Timpdon Electronics

Technical Note - No. 20
DC Motor Performance

Introduction

When you are thinking about a new model, the electric motor which drives it is likely to be one of the last things to be considered. Indeed, if you have bought a ready to run model, you have probably not thought about it at all.

You should though, as the operation and performance of your model is critically dependent on the motor driving it, and some understanding of motor performance will help you avoid ending up with a model which does not perform as you expect.

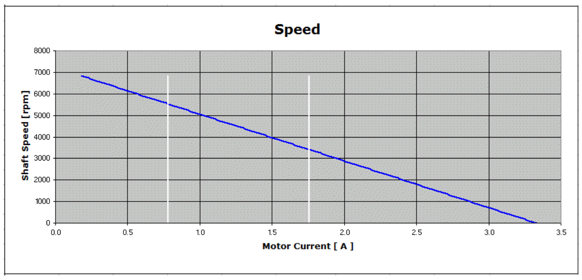
This Technical Note is intended to give an introduction to model d.c. motor design and performance, as well as a means of comparing the performance of different motors and gearbox ratios.

Motor Basics

All electric motors convert **electrical** energy, in a model supplied usually by a battery, into **mechanical** energy, in the form of **torque** [**force**] on a rotating shaft and mechanical **power**, which is **torque** multiplied by rotational **speed**. Our object in choosing a motor is to generate enough mechanical power to propel the model at a suitable **speed**, pulling the required load, with the minimum of electrical **energy**. The ratio of mechanical power out to electrical power in gives us the overall **efficiency** of the motor.

All model d.c. motors use permanent magnets to generate the magnetic flux required for the motor to operate. A permanent magnet generates a fixed flux level, irrespective of the motor voltage and current, and this significantly simplifies calculations of motor performance.

The graphs below show the shape of the relationships between electrical power, mechanical power, motor efficiency and motor speed. These graphs are similar in shape for all permanent magnet d.c. motors. Only the actual numbers vary between motor types. The graphs shown are based on an MFA-Como RE385 motor, commonly used in battery powered model railway vehicles in 16 mm railway modelling and similar scales.



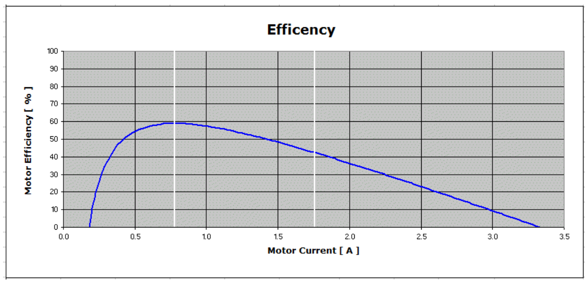
Speed

The maximum motor speed at any fixed motor voltage is the **no load speed**, with a corresponding **no load current**. The **no load current** is needed to overcome windage and friction within the motor itself and is usually quite low.

As the mechanical load on the motor is increased from zero, the motor current rises.

The motor speed then falls linearly with motor current, until the speed reaches **zero**, at the **stall current**.

If the motor voltage is increased, both the **no load speed** and the **stall current** increase in proportion to the change in voltage, usually with only a small change in the **no load current**.



Efficiency

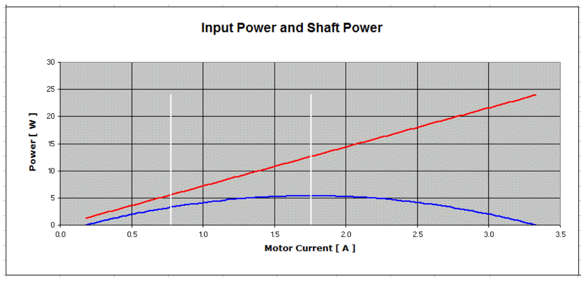
Motor efficiency is the ratio between mechanical power out and electrical power in.

At **no load** current, the motor generates no usable mechanical power, and the efficiency is **zero**.

When the motor speed reaches **zero**, at **stall current**, the motor also generates no mechanical power and the efficiency is **zero**.

Between these two points, the motor efficiency first rises rapidly, to a maximum value and then falls.

For most model motors, the **maximum efficiency** is usually between 50% and 80%, at a motor current level of about 20% of **stall current**.



Power

Because the motor voltage is fixed, electrical **input power** is proportional to motor current, and rises continuously as motor current increases.

Mechanical **shaft power** at any motor current is the product of electrical input power and motor efficiency at that current.

The **shaft power** therefore rises from **zero** at **no load** speed to a maximum value at about 50% of **stall current**, and then falls away to zero again at **stall current**.

Any model operation, therefore, at motor currents greater than about 50% of **stall current** simply results in a falling shaft power output and significantly increased motor heating, as the wasted electrical power has to go somewhere.

Choosing a Motor

From the graphs above, you will see that there is only a limited range of motor currents over which any motor will deliver useful mechanical power, at reasonable efficiency.

For optimum motor operation, the maximum motor current should be maintained within the current levels corresponding to **maximum efficiency** and **maximum power**, at about 25% of the stall current level. The motor speed corresponding to this level will be about 75% of the no load speed. If this speed is less than you require for maximum speed at maximum load, or if the motor current, and hence motor power, is too low for the loads you wish to pull, then the motor is not man enough for the job, and you probably need a bigger one. Alternatively, you can increase the motor voltage, although this will increase motor power and hence possible over-heating.

If the motor speed is too high, then the easy way to reduce it is to fit a reduction gearbox. This will reduce the maximum speed without affecting power output or efficiency, other than from losses within the gearbox, and as a consequence, increase the output shaft torque at any current by the same gearbox ratio.

How to Calculate Performance of a Motor

To calculate the performance graphs for any d.c. permanent magnet motor [and gearbox], you only need to know four measured data values:

- The **no load speed** of the motor
- The **no load current** of the motor
- The **stalled motor current** of the motor
- The **motor voltage** at which the other three parameters were measured

and in addition:

- The **actual motor voltage** to be used, if different
- The **gearbox ratio**, if fitted

All four base parameters required to perform these calculations are normally published by the motor manufacturer, or can be measured relatively easily.

Motor Performance Calculator Spreadsheet

To make it easy for you to do these calculations, *Timpdon Electronics* has created a simple interactive spreadsheet to do all the hard work for you.

The spreadsheet is written in **Microsoft Excel**, and is available as a free download from the *Timpdon Electronics* website:

- Go to **www.timpdon.co.uk**
- Select ***Timpdon Electronics*** and then **Downloads**
- From within the **Technical Notes** section, download **Motor Performance Calculator.xls**
- Open this file in **Microsoft Excel** and follow the instructions on the **README!** page

This spreadsheet will output results in both tabular and graphical format set up ready for printing. We have even included a list of the required data parameters for many popular motor types used by modellers, as well as the motor equations on which the calculations are based, for the more technically minded.

All of the graphs shown in this Technical Note were generated using this spreadsheet.

Afterword Note

Everything in this Technical Note is based upon an ideal motor model, and takes no account of brush gear and other losses and motor tolerances. However, prolonged experiments with a wide range of model railway and model boat motors have shown that it is adequately accurate enough for our modelling purposes, and should be an invaluable aid to selecting the right motors for your models.

Happy Calculating !!

Geoff Garside
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