



## Comparing Miniature DC Motors and Gearboxes from Multiple Vendors

Unlike their fractional and integral horsepower cousins that can be "Rated" using norms by such organizations as the National Electrical Manufacturers Association (NEMA) or the International Electrotechnical Commission (IEC) there are no such standards for rating small fractional and sub-fractional horsepower dc and stepper motors.

Each Manufacturer must decide their own rating system.

Trying to compare published data from multiple manufacturers is akin to having a conversation in the Tower of Babel. Nobody speaks the same language!

To exacerbate this situation is the fact that today engineer routinely download PDF datasheets from the Internet and/or receive them by email. Important supporting information is usually omitted.

As an example, in the case of the Faulhaber Group, the 8 pages of carefully prepared Technical Information in the published catalog are not routinely attached to a PDF datasheet. This results in important details regarding how the technical figures were arrived at not being readily available to an engineer about to make a decision on which motor to choose.

The following example will illustrate that not being conscious of the differences between how manufacturers "rate" their products can cause compromises in the selection of a small dc motor.

### Example

Let's assume that for a new design a 13 mm diameter motor will be the perfect diameter mechanically. Looking at the Faulhaber 1336 series of motors you notice that the 6 Volt winding is "rated" for 1.75 Watts. Comparing this with a similarly constructed motor from Vendor X, you notice that they have a 13 mm diameter motor of similar length but it is rated for 3 Watts.

The decision seems rather easy. You take the motor with more than 70% higher power. More "head room". Right? In this example... **WRONG!**

### Calculating Stall Torque of a Mechanically Commutated (Brush) DC Motors

What could possibly be subject to interpretation when it comes to Stall Torque? It is one of the two points on the ubiquitous speed/torque curve.

There are at least 4 methods used to calculate Stall Torque in sub-fractional horsepower dc motors. The key word here is 'calculate'. Unlike stepper motors where holding torque, pull in and pull out torque are measured, in small dc motors stall torque is calculated.

Here are some methods:

Variables:

$I_o$	No Load Current
$K_T$	Torque Constant
$R_c$	Terminal Resistance
$T_s$	Stall Torque
$V$	Applied Voltage

### Theoretical Stall Torque Method

Generally Stall Torque is defined as the Starting Current multiplied by the Torque Constant. Simple enough! This is how many vendors specify Stall Torque. This is the simplest method and gives the most favorable results.

$$T_s = (V / R_c) \times K_T$$

### Friction Torque Compensation Method

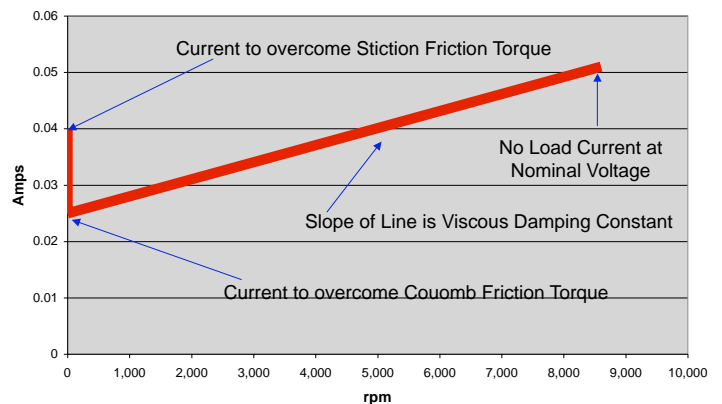
For a few motor vendors, including the members of the FAULHABER GROUP, it is defined as Starting Current minus No Load Current, multiplied by the Torque Constant. This is the technique for Precious Metal Commutated Motors of the Faulhaber Group.

$$T_s = (V / R_c - I_o) \times K_T$$

This is a conservative approach because the friction torque of the dc motor near zero speed will be lower than at a typical high no load speed. This method is particularly brutal for smaller motors, graphite commutated motors, and conventional iron armature motors.

Graph 1 illustrates this rather well.

Graph 1  
Typical No Load Current vs Speed



### Friction Torque and Brush Voltage Drop Compensation Method

For Graphite Commutated Motors the Faulhaber Group, as an example, subtracts a 0.5 Volt Brush Drop from the Applied Voltage before the stall current is calculated and then the no load current is subtracted. The Voltage drop across the brushes is real but the actual value of Voltage drop is subject to many variables beyond the scope of this paper.

$$T_s = ((V - 0.5 \text{ Volts}) / R_c - I_o) \times K_T$$

This conservative method can easily reduce the calculated Stall Torque by more than 10% vs. the more typical method. Additionally, the lower the motor voltage rating, the more penalizing the calculated results.

### Extrapolated Stall Torque

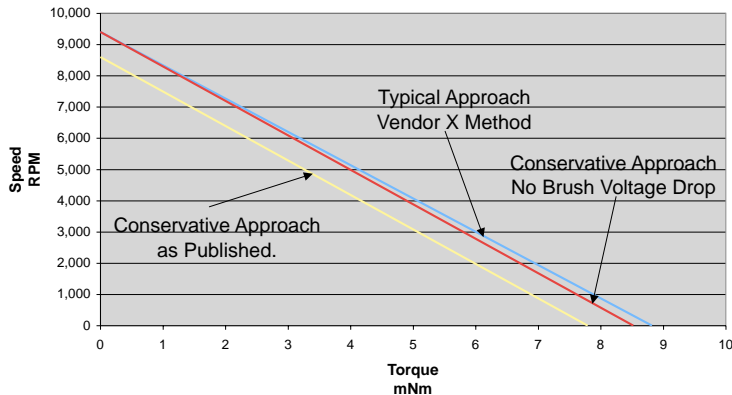
This technique is used particularly by Asian Motor Vendors. From the no load speed and rated speed and torque a slope of the speed torque curve is calculated. This is extrapolated to zero speed and the stall torque is then computed. Any rounding of the no load speed, rated speed and rated torque generate wide variations in the extrapolated Stall Torque. In other words, the numbers seldom match.

## Impact on Stall Torque depending on Calculation Method Employed

Graph 2 illustrates the effect of the first three methods of Calculating Stall Torque. Keep in mind that exactly the same Nominal Voltage was used. These 3 curves are for the identical motor at exactly the same nominal Voltage! Which one is correct?

Frankly it could be argued that none of them are!

**Graph 2**  
Speed/Torque with Different Calculation Methods  
Graphite Commutated FAULHABER 1336U006



## How DC Motors are Rated?

There can be a multitude of criteria on how to rate a motor. Since output power is a function of the Voltage squared even relatively small increases in rated Voltage for a particular motor will result in a large increase in power.

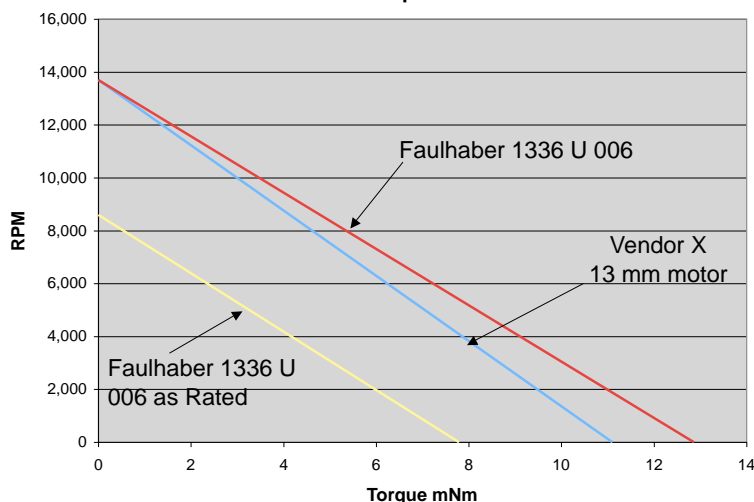
In comparing the two subject motors you will notice that Motor Vendor X "rates" their motor for a significantly higher no load speed. So it will indeed have a significantly higher power. Graph 3 shows the comparison when the no load speeds are equalized.

The FAULHABER approach for Graphite Commutated Coreless motors is to "rate" the motor for 3,000 hours or greater MTBF under controlled test conditions at room temperature. If the target life was 1,000 hours minimum the same motor would be "rated" for a higher voltage and be significantly more "powerful".

## Leveling the Playing Field

Graph 3 illustrates what happens when the no load speed is increased for the Faulhaber motor so that it is the same as Vendor X. Now the stall torque, using Vendor X's method, shows the Faulhaber motor has higher stall torque. And when perusing the published specifications we find that Vendor X's motor is rated for a maximum coil temperature of 85°C whereas the Faulhaber is rated for scorching 125°C. That is a

**Graph 3**  
Comparison with same No Load Speed  
Same Stall Torque Calculation Method



significant difference!

The bottom line is the Faulhaber motor can actually be more powerful than Vendor X's motor and it is "rated" for significantly higher continuous torque levels, due mainly to the superior rotor construction and temperature rating.

## Questions to Ask a Vendor

Clearly, starting at the datasheet makes sense but more importantly understand what the ratings mean between vendors. In many cases you will have to pose the question directly to the vendor, especially if you have simply downloaded a data sheet from their website.

Frankly, in general, this important information is not usually published. There is more information on reliability published on a carton of light bulbs bought at the home Depot than is generally published for sub-fractional dc motors and gearboxes!

Is the maximum speed and torque a rating for a certain amount of brush life or is it a thermal limit? Or a mechanical limit!

If it is for brush life and you are designing a fin control system for a shoulder-launched rocket you may be able to significantly up the motor's power because the total operating time will be relatively short. Who needs a motor "rated" for 3,000 hours MTBF if the total operating time is 5 minutes or less?

Are the thermal ratings for nominal values or are they worst case? If they are nominal values be careful. A 12% tolerance on winding resistance and torque constant means that worst case you will be dissipating more than 27% more heat for the same torque load.

In the case of mating gearboxes exactly the same types of questions should be asked.

If you operate it within its ratings how long would you expect the gearbox to last? What happens if you exceed the maximum input speed? Does the gearbox catastrophically disintegrate or will the life be somewhat less?

Why does the Faulhaber Group's 10 mm planetary gearbox have a maximum recommended input speed of 5,000 rpm whereas Vendor Y's 10 mm planetary is rated for 10,000 rpm and Vendor X's is rated for 8,000 rpm! All 3 planetary gearboxes have exactly 0.1 Nm of maximum rated continuous torque, by the way!

In general be suspicious of similarly constructed and dimensioned motors from different vendors that have significantly different values for such parameters as thermal resistance. The laws of thermodynamics and physics have not changed the last time I checked. Likely the "specification" methodology is different or there is a heat sinking disparity. Or an exciting new thermally conductive material has been utilized.

In the end testing is imperative. But by asking educated questions and understanding what the "ratings" mean your selection process will be more focused and your testing will have fewer disappointments.

Most importantly never forget the old adage 'caveat emptor'!

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