Electric Motors

F1 General Principles

Electric motors work by having a wire carrying an electrical current in a magnetic field, which produces a force that causes the motor to rotate (according to Fleming's right-hand rule). The magnetic field can be produced by a permanent magnet or by an electromagnet. Either the wire moves or the magnet moves in a circular motion.

Washing machines use several types of single-phase electric motors. There are series motors or induction motors; the three types of induction motors are shown in the table.

Type of Motor	*Speed*	*Starting Torque*	*Starting Current*	*Comment*
Series Motor	Variable with load	High	High	Power tools, vacuum cleaner, front loader washing machines
Induction: Split Phase	Almost Constant	Medium	Medium	General purpose motor. USA and old Aust. machines
Induction: Capacitor Run	Almost constant	Lower	Lower	Used in Asian & Australian Machines
Induction: Shaded Pole	Almost constant	Low	Low	Small fans & small drain pumps Low efficiency, suitable only for very small motors

F2 Motor Speed

Series motors will have a variable speed depending on the load. Induction motors will run at a constant speed determined by the mains frequency.

$$50\text{Hz} = 50\ \frac{\text{rev}}{\text{s}} \times \frac{60\ \text{s}}{1\ \text{min}} = 3000\ \text{rev/min}$$

e motor will have a little slippage loss and rotate a little less than the theoretical speed. The motor speed will be 2880rev/min, 1440rev/min as indicated by the table.

No of Poles	*Speed Factor*	*Speed (Rev/min)*	*Comment*
2 poles (1 pair)	1	2880	Pumps and fans motors
4 poles (2 pair)	½	1440	Single speed motor, fast speed in 2 speed motor
6 poles (3 pair)	1/3	960	Slow speed on 2 speed motor
16 poles (8 pairs)	1/8	310	Wash speed on “cap run” front loader motor

F3 Motor bearings

The bearings in an electric motor can be "**ball bearings**" or "**bush bearings**". Ball bearings have the advantage of lower friction, and, as universal parts, they can be purchased and replaced. Bush bearings are made from self-lubricating sintered brass bushes and have the advantage of being cheaper and quieter in operation. They can be replaced, but they are usually not available as a spare part. Also, when they wear, the shaft also becomes worn or scored, and replacement is not always recommended. There is not much clearance between the fixed and rotating parts. When the bush bearings wear, the rotor will "pole" on the field, preventing it from rotating. The magnetism from the working motor will force the two parts together, preventing movement. The motor will rotate by hand, but will not run. Test for sideways wear (movement) in the motor bush. Some motors will have end-to-end movement, and this is OK.
Both types of bearing can be used in all types of motors.

F4 Motor Windings

The motor windings are usually made from enameled copper. When the copper overheats, it turns a bluish colour. Also, the string holding the winding together will break. When the winding is burnt, it will be black in colour. Some motors are open construction, with the windings visible; others are enclosed, and the motor has to be pulled apart to see the windings. Some motors can have the windings made from aluminum and the aluminum is anodized to look a bit like copper (gold colour). I have found some aluminum winding going into an open circuit. I think this happens where the copper wires join the aluminum wires. I have not been able to confirm this, as the motor was glued together, preventing disassembly. Some motors have a thermal fuse or thermal cutout to prevent motor burnout in series with one of the windings. Some can be replaced, others cannot.

F5 Series Motors

These are sometimes called universal motors as they can run on either AC or DC electricity. **They have carbon brushes.** They are commonly used in electric drills and other power tools. They can be used in front loader washing machines, vacuum cleaners, and the spin motor in the Hoover Twin Tub (now past its use-by date).

The electric current passes through the field winding to produce the magnetic field, then by carbon brushes to the armature. The armature has several wires perpendicular to the magnetic field, and the current produces the rotation. After the rotation, the carbon brushes move to a new part of the commutator and send electrical current through a new set of wires.

Series motors run at higher speeds than induction motors, making them ideal for vacuum cleaner motors.
The speed will vary with the load. By varying the power input, the speed can be varied. Simple electronic circuits using a Triac can do this. Some motors have speed sensors consisting of a permanent magnet on the end of the shaft rotating inside a coil. The coil's output is fed to the speed controller to maintain the required speed.
Series motors can be reversed by switching the connections between the field and the armature. The motor may not run and use the same amount of electrical current in both directions, as the carbon brushes are "timed" like the ignition in a car engine to give better performance. Reversing is only

possible if the field and armature connections are made external to the motor. (4 connections plus the earth)

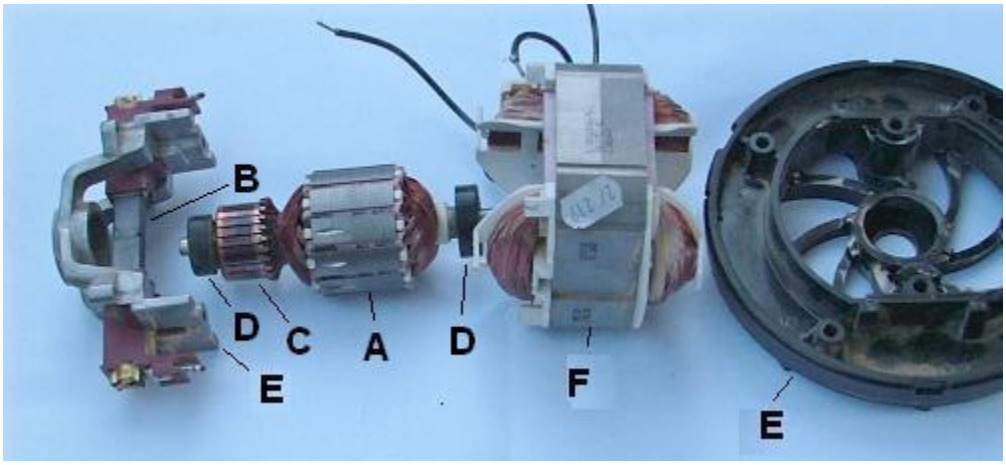

Illustration 1: Series Motor (Vacuum Cleaner)

A Armature B Carbon brushes C Commutator D Bearings (ball)

F Field windings E Motor end brackets

F5.3 Variations

- The field windings can be replaced with permanent ceramic magnets as used in car heater fans.
    - The field windings can be in parallel rather than in series with the armature. Also, they may have some of the field winding in parallel and some in series. (Illustration 5)

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F5.4 Common Faults

The most common fault is worn carbon brushes. Other faults include dirty or damaged commutators, burnt field windings, burnt armatures, and bearing failures.

F6 Induction Motors

The rotor consists of a rotor made from soft (magnetic) iron laminate with slots, which is then filled with cast aluminum to form a single conductor. The field windings are attached to the outer case. The Windings and the rotor act like a transformer. Electrical current is induced into the rotor. Single-phase motors are not self-starting, and various methods are used to start them, such as split-phase, capacitor run, or shaded-pole, as described in the rest of this chapter. The rotation speed is determined by the mains frequency and winding arrangement. (F2)

F6 Split Phase Motors

These are general purpose single phase motors and are used in various forms in washing machines and clothes dryers. They are used in old Australian washing machines, but current machines now use capacitor run motors. USA made washing machines still use these motors. Smaller versions are used in clothes dryers but capacitor run motors are now more popular.

F6.0 Standard Split Phase Motor

These have a second start winding for starting the motor. When the motor reaches its speed, a

centrifugal switch switches off the current to the start winding. The start windings are wound halfway between the run windings so that the motor can start in either direction. The run winding is usually made from thinner copper wire, since it carries electrical current only for a short time. Excessive load on the motor when starting can cause this winding to burn out. There are generally 4-pole motors (1440rpm), but when used for pumps, they may be 2-pole (2880rpm). These motors can be reversed and often have terminals for each winding with external connections. Switching the run and start windings reverses the rotational direction, as shown in Illustration 8.

F6.1 Capacitor Start Motors
These have a 60µF capacitor (start capacitor) in series with the start winding and are called capacitor start motors. Sometimes the capacitor is mounted on the motor under a removable cover. With washing machines, the start capacitor is some distance from the motor. ***See F7.4 on the danger of capacitors.***

F6.2 Two Speed Motors
These have 3 sets of windings, a 4-pole start winding, a 4-pole fast run winding (1440rpm) and a 6-pole slow run winding(960rpm). They have 2 centrifugal switches. They start at a fast speed and switch to a slow speed using the centrifugal switch. They are used on the gentle wash cycle in washing machines. (They are an added expense, and do consumers use them? Or are they a selling point?) Starting the motor at low speed under a heavy load can cause it to fail.

F6.3 Other Variations

- Fridge sealed units consist of a split-phase motor with a compressor, enclosed in a sealed unit, with 3 wires to the run and start windings. Instead of having a centrifugal switch, it uses a 'Start Relay' to turn off the power to the start winding. See my book on refrigeration.
- Whirlpool has a split winding, see the Whirlpool section "N".
- Some "larger powered" motors have 2 capacitors, a 200µF as a start capacitor (connected to the start winding by the centrifugal switch) and another smaller one (about 20µF), which is permanently connected to the start windings. The start winding increases the motor's power output. In run mode, they work like a capacitor-run motor; see section F7.

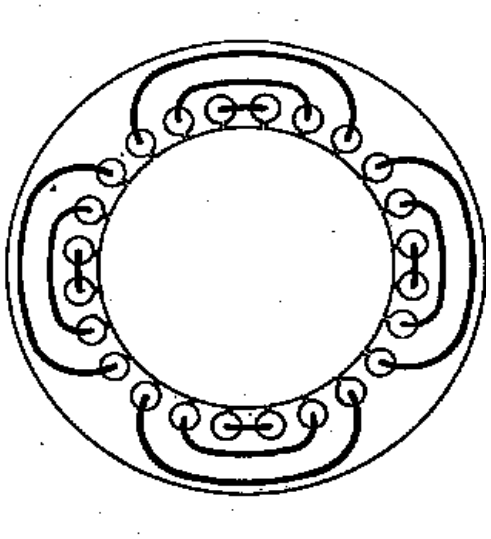

Illustration 2: Induction motor windings with 4 poles

F6.6 Other Uses (Reuse)
Washing machine motors can be used in other equipment. Most washing machine motors are open construction and require guards to prevent contact with live connections and moving parts.

F7 Capacitor Run Motors

These are used in current Australian and Asian washing machines, where agitation is achieved by

forward and reverse motor rotation via simple switching. They are also used in clothes dryers for the same reason. They are also used in small pumps such as dishwasher wash pumps and swimming pool pumps. They do not have the same starting torque as the split-phase motors, but they are sufficient for most applications. The electrical current they use depends on the load.
They have no centrifugal switch and are of simple construction. These have two sets of windings with a common connection, as shown in diagram 15. The common return to the neutral, while the others are powered from the active, with one through a capacitor (usually 8 - 12 mF). Swapping the windings A1 and A2 will reverse the motor's rotation direction. You have to wait for the rotation to stop for the reverse direction to take place.

Illustration 3:Capacitor Run Motor (Late Simpson)

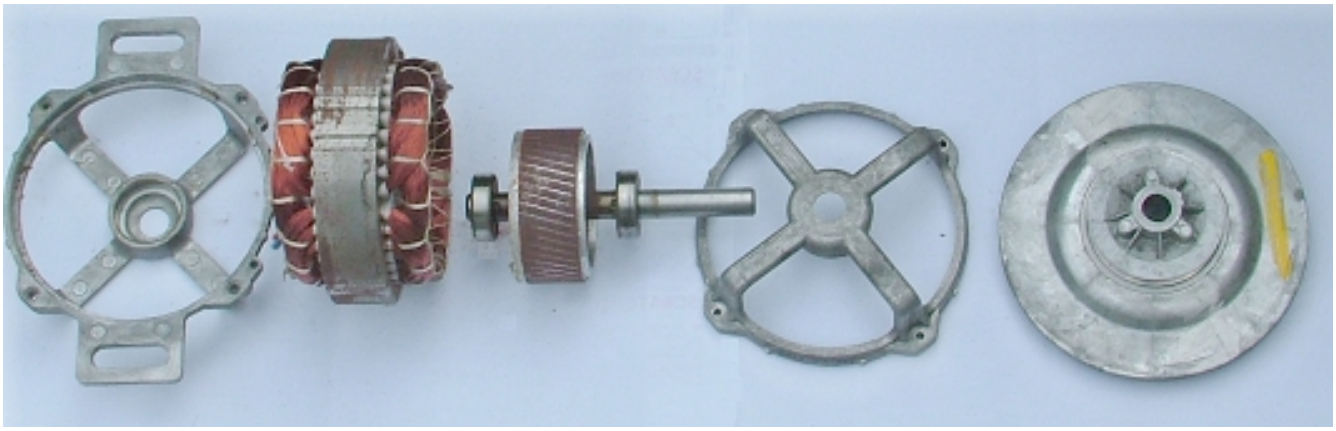

Illustration 4: Exploded View of Capacitor Run Motor (Late Simpson)

F8 Shaded Pole Motors

Shaded-pole motors have two copper loops in the field laminates to distort the magnetic field, allowing the motor to start. They are not very efficient, but acceptable for very small motors. They also have low starting torque and are used in drain pumps and small fans in refrigerators and other appliances. They are also used in small ventilation fans in houses. Large shaded pole motor where is in old Hoover dryers and Twin Tubs. Later, they were replaced by capacitor-run motors.

Faults: windings, bearing or poling see drain pumps (E5.1.3 and E5.2). Tight bush bearings are enough to stop the motor from working. Oiling the bush bearings with thin oil can fix most motors. They have 2 terminals with no polarity. They are not reversible by swapping the Active and Neutral wires. The only way to change the direction is to reassemble the field winding the opposite way around. They rotate at 2880rpm.

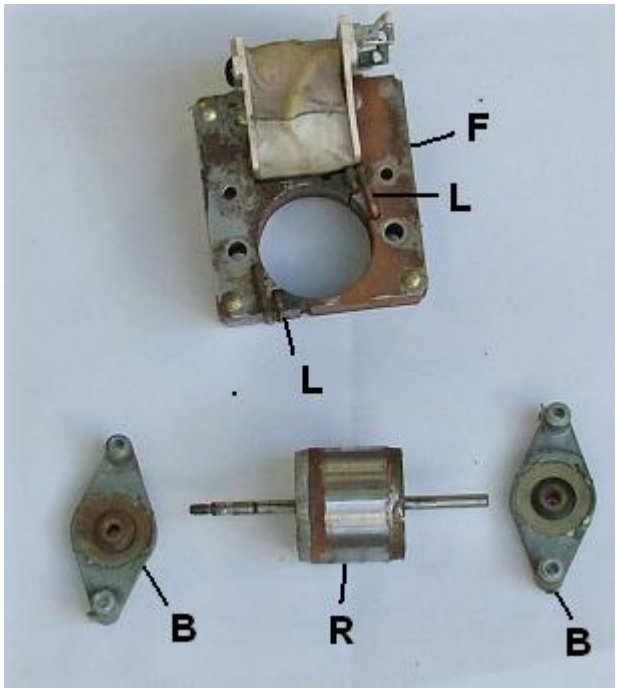

Illustration 5: Shaded Pole Motor

B Bearings F Field windings

L Copper Loops R Rotor

F9 Synchronous Motors

Synchronous motors have a permanent ceramic magnet inside the field. These motors will run in either direction when turned on, depending on the part of the sine wave of the AC supply at this instant. Some motors have a mechanical mechanism that reverses rotation, so they rotate in one direction only.

Uses:

- Timer motors and electric clocks.
- Drain pumps, see section E5.1.4

Faults. Same as shaded pole motors (F8 above (E5.2)).

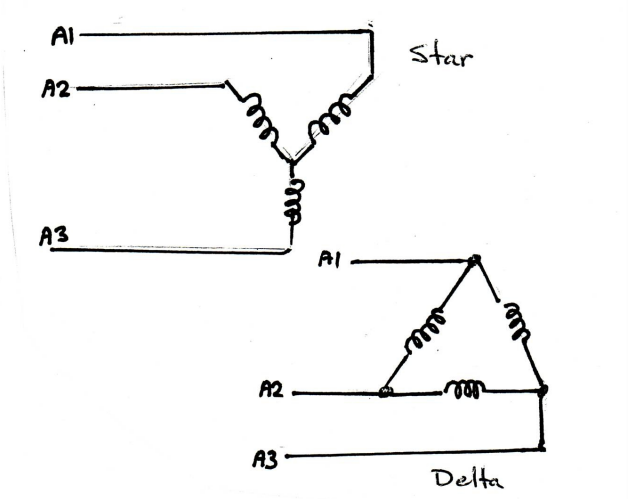

Illustration 6: Star & Delta Windings

F10 Three Phase Motors

Three-phase motors have 3 sets of windings at 120 degrees apart. They are simple constructions with no centrifugal switch and are similar in construction to capacitor-run motors. (or the other way round) The motor winding can be in a star or a delta form. They are induction motors, and the speed is determined by the mains frequency(F2). Reversing the motor is done by swapping the connections of two of the phases. Switches or relays are used. The most common type of large motor used in industry. The resistance of the good windings will be the same between each terminal and the insulation to the metal frame. If one winding is faulty, the resistance will change.

F11 Inverter Technology

This technology is used in Fisher & Paykel and LG washing machines, as well as in some air conditioners. They consist of a 3-phase motor with computer-controlled electronics that produce variable-frequency 3-phase electricity to control the speed and direction of rotation. Fisher & Paykel and LG have a rotating multi-pole permanent magnet that rotates around the fixed 3-phase windings. (Illustration 19) Between the windings is a speed sensor which tells the computer the speed and direction of rotation. The speed sensor consists of Hall-effect transistors that conduct when in a magnetic field. See the section on Fisher & Paykel washing machines. (Section K) Other names used include “stepper motor” and “direct drive motor” (LG front loader). The resistance of the winding is the same as that of a three-phase motor.

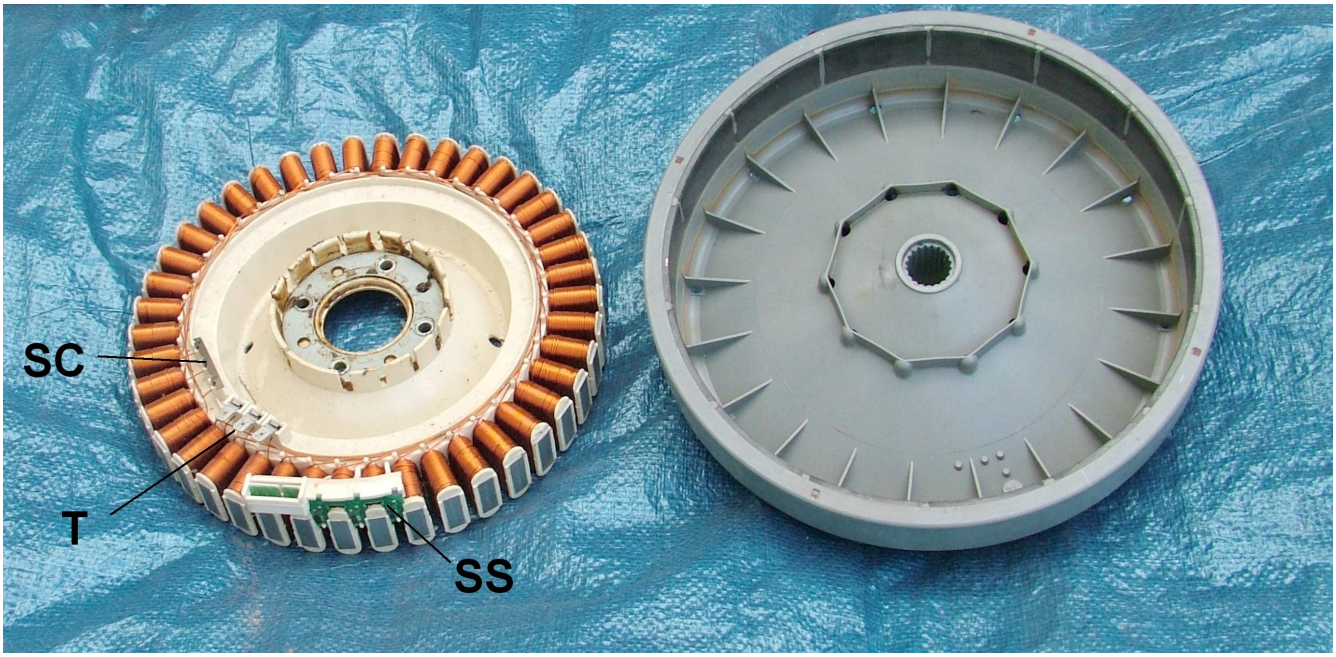

Illustration 7: Fisher & Paykel Inverter Motor

T Motor Terminals SC Star Connections SS Speed Sensor

F12 Brush-less DC Motors

Brushless DC motors use switching transistors to convert DC to AC. AC electricity is fed into a 3-phase motor. Examples are some computer fans and newer power tools.

Also used washing machine motors with or without optional forward/reverse switches

