All you need to Know....

Electric Motors

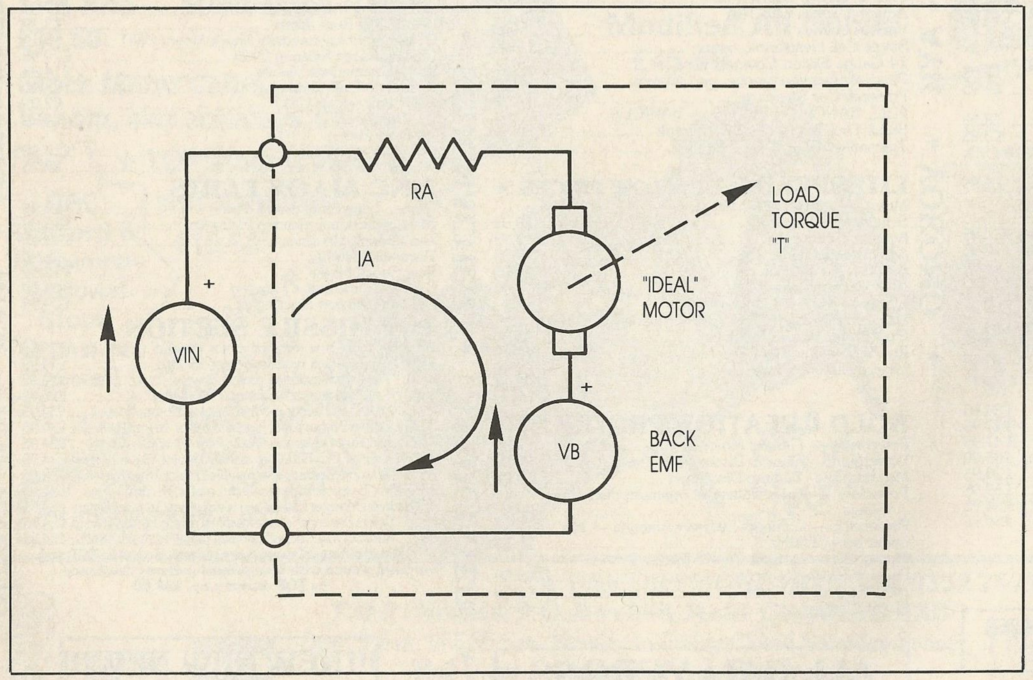
Part Three

Last month we started looking at the way in which an electric motor works. This month we will attempt to define the variables that are of particular interest to us, and look at how these can be explained in terms of track behaviour. Later we will look at the differences between a theoretical, and practical motor.

Equations Governing Motor Performance

For a permanent magnet motor such as we use, there are a few important equations that define how the motor operates. Where possible I have tried to keep things as simple as possible, and in doing so have assumed that we are dealing with a "perfect", or "ideal" motor.

To help us understand, it is easier to visualise the motor as below:



The voltage we apply is Vin. Vb is the back EMF generated by the motor as it rotates. Ra is the resistance of the armature. T is the torque generated at the output of the motor.

For the electrical circuit above, we can see:

$Vin=La*Ra+Vb$

Where:

Vin=Applied voltage
Ia=Armature current
Ra=Armature resistance
Vb=Back Emf

But Back EMF, Vb, can also be given by:

$Vb=K2*n*s*M$

Where:

K2 is a constant for the motor
n is the number of turns
s is the speed at which the motor is rotating
M is the magnetic field strength

For an ideal motor, the torque generated at the load is proportional to the armature current at any given time:

$T=K1*Ia*M*n$

Where:

K1 is the "motor" constant
M is the magnetic field strength
n is the number of turns
Ia is the armature current

If we substitute equations 2 and 3, into equation 1, we can get a general expression for the torque in relation to the above parameters.

$$T=K1*n*M\,\frac{(Vin-Vb)}{Ra}$$

Or

$$T+K1*n*M\,\frac{(Vin-K2*n*s*M)}{Ra}$$

From the above, there are three cases of interest.

* At zero revs (s=0), the equation simplifies to give us the stall torque, which is clearly the maximum amount of torque that the motor can possibly supply.

* At maximum speed (s=max), when the back EMF, Vb almost equals the applied voltage, Vin, the torque available is close to zero. In practice however there must always be some torque to overcome frictional losses. At this point, the maximum speed is approximately:

$$S(max)=\frac{Vin}{(n*M*K2)}$$

* At any other speed, the torque is inversely proportional to the speed of rotation, and largely dependant on the back EMF term.

Several things are also apparent from the general torque equation.

Reducing the armature resistance, Ra will increase the torque throughout the entire speed range. It must also increase the current as well. This is why an armature with a large cross sectional wire area will have very good acceleration, but tend to go flat if driven unsympathetically.

If the magnetic field strength is increased, the stall torque will be increased, but the off load speed will be reduced as well.

Similarly, if the number of turns is increased, the stall torque will increase, and off load speed reduced.

A good motor is one that will have a large stall torque, but generates less back EMF. By looking at the equation, clearly one that has a high K1 constant, and low K2 constant would give the best motor performance. Conversely a low K1 constant, and high K2 would made a poor motor. It would incidentally make a very good dynamo or generator! When we look for a good motor, then this is what we are generally trying to find, a motor with good "motor" characteristics, and poor "generator" characteristics.

Note: The effect of either increasing the number of turns, or magnetic field strength is identical. This is because they both alter the stall torque, and back EMF terms in the equation. This also explains why we have ended up running motors with less turns to give the same performance, as the strength of the magnets has increased.

Effect of Altering the Motor Timing

On most modified motors, there is the option of adjusting the timing of the motor, by "advancing" the brushes with respect to the magnetic field.

Normally a motor would have the brushes at right angles to the axis of the magnetic field, as this gives the largest arc through which the armature coils can travel, and hence for a given current produce maximum torque. When we alter the timing of the motor, the net effect is to reduce the strength of the magnetic field. This reduces the amount of torque, but it also reduces the back EMF generated at a given speed, and hence the RPM's will increase. This is why it is sometimes faster to increase the advance on a motor, and then gear it down.

It is possible to reduce the strength of the magnetic field by increasing the air gap between the armature, and magnets. Again this will reduce the amount of torque, but increase the RPM's, in much the same way as altering the advance does.

The "Practical" Motor

Most of the previous text refers to "the ideal" motor, which as we all know is very hard to come by. It is all very well relying on theory, but on the racetrack, actions speak louder than words, and most of what you have just read will rarely apply. Quite why this should be, I am not entirely certain, but I think it is to do with the way we use the motors.

What we want is a motor that feels (and is) fast, whist at the same time being easy to drive. A motor that gets to its top speed very quickly, can be very boring to drive if its top speed is low. Also, as I mentioned several times, torque is a function of current, and as we all know, batteries only have a limited capacity — ie if we want more torque, we need better batteries and so on. This is made worse by the fact that the highest capacity batteries tend to have more resistance, and this tends to reduce the torque available.

In the next few sections, we will try and isolate some of the major differences between and ideal, and practical motor.

Magnets

The magnets we use tend to suffer from a variety of problems. In general, all magnets tend to lose their strength as they get hotter. This was particularly noticeable with the older ceramic type magnets, and modern ones are much better. They can also become demagnetised if they are knocked about too much, or if the armature current exceeds a certain limit (normally very high, say above 100 amps). Demagnetisation is not a major problem however, at most accounting for a 5-10% drop in performance over a season. Whilst this may seem quite a large amount, it doesn't mean that there will be a corresponding drop off in performance, only a subtle change in motor characteristics, which may sometimes be better depending on the motor in question.

Armature

Besides producing a load torque, the current that passes through the armature windings also generates heat in the windings. Since the copper wire used to wind the armature has a positive temperature coefficient, its resistance will increase as it gets hotter. This is much more of a problem with armatures that have a small cross sectional area as there are greater losses, and the drop in performance can be quite noticeable, especially towards the end of a race. Incidentally most of the heat generated within a motor is probably due to the arcing at the brushgear, rather than resistive losses in the armature windings.

Commutator

In an ideal motor the commutator must be perfectly round, to ensure a perfect contact with the brushes as it rotates. In practice this is impossible to achieve even under laboratory conditions, as there will always be some play in the bearings or flex in the shaft. If there is one factor that governs performance, the action of the commutator is by far the most important. This is why there are many different lathes available for truing, and believe me, they are not just a gimmick, as some would volunteer.

In use, there are two processes that made the commutator become out of true, warping and erosion. Warping takes place as the commutator heats up, and can cause segments to lift or drop. Erosion takes place near the slots in the commutator, and is a form of spark erosion. The net effect of these is to rescue the contact to the brushes, and so limit the torque and power available. It is worth noting that a "hotter" motor is likely to do more damage to the commutator. This is because the commutator and brush are switching more often due to the increased motor speed.

Brushes

Again, like the roundness of the commutator, the perfect contact required from the brushes is seldom achieved in practice. This is mainly because good electrical contact and low mechanical wear are mutually exclusive to one another — ie we have to include a lubricant to prevent excessive wear. This means that a brush is made up from a compressed mixture (called sintering) of lubricant and conductive metal, normally graphite and copper. In terms of torque, a brush with the minimum amount of lubricant will provide maximum acceleration, but at the expense of commutator life. A brush with a larger lubricant content will have less acceleration, but will normally perform very well in terms of top speed.

Another problem with some brushes is that they can cause deposits to form on the faces of the brush and commutator. This seems to be formed when the lubricant is burned off due to arcing at the trailing edge of the brush. With such a build up, the contact between the brush and commutator is reduced, along with performance. A good brush will normally look "wet" where it touches the commutator, with the copper just visible through the film of lubricant. In my experience one that looks dull, and "sooty" is not performing well, and needs to be replaced. Sometimes cleaning with motor spray works well, but this can also remove lubricant from the brush causing damage to the commutator.

Finding the right brush is not an easy task, and it is very important that you keep note of what you use, so that you can get repeatable performance. I try and find the brush that gives me the best combination of performance, lack of deposits, and minimal damage to the commutator.

Overall, I have found the Corally brushes to be best, with Reedy/Associated competition brushes a very close second. Beware there are a large number of bad brushes about, so be very wary when changing to a new type. To monitor performance, it is very helpful to use a magnifying glass to see how the surfaces of the brush and commutator are behaving. This is especially useful when evaluating different brush types. Another point that is worth mentioning, is that cut brushes will cause more damage to the commutator that a full width one.

Brush Alignment

Another factor relating to the contact between the brush and commutator is the alignment. Ideally the centre of the face of the brush should lie on the axis of the motor shaft, otherwise the motor will not perform correctly.

This may only mean a slight change in the advance of the motor, but it could also result in one or more of the armature poles being shorted out. It is mainly for this reason that you should never run brushes that have worn more than about 3mm, as they will not locate properly in the brush holders.

If a commutator has been trued often, its diameter will be significantly less than its original size. Normally this will not cause any problems, but if the brush alignment is out, then this will exaggerate the problem.

Bearings

Ballbearings are manufactured to very tight tolerances, but even so, it is impossible to remove all traces of play. This is normally insignificant for a new bearing, but as the bearing wears, this can increase to the point where the commutator is not allowed to run true, and performance suffers, in much the same way as an out of true commutator. For standard class motors, and brushed bearings, they will get worse with every run as they wear.

Next month we will look at how to keep motor in top condition, and some basic advice on gearing etc.

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