG.6h

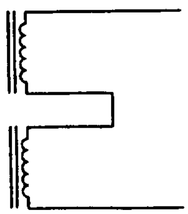
FIG.6i

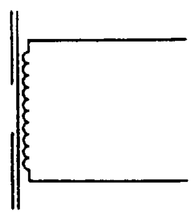
FIG.6j

FIG.6k

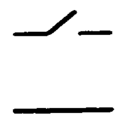
FIG.6l

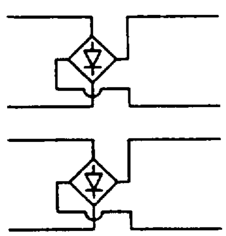
FIG.6m

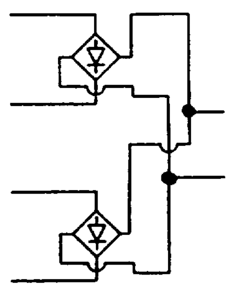
FIG.6n

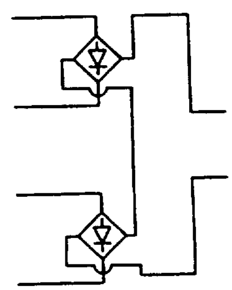
FIG.6o

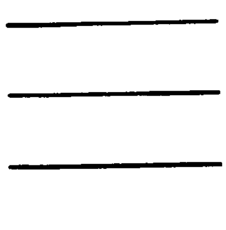
FIG.6p

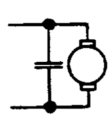
FIG.6q

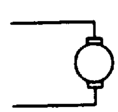
FIG.6r

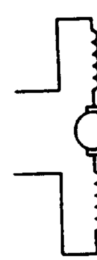
FIG.6s

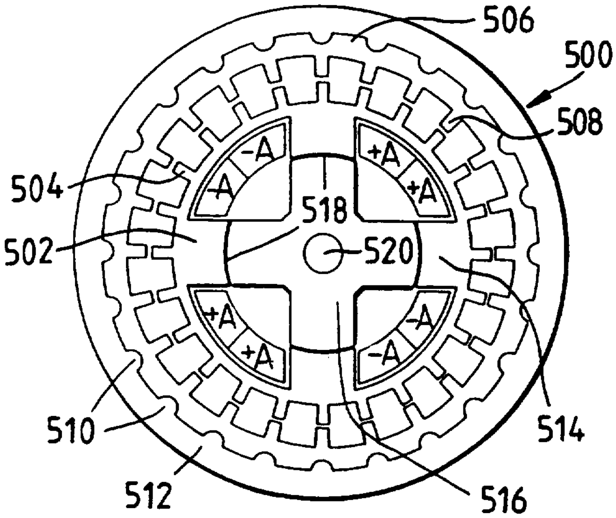

FIG.7a

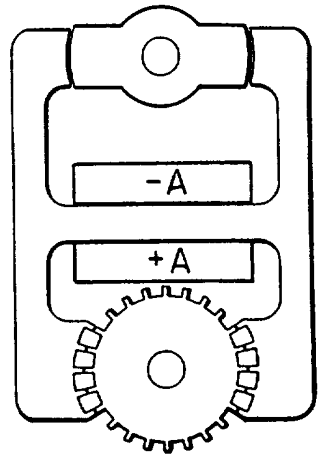

FIG.7b

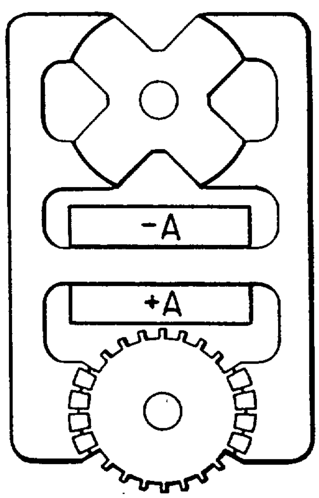

FIG.7c

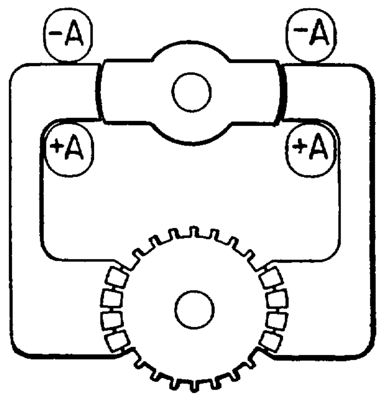

FIG.7d

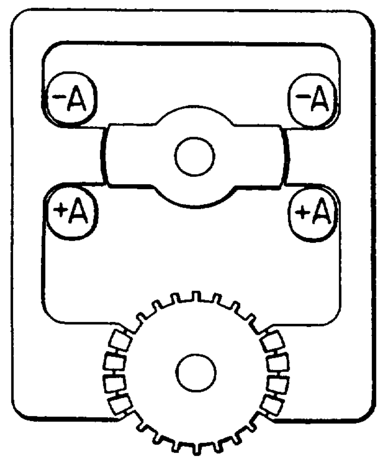

FIG.7e

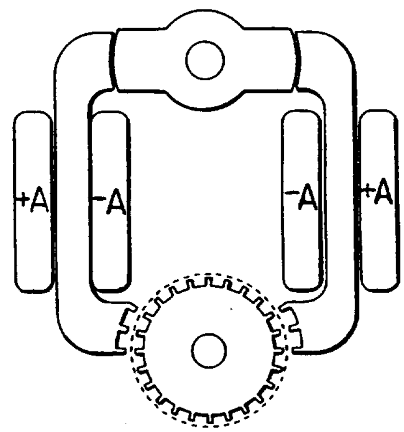

FIG.7f

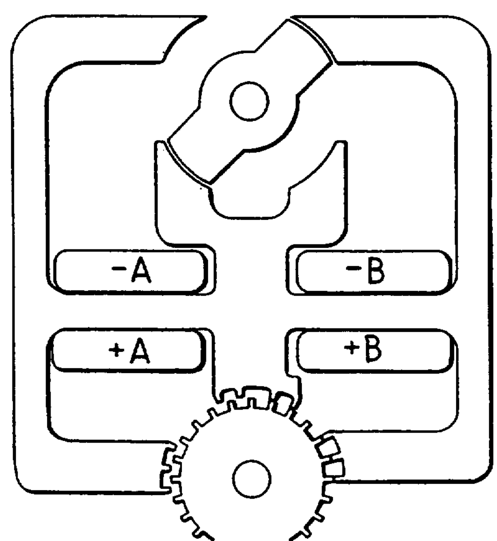

FIG.7g

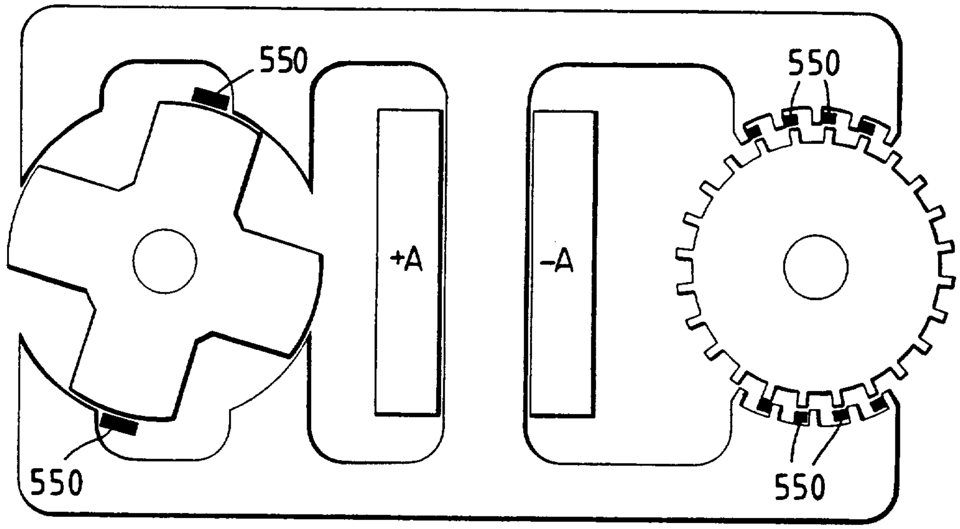

FIG.8a

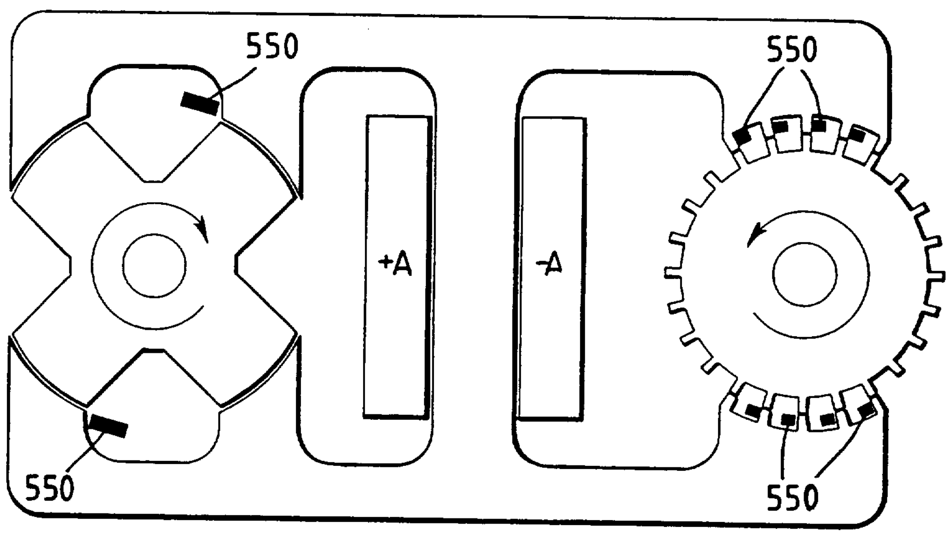

FIG.8b

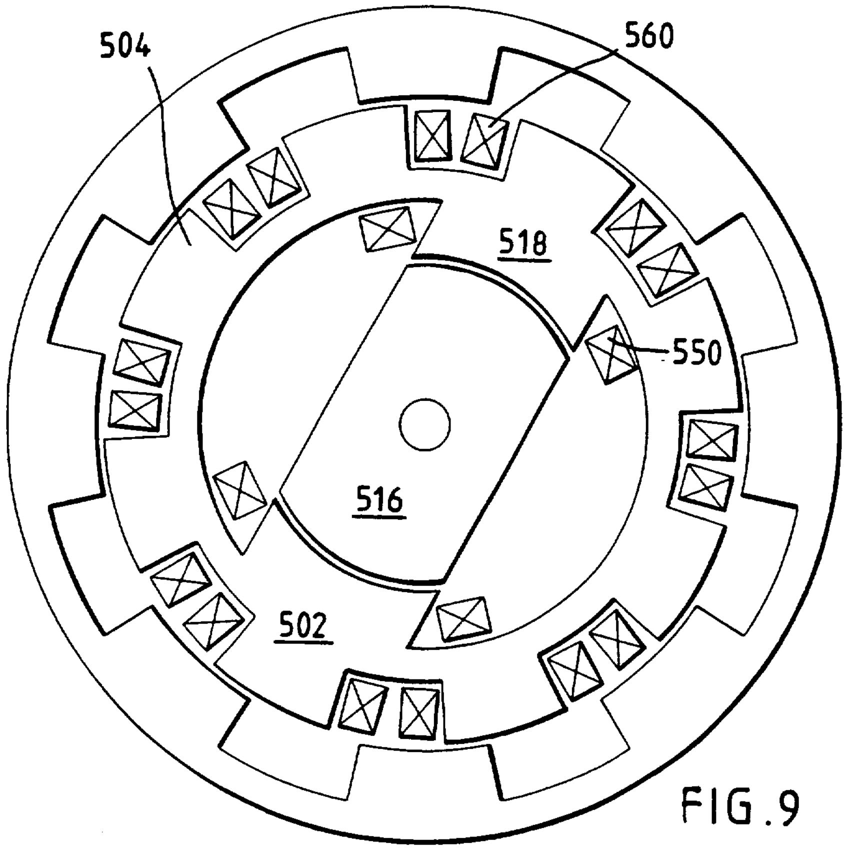

FIG.9

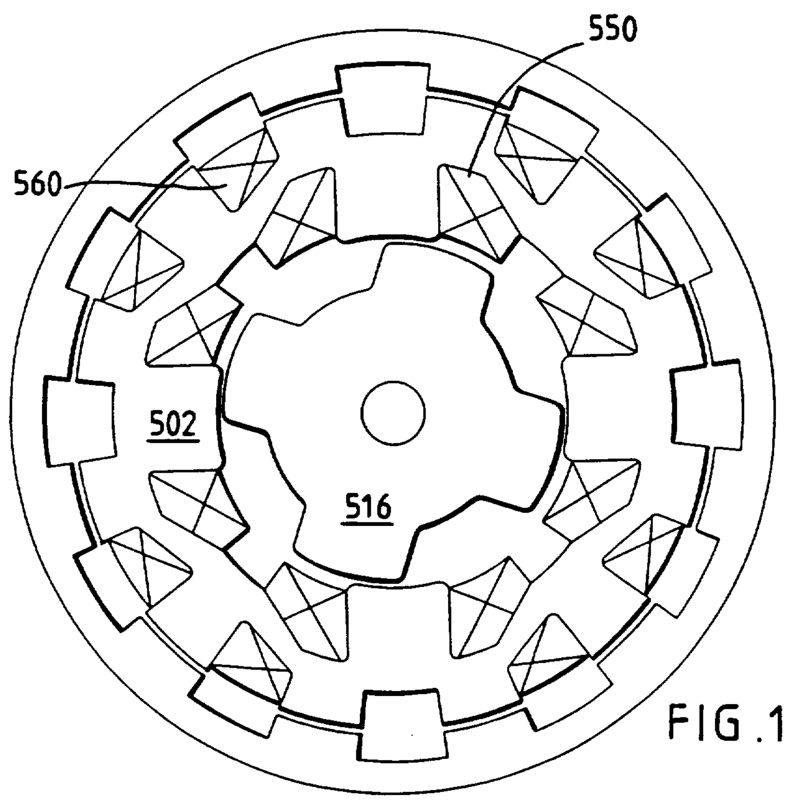

FIG.10

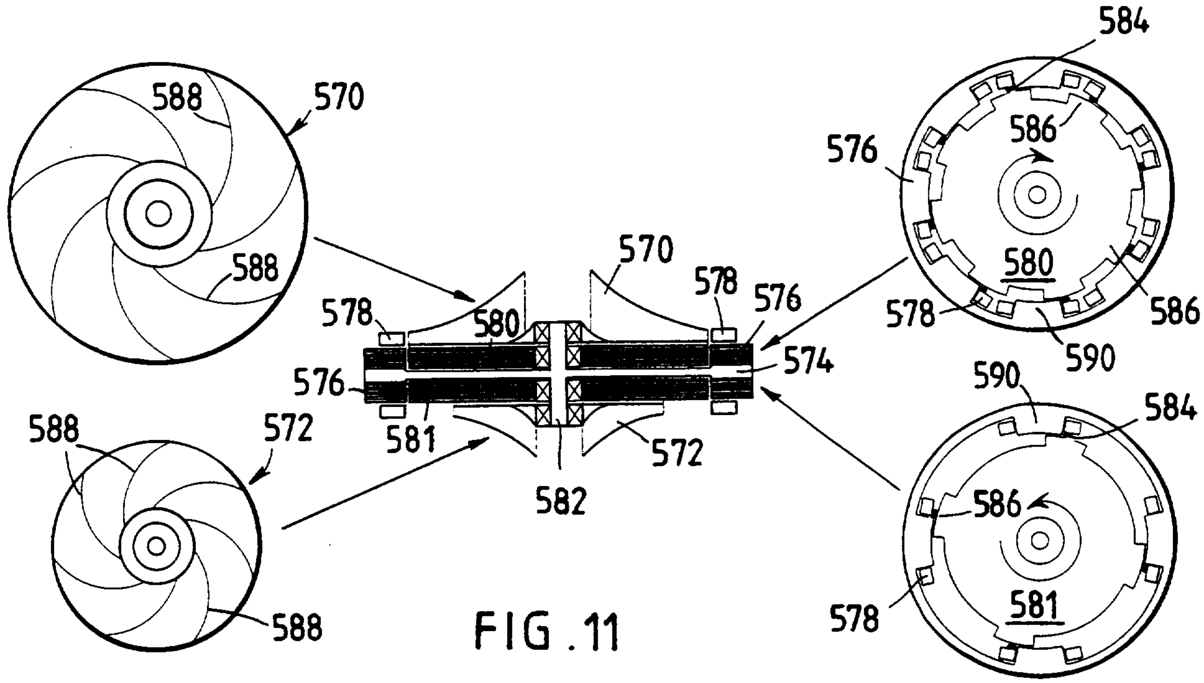

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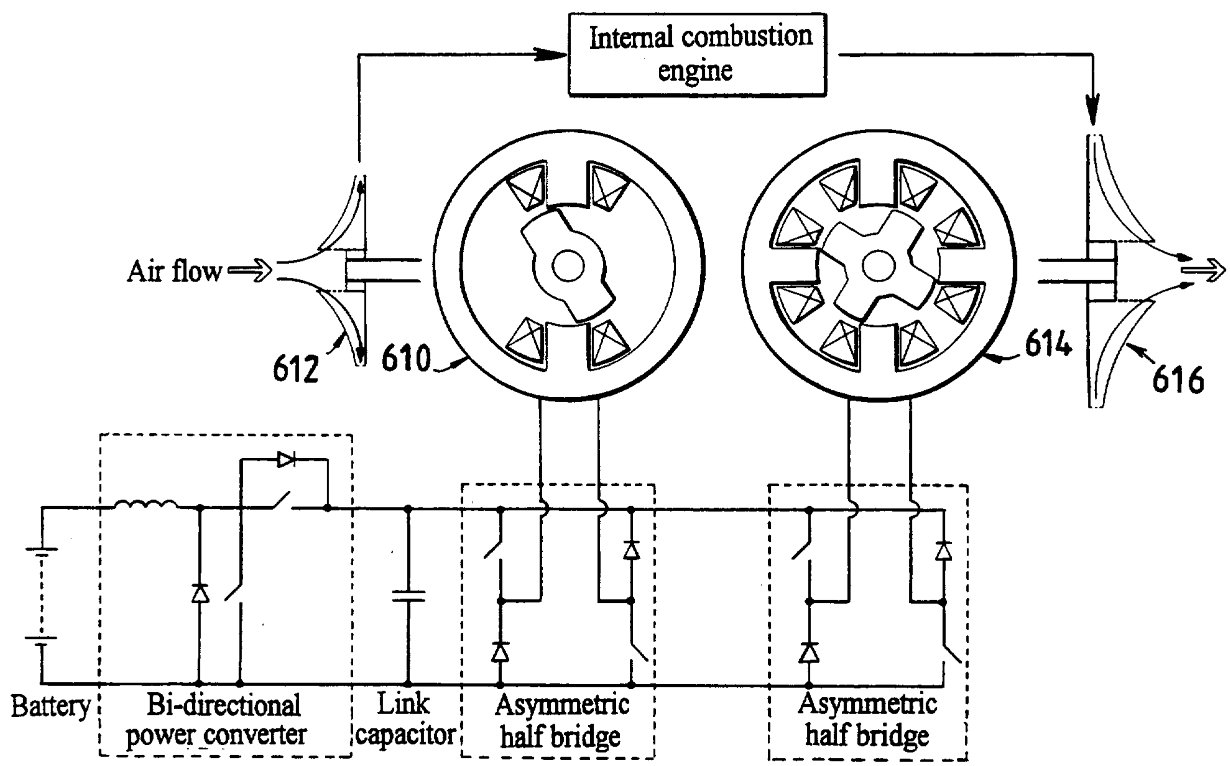
FIG. 11



Internal combustion engine
Air flow
612
610
614
616
Battery
Bi-directional power converter
Link capacitor
Asymmetric half bridge
Asymmetric half bridge

FIG. 12

DOMESTIC HOUSEHOLD APPLIANCE AND MOTOR

The invention relates to a domestic household appliance, particularly but not exclusively to a vacuum cleaner. The invention also relates to a motor.

Many developments have been made over the years to the motors which are used in domestic household appliances. However, it is generally believed that the trend of improvements in relation to universal motors is nearing its end. It is therefore an object of the present invention to provide a domestic household appliance having a motor which is suitable for providing the appropriate power to various parts of the appliance and which also has scope for improvement beyond the potential of known universal motors.

Domestic vacuum cleaners very often include a universal motor adapted to drive the fan used to create the suction by means of which air is drawn into the vacuum cleaner. When the vacuum cleaner is an upright cleaner, a brush bar is usually mounted rotatably in the dirty air inlet located in the cleaner head. The brush bar is rotated by means of a drive belt extending between the motor and the brush bar. There are many disadvantages of this arrangement, not least of which is the vulnerability of the drive belt itself. Other disadvantages include the fact that, in most cases, the drive belt engages with a portion of the outer surface of the brush bar which means that brush bristles cannot be located in that area. It is also advantageous to have some sort of mechanism for preventing the brush bar from rotating against a carpet to be cleaned if, for any reason, the motor is left running whilst the vacuum cleaner remains stationary, for example, whilst carrying out above-floor cleaning.

In a cylinder cleaner, the dirty air inlet is situated at the end of a hose, hence a drive belt to the main vacuum motor is impractical, and driving the brush bar directly by a secondary universal motor has practical difficulties.

It is therefore an object of the invention to provide a vacuum cleaner having a driven brush bar but which reduces or eliminates the problems identified above.

In a first aspect of the invention, a domestic household appliance as set out in claim 1 is provided. Preferred features of the invention are set out in subsidiary claims 2 to 10.

The provision of a brushless motor, such as a switched reluctance motor or a stepper motor, in a domestic household appliance allows much greater use to be made of the power available from the motor. Voltage and frequency transformation can be carried out using components which are compact and inexpensive when the transformation takes place at high frequencies. Power can then be supplied to a plurality of separate features of the appliance without significantly increasing the volume of the appliance or its overall mass. The components required to convert the power supply from a universal motor to suitable voltages and frequencies for the separate features of the appliance would be more expensive, more bulky or both.

According to a second aspect of the invention, a vacuum cleaner is provided in accordance with the features of claim 11. Preferred features of the invention are set out in subsidiary claims 12 to 18.

The provision of a motor mounted inside the brush bar completely removes the need for a drive belt extending between the fan motor and the brush bar. The elimination of such a drive belt is a major improvement in vacuum cleaner technology. Providing a brushless motor, such as a switched reluctance motor, inside the brush bar is a further improvement in that the motor requires little or no maintenance and has an extended life in comparison with universal or DC motors. Furthermore, a directly mains fed universal or DC motor would require a comparatively high level of electrical insulation to meet safety requirements for use in a domestic household appliance. Brushless motors can operate at voltages which comply with safety regulations enforceable throughout the EU. This enables a brush bar in a cylinder vacuum cleaner to be powered by a motor which is safely supplied with current via the hose.

According to a third aspect of the invention, a motor is provided in accordance with the features of claim 19. Preferred features of the invention are set out in subsidiary claims 20 to 28.

The provision of at least two rotors in the motor has been identified as an economical and compact way of driving two separate features of a household appliance such as a vacuum cleaner at different speeds. Making use of the same winding or windings to drive two separate rotors is clearly advantageous in an environment in which consumers demand small, lightweight appliances.

According to a fourth aspect of the invention, there is provided a vacuum cleaner comprising an active electrostatic filter, as set out in claims 29 to 33. Such a vacuum cleaner will be particularly effective in cleansing an environment of substances of the type that can aggravate asthmatics.

A number of alternative embodiments of all aspects of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic view of a primary and secondary motor arrangement which embodies both aspects of the invention:

Figures 2a-2d are sectional and cross-sectional views of the brush bar incorporating the secondary motor of Figure 1;

Figures 3a-3d are sectional and cross-sectional views of a second brush bar incorporating a secondary motor such as shown in Figure 1;

Figures 4a-4c are sectional and cross-sectional views of a third brush bar in accordance with the invention;

Figure 5 is a variation of the brush bar of Figure 4;

Figure 6 is a schematic cross-sectional view of a single-phase switched reluctance motor suitable for use as a secondary motor in accordance with the present invention;

Figures 7a-7g show portions of electrical circuits suitable for powering a secondary two-phase switched reluctance motor from a primary two-phase switched reluctance motor in accordance with the invention;

Figures 8a-8k show electrical circuit portions for use in powering a secondary single phase switched reluctance motor from a primary single phase switched reluctance motor in accordance with the invention;

Figure 9 shows a series of circuit portions which can be combined together for powering a secondary motor from a two-phase switched reluctance motor in accordance with the invention;

Figure 10 is a schematic view of an embodiment of the invention in which a high voltage power supply feeds an active electrostatic filter from a high frequency motor winding;

Figures 11a-11g are sectional and cross-sectional views of a brush bar with an integrated DC motor in accordance with the present invention;

Figures 12a-12f are sectional and cross-sectional views of another vacuum cleaner brush bar with an integrated DC motor in accordance with the invention;

Figure 13 shows an embodiment of the invention suitable for powering a secondary induction motor from a main induction motor;

Figure 14 corresponds generally with Figure 13, but shows an arrangement wherein the secondary induction motor is substituted with either a DC motor, a smoothed DC motor or an AC series motor;

Figures 15a-15g are schematic cross-sectional views of various alternative motors in accordance with the present invention;

Figures 16a-16d are schematic cross-sectional views of various alternative motor arrangements in accordance with the invention;

Figures 17a-17e are sectional and cross-sectional views of a motor and fan arrangement in accordance with the present invention;

Figures 18a-18f are sectional and cross-sectional views of a further motor and fan arrangement in accordance with the present invention;

Figure 19a-19e are sectional and cross-sectional views of a further motor and fan arrangement in accordance with the present invention;

Figures 20a-20g are sectional and cross-sectional views of two further motor and fan arrangements in accordance with the present invention;

Figure 21 is a schematic cross-sectional view of a motor in accordance with the present invention; and

Figure 22 is a still further cross-sectional view of a motor in accordance with the present invention.

Figure 1 shows a primary 4/2 two-phase switched reluctance motor 2, a secondary 24/16 two-phase switched reluctance motor 4 and a power supply circuit which is connected to the primary motor 2. Other types of switched reluctance motor, (e.g. three phase or four phase) could be used for either motor, if desired.

In common with known switched reluctance motors, the primary motor 2 comprises a stator 16 with four salient poles 18a-18d. Opposed poles 18a and 18b each support a like armature winding +A,-A which form a first phase. Opposed poles 18c and 18d accommodate respective like armature windings +B,-B which represent a second phase. A rotor 20 is rotatably mounted upon an axis 21 within the stator 16 and comprises opposed poles 22. The rotor 20 is formed from steel laminated in the axial direction.

Power is supplied to the motor 2 from a mains supply 6 which is rectified by a bridge rectifier 8. A capacitor 10 is provided for smoothing the bridge output. Each of the armature winding pairings A,B is fed via a respective asymmetric half bridge 12,14. Each half bridge 12,14 relates to a respective one of the two phases. In this regard, half bridge 12 supplies the A windings and half bridge 14 supplies the B windings.

For continuous operation, current is applied to each of the stator phases in turn at a rate which is dependent on and determined by the variation of the rotor position with time. The timing of the asymmetric half bridges 12,14 is determined by reference to the rotor position by means of either optical or Hall effect sensors or any other suitable means.

The primary reluctance motor 2 also includes two additional winding pairs: C and D. One winding of winding pair C is accommodated on each of salient poles 18a and 18b. One winding of the winding pair D is accommodated on each of the salient poles 18c and 18d.

The respective pairings of windings A and C on the one hand and B and D on the other each operate in the manner of a transformer. The current induced in winding pairs C and D by winding pairs A and B is supplied to the secondary reluctance motor 4. For convenience of assembly within the brush bar of the vacuum cleaner, this motor is structurally the inverse of the primary motor 2. That is to say, the rotor 30 is situated radially outside the stator 26, which is located upon a fixed axis 34. The radially inner surface of the brush bar 36 is fitted directly upon the radially outer surface of the rotor 30 and secured in place by splines 37.

Closer reference to Figure 1 will reveal that the stator 26 comprises sixteen poles 32. The rotor 30 comprises twenty-four radially inwardly directed poles 28. The poles 32 situated upon the stator 26 are arranged in pairs, with each pair being surrounded by a respective winding. The windings themselves are paired circumferentially and then these pairs of windings are in turn paired with a similar pair of windings situated on the radially opposite side of the stator. For example, poles 32a and 32b are provided with a D winding. Circumferentially adjacent poles 32c and 32d are provided with a second D winding. Radially opposite, poles 32e-32h are arranged in a similar fashion. The spacing between the poles 32a-32h is such as to enable their simultaneous radial correspondence with rotor poles 28, as shown in the figure. However, the poles associated with the D windings are radially off-set from the coils associated with the C windings, such that radial correspondence with the rotor poles cannot be achieved by the poles associated with the C coils at the same time as the poles associated with the D coils. Hence a two-phase structure results.

The number of poles provided in the secondary switched reluctance motor 2 ensures smooth rotation of the brush bar 36.

The power supply to the primary reluctance motor 4 is typically switched at a frequency of the order of 1.25 kHz per phase, (if a 4/4 single phase switched reluctance motor were used as the primary a switching frequency of about 2.5 kHz would be comparable). The secondary reluctance motor can be switched at the same, high frequency. As a consequence of this magnitude of frequency, there is no need to provide for a high level of flux build-up in the coil armature of the primary motor (or an intermediate transformer, if the voltage is stepped down outside the primary motor). Because the voltage to the secondary motor 4 is stepped-down and isolated from the voltage of the primary motor 2, the supply of power to the secondary motor is very safe. In fact, the supply is so safe that the power can be fed via the hose to the suction head of a cylinder vacuum cleaner without a risk of compromising safety.

By using a switched reluctance motor as the secondary motor 4, significant advantages arise. Due to the lack of commutating brushes, no carbon powder is generated by brush wear. Furthermore, the motor has a relatively long life and its speed is not limited by the need to maintain a reasonable brush life. Use of a switched reluctance motor as the primary motor enables a switched reluctance motor to be used as the secondary motor with relative ease.

Figures 2a-2d show the secondary motor 2 of Figure 1, situated within the brush bar 36 in more detail. Figure 2a is a section. Views 2b-2d are cross-sections taken along lines I to III in Figure 2a, respectively. Referring to Figure 2a, it will be seen that the brush bar 36 and rotor 28 are together mounted by means of bearings 40 upon the shaft 34 that supports the stator 26. The shaft 34 is mounted at each end to a housing 42 of the vacuum cleaner. From cross sectional Figure 2c, it will be seen that the shaft 34 includes four axial grooves 42 situated at circumferential intervals of 90°. Each groove 42 accommodates a wire for supplying current from the primary motor 2 to the secondary motor 4.

Figures 3a-3d show a variation of the arrangement of Figure 2. Figure 3a is a section and Figures 3b to 3d are cross-sections taken along lines I to III in Figure 3a, respectively. In this embodiment, the shaft 34 is hollow and the wires for supplying current to the windings of the secondary motor run inside the shaft, as can clearly be seen from cross sectional Figure 3c.

Figures 4a-4c and 5 show an alternative arrangement in which two secondary switched reluctance motors are situated at different axial positions within the brush bar. Figures 4a and 5 are sections. Figures 4b and 4c are cross-sections taken along lines I and II in Figure 4a, respectively. Each motor has a configuration generally similar to that of the motor of Figure 2 but is a single-phase motor. However, by arranging the motors to be mutually out of phase, the arrangement effectively defines a two-stack construction. In a similar manner to the embodiment of Figure 2, the shaft 34 comprises two channels 42 for accommodating the wires for feeding current to the stators 26. Bearings 40 for supporting the brush bar 36 are situated at the axial ends of the shaft 34. Whilst this provides a particularly stable arrangement, the bearings 40 can nevertheless be situated in a position which is axially between the two motors, as shown in Figure 5.

Figure 6 shows a cross-section through a 24/16 single-phase switched reluctance motor such as used in Figures 4 and 5. It will be seen that all of the stator poles 32 can simultaneously achieve radial alignment with the poles 28 of the rotor 30, unlike those of the secondary motor 4 in Figure 1.

Although the above embodiments have a greater number of poles in the secondary motor than in the primary motor, this is not necessary. The primary motor can have an equal or greater number of poles relative to the secondary motor if circumstances require it. For example on a washing machine, a primary motor used as a direct drive could operate at about 0-2000 rpm and drive a secondary motor for a high-speed water pump operating at 0-10,000 rpm. In such a case, it would be appropriate for the primary motor to have a greater number of poles than the secondary motor.

Figure 7 shows some alternative circuit arrangements for supplying power from the primary two-phase switched reluctance motor 2 to the secondary switched reluctance motor 4 of Figure 1.

In each case, the first stage of the power supply circuit is the same as in Figure 1, that is to say it comprises an AC mains supply, a bridge rectifier and a smoothing capacitor. The circuits also each include a half bridge 12, 14 for supplying each respective phase winding of the primary motor as before. However, the connections for supplying the secondary motor are different in each case.

Figure 7g corresponds to the arrangement of Figure 1. That is to say it comprises a pair of additional windings on the primary motor which are connected directly to windings provided on the armature of the secondary motor.

In Figure 7a, each of the windings on the secondary motor is connected in parallel with a respective one of the windings on the primary motor. Whilst this arrangement is relatively simple, it does not isolate the windings on the secondary motor from those on the primary motor or provide for a voltage drop from the primary motor to the secondary motor.

Figure 7b shows a circuit in which each of the windings on the secondary motor is connected in series with a respective one of the windings on the primary motor. Once again, this does not provide for isolation of the secondary windings from the primary windings.

Figure 7c shows a circuit in which each of the secondary motor windings is tapped from a respective winding of the primary motor. This arrangement enables a voltage drop between the primary motor and the secondary motor to be effected. However, the two motors are not electrically isolated.

Figures 7d-7f correspond with Figures 7a-7c, except, in each case, a transformer is introduced between each secondary motor winding and its associated primary motor winding. This arrangement has the advantage of isolating the secondary motor windings from the primary motor windings and enabling the voltage to be stepped down between the primary motor windings and the secondary motor windings. By using switched reluctance motors operating at relatively high frequencies, such as 1.5 kHz per phase, flux build-up within the transformer will be relatively small and, therefore, a relatively compact, lightweight unit can be used which provides significant cost-savings and enables the overall weight of the appliance to be kept low.

Figure 8 relates to an appliance in which both the primary motor 2 and the secondary motor 4 are single-phase motors. Reference to Figures 8a-8e and 8i-8k will show that circuits corresponding to those of Figure 7 may just as easily be employed in a single-phase arrangement as in a two-phase arrangement. Figures 8f and 8g correspond with Figure 8e, but incorporate an additional switch between the primary motor winding and the secondary motor winding, the switch being on an opposite side of the intermediate transformer in each respective case. Figure 8h corresponds with Figure 8k but, like Figures 8f and 8g, incorporates a switch between the primary motor winding and the secondary motor winding. These additional switches enable the frequency of operation of the secondary switched reluctance motor to be varied from the frequency operation of the primary switched reluctance motor. The switches hence enable the secondary motor to be re-started if it stalls, by switching the applied current and thereby allowing sufficient inertia to build up in the rotor. In addition, the switches enable the supply to the secondary motor to be cut off, for safety, whilst cleaning with the vacuum cleaner hose/wand or cleaning the brush bar.

Figure 9 shows some further variations for powering a secondary switched reluctance motor from a primary two-phase switched reluctance motor.

Figure 9a is identical to the first stage of the power supply shown in Figure 1, that is to say it comprises an AC source coupled with a bridge rectifier and a smoothing capacitor. Figure 9b differs from the Figure 9a only in that the smoothing capacitor has been omitted. Although this results in a consequent degradation in the DC waveform, benefits include significant cost and weight savings and a potential increase in long-term reliability since there is no electrolyte which can detrimentally dry-out.

Figures 9c-9f correspond exactly with Figures 7d-7g, as does Figure 9g.

Figures 9h and 9j show parallel and series connection of the intermediate transformers, respectively. Figure 9k shows a common secondary winding in the intermediate transformer. The arrangements in Figures 9h-9k enable the output from both phases of a two-phase switched reluctance motor to be fed to a single-phase secondary switched reluctance motor.

As shown in Figure 9m, a triac or other switch may be connected to the output of Figures 9g-9k for motor speed control. Figure 9n shows rectified connections for powering a pair of DC motors. These motors may be smoothed, as shown in Figure 9r, or not, as in Figure 9s. Figures 9o and 9p show rectified parallel and series connections, respectively, for supplying a single DC motor. Of course, an AC motor, as shown in Figure 9t may be employed using the direct connections of Figure 9q.

Although the above embodiments make use of the power from the primary motor to supply a secondary motor, other features may be supplied instead. For example, Figure 10 shows an alternative embodiment in which power from a single-phase primary motor winding is used to supply an active electrostatic filter feed, rather than another motor. In this case, the high switching frequency associated with the use of a brushless motor facilitates the use of capacitors with smaller capacitance than would otherwise be required if the illustrated voltage doubler network was supplied at normal mains frequency. This results in considerable savings in the cost, physical size and weight of the power electronics required to feed the active electrostatic filter. Such a primary motor and filter arrangement will find uses in dual cyclone and other vacuum cleaners and air purification units, for example.

Although the arrangement shown in Figure 10 has the described benefits, other arrangements can be employed. For example, the voltage doubler network may be replaced by a step-up transformer. The transformer can have a ferrite core.

The active electrostatic filter itself provides significant advantages when used in a dual cyclone vacuum cleaner, regardless of whether it is supplied with power from a primary motor such as described above. Because it is actively charged the filter is extremely effective at removing very fine particles from air. In fact, it has been found that such a filter can remove particles as small as 0.5 microns and less. This complements a dual cyclone particle separation system, which is generally less effective at extracting particles of this size due to their relatively small mass. A vacuum cleaner incorporating such an active filter will, in view of the above, be particularly effective in cleansing an environment of substances that can aggravate asthmatics. Furthermore, an electrostatic filter is relatively easy to maintain. It does not require frequent replacement, like a passive filter. Instead, it can simply be removed and cleaned. Furthermore, it is possible to construct an active filter with relatively large separation between collecting surfaces, thereby presenting a significantly lesser physical obstruction to air flow than a passive filter. In a dual cyclone vacuum cleaner, the bins could be used as electrodes.

As will be apparent from Figure 9, the secondary motor need not be a switched reluctance motor.

Figures 11 and 12 show alternative forms of a DC motor that can be located within the brush bar of a vacuum cleaner in accordance with the present invention. Figures 11a and 12a are sections. Figures 11b to 11g are cross-sections taken along lines I to VI in Figure 11a, respectively. Figures 12 to 12f are cross-sections taken along lines I to V in Figure 12a, respectively. In Figure 11, a DC motor 104 is mounted within a cylindrical housing 105 that is integrally formed with a coaxial shaft 134 on one side and a coaxial annular body portion 135 of a lesser diameter on the other side. The annular portion 135 and the shaft 134 are each provided with a respective bearing 140 upon which the brush bar 136 is mounted. The distal end of the shaft 134 is fixedly mounted within part of the housing 142 of the vacuum cleaner. The annular portion

135 is integrally formed with the housing 142. The motor 104 is fixed within the housing 105 and provided with a drive shaft which extends axially from each end.

At a first motor end, which is situated in a axial end region of the brush bar 136, the projecting portion of the drive shaft 151 is provided with teeth which mesh with the teeth of two gear wheels 152 of larger diameter, which in turn mesh with inwardly directed teeth of a gear ring 154, so as to define an epicyclic gear train 150. Each of the intermediate gear wheels 152 is mounted upon a respective shaft 153 which extends from the housing 105. The epicyclic gear train 150 transmits the torque from the drive shaft 151 to the brush bar 136, upon a radially inner surface of which the gear 154 is mounted.

At the opposite end of the motor, which is generally in an axially central region of the brush bar 136, the drive shaft 155 is provided with an axially facing fan 160 which circulates air within the brush bar for cooling purposes. A series of circular apertures 162 are provided in the axial end of the housing 105 in order to facilitate air circulation.

The motor housing 105 steps down to the annular section 135 via an intermediate frustoconical section 121 which extends around part of the circumference of the housing 105 but incorporates gaps for accommodating the intermediate gears 152. An annular gap 138 is provided between the radially outer surface of the motor housing 105 and the radially inner surface of the brush bar 136. This annular gap 138 defines a flow path for cooling air around the outer surface of the motor. The frustoconical portions 121 serve to assist in the air flow.

Figures 12a-12f show views of a further embodiment, wherein a DC motor 104 is fitted within a vacuum cleaner brush bar 136. This embodiment is broadly similar to the embodiment of Figure 11, but differs in several ways. First, the epicyclic gear train 150 is fitted at an end of the DC motor 104 which is located towards the axial centre of the brush bar 136, rather than at the opposite end of the DC motor 104, as in the previous embodiment. The epicyclic gear train 150 also includes a third intermediate gear wheel 152, making three in total. By this arrangement, the brush bar 136 is effectively radially supported by the epicyclic gear train 150 and the shaft 134 of the embodiment of Figure 11 can, therefore, be omitted. The ends of the brush bar 136 are supported by respective bearings 140 as in the previous embodiments. One of the bearings 140 is mounted upon an axial projection 143 extending from a part of the vacuum cleaner housing 142. The opposite bearing 140 is supported upon an axially extending annular portion 135 of the motor housing 105, as in the previous embodiment.

This embodiment comprises a first fan 160 mounted upon the pinion 150 of the epicyclic gear train. The position of this fan corresponds to the position of the fan 160 of Figure 11. However, this embodiment also includes an additional fan 160 mounted at the opposite end of the motor 104, in a region close to the axial end of the brush bar 136. In this case, the fan 160 circulates air via the axial bore 137 of the annular portion 135, which communicates with the outside atmosphere. A radial gap 138 is provided between the radially outer surface of the motor housing 105 and the radially inner surface of the brush bar 136, so as to provide an effective flow-path for enabling cooling air to cool the motor.

Figures 13 and 14 show embodiments of the invention in which the primary motor is a three-phase induction motor operating at about 600 Hz. In each case, the first stage of the circuit corresponds with that of the previous embodiments, that is to say it includes an AC supply 6 rectified by a bridge 8 and smoothed by a parallel capacitor 10. The capacitor stage is followed by an inverter 220 which provides three-phase voltages and currents to a primary induction motor 202 which are adjustable in magnitude and frequency. In the arrangement of Figure 13, a secondary induction motor 204 is fed directly from the primary induction motor 202 using any suitable arrangement such as those shown in relation to previous embodiments. In Figure 14, a rectifier 203 is provided after the primary induction motor 202, so as to enable a DC motor 204b or smoothed DC motor 204a to be driven from the primary induction motor 202. Alternatively, an AC series motor 204c can be used instead.

From Figures 13 to 14, it will be apparent that the primary motor need not be a switched reluctance motor. Other brushless motors, such as brushless DC motors, induction motors and stepper motors, will be perfectly suitable for many applications.

Figure 15 illustrates various embodiments of the third aspect of the invention. According to this aspect of the invention, one or more windings are used to drive more than one rotor of a single motor. Figure 15a illustrates an embodiment similar to those illustrated in Figures 1 to 6. The motor 500 has a stator 502 carrying a winding A and twenty four external poles 504. Rotatably mounted radially outwardly of the stator 502 is an external rotor 506, also carrying twenty four poles 508. A plurality of splines 510 are arranged between the external rotor 506 and the interior surface of a brush bar cylinder 512. This arrangement can be used to cause rotation of the brush bar 512 in the same way as is described in relation to the earlier figures.

The main difference between the motor illustrated in Figure 15a and the previously illustrated motors is the provision of four internal poles 514 on the stator 502. Radially inwardly of the stator 502 is mounted a second, inner rotor 516 having four equispaced poles 518. The inner rotor 516 is rotatably mounted about a central axle 520.

It will be appreciated that, simultaneously with the rotation of the external rotor 506 when power is supplied to the winding A, the inner rotor 516 will also rotate. However, the speed of rotation of the inner rotor 516 will be one sixth of the speed of rotation of the external rotor 526 due to the difference in the number poles provided on each rotor.

It will also be appreciated that this principle can be applied to many alternative arrangements and very many alternative variations are possible. Figures 15b, c, d, e and g each show, schematically, different arrangements of a single switched reluctance motor having a single winding driving two separate rotors. In each case, the number of poles carried by each rotor is different. It will be appreciated that the number of poles on each rotor can be varied at will. Figure 15f illustrates schematically a two phase switched reluctance motor having two windings instead of one and also driving two separate rotors. The advantage of driving two separate rotors by means of one winding or set of windings is that the space occupied by the motor will be reduced and the associated mass will therefore also be reduced.

The rotors of a motor in accordance with a third aspect of the invention can either rotate uni-, contra- or multi-directionally.

In the case of a switched reluctance motor, the initial direction of rotation is usually determined by the initial position of the rotor pole(s) relative to the stator pole(s) and/or the phase switching sequence(s) when a current pulse is applied to the winding(s).

If one considers the motors shown in Figure 15, it is possible to obtain either uni- or contra-directional rotation by locating the rotors at suitable respective orientations relative to the stator prior to the application of a current pulse. Figures 16a-16d show motors in which magnets 550 are provided for parking the rotors when the driving current is terminated, so that the rotors will be in a suitable position for contra-directional rotation when a current is next applied. In this regard, Figure 16a shows a motor with the same speed outputs at an initial parking position prior to the application of a driving current. Figure 16b shows the direction of rotation of the respective rotors after the winding is excited. It will be seen from the figure, that the two rotors rotate in respectively opposite directions. Figures 16c and 16d are corresponding views for a motor having two different speed outputs. In each case, it will be seen that the magnets are strategically positioned in order to align each of the poles of the rotors to be closer to a particular pole than an adjacent pole. Therefore, when the coil is excited, each rotor pole moves towards that closest stator pole, thereby determining the direction of rotation. Naturally, a mechanism could be provided for adjusting the position of the magnets, so as to change the direction of rotation of a particular motor.

An alternative for multi-phase switched reluctance motors having more than one rotor is to arrange the phase sequences to be such that they produce contra-directional rotation in the rotors. It is also possible to control the direction of the rotation by providing asymmetrical air gaps between the rotor and stator poles.

The above motor arrangements allow contra-directional rotating elements to be provided without a prohibitive increase in cost or mechanical complexity. The motor arrangements can also provide significant additional advantages as follows. First, net angular momentum can be cancelled or reduced. This leads to the minimization of acceleration/retardation reaction torques on both the motor and/or the appliance or product to which it is fitted. Furthermore, net gyroscopic effects can be cancelled or reduced. This leads to a minimization of gyroscopic forces on the motor and/or the appliance or product when subject to general movement. Such motor arrangements also enable a reduction of acoustic and mechanical vibrations through various methods including superposition cancellation.

A motor having contra-directional rotors, such as described above, can provide significant advantages when used in a vacuum cleaner for rotating motorized dual or multiple cyclones. More specifically, the motor can be used to drive the impellers inside the inner and outer bins directly. Further, if desired, the air flows through the inner and outer cyclones can be connected in series - resulting in a potential load matching between the motor's outputs and thus a simplification and reduction of the power electronics.

In the case of switched reluctance motors, the switching times of primary and/or additional windings can be controlled using information from position sensor(s) on the primary and/or additional rotor(s). If desired, the positional information of the rotors can be combined (e.g. via a microprocessor, combinational logic or physical construction of the sensor(s)) to give the desired operating characteristics for the motors and/or the product/appliance they are used within or in combination with. This allows for a potential simplification of the power electronics circuitry and thus a potential reduction in the overall cost, size and weight of the product/appliance.

Figures 17 to 20 show embodiments of the invention in which the impellers of a motorized dual cyclone vacuum cleaner are driven.

Figure 17a is a section through a motor arrangement 600. The motor arrangement comprises an axially central stator 602 provided with laminated poles 604. The poles 604 are provided with windings 606. A pair of axially aligned rotors 608,608 are provided on respective axial sides of the stator 602. Moving away from the stator, an impeller 610 is provided on a respective opposite side of each of the rotors 608. The impellers 610 and rotors 608 are mounted upon a central shaft 612 that is integrally formed with the stator 602. Figures 17d and 17e are cross-sections through the arrangement 600 showing the upper and lower rotors 608 respectively. The views are seen from the same direction. It will be seen from these figures that parking magnets 614 are provided for locating the poles 609 of each rotor 608 closer to poles which are respectively on circumferentially opposite sides of the mid-point between any given adjacent pairing of stator poles. This has the effect of causing the rotors to rotate in opposite directions when the windings 606 are excited. To ensure that the impellers 610 both draw air in towards axial centre of the device, they have vanes which are orientated in respectively opposite directions, as can be seen from Figures 17b and 17c, which are viewed from the same direction.

Figures 18a-18f show a motor arrangement which has general similarities to that of Figure 17. However, in this case, each of the rotors 608 has only four poles 609. Once again, means are provided for causing the rotors to commence rotation in mutually opposite directions upon excitation of the coil. This means may take the form of a set of parking magnets, such as in the previous embodiment, or some other suitable means such as an asymmetrical air gap between the poles, for example. Appropriate direction controlling techniques are known in the art and will not be elaborated upon further.

In this embodiment, the coils 606 are each wound around an axis which is generally parallel with the rotational axis of the rotors 608. The coils are wound around respective armatures 604 which are situated at 90° intervals upon a ring 602, made of any suitable material, to define a stator. As in the previous embodiment, a pair of impellers 610,610 are provided upon axially opposite sides of the rotors 608. The impellers and rotors are rotationally mounted upon a shaft 612 via bearings. Cross-sections of the device are shown in Figures 18b-18f in a corresponding fashion to Figure 17.

Figures 19a-19d show a still further embodiment of this aspect of the invention. This arrangement also corresponds generally with that of Figure 17. It will be seen that a pair of single phase rotors 609 are mounted upon a shaft 612 via bearings. The rotors each comprise three rotor poles at 120° intervals. As can be seen from Figure 19a, each of the poles is generally C-shaped in section. In this example, the stator 602 is cylindrical and surrounds the rotors 608 coaxially. The stator 602 is provided with three poles 604, also at 120° intervals for addressing the poles 609 of the rotors 608. As will be seen from Figure 19a, the armature of the stator 602 is E-shaped in section and provided with a pair of radial coils which are coaxial with the rotors 608 and the shaft 612. The windings 606 are axially separated, each one addressing a respective one of the rotors 608.

As in the previous embodiments, means are provided for causing contra-rotation of the rotor 608 upon the application of an exciting current to the windings 606. Impellers 610,610 are provided on respectively opposite axial sides of the rotor 608.

Figures 20a-20g show slightly differing further embodiments of this aspect of the invention. In Figure 20a, it can be seen that the motor arrangement 600 comprises a pair of rotors 608a and 608b. These are coaxial with a radially intermediate stator 604. The stator 604 comprises a pair of coaxial windings 606. Each of the rotors 608a,608b is rotationally mounted upon a respective shaft 612a,612b. As in previous embodiments, impellers 610 are mounted on respectively opposite axial sides of the device.

The arrangement shown in Figure 20b corresponds with that shown in Figure 20a. However, in this case, the impellers 610,610 are mounted coaxially and on the same axial side of the device. The radially outer rotor 608b is supported upon a first annular flange 658b and the stator 604 is mounted upon a second annular flange 654. The stator flange 654 is integrally formed with a shaft, 612 which extends perpendicularly from either face of the flange 654. The radially outer rotor flange 658b comprises a collar 659b which mounts the flange and, hence, the stator for rotation via a bearing. The radially inner stator 608a is mounted via bearings directly on the shaft 612.

Figures 21 and 22 show variations of the winding structure for a dual output single phase motor, such as shown in Figure 15a, for example. In each of Figure 21 and 22, the stator is provided with two sets of windings. In this regard, a first winding 550 is wound around the radially inwardly directed poles 518 and a second winding 560 is wound around the radially outwardly directed poles 504.

Figure 22 shows a broadly similar arrangement, however there is some radial overlap between the radially inner windings 550 and the radially outer windings 560. This arrangement enables significant reductions in size for a given number of winding turns.

In vacuum cleaner applications, the impeller inside the outer cyclone bin can be rotated more slowly than the impeller inside the inner cyclone but have a larger size to accommodate the passage of larger dust particles. The impeller in the inner cyclone can be made relatively smaller because it only sees finer dust particles. This facilitates an elevated operating speed which further improves the cyclonic removal of fine dust particles within the inner cyclone. A third motor output could be provided to rotate a brush bar.

Many further modifications and variations will suggest themselves to those versed in the art upon making reference to the foregoing description which is given by way of example only and is not intended to limit the scope of the invention, that being determined by the appended claims.

CLAIMS

1. A domestic household appliance incorporating a brushless motor which, in use, is used to power a plurality of separate features of the appliance.

2. An appliance as claimed in claim 1, wherein the voltage and/or frequency of the power supplied to the brushless motor is stepped up or down in dependence upon the requirements of each respective one of the said separate features prior to being supplied to the feature.

3. An appliance as claimed in claim 1 or 2, wherein the appliance is a vacuum cleaner.

4. An appliance as claimed in claim 3, wherein one of the separate features powered by the brushless motor is a rotatable brush bar.

5. An appliance as claimed in any preceding claim, wherein one of the separate features powered by the brushless motor is an active electrostatic filter.

6. An appliance as claimed in one of claims 3 to 5, wherein one of the separate features powered by the brushless motor is a traction motor.

7. An appliance according to any preceding claim, wherein the motor is a switched reluctance motor.

8. An appliance according to any one of claims 1 to 6, wherein the motor is an inverter fed induction motor.

9. An appliance according to any one of claims 1 to 6, wherein the motor is a brushless DC motor.

10. An appliance substantially as hereinbefore described with reference to the accompanying drawings.

11. A vacuum cleaner having a cleaning head with a dirty air inlet, a rotatable brush bar being arranged in the dirty air inlet, wherein the rotatable brush bar is driven by a motor mounted inside the brush bar.

12. A vacuum cleaner as claimed in claim 11, wherein the motor is a switched reluctance motor.

13. A vacuum cleaner as claimed in claim 11 or 12, wherein the switched reluctance motor is a two-phase switched reluctance motor.

14. A vacuum cleaner as claimed in claim 11 or 12, wherein the switched reluctance motor is a first single-phase switched reluctance motor.

15. A vacuum cleaner as claimed in claim 14, wherein a second single-phase switched reluctance motor is provided inside the brush bar and is mounted so as to be out of alignment with the first single-phase switched reluctance motor.

16. A vacuum cleaner as claimed in claim 11, wherein the motor is a brushless DC motor.

17. A vacuum cleaner as claimed in claim 11, wherein the motor is an inverter fed induction motor.

18. A vacuum cleaner substantially as hereinbefore described with reference to the accompanying drawings.

19. A motor comprising a stator and at least one winding, wherein at least two rotors are provided and the stator is configured such that, in use, the magnetic flux developed by the or each said winding is directed through each rotor.

20. A motor as claimed in claim 19, wherein the motor is a switched reluctance motor.

21. A motor as claimed in claim 20, wherein the switched reluctance motor is a single phase switched reluctance motor.

22. A motor as claimed in claim 20, wherein the switched reluctance motor is a two phase switched reluctance motor.

23. A motor as claimed in claim 22, wherein two windings are provided.

24. A motor as claimed in any one of claims 19 to 23, wherein the rotors have different numbers of poles.

25. A motor as claimed in any one of claims 19 to 24, wherein the motor is adapted for use in a vacuum cleaner.

26. A motor according to any one of claims 19 to 25, wherein means are provided for causing the rotors to rotate in mutually opposition directions.

27. A motor according to Claim 26, wherein the means comprises magnets which are located in such positions as to prime the rotors, when stationary, for rotation in mutually opposite directions by locating each rotor pole closer to a predetermined one of two adjacent stator poles.

28. A motor substantially as hereinbefore described with reference to the accompanying drawings.

29. A vacuum cleaner comprising a dirty air inlet and an active electrostatic filter for removing particles from a flow of air drawn into the vacuum cleaner via the dirty air inlet.

30. A vacuum cleaner according to claim 29, comprising a plurality of motorized cyclones.

31. A vacuum cleaner according to claim 29 or 30, wherein the electrostatic filter is supplied with power via a voltage doubler.

32. A vacuum cleaner according to claim 29 or 30, wherein the electrostatic filter is supplied with power via a step-up transformer comprising a ferrite core.

33. A vacuum cleaner substantially as hereinbefore described with reference to Figure 10.

The Patent Office

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Application No: GB 9709179.7
Claims searched: 19-28

Examiner: John Cockitt
Date of search: 4 December 1997

Patents Act 1977
Further Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H2A [AKQQ, AKQ1, J9B]

Int Cl (Ed.6): H02K [16/02, 07/14]; A47L [9/04, 09/22]

Other: ONLINE: WPIL,IFIPAT,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2125229A	BOSCH - see plural rotors	19 at least
X	GB2086777A	HILTI - see independent rotors	19 at least
X	WO80/01524A1	MASON - see plural rotors and single stator winding/structure	19 at least
X	US4829205A	LINDGREN - see reluctance rotor 1, induction rotor 8	19-24 at least
X	US4563604A	OMEGA - see figs	19 ,23 at least
X	US5124606A	PFAFF - see claims 10	19 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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Application No: GB 9709179.7
Claims searched: 11-17

Examiner: John Fulcher
Date of search: 20 October 1997

Patents Act 1977
Further Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): A4F(FSND,FSCB)

Int Cl (Ed.6): A47L 9/04

Other: Online:- WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	US 4384386 (DORNER ET AL)	11 at least
X	US 4268769 (DORNER ET AL)	11 at least

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
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P Document published on or after the declared priority date but before the filing date of this invention.
E Patent document published on or after, but with priority date earlier than, the filing date of this application.

Patent Office

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Application No: GB 9709179.7
Claims searched: 29-32
Examiner: John Fulcher
Date of search: 20 October 1997

Patents Act 1977
Further Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): A4F(FC,FFD); B2J(JA)

Int Cl (Ed.6): A47L 9/10,9/12; B03C 3/01,3/011,3/017

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2295311 A	(NOTETRY)	29,30
X	EP 0578365 A1	(SCOTT FETZER)	29
X	EP 0443254 A1	(SCOTT FETZER)	29
X	WO 85/02100 A1	(PROGRESS-ELEKTROGERATE)	29
X	US 4399378	(KRUMM ET AL)	29

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Application No: GB 9709179.7
Claims searched: 1-10
Examiner: John Fulcher
Date of search: 23 July 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): A4F(FC,FFA,FFD,FK,FSCB,FSDM,FSDT,FSDX,FSLA,FSND,FSNS)

Int Cl (Ed.6): A47L 7/02,9/04,9/10,9/12,9/28,11/202

Other: Online:- WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	GB 2253779 A (USESTONE) see whole document	1,3,4
X	GB 2247831 A (BISSELL) see whole document	1,3,4
X	GB 2106200 A (HOOVER) see whole document	1
X	GB 2089463 A (HOOVER) see whole document	1,3
X	US 4384386 (DORNER ET AL) see whole document	1,3

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E Patent document published on or after, but with priority date earlier than, the filing date of this application.