Motor Sizing Example
BJ Furman
19OCT2010

Reference: Maxon 02/03 Catalog

\[ J_L := 120000 \text{ gm-cm}^2 \quad J_L = 0.012 \text{kg-m}^2 \quad \text{RPM} := \frac{2 \pi}{60 \text{s}} \quad \text{unit definition for RPM} \]

\[ T_{\text{fric}} := 300 \cdot 10^{-3} \text{ N-m} \quad T_{\text{ext}} := 0 \text{ N-m} \quad V_S := 24 \text{ V} \quad \text{Supply voltage} \quad t_{\text{supply max}} := 5 \text{ A} \]

\[ \omega_{\text{load}} := 60 \text{ RPM} \quad \omega_{\text{load}} = 6.283 \frac{\text{rad}}{\text{s}} \quad \text{Maximum rotational speed of the load} \]

Motion Profile

\[ t_{\text{accel}} := 0.5 \text{ s} \quad t_{\text{slew}} := 2.5 \text{ s} - t_{\text{accel}} \quad t_{\text{dec}} := 3.0 \text{ s} - 2.5 \text{ s} \quad t_{\text{dwell}} := 3.7 \text{ s} - 3.0 \text{ s} \quad t_{\text{cycle}} := 3.7 \text{ s} \]

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

Find \( T_{\text{peak load}} \), which must be delivered to the load

\[ T_{\text{peak load}} := J_L \cdot \alpha + T_{\text{fric}} + T_{\text{ext}} \quad T_{\text{peak load}} = 0.451 \text{ N-m} \]

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

\[ T_{\text{accel}} := J_L \cdot \alpha \quad T_{\text{accel}} = 0.151 \text{ N-m} \quad T_{\text{slew}} = T_{\text{fric}} \quad T_{\text{slew}} = 0.3 \text{ N-m} \]

\[ T_{\text{dec}} := -T_{\text{peak load}} + T_{\text{fric}} \quad T_{\text{dec}} = -0.151 \text{ N-m} \quad T_{\text{dwell}} := 0 \]

\[ T_{\text{RMS}} := \sqrt{\frac{1}{t_{\text{cycle}}} \left( t_{\text{accel}} T_{\text{peak load}}^2 + t_{\text{slew}} T_{\text{slew}}^2 + t_{\text{dec}} T_{\text{dec}}^2 + t_{\text{dwell}} T_{\text{dwell}}^2 \right)} \]

\[ T_{\text{RMS}} = 0.281 \text{ N-m} \]

\( T_{\text{rms}} \) is the effective continuous torque

\[ P_{\text{max}} := T_{\text{peak load}} \omega_{\text{load}} \quad P_{\text{max}} = 2.832 \text{ W} \]

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

\[ \omega_{\text{max gear}} := 6000 \text{ RPM} \quad G_{\text{red max}} := \frac{\omega_{\text{max gear}}}{\omega_{\text{load}}} \quad G_{\text{red max}} = 100 \]

\( G_{\text{red}} = 84 \quad \eta_G = 0.59 \quad \text{The gear reduction cannot be larger than } G_{\text{red max}}, \text{ or else the motor won't be able to rotate the load up to 60 RPM} \)

The gearhead must be able to handle \( T_{\text{peak load}} \) and \( T_{\text{RMS}} \)

\[ G_{\text{red}} = 84 \quad \eta_G = 0.59 \quad \text{Of the available gearheads listed in the catalog, a 22mm dia planetary gear type will handle the peak and RMS torques. The closest ratio available that is less than } G_{\text{red max}} \text{ is 84:1. It has an efficiency of } 59\%. \]
Find speed and torque at the motor shaft (i.e., "reflected" through the gearhead)

\[ \omega_{\text{mot}} := \frac{G_{\text{red}} \omega_{\text{load}}}{G_{\text{red}} \eta_G} \quad \omega_{\text{mot}} = 5.04 \times 10^3 \text{ RPM} \]

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

\[ S_{\text{grad}} := \frac{480 \text{ RPM}}{N \cdot \text{m} \cdot 10^{-3}} \quad \text{For the A-max 22mm dia, 6W type motors in the catalog, this is the average speed-torque gradient (i.e., the slope of the operating line in the torque-speed graph.)} \]

\[ \omega_{\text{NL, targ}} := \omega_{\text{mot}} + S_{\text{grad}} T_{\text{mot, max}} \quad \omega_{\text{NL, targ}} = 9.406 \times 10^3 \text{ RPM} \]

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

\[ V_{\text{wind}} := V_S - 6 \text{ V} \quad V_{\text{wind}} = 18 \text{ V} \quad \text{This is the maximum voltage available to be applied to the motor. The drive electronics (power amplifier) will have a voltage drop of about 6V, according to Maxon.} \]

\[ k_{\text{speed}} := \frac{\omega_{\text{NL, targ}}}{V_{\text{wind}}} \quad k_{\text{speed}} = 522.559 \frac{\text{ RPM}}{\text{V}} \quad \text{This is the minimum speed constant that the motor must have. (The speed constant is the reciprocal of the back EMF constant, } K_E) \]

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.

\[ K_T := 13.9 \times 10^{-3} \frac{\text{ N \cdot m}}{\text{A}} \quad \text{Torque constant for the 110162 motor} \]

Check the maximum current

\[ I_{\text{max}} := \frac{T_{\text{mot, max}}}{K_T} \quad I_{\text{max}} = 0.654 \text{ A} \quad \text{Imax is lower than 2A of that the power amplifier can deliver.} \]

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.