Motor Sizing Example
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Reference: Maxon 02/03 Catalog

$J_L := 120000 \cdot gm \cdot cm^2$ $J_L = 0.012\, kg \cdot m^2$ $RPM := \frac{2 \cdot \pi}{60 \cdot s}$ unit definition for RPM

$T_{fric} := 300 \cdot 10^{-3} \cdot N \cdot m$ $T_{ext} := 0 \cdot N \cdot m$ $V_S := 24 \cdot V$ Supply voltage $i_{supply\_max} := 5 \cdot A$

$\omega_{load} := 60 \cdot RPM$ $\omega_{load} = 6.283 \frac{rad}{s}$ Maximum rotational speed of the load

Motion Profile

$t_{accel} := 0.5 \cdot s$ $t_{slew} := 2.5 \cdot s - t_{accel}$ $t_{dec} := 3.0 \cdot s - 2.5 \cdot s$ $t_{dwell} := 3.7 \cdot s - 3.0 \cdot s$ $t_{cycle} := 3.7 \cdot s$

$\alpha := \frac{\omega_{load}}{t_{accel}}$ $\alpha = 12.566 \frac{rad}{s^2}$ Angular acceleration of the load

Find Tpeak, which must be delivered to the load

$T_{peak\_load} := J_L \cdot \alpha + T_{fric} + T_{ext}$ $T_{peak\_load} = 0.451\, N \cdot m$ The motor chosen needs to be capable of delivering at least this torque to the load.

Find the RMS torque, which must be delivered to the load

$T_{accel} := J_L \cdot \alpha$ $T_{accel} = 0.151\, N \cdot m$ $T_{slew} := T_{fric}$ $T_{slew} = 0.3\, N \cdot m$

$T_{dec} := -T_{peak\_load} + T_{fric}$ $T_{dec} = -0.151\, N \cdot m$ $T_{dwell} := 0$

$$T_{RMS} := \sqrt{\frac{1}{t_{cycle}} \cdot \left(t_{accel} \cdot T_{peak\_load}^2 + t_{slew} \cdot T_{slew}^2 + t_{dec} \cdot T_{dec}^2 + t_{dwell} \cdot T_{dwell}^2 \right)}$$

$T_{RMS} = 0.281\, N \cdot m$ T_{rms} is the effective continuous torque

$P_{max} := T_{peak\_load} \cdot \omega_{load}$ $P_{max} = 2.832\, W$ The motor chosen needs to be capable of delivering at least about 3 W. This number can be used to 'get in the ballpark' for choosing a motor.

Select the gearing

$\omega_{max\_gear} := 6000 \cdot RPM$ $G_{red\_max} := \frac{\omega_{max\_gear}}{\omega_{load}}$ $G_{red\_max} = 100$ The gear reduction cannot be larger than G_{red_max}, or else the motor won't be able to rotate the load up to 60 RPM

The gearhead must be able to handle T_{peak_load} and T_{RMS}

$G_{red} := 84$ $\eta_G := 0.59$

Of the available gearheads listed in the catalog, a 22mm dia planetary gear type will handle the peak and RMS torques. The closest ratio available that is less than G_{red_max} is 84:1. It has an efficiency of 59%.

Find speed and torque ***at the motor shaft*** (i.e., "reflected" through the gearhead)

$\omega_{mot} := G_{red} \cdot \omega_{load}$ $\qquad \omega_{mot} = 5.04 \times 10^{3}\,RPM$

$T_{RMS\_mot} := \frac{T_{RMS}}{G_{red} \cdot \eta_G}$ $\qquad \boxed{T_{RMS\_mot} = 5.678 \times 10^{-3}\,N \cdot m}$

$T_{mot\_max} := \frac{T_{peak\_load}}{G_{red} \cdot \eta_G}$ $\qquad \boxed{T_{mot\_max} = 9.096 \times 10^{-3}\,N \cdot m}$

Use these torque values to find a motor from the catalog. Note that these are *minimum* values. Your choice of a motor should allow for some margin (at least 20% beyond the minimum values). A Maxon A-max 22mm dia, 6W type will work (actually several model numbers in this category will work.) Select the most appropriate one by looking at the operating point on the speed-torque curve and the margin for speed control.

Select the motor winding

$ST_{grad} := 480 \cdot \frac{RPM}{N \cdot m \cdot 10^{-3}}$

For the A-max 22mm dia, 6W type motors in the catalog, this is the average speed-torque gradient (i.e., the slope of the operating line in the torque-speed graph.)

$\omega_{NL\_targ} := \omega_{mot} + ST_{grad} \cdot T_{mot\_max}$ $\qquad \omega_{NL\_targ} = 9.406 \times 10^{3}\,RPM$

This is the no-load speed corresponding to the speed-torque line that passes through the operating point of the motor: (T_{peak_mot}, ω_{mot})

$V_{wind} := V_S - 6 \cdot V$ $\qquad V_{wind} = 18\,V$

This is the maximum voltage available to be applied to the motor. The drive electronics (power amplifier) will have a voltage drop of about 6V, according to Maxon.

$k_{speed} := \frac{\omega_{NL\_targ}}{V_{wind}}$ $\qquad k_{speed} = 522.559\,\frac{RPM}{V}$

This is the *minimum* speed constant that the motor must have. (The speed constant is the reciprocal of the back EMF constant, K_E.)

Looking at the catalog page for the A-max, 22mm, 6W motors, model 110163 would just about meet the requirements, but with almost no margin. Choose motor **110162** instead, because it has a slightly larger speed constant, so it will have more than the desired 20% margin for meeting the speed requirements given that only 18V is available for driving the motor.

$K_T := 13.9 \cdot 10^{-3} \cdot N \cdot \frac{m}{A}$

Torque constant for the 110162 motor

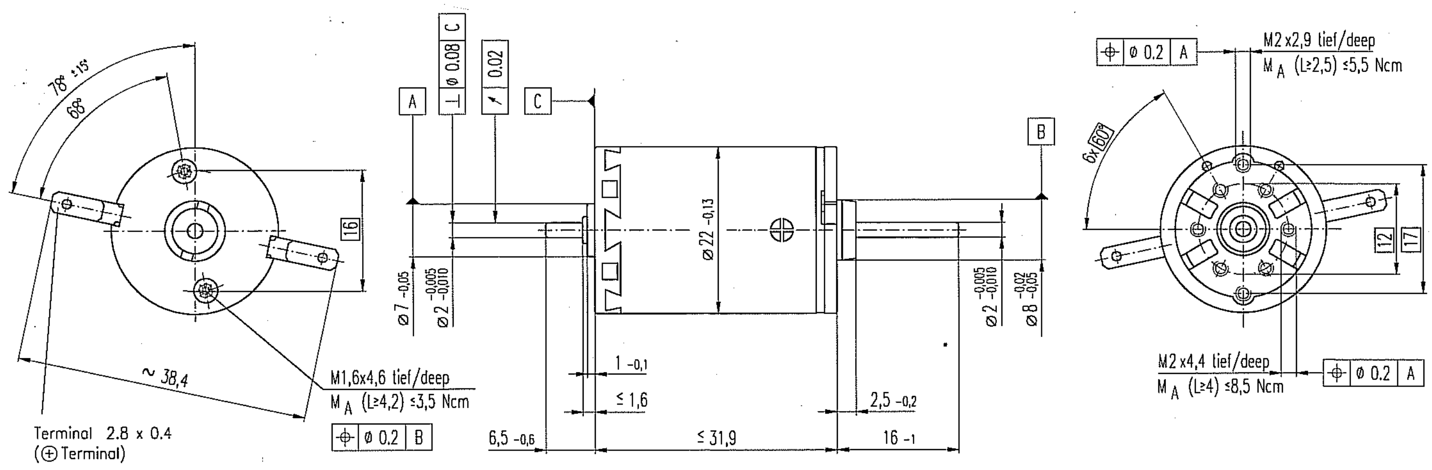
Check the maximum current

$I_{max} := \frac{T_{mot\_max}}{K_T}$ $\qquad I_{max} = 0.654\,A$

Imax is lower than 2A of that the power amplifier can deliver.

It would also be a good idea to check the temperature rise under the ambient operating conditions. More information on how to do this can be found in the Maxon catalog.

A-max 22 ∅22 mm, Graphite Brushes, 6 Watt



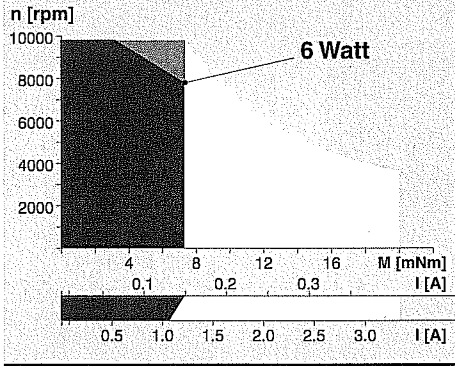
- Stock program
- Standard program
- Special program (on request!)

Order Number		110156	110158	110159	110160	110161	110162	110163	110164	110165	110166	110167	110168
Motor Data													
1 Assigned power rating	W	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
2 Nominal voltage	Volt	6.0	9.0	9.0	12.0	12.0	15.0	18.0	24.0	24.0	36.0	48.0	48.0
3 No load speed	rpm	9240	9700	8520	10200	9190	10100	9780	10500	8490	9640	9120	8210
4 Stall torque	mNm	15.6	19.7	18.0	22.0	19.7	21.9	21.4	23.4	18.8	21.1	19.3	17.7
5 Speed / torque gradient	rpm / mNm	624	511	490	477	482	472	468	462	464	468	484	476
6 No load current	mA	83	58	50	46	41	36	29	24	18	14	10	9
7 Starting current	mA	2640	2300	1850	2020	1630	1580	1250	1100	716	606	395	327
8 Terminal resistance	Ohm	2.27	3.91	4.86	5.95	7.38	9.49	14.4	21.8	33.5	59.4	122	147
9 Max. permissible speed	rpm	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800
10 Max. continuous current	mA	1080	841	756	680	612	539	439	356	287	216	151	137
11 Max. continuous torque	mNm	6.37	7.19	7.36	7.43	7.40	7.47	7.51	7.56	7.55	7.51	7.38	7.45
12 Max. power output at nominal voltage	mW	3480	4740	3820	5640	4550	5580	5340	6300	4070	5210	4520	3730
13 Max. efficiency	%	65	69	69	71	70	72	72	73	71	72	71	70
14 Torque constant	mNm / A	5.90	8.55	9.73	10.9	12.1	13.9	17.1	21.2	26.3	34.8	49.0	54.3
15 Speed constant	rpm / V	1620	1120	981	875	790	689	558	450	364	274	195	176
16 Mechanical time constant	ms	25	22	21	20	20	20	19	19	19	18	18	18
17 Rotor inertia	gcm²	3.81	4.03	4.09	4.06	3.97	3.96	3.90	3.89	3.84	3.77	3.63	3.68
18 Terminal inductance	mH	0.11	0.22	0.29	0.36	0.45	0.59	0.89	1.37	2.10	3.69	7.30	8.98
19 Thermal resistance housing-ambient	K / W	20	20	20	20	20	20	20	20	20	20	20	20
20 Thermal resistance rotor-housing	K / W	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
21 Thermal time constant winding	s	9	10	10	10	9	9	9	9	9	9	8	9

Specifications

- Axial play 0.05 - 0.15 mm
- Max. **sleeve bearing** loads
  - axial (dynamic) 1.0 N
  - radial (5 mm from flange) 2.8 N
  - Press-fit force (static) 80 N
  - (static, shaft supported) 440 N
- Max. **ball bearing** loads
  - axial (dynamic) 3.3 N
  - radial (5 mm from flange) 12.3 N
  - Press-fit force (static) 45 N
  - (static, shaft supported) 440 N
- Radial play **sleeve bearing** 0.012 mm
- Radial play **ball bearing** 0.025 mm
- Ambient temperature range -30 / +85°C
- Max. rotor temperature +125°C
- Number of commutator segments 9
- Weight of motor 54 g
- Values listed in the table are nominal. For applicable tolerances (see page 43). For additional details please use the maxon selection program on the enclosed CD-Rom.
- Options: Ball bearings in place of sleeve bearings and pigtails in place of terminals.

Operating Range



Comments Details on page 49

Recommended operating range

Continuous operation
In observation of above listed thermal resistances (lines 19 and 20) the maximum permissible rotor temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

110167 Motor with high resistance winding

110156 Motor with low resistance winding

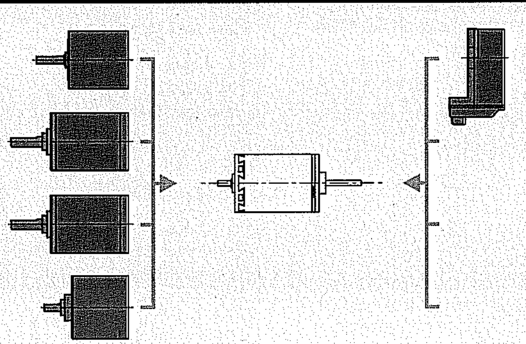
maxon Modular System

Planetary Gearhead
∅22 mm
0.1 - 0.6 Nm
Details page 175 / 176

Planetary Gearhead
∅22 mm
0.5 - 1.0 Nm
Details page 177

Planetary Gearhead
∅22 mm
0.5 - 2.0 Nm
Details page 178

Spur Gearhead
∅24 mm
0.1 Nm
Details page 179



Digital Encoder
22 mm
100 CPT, 2 channels
Details page 204