How real electric motors work

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1. Induction motors

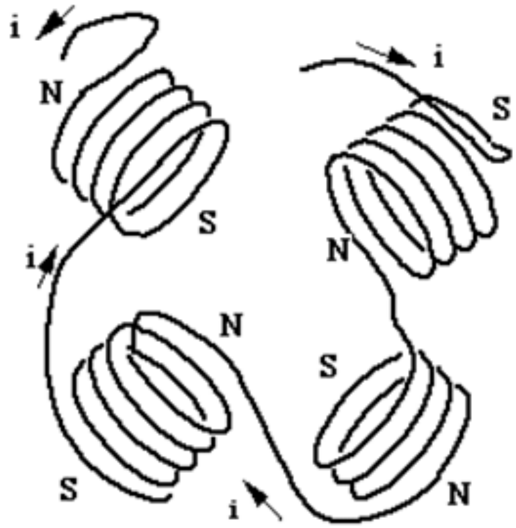
No modern home should be without one – or maybe a dozen. You'll find an induction motor in the fan, fridge, washing machine, dishwasher, clothes drier, and the little pump that circulates water in the fish tank to stop the water turning green and the fish going belly-up. Chances are there's also one in the air conditioner – unless it's a particularly high-tech one.

Advantages:
• Cheap
• Quiet
• Long lasting
• Creates no interference

Disadvantages:
• Wants to turn at constant speed (50Hz divided by half the number of poles)
• Cannot turn faster than 1500rpm (4-pole motor)
• Draws a massive starting current, or is inefficient, or both
• Kind of big and bulky for the power it develops

This one came out of a fan.

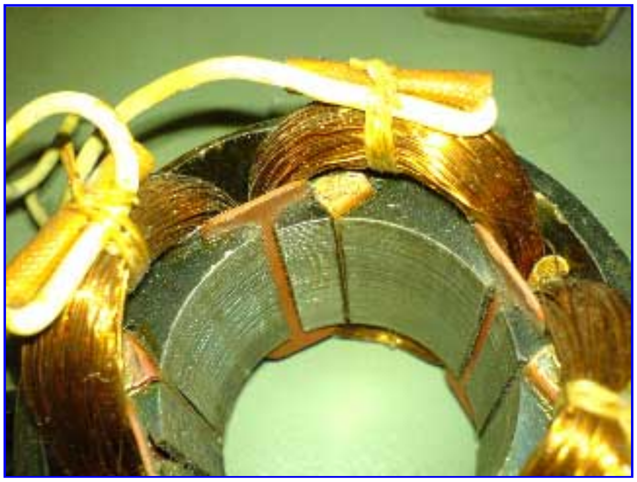
Actually, the bearings and end-caps of the motor have already been removed. (In retrospect, I should have used something more delicate than an axe to disassemble the fan.) We can pull the rotor out and this is what we're left with. There are four windings, and they are all simply in series.



Well, not quite simply – the current comes in the white wire, then the first winding (top right) is clockwise, the next one (bottom right) is anticlockwise, bottom left is clockwise again, top left is anticlockwise, then out the other white wire. So, imagine a positive half-cycle of the mains, with the current actually coming in that first wire. The first winding produces a north pole facing in; the second a south pole facing in; etc, like this: N-S-N-S.

Half a mains cycle later (10 ms) the current has reversed and so must the magnetic sense of the poles, which are now: S-N-S-N. The rotor is an electrical conductor, and therefore tries to follow this field. To do so it has to rotate through 90 degrees. The rotor thus takes two full cycles of the mains (40 ms) to make a complete rotation, and so revolves at 1500 rpm. At least, it would if it could keep up with the rotating field. But it can't, quite, and in fact it's only because it's slipping behind that any torque is developed at all. So, it rotates a bit slower than 1500 rpm (typically 1440 rpm) depending on how much torque it is being called upon to produce.

Note that the motor, as described so far, could rotate happily clockwise or anticlockwise. This kind of motor therefore needs some kind of internal cleverness to ensure it only turns in the right direction. This is achieved, in this motor, by the use of shaded poles.



Notice the winding at the top of the picture. See how there is a small additional pole (or set of iron laminations) off to the left of the main pole. It's excited by the same winding as the main pole, but is "shaded" from it by a thick copper band that wraps around the laminations and acts like a shorted electrical turn. The current induced in this band by the magnetic field generates a phase shift so that the shaded pole can generate a small component of magnetic field at right angles to the main field, and with the correct phase to ensure the fan turns the right way (otherwise the fan would suck instead of blowing).

So in fact our induction motor is using induction already, and we haven't even got to the rotor yet!

Now we look at the rotor. This is a real disappointment – it looks nothing like the "squirrel cage" in the text book! Where's the squirrel supposed to go, for starters?

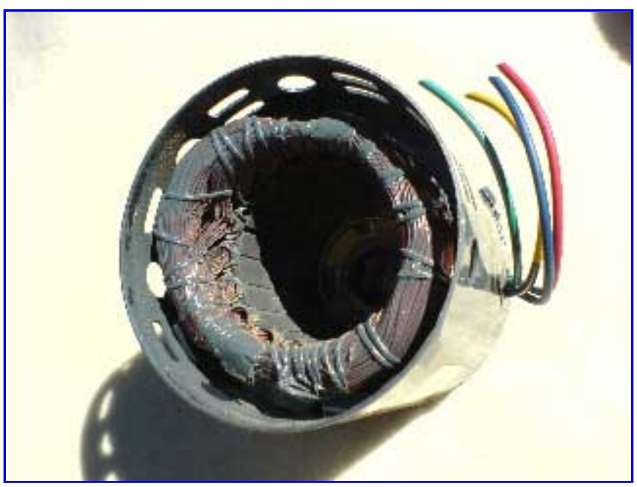
What's happened here is that the rotor is actually made up of a stack of disc-shaped laminations of soft iron. That's right – it's solid. This concentrates the magnetic field (generated by the windings) into the region where it will do the most good (the conducting bars of the rotor).

You can actually see the edges of the bars that run along the axis of the rotor, but they're at an angle of maybe 30 degrees to the shaft. What's going on here? Bad day at the factory? Chances are it's been designed that way to reduce *cogging torque*. If the bars ran parallel to the axis, the torque would rise and fall as each bar passed under the windings. By slanting the bars, the torque is kept more uniform as the rotor turns.

Now let's look at a different type of induction motor.

This induction motor came out of an astronomical telescope. It was part of the photographic film transport, and needed to be able to turn both forwards and backwards. It therefore has two separate windings, and four wires coming out. One winding is fed directly from the mains (or *"line"* as our US colleagues call it); the other is fed through a capacitor that provides the necessary 90 degree phase shift. Swap the windings over, or reverse the connections to one of the windings, and the motor goes the other way.

No surprises when we take it apart, although note a very different winding pattern to the previous motor. It has more poles, and therefore turns slower.



Once again, the rotor is solid, and we can't see what's inside. The aluminium plate at the end of the rotor has been stamped and turned up into a series of small fins to make a crude cooling fan. (This wasn't necessary with our first motor – it kept itself cool by the simple expedient of placing itself in the middle of, well, a fan.)

Since astronomical telescopes no longer use film, we may as well cut the rotor in half and see if there's a squirrel in there.

No squirrel, but a magnificent set of aluminium conducting bars, just like in the text books. If you think of the rotor bars as forming (via the end rings) a single-turn secondary winding of a transformer, the primary of which (the windings on each pole) has some 50 ~ 100 turns, it is clear that the current through the rotor bars can be very high – as much as 100 amps for a 240 watt motor. This explains the need for really chunky bars!

One disadvantage of the shaded pole motor is that the *starting torque* is rather low. This doesn't matter for something like a fan, where the load when stationary is almost zero. For other applications, like a washing machine, it would be a disaster. Such motors therefore use a capacitor to generate the required phase shift for the quadrature windings, as in this example.

Induction motors also come in other variations, but the two described above are the most common in domestic use.

For serious grunt, however, you need a *three-phase* induction motor. This takes advantage of the fact that commercial 3-phase power is delivered by three conductors, each of which carries a 50 Hz sine wave with 120 degrees of phase shift relative to the other two [See 3 phase power]. A

3-phase motor simply places three windings at 120 degree intervals around the casing, and a rotating magnetic field is automatically produced. Three-phase induction motors are the "workhorse" of industry, with large units having ratings well in excess of a megawatt.

Sydney's new Millenium trains use 3-phase induction motors, each rated at 226 kW, breaking away from the traditional DC motors used on Tangara trains and earlier models. However, since the overhead power to the train is 1500 volts DC, each Millenium train must use an *inverter* to create the three AC phases to feed to its motors.