Copper and Electricity: Efficient Motors

Electric motors are vital in industry. They account for two-thirds of all the electricity used in industry and half of the total electricity used in the UK. In UK industry:

- over 10 million electric motors are at work.
- 3000 new motors are sold each day.
- industrial motors have an average life expectancy of 13 years.
- a lifetime's supply of electricity can cost over 200 times the initial capital cost of the motor.

Motors are relatively cheap, but are expensive to run. A modest-sized 11 kW induction motor could cost as little as £300 to buy, but its running costs over ten years could be £44,000. Up to 15% of this cost could be due to waste within the motor. Below are different sections of this e-source, for quick navigation.

Using Electric Motors

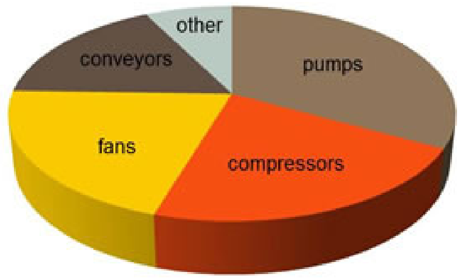
Making motors more efficient

Electric motors can be made more efficient in a number of ways. Some of these are subtle improvements to design and to the precision construction of components within the motor. However, using more copper in motors has a big impact. The high conductivity of copper means that components can be made smaller and kept closer together. Induction motors are widely used. Their efficiency can be improved using cast copper rotors - again because currents will flow so easily in copper.

Electric motors are typically 85 to 95% efficient in transferring energy to their load. However, the difference between 85 and 95% is enormous. Saving 5 % of the energy supplied would cut running costs for the 11kW motor by £2,200 over ten years, and reduce CO_2 emissions by about 25 tonnes.

Did You Know?

70% of copper goes into electrical applications that benefit from its energy efficiency. Over its lifetime use, one tonne of copper in conductive applications will save users between £16,000 and £1.6 million dollars due to reduced energy consumption.



Systems driven by electric motors consume half of all the electricity generated in the UK.

Component	Existing motor	New motor
Cost	Already paid for	£400
Efficiency	90%	95%
Annual electricity cost	£2,800	£2,600
The new motor will pay for itself in 2 years and make savings from then on.		

Making savings

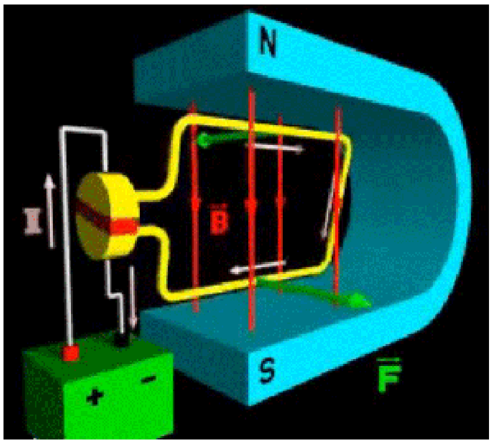
It is often better to buy a more expensive, more efficient motor if it will consume less electricity than a cheaper one. This is particularly true if the motor is used for 24 hours a day. If it has a shorter duty cycle (i.e. it is used for only an hour or so a day), then replacing an existing motor with an energy efficient one may not make such a good saving.

How do Electric Motors Work?

The motor effect

There are different ways of thinking about how electric motors work:

- a rotating electromagnet.
- two parallel forces producing a torque.



There are animations showing the motor effect online such as this.
Watch the YouTube video.
(Courtesy of PelletierPhysics.)

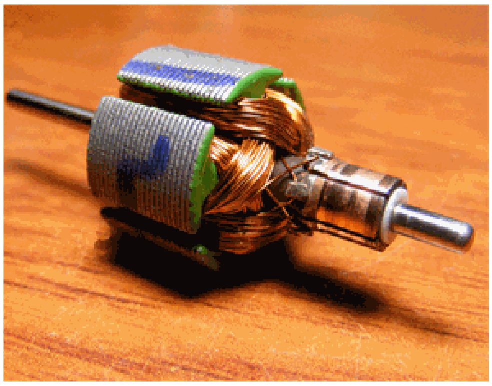
Rotating electromagnet

When the rotor coil is connected to a battery, a current flows through it. This turns it into an electromagnet. The top of the coil becomes a north pole, so the top is attracted to the south pole of the permanent magnet on the left. Hence the rotor starts to turn anticlockwise.

When the rotor is vertical, the turning effect stops (the rotor electromagnet is lined up with the permanent magnets). Therefore, at this point the current is reversed (by the commutator) and the rotor has to turn round by 180° to line up again.

The current is reversed every 180° to keep the rotor turning.

However, the force on the rotor is quite weak as it approaches the swap over point. Let's see why by looking at it a different way.



Rotor from a small DC electric motor. This motor has 3 coils and the commutator can be seen at the near end. (Wikimedia Commons.)

Parallel forces

The current I flows along the sides of the coil. Each side is of length L.

As it flows across the magnetic field of flux density B, it experiences a force, F.

The size of this force is:

$$F = B\,I\,L$$

The current and magnetic field are at right angles to each other. The force will be at right angles to both of them.

We can use Fleming's Left Hand Motor Rule to see that the force on the right is upwards and the force on the left is downwards.

Two equal, anti-parallel forces like this are called a couple. They produce a turning effect, or torque, on the coil. The size of the torque is

$$T = F\,d$$

where d is the perpendicular distance between the forces.

The biggest torque
The torque can be increased by:

- increasing the magnetic field strength.
- increasing the current.
- increasing the length, L.
- increasing the number of turns on the coil.

Also, the torque is a maximum when the perpendicular distance between the forces is biggest. This is when the coil is in the horizontal position.

Coil in different positions
As the coil rotates, the perpendicular distance between the forces gets less. Therefore, the moment of the couple decreases.

When the coil has turned through 90°, the moment is zero because the forces are acting along the same line (i.e. the perpendicular distance between them is zero). This is one reason why practical motors do not have a single rotor coil like this.

A single coil drives the rotor round for 180° before the contacts are swapped. The torque is reduced considerably once the plane of the coil is more than 30° to the magnetic field. To avoid this loss of torque, most motors use more than one coil.

For example, the motor in a toy car or train will usually have three coils. Instead of driving the rotor for 180°, each coil drives it for just 60° (30° each side of horizontal). In this way, the coil in use is always feeling nearly its maximum torque.

Energy Efficient Motors

Types of motor
You will be familiar with the model motor in the section 'Rotating electromagnet'. A simple d.c. motor works on the same principles except that it has more coils. This makes it more efficient.

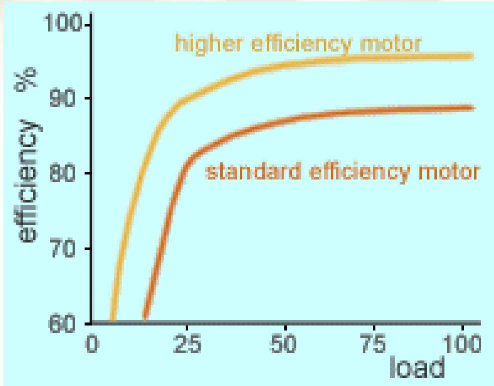
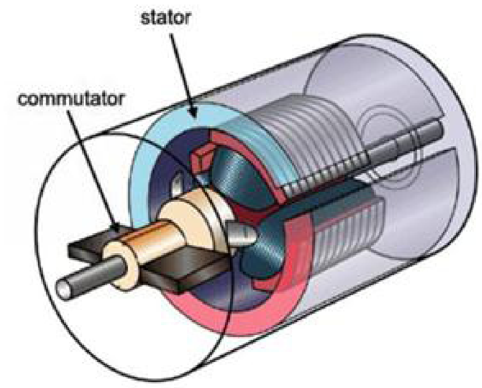
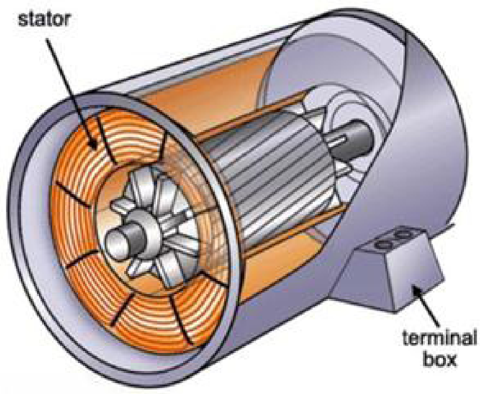


Figure 1: Comparison of efficiencies of standard and high-efficiency motors.



A simple d.c. electric motor.



An induction motor.

However, it is still very wasteful because of:

- friction between the commutator and brushes.
- loss of torque at some angles.

Also, if the motor gets stuck (possibly through trying to lift too big a load), the rotor coils can overheat and melt. Therefore, most industrial and heavy home appliances use an induction motor. They are used in washing machines, fridges, central heating pumps etc.

Induction motor / model motor

The table below compares the parts of a simple d.c. motor with those of an induction motor.

Component	d.c. motor	Induction motor
Rotor	Rotating coil of copper wire	Aluminium or copper bars in an iron core; copper bars are more efficient
Stator	Permanent magnets	Coils of copper wire provide magnetic field
Connection	Commutator and brushes carry the d.c. current to the rotor	Terminal box connects the stator coils to the 3-phase a.c. supply
Cooling		Fan to cool the rotor

Energy efficient induction motors

Induction motors can be made more energy efficient by:

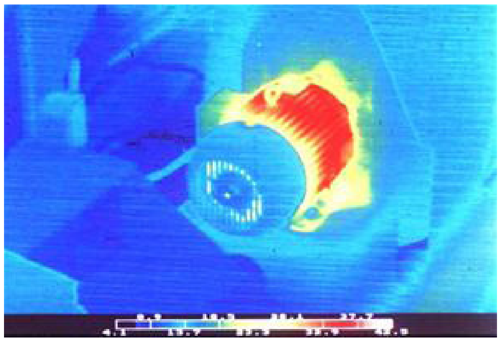
- using copper windings in the stator coils.
- using copper bars in the rotor.
- machining all moving parts to a high precision.
- using a special, high quality steel for the rotor and stator.
- keeping the rotor and stator as close as possible without touching – again through precision manufacture.

Energy efficiency and load

Even the most efficient motors are going to lose energy in some places. The efficiency varies with the load. This is measured by getting the motor to do work. This could be lifting up a weight or getting it to pull against a braking system.

The total efficiency of a motor is zero when there is no load (it is doing no useful work). As the load increases, so the efficiency increases because it starts to do some work. The efficiency then levels off. At this point, any extra load causes the motor to draw a bigger current. This increases both the useful work and the

How electric motors are made



Infra-red image showing energy lost as heat in an induction motor. (Courtesy of Future Energy Solutions.)

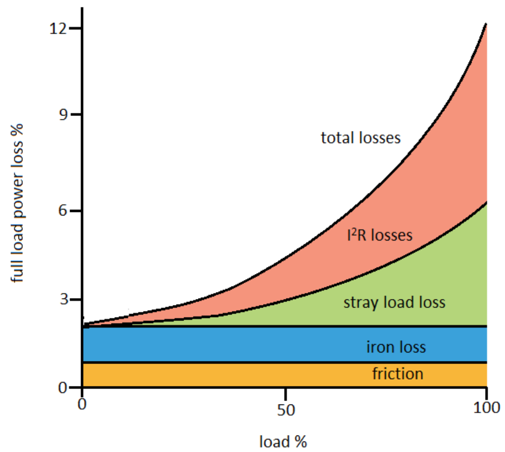


Figure 2: Losses in different parts of a motor.

joule heating in the motor. They increase in proportion to each other, keeping the efficiency almost constant.

Where losses come from

A motor loses energy in a number of ways.

- Friction - of moving parts.
- Core (iron) loss - due to changing magnetic fields in the rotor and stator cores.
- Stator loss- joule heating (I^2R) when current flows through stator coils.
- Rotor loss - joule heating (I^2R) when current flows through rotor.

These vary differently with the load. The friction and the core loss stay constant - they depend on the speed of the motor rather than the current being drawn. The joule heating losses increase with the load. This is because the motor has to draw a bigger current to do more work. And this bigger current causes more heating in the coils. However, although the losses are increasing with load, so is the useful work being done. So the efficiency of the motor is pretty constant after about 25% maximum load.

Questions

1. Figure 1 shows how the efficiencies of two motors depend on their load. (100% load means that they are turning the maximum load for which they were designed.)

a) What would the efficiency be at zero load? Explain your answer.

b) At what load are these motors operating most efficiently?

c) Suppose the standard motor cost half the price of the more efficient motor. Use the graph to explain why this doesn't necessarily make it a good choice.

2. **The force on a current-carrying conductor varies with the current, the magnetic field strength and the length of the conductor. How does force vary with:**

a) current?

b) magnetic field strength?

c) length of the conductor in the magnetic field?

3. **The torque on a rotor varies with the angle of the plane of the rotor coil to the magnetic field. At what angle is the torque**

a) a maximum?

b) zero?

4. **Calculate the force on a wire of length 5 m carrying a current of 4 A at 90 ° to a magnetic field of flux density 2×10^{-3} T.**

5. **Referring to Figure 2, for which two types of losses are all of the following statements true?**

i) Increase as load increases

ii) Zero when there is no load

iii) Related to resistance

iv) Related to flow of current

Click here for answers

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