All you need to Know....

Electric Motors

Part Two

Last month we took a look at some of the history behind the use of Electric motors in RC car racing, and how things have changed over the years. This month, we are going to start looking at the theory governing their operation, and how this can effect their performance on the racetrack.

Before we start, I would like to make an observation, and this concerns the differences between an electric and IC motor. An electric motor produces maximum torque from rest, which decreases as the speed increases. Conversely an IC engine has very low torque at low speed (stalls), and generally produces more torque as the speed increases, up to a peak at some point in it's range.

This is a fundamental difference in characteristics, and as a result, the two should never be compared as equals, as what is good for one, is likely to be bad for another.

The Electric Motor

It was Michael Faraday who was responsible for discovering the principles from which an electric motor could be designed. He found that a current passing along a length of wire in a magnetic field would be deflected by a force at right angles to the field. He also found that a wire being moved through a magnetic field would produce a voltage between the ends of the wire. From these two discoveries, he went on to design the generator from which electricity could be produced, a development of which was the electric motor.

So we know that the torque generated by an electric motor is due to the reaction between a magnetic field, and a current carrying conductor, but how is this arranged in the motors that we use?

The magnetic field is produced by a pair of permanent magnets, which are mounted inside a metal can. The current carrying conductor is wound onto a former or "armature" and is normally wound so that there are many turns in order to maximise torque. In our case, there are three sets of windings, making up what we call the pole armature. It could be possible to increase the number of poles, but for our use, three poles is probably the optimum, although it does mean that the torque produced as the armature revolves is very "notchy". It is also the minimum number of poles for which the motor can be guaranteed to start from rest, a two pole motor for example would not start in certain positions.

OK, so we have three sets of windings, but how is current fed to each winding?

In our case, we use a mechanical switch arrangement made from the "commutator" and brushes, the idea of which is to supply current only to the coils which are in the field of the magnets. It also ensures that the current is reversed as the armature rotates, so that opposite poles of the armature produce torque in the same direction, and do not oppose one another.

The can and armature are designed so that where possible the magnetic field inside the motor is at right angles to the windings, as they pass current. This is to maximise torque as the armature rotates, as any other angle will produce torque at a tangent. It is important to realise that there is a magnetic circuit inside the motor, as well as the more obvious electrical one. This is because the magnets are a source of MMF (magneto motive force) and can be considered to be equivalent to a battery in an electrical circuit. Instead of current, the magnets produce a field, or flux which "flows" from the north pole of the magnets, through any resistance, called reluctances to the south pole. In our case, there are two magnets inside the can to concentrate the field around the armature.

The diagram below shows how the flux "flows" from the two magnets, and through the armature.

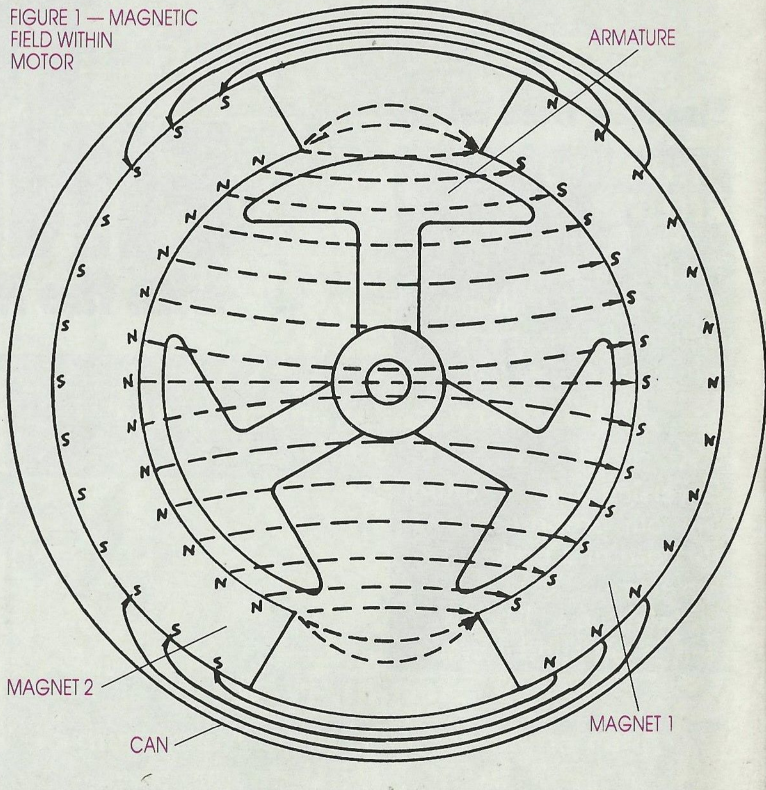


FIGURE 1 — MAGNETIC FIELD WITHIN MOTOR

Notice that an air gap produces a high resistance to the magnetic flux, and so the air gap between the magnets and armature can make a large difference to the characteristics of a motor. This can also very important, as it needs to pass a relatively large amount of flux, and so prevent it from leaking outside the can, which can interfere with the intended magnetic field around the armature.

Relationship Between Armature Current and Torque

For a given motor, there is a linear relationship between the armature, current and a load torque, ie the higher the current, the greater the torque. Maximum current is taken from a standing start, as this is when there is maximum torque available. It is also very important to realise that a car that is going down the straight is actually using relatively little current, compared with one accelerating onto the straight.

Being more specific, the load torque is actually proportional to three things, the magnetic field strength, the number of turns and the armature current. Increasing any one of these, while keeping the others constant will increase the available torque.

Note: This implies that a 17 turn motor will produce more torque than a 13 turn motor. However, in practice, as the number of turns reduces, the current taken by the motor increases and this gives an overall increase in torque for the hotter motor.

Motor Wind Specifications and Torque

One of the most quoted specifications given for a model car motor, is the number of turns and the way it is wound. A typical example would be a 12 triple. What this means is that there are three separate wires wound in parallel 12 times for each pole of the armature. A seventeen single would have a single wire wound 17 times around each pole of the armature.

Whilst most people can understand the difference between motors with different numbers of turns, there is always some confusion concerning the differences between single, doubles, triples, quads, quins etc etc. This has led to assumptions that are false regarding the differences in performance. Typically, quads are quoted as being soft and singles as having more punch with doubles and triples being intermediates. What really makes the difference is the effective cross sectional area of the wires used for the motor and hence it's resistance.

To demonstrate the point, suppose we have two 15 turn armatures, a double of 0.5mm wire and a quad of 0.3mm wire. Which would have the most punch/torque if geared on the same ratio?

Answer.....

To do this we need to calculate the total cross sectional area of each armature.

a) for the 15 double 0.5mm wire.

area of single wire = Pi*radius^2
= 3.142*0.25*0.25 = 0.196mm^2
Hence total area = 0.393mm^2

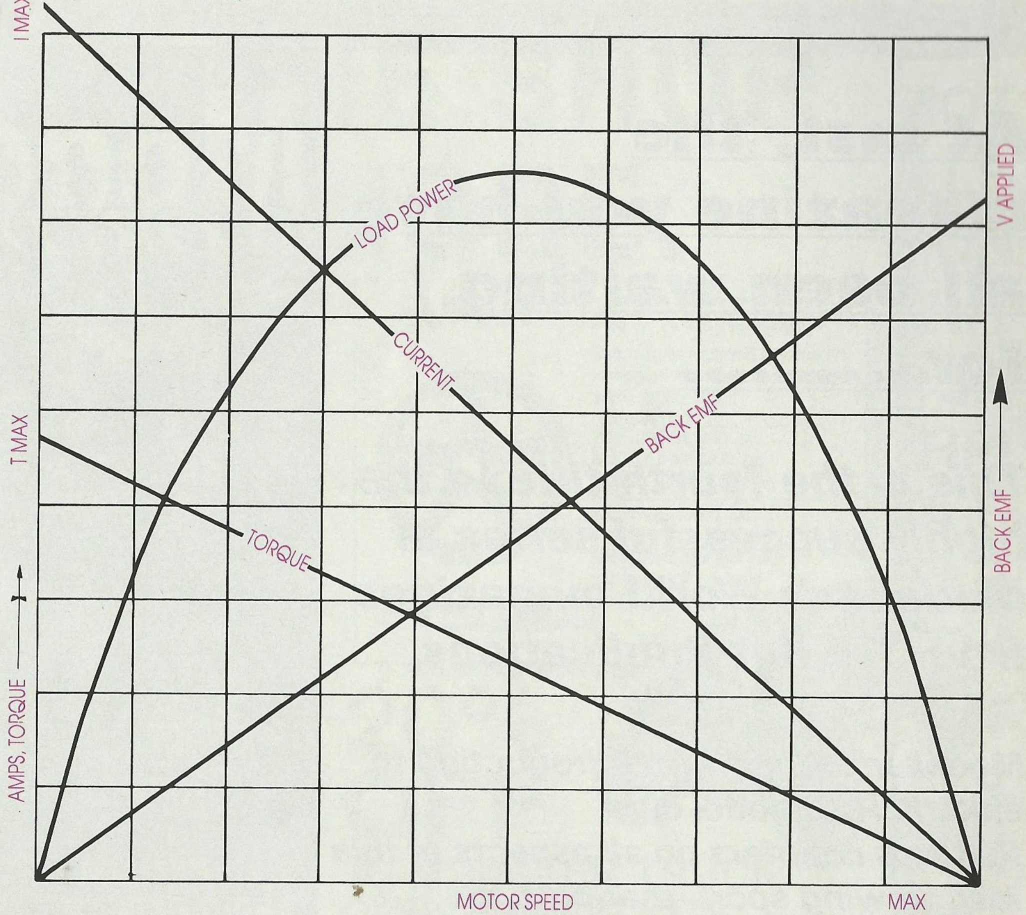
b) for 15 quad 0.3mm wire.

area of single wire = Pi*radius^2
= 3.142*0.15*0.15 = 0.070mm^2
Hence total area = 0.283mm^2

From the above example, it is clear that the quad has a much lower cross sectional area and hence a higher resistance. This higher resistance will limit the current and in doing so reduce the amount of punch/torque available. Note that the lower resistance of the 15 double will give it more punch, but it will also take more current and may need to be geared lower to compensate.

Note that this assumes that the two armatures used the same total length of wire for the 15 turns when making the comparison. Sometimes there may be differences in the total length of wire, due to the way in which the armature is wound, this is especially true when thick wires are used, as they can be very difficult to wind tightly, meaning that more wire is used.

FIGURE 2 — TYPICAL CHARACTERISTICS



The Electric Motor Power with Power Applied

When we apply power, it is important to realise that there are two basic actions occurring within the motor as it rotates. Firstly the armature current will produce a reaction with the magnetic field, to supply torque to the load. Secondly a voltage (normally called the "back EMF") will be generated within the windings of the armature.

The back EMF is generated by the action of rotating the armature windings in a magnetic field (Faraday's second law) and is proportional to the field strength, the number of turns on the armature and the speed of rotation. If a motor can has very good magnets, it will produce more back EMF than a motor with lesser magnets and will rev lower. A motor with less turns will produce a lower back EMF and will hence rev higher.

As implied, the back EMF opposes the applied voltage and will act in order to minimise the difference between them. For no load conditions, the back EMF will almost equal the applied voltage. However, at higher loads, the motor will need to supply torque to the load and since this requires current, there will be a corresponding drop in the armature windings due to their resistance.

When voltage and load are applied to any motor, it will accelerate to the speed at which the back EMF, added to the voltage drop across the armature windings, are equal to the applied voltage.

If the load is increased, the current required to supply enough torque will increase and hence, the back EMF must drop to allow this to happen, as the voltage drop across the windings increases. This means that the speed must reduce. If the load is reduced, the current required to supply the torque will be reduced and the back EMF can increase, along with the motor's speed.

The graph in figure two shows how the armature current, load torque, power and back EMF carry for an "ideal" motor. Notice in particular the differences between high and low speed characteristics. At low speed there is more torque available, because the back EMF is low, allowing more current to flow in the windings. At high speed, there is much less torque available, because the back EMF is much higher. The Load power "peaks" at half the no load speed and reduces either side of this to zero at the extremes. Also note that the graph applies for all specifications of motor, the only differences being the scaling of the axes.

Next month we will continue looking at the way in which electric motors work and attempt to explain how a practical motor differs from an "ideal" one.

DAVE GALE