maxon

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Motor data and simulation
knowledge document

Content

1 Introduction

Every simulation is only an approximation to reality. Tests with physical drive systems are therefore preferable. For good results, it is worth testing several drives in parallel, as tolerances will lead to deviations in the results.

maxon is not specialized in the simulation of drives. We test the physical drives (motors) directly. However, since we are receiving more and more requests for simulations, we have created this document. Here you will find answers to common questions. If your question is not answered here, please first search for solutions on the Internet, since we probably cannot help you either.

If you are familiar with simulations and discover errors in this document, please report them to us. We have made the document to the best of our knowledge, but we cannot rule out errors.

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2 maxon motor data

You can find information about the motor data on our website (www.maxongroup.com) or in the maxon catalog (epaper.maxongroup.com).
Motor data are subject to tolerances and often depend on the environmental conditions, the way of installation and the parameters and properties of the control loop. A warm motor is different from a cold one.

Please also note the **maxon standard specification 100** (DC motor) or **101** (EC motor) in the catalog (Catalog 2020 on page 68) and the **explanation of terminology** in the beginning of each capture in the catalog.

2.1 Explanation videos

We have prepared a few short videos where you can learn which motor data are important and how the data are to be interpreted. You can find the complete list of all videos at academy.maxongroup.com.

An extract in this table:

maxon motor data 1: The operation range limits	YouTube	Vimeo
maxon motor data 2: The speed-torque line	YouTube	Vimeo
maxon motor data 3: The windings	YouTube	Vimeo
Commutation maxon DC Motor	YouTube	Vimeo
Block commutation of a brushless maxon EC-motor	YouTube	Vimeo
Commutation multi-pole maxon EC-motor	YouTube	Vimeo
Brushed vs Brushless DC motor	YouTube	Vimeo
Motor & Drive selection	YouTube	Vimeo

2.2 BLDC / EC motors (brushless design)

A BLDC motor is only fully defined together with the commutation electronics. The data in the catalog apply using a simple block commutation.

For sinusoidal commutation or FOC (field-oriented control), **the motor parameters are different**.

- Strength of BLDC (EC) motor with sinusoidal commutation

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3 Constants

The motor constants describe the general behavior. They have tolerances of up to about 10% and change with motor temperature. The values given in the maxon catalog apply to maxon standard conditions of 25°C. (for BLDC motors read capture 2.2 in this document).

3.1 Speed/torque gradient Δn/ΔM [rpm/mNm] (catalog line 14)

The speed/torque gradient indicates how much speed is lost with increasing torque. The smaller the value, the more powerful the motor and consequently the less the motor speed changes upon load variations. The speed/torque gradient is constant for most motors and can be calculated by the quotient of ideal no load speed and ideal stall torque. However, the hotter the motor gets, the weaker the motor and the value increases.

$$\text{speed/torque gradient} \quad \frac{\Delta n}{\Delta M} = \frac{30000}{\pi} \cdot \frac{R}{{K_M}^2}$$

Δn/ΔM : speed/torque gradient [rpm/mNm] (line 14)
R : Terminal resistance [Ω] (line 10)
K_M : Torque constant [mNm/A] (line 12)

For motors with **cored windings** (maxon flat, EC-i, frameless and ECX TORQUE), the speed torque line is not a straight line. The speed/torque gradient is not constant and depends on speed. In the continuous operation range, the speed/torque gradient can be approximated using the following formula:

$$\text{speed/torque gradient} \quad \frac{\Delta n}{\Delta M} = \frac{n_0 - n_N}{M_N}$$

Δn/ΔM : speed/torque gradient [rpm/mNm] (not use line 14)
n_0 : No load speed [rpm] (line 2)
n_N : Nominal speed [rpm] (line 4)
M_N : Nominal torque MN [mNm] (line 5)

3.2 Motor constant K [$NmW^{-1/2}$]

In the literature, one often finds the motor constant K instead of the speed/torque gradient. The motor constant gives the amount of torque per square root of power loss. The relation between the two parameters is (in appropriate units)

$$K = \frac{1}{\sqrt{\frac{\Delta n}{\Delta M}}} = \frac{M}{\sqrt{P_R}} = \frac{k_M}{\sqrt{R}}$$

K : motor constant [$NmW^{-1/2}$]
R : Terminal resistance [Ω] (line 10)
K_M : Torque constant [mNm/A] (line 12)
P_R : Resistive power loss [W]
Δn/ΔM : speed/torque gradient [rpm/mNm]

The motor equation, i.e. the dependence of the angular velocity ω on the torque M, can be rewritten as:

$$\omega = \frac{U}{K\sqrt{R}} - \frac{M}{K^2}$$

3.3 Torque constant k_M [mNm/A] (catalog line 12)

The torque constant gives the proportional relation between input current and output torque. The torque constant is a design parameter, including geometry and the magnetic field density and the winding. The physics behind is that of the force felt by a current-carrying wire in an external magnetic field (Lorentz force).
Torque and current are strictly proportional for coreless maxon motors. Basically, one can say that the two are equivalent for a given motor. This allows to use a motor as a torque probe; all you have to do is to measure the current.
For motors with iron core, the proportionality still holds for realistic current values. Only at extremely high currents (that can hardly ever be reached) the produced torque would be smaller due to saturation effects in the iron core.

3.4 Speed constant kn [rpm/V] (catalog line 13)

The speed constant is the inverse of the generator constant. They both give describe the proportionality between motor speed and induced voltage (back EMF). The speed constant is mostly used to calculate the ideal no-load speed for a given input voltage, friction losses not considered.
The speed constant is the inverted value of the torque constant.

$$k_n \cdot k_M = \frac{30000}{\pi}\left[\frac{rpm}{V} \cdot \frac{mNm}{A}\right] = 1$$

3.5 Back EMF constant or generator constant k_G [V/rpm]

Hence, the back EMF constant is identical to the torque constant (line 12 in the catalog). Only given in different units (Nm/A · π/30 = V/rpm).

4 Induction

Inductance is defined as the ratio of the induced voltage to the rate of change of current causing it. It is a proportionality factor that depends on the geometry of circuit conductors and the magnetic permeability of nearby materials. The inductance is therefore dependent on the current signal (sine, block, trapezoidal) and the respective frequency.

4.1 Terminal inductance L [mH] (line 11)

The catalog value is the winding inductance when stationary and measured at 1 kHz, sinusoidal. The effective motor inductance in the case of square PWM excitation only amounts to approx. 30-80% of the catalog value.

4.2 d- and q- axis stator self-inductance Ld / Lq [mH]

For almost all maxon EC motors, we have $L_d = L_q = 1/2\ L_{ph\text{-}ph}$
(where $L_{ph\text{-}ph}$ is the catalog value phase to phase)

Exceptions are the EC-i High torque and the ECX TORQUE motors, where Ld < Lq. However, the difference is small (approx. 10%) and needs not to be taken care of in field-oriented control (FOC), since the goal is to minimize the field current I_d.

4.3 Leakage/Mutual inductance L_M [mH]

Mutual induction is the current flowing in one winding that induces a voltage in an adjacent winding. For the sake of simplicity, we assume the perfect motor. The mutual inductance is half the self-inductance. The exact calculation is complicated, on the Internet you will find ways how you can calculate it without further information by maxon.

4.4 Zero-Sequence Inductance L_0 [mH]

According to the equation $L_0 = L - 2\,L_M$, an ideal motor has a zero ZS inductance ($L_0 = 0$).

4.5 Stator inductance fluctuation Lx [mH]

This value is the fluctuation in self-inductance and mutual inductance with changing rotor angle.
$Lx = 0.5 \cdot (L_d - L_q)$

5 Rotor damping: Friction and iron losses

Rotor damping in the motors stem from friction in bearings and at the brushes as well as from iron losses (hysteresis and eddy currents). In the maxon catalog, the damping is given as the no-load current (tolerance ±50%) corresponding to a friction torque ($M_R = I_0 \cdot k_M$) at no-load speed.
Rotor damping is approximated by two parameters, a constant damping torque and a speed dependent damping parameter (viscous).

- M_{VA} [mNm] constant factor (static damping)
- c_5 [nNm/rpm] speed dependent factor (viscous damping)

For maxon DC motors, the speed-dependent factor (c_5) is rather small. For most practical purposes we can neglect the speed dependency of the no-load current. For EC motors, c_5 might have a larger influence due to the strong speed dependency of the eddy current loss friction torque ($M_R = I_0 \cdot k_M$) at no-load speed.es.

The values for M_{VA} and c_5 cannot be found in the maxon catalog specification, only the combined no-load current value at no-load speed. If you need static and viscous damping parameters, open a support ticket with the part number of the motor.