

Motion Control Primer *By David Palombo*

Sizing an Industrial Motor for the Job

Selecting the right motor for the job can sometimes be the most confusing aspect of a motion control problem. A priority list must be made to determine what properties of the motor system are to be optimized. These properties may include: motor efficiency, motor torque, motor power, reliability, and of course, cost. Generally torque is the driving factor in a motor's weight, size and consequently cost, so knowing the torque requirements is paramount.

Any DC permanent magnet motor has a figure of merit called the motor Constant (K_m). This rating is usually in units of inch ounces per root watt ($K_t/\sqrt{R_m}$) which is a very useful measure because it describes a motor's ability to produce torque as a function of heat. As you can see, the heat dissipated goes up with the square of the torque. This power produced is solely from I^2R loss in the copper winding and does not describe the heat produced by iron loss. In most applications, I^2R loss is the predominant loss, except when the motor is moving at a very high speed. Ultimately, one must look at the thermal dynamics of the motor system because, other than a maximum RPM limit, a motor usually has a maximum operating temperature. The total surface area of the motor must be able to dissipate the total power loss in the motor, while keeping the temperature below the manufacturer's maximum rated temperature. A good rule of thumb is to keep the total loss in the motor less than .5 to 1W per square inch of motor area. It should be apparent that a motor's torque capability can be dramatically increased by keeping the motor cool.

The key is to try to reduce the torque requirements of the motor by increasing the RPM or the mechanical advantage (gearing). This can work to a degree. At some point, the iron loss due to higher RPM can cause a loss in the motor greater than the copper loss. The motor is at its peak efficiency when the iron loss equals the copper loss.

Which Type - Brush or Brushless?

Although we manufacture only brushless motors, I find myself frequently recommending brush motors to customers. A brushless permanent magnet motor is the highest performing motor in terms of torque vs. weight or efficiency. Brushless motors are usually the most expensive type of motor as well, making them practical only in situations where their features make them absolutely necessary. Usually, there must be a compelling need for a brushless motor. Some of its outstanding features are:

- Very high torque to inertia ratio (on interior rotors only)
- Zero out-gassing (no brush dust)
- Very high peak torque (on interior rotors)
- No arcing (use in explosive environments)
- Very high reliability (no commutator or brush to wear out)
- Potentially higher efficiency (due to no brush friction)

Of course there are good brushless motors and bad brushless motors just like there are good and bad brush motors. What is considered a "good" motor will be different for every user. Always look carefully at your application and try to figure out what motor is "good enough" to do the job.

Is not the size that counts, its how you use it

Bigger is not always better. As I have already said, the most important parameter to optimize in a motion system is torque. If you have an application that requires high torque at slow speed, a gear reduction of some sort can sometimes dramatically reduce the motor size or increase the motor's efficiency. If you need high speed at low torque, a large motor can have excessive iron loss. This will manifest itself as a high no-load current. If you notice that the no-load current goes up dramatically with speed, then the motor probably has a lot of eddy current loss. If the no-load current remains the same over its RPM range, the iron loss is mostly attributable to hysteresis drag torque. Knowing what components make up the iron loss is

important because it can point you in two different directions: 1. reduce the frequency (RPM) of the motor to reduce the eddy current loss or, 2. reduce the size of the motor to reduce the hysteresis drag.

Measuring Motor Parameters

With just a few motor parameters, the steady state performance can accurately be calculated. These parameters are the motor's torque constant (oz-in/A), terminal resistance, and no-load current.

The torque constant and terminal resistance is usually supplied by the motor manufacture, but should be measured to accurately predict motor performance.

Any DC, permanent magnet motor has a linear relationship to motor torque and current. This ratio is called the motor torque constant and is usually in units of oz-in/Amp or NM/Amp. The torque constant is directly proportional to the voltage constant which describes the voltage generated per RPM or per rad/sec. This is also called the back EMF constant. Since the torque constant is difficult to measure directly without sophisticated equipment, it is best to measure the voltage constant and calculate the torque constant.

The best way to measure the voltage constant is to drive the motor at a known constant speed and measure the voltage at the terminals. If you lack the means to back-drive the motor you can use the amplifier and measure the no-load RPM of the motor at a fixed voltage.

Most digital volt meters cannot accurately measure low resistance as is usually the case in the motor's terminal resistance. Connect a good current source (1A or less) while measuring the voltage drop across the motor terminals. The voltage divided by the current is the terminal resistance.

The no-load current is a combination of a motor's friction (bearing and/or brush), hysteresis iron loss, eddy current loss and viscous fluid loss. The no-load current should really be thought of as a no-load torque. Although the no-load current varies slightly with RPM, it is more or less a constant torque. Making this assumption greatly simplifies the mathematical model of the motor, but may be inaccurate in some instances. The no-load current should be measured at the RPM at which the motor is intended to run.

Calculating Motor Performance

Use these handy equations to calculate steady state motor performance. A spread sheet will help in visually graphing motor parameters. If the Torque constant is not supplied by the motor manufacturer, you can measure the motors no-load RPM/Volt and use the following equations to calculate the torque constant.

Torque constant: $K_t = K_b \times 1.345$

Current draw of motor: $I = [V - (K_b \times \text{kRPM})] / R_m$

Torque output of motor: $J = (K_t \times I) - (K_t \times I_{nl})$

RPM of motor: $\text{kRPM} = (V - R_m I) / K_b$

Power output of motor: $P_o = (J \times \text{RPM}) / 1345$

Power input: $P_i = V \times I$

Motor efficiency: $\text{Eff} = (P_o / P_i) \times 100$

Current at peak motor efficiency: $I_{e \text{ max}} = \text{Sqrt} [(V \times I_{nl}) / R_m]$

Symbol Definitions:

Eff = Efficiency

I = Current

I_{emax} = Most efficient current

I_{nl} = No load current

J = Torque (oz-in/A)

K_b = Voltage constant (Volt/1000 RPM)

K_t = Torque constant (oz-In/A)

P_i = Power input (Watts)

P_o = Mechanical power output (Watts)

Rm = Terminal resistance
RPM = Revolutions/minute
V = Voltage