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A shortcut to sizing motors

Motor constant aids in selecting dc motors in motion-control applications.

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A lot of times, a dc motor or generator data sheet will include the motor constant K_m, which is the torque sensitivity divided by the square root of the winding resistance. Most designers view this intrinsic motor property as an esoteric figure of merit useful only to the motor designer, with no practical value in selecting dc motors.

But K_m can help reduce the iterative process in selecting a dc motor because it is generally winding independent in a given case or frame size motor. Even in ironless dc motors, where K_m depends on the winding (due to variations in the copper fill factor) it remains a solid tool in the selection process.

Because K_m does not address the losses in an electromechanical device in all circumstances, the minimum K_m must be larger than calculated to address those losses. This method is also a good reality check because it forces the user to compute both the input and output power.

Brushed and brushless dc motors are a good choice in power sensitive or efficiency craving applications.

The motor constant addresses the fundamental electromechanical nature of a motor or generator. Selecting a suitable winding is simple after determining an adequately powerful case or frame size.

The motor constant K_m is defined as:

$$K_m = K_T / R^{0.5}$$

In a dc motor application with limited power availability and a known torque required at the motor shaft, the minimum K_m will be set.

For a given motor application the minimum K_m will be:

$$K_m = T / (P_{IN} - P_{OUT})^{0.5}$$

The power into the motor will be positive. P_{IN} is simply the product of the current and voltage, assuming no phase shift between them.

$$P_{IN} = V \times I$$

The power out of the motor will be positive, since it supplies mechanical power and is simply the product of the rotational speed and torque.

$$P_{OUT} = \omega \times T$$

A motion-control example includes a gantry-type drive mechanism. It uses a 38-mm-diameter coreless dc motor. The decision is made to double the slew speed with no change in the amplifier. The existing operating point is 33.9 mN-m (4.8 oz-in.) and 2,000 rpm (209.44 rad/sec) and the input power is 24 V at 1 A. Furthermore, no increase in motor size is acceptable.

The new operating point will be at twice the speed and the same torque. Acceleration time is a negligible percentage of the move time, and slew speed is the critical parameter.

Calculating the minimum K_m

$$K_m = T / (P_{IN} - P_{OUT})^{0.5}$$

$$K_m = 33.9 \times 10^{-3} \text{ N-m} / (24 \text{ V} \times 1\text{A} -$$

$$418.88 \text{ rad/sec} \times 33.9 \times 10^{-3} \text{ N-m})^{0.5}$$

$$K_m = 33.9 \times 10^{-3} \text{ N-m} / (24 \text{ W} - 14.2 \text{ W})^{0.5}$$

$$K_m = 10.83 \times 10^{-3} \text{ N-m}/\sqrt{\text{W}}$$

Account for the tolerances of the torque constant and winding resistance. For example, if the torque constant and the winding resistance have ±12% tolerances, K_m worst case will be:

$$K_{MWC} = 0.88\, K_T/\sqrt{(R \times 1.12)} = 0.832\, K_m$$

or almost 17% below nominal values with a cold winding.

Winding heating will further reduce K_m since copper resistivity rises almost 0.4%/°C. And to exacerbate the problem, the magnetic field will attenuate with rising temperatures. Depending on the permanent-magnet material, this could be as much as 20% for a 100°C rise in temperature. The 20% attenuation for 100°C magnet temperature rise is for ferrite magnets. Neodymium-boron-iron has 11%, and samarium cobalt about 4%.

Interestingly, for the same mechanical input power, if the target is 88% efficiency, then the minimum K_m would go from 1.863 N-m/√W to 2.406 N-m/√W. That is equivalent to having the same winding resistance but a 29% greater torque constant. The higher the efficiency desired, the higher the K_m required.

If in the case of the motor application the maximum current available and the worst-case torque load is known, compute the lowest acceptable torque constant by using

$$K_T = T/I$$

After finding a motor family with sufficient K_m, select a winding that has a torque constant that slightly exceeds the minimum. Then commence determining if the winding will, in all cases of tolerances and application constraints, perform satisfactorily.

Clearly, choosing a motor or generator by first determining the minimum K_m in power-sensitive motor and efficiency-challenging generator applications can speed the selection process. The next step will then be to select a suitable winding and ensure that all application parameters and motor/generator limitations are acceptable, including winding-tolerance considerations.

Because of manufacturing tolerances, thermal effects, and internal losses, one should always choose a K_m somewhat larger than the application requires. A certain amount of latitude is needed since there aren't an infinite number of winding variations available from a practical point of view. The larger the Km, the more forgiving it is in satisfying a given application's requirements.

In general, practical efficiencies above 90% may be virtually unobtainable. Larger motors and generators have larger mechanical losses. This is due to bearing, windage, and electromechanical losses like hysteresis and eddy currents. Brush-type motors also have losses from the mechanical commutation system. In the case of precious metal commutation, popular with coreless motors, losses can be extremely small, less than the bearing losses.

Ironless dc motors and generators have virtually no hysteresis and eddy current losses in the brush variant of this design. In the brushless versions, these losses, although low, do exist. This is because the magnet is usually rotating relative to the back iron of the magnetic circuit. This induces eddy current and hysteresis losses. However, there are brushless dc versions that have the magnet and back iron moving in unison. In these cases, losses are usually low.

Nomenclature

SYMBOL	DEFINITION	UNIT(S)
I	Current to motor	A
K_{ER}	Back emf constant	*V-sec
K_m	Motor constant	N-m/√W
K_{MWC}	Motor constat-worse case	N-m/√W
WITH TOLERANCES CONSIDERED		
K_T	Torque Sensitivity	N-m/A
n	Efficiency of electrical to mechanical or mechanical to electrical conversion	%
P_{IN}	Input Power	W
P_{OUT}	Output power	W
R	Cold-winding resistance specified	Ω
BY MANUFACTURER		
T	Load torque or driving torque	N-m
ω	Motor rotational speed	Rad/sec
V	Motor applied voltage	V

*V-sec is equivalent to V/(rad/sec)

MOTOR PERFORMANCE COMPARISON

PARAMETERS	MOTOR A	MOTOR B	MOTOR C	MOTOR D
Motor constant (mN-m/√W)	14.44	19.45	17.48	30.33
Speed (rpm)	2,000	4,000	4,000	4,000
Torque (mN-m)	33.9	33.9	33.9	33.9
Voltage (V)	19.99	19.82	24.49	21.93
Current (A)	0.69	0.92	0.80	0.79
Efficiency	51.7%	77.7%	72.5%	81.5%
Power delivered (W)	7.1	14.4	14.4	14.4

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