Rotary System Selection

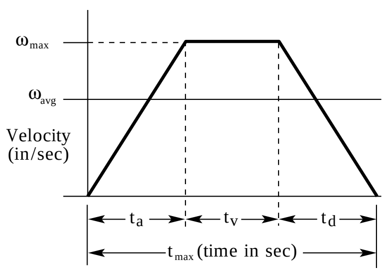
This section provides useful information for calculating your application's mechanical requirements, and selecting the proper motor and drive to meet your needs. To insure the proper motor/drive system is selected, follow these steps:

1. Sketch the **move profile** and calculate acceleration, deceleration and maximum velocity required to make the desired move.
2. Select **mechanical drive mechanism** to be used and calculate inertia, friction and load torque using formulas for the mechanical drive mechanism.
3. Determine **peak and continuous (RMS) torque** requirements for the application.
4. **Select a system** – choose the appropriate motor and drive combination that meets all of the application requirements.

1. Move Profile

Refer to the Move Profile section on page K-10 to determine your peak velocity and acceleration. Rotary distance units should be radians. Time units are seconds. **NOTE: 1 rev = 2π radians.**

Example: We need to move a total distance of 10 revolutions in 1 second using a 1/3, 1/3, 1/3 trapezoidal move profile. What is the distance (d_{tot}), peak velocity (ω_{max}) and acceleration (α) required to make the move.



$$\text{Total distance, } d_{tot} = 10\text{ rev} \cdot 2\pi \frac{\text{rad}}{\text{rev}} = 63\text{ rad}$$

$$\text{Max velocity, } \omega_{max} = \frac{1.5 d_{tot}}{t_{tot}} = \frac{1.5 \cdot 63}{1} = 95\ \frac{\text{rad}}{\text{sec}}$$

$$\text{Acceleration, } \alpha = \frac{4.5 d_{tot}}{(t_{tot})^2} = \frac{4.5 \cdot 63}{12} = 284\ \frac{\text{rad}}{\text{sec}^2}$$

2. Mechanical Drive Mechanisms

The system equations on the following page will help you calculate the reflected inertia (J), reflected applied loads (T), motor speed (ω), and acceleration (α), based on the move requirements that were determined in step one.

3. Peak Torque and RMS Torque Requirements

To find the peak and RMS torque required by the motor to make the move successfully, the Reflected Torque, T_{RL}, is added to the Torque required to accelerate (or decelerate) the load. T_{RL} includes all external forces, such as gravity, friction, and applied forces. The equations for peak torque and RMS torque required are:

$$T_{PEAK} = T_{RL} + \left[\frac{J_T\,\alpha}{e}\right]$$

$$T_{RMS} = \sqrt{\frac{T_A^{\,2} t_A + T_{RL}^{\,2} t_R + T_D^{\,2} t_D}{t_c}}$$

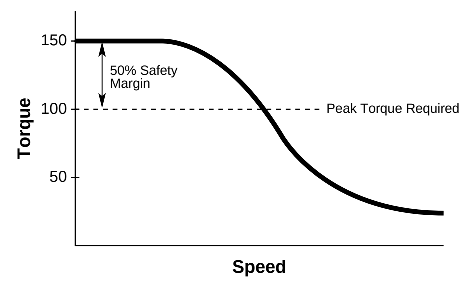
4. Selecting a System

Once the above torques have been calculated, a safety factor needs to be added. The safety margin varies with the motor type desired.

$$\text{Safety Margin} = \left(\frac{(\text{Torque Avail})-(\text{Torque Req.})}{(\text{Torque Req.})}\right) \times 100$$

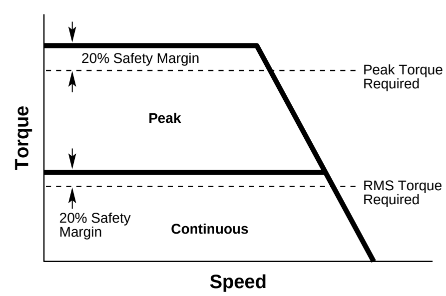
Stepper Systems

When selecting a step motor system, you should allow a torque safety margin of 50% above your calculated peak torque requirements at the peak speed required by your application.



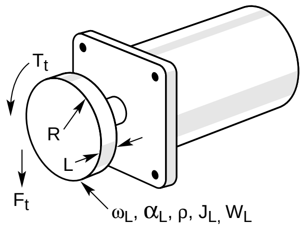
Servo Systems

For servo systems, a torque safety margin of at least 20% is recommended. The peak torque required by the application must fall within the peak torque rating of the motor at the peak speed. You must also calculate the RMS torque based on your application's duty cycle. The RMS torque must fall within the continuous area of the speed torque curve at the peak speed of the application.

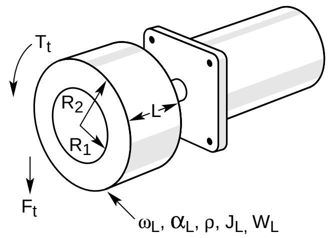


Rotary System Selection

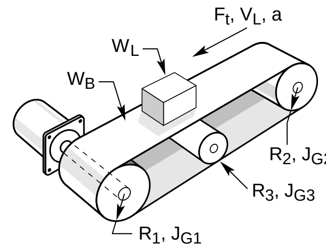
Inertia Solid Cylinder



Inertia Hollow Cylinder

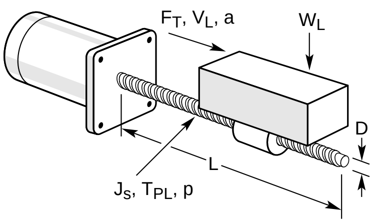


Tangential
(Conveyor, Rack and Pinion, etc.)

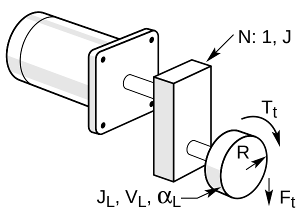


	Inertia Solid Cylinder	Inertia Hollow Cylinder	Tangential
ω	$\omega = \omega_L$	$\omega = \omega_L$	$\omega = \frac{V_L}{R_1}$
α	$\alpha = \alpha_L$	$\alpha = \alpha_L$	$\alpha = \frac{a}{R_1}$
J_T	$W_L = \pi L \rho R^2$ $J_T = J_L + J_{Motor}$ $J_L = \frac{1}{2}\frac{W_L}{g} \cdot R^2$	$W_L = \pi L \rho [R_2^2 - R_1^2]$ $J_T = J_L + J_{Motor}$ $J_L = \frac{1}{2}\frac{W_L}{g}[R_2^2 + R_1^2]$	$J_{RL} = \frac{W_L + W_B}{g} \cdot R_1^2$ $J_T = J_{Motor} + J_{RL} + J_{G1} + J_{G2}\left(\frac{R_1}{R_2}\right)^2 + J_{G3}\left(\frac{R_1}{R_3}\right)^2$
T_{RL}	$F_t = F_{Friction} + F_{Applied} + F_{Gravity}$ $T_{RL} = F_t \cdot R + T_t$	$F_t = F_{Friction} + F_{Applied} + F_{Gravity}$ $T_{RL} = F_t \cdot R_2 + T_t$	$F_t = F_{Friction} + F_{Applied} + F_{Gravity}$ $T_{RL} = \frac{F_t \cdot R_1}{e}$

Leadscrew



Gear Box



	Leadscrew	Gear Box
ω	$\omega = 2\pi p V_L$	$\omega = \frac{V_L}{N}$
α	$\alpha = 2\pi p a$	$\alpha = \frac{\alpha_L}{N}$
J	$J_S \approx 0.0012\ LD^4$ (for steel) $J_{RL} = \frac{W_L}{g}\left[\frac{1}{2\pi p}\right]^2$ $J_T = J_{RL} + J_S + J_{Motor}$	$J_{RL} = \frac{J_L}{N^2}$ $J_T = J_{RL} + J_{Reducer} + J_{Motor}$
T	$F_t = F_{Friction} + F_{Applied} + F_{Gravity}$ $T_{RL} = \frac{F_t}{2\pi \cdot p \cdot e} + T_{PL}$	$F_t = F_{Friction} + F_{Applied} + F_{Gravity}$ $T_{RL} = \frac{(F_t \cdot R) + T_t}{N \cdot e}$

Gear Reducers

Follow these guidelines when selecting an IDC precision gearhead:

1. Be sure your application's peak torque is less than the maximum momentary torque rating of the gearhead. Be sure to multiply the motor's torque by the gearhead efficiency and gear ratio when determining output torque from the reducer.

2. Be sure your application's RMS torque is less than the rated continuous torque of the gearhead.

Units

- a = acceleration rate (rad/sec^2)
- α = rotary acceleration (rad/sec^2)
- D = diameter
- e = efficiency of mechanism
- F_t = total load force including friction, gravity, or other external forces (oz)
- g = gravity = 386 in/sec^2
- J = rotary inertia (oz-in-sec^2)
- J_T = total inertia seen by motor (oz-in-sec^2)
- J_{RL} = reflected load inertia (oz-in-sec^2)
- L = length (in)
- ρ = material density (oz/in^3)
- p = pitch of screw (rev/in)
- R = radius (in)
- t_A = acceleration time (sec)
- T_A = acceleration torque (oz-in)
- t_D = deceleration time (sec)
- T_D = deceleration torque (oz-in)
- T_{PL} = preload torque of leadscrew (oz-in)
- t_R = running time (sec)
- T_R = running torque (oz-in)
- T_{RL} = reflected load torque due to friction, gravity, or other external forces (oz-in)
- V_L = linear velocity of load (in/sec)
- ω = rotary velocity (rad/sec)
- W = weight (oz)

Rotary System Selection

EXAMPLE 1–STEPPER: Calculate the motor torque required to accelerate a solid cylinder of aluminum 5" in radius and 0.40" in length from rest to 10 rev/sec in 0.3 seconds. Assume no friction is present and there are no applied forces or gravity forces opposing the motor's rotation.

1

Calculate maximum velocity and acceleration rates.

$$\omega = 10\,\frac{rev}{sec} \bullet 2\pi\,\frac{rad}{rev} = 63\,\frac{rad}{sec}$$

$$\alpha = \frac{\omega_{final} - \omega_{initial}}{t_A} = \frac{63 - 0}{0.3} = 210\,\frac{rad}{sec^2}$$

2

Mechanical drive mechanism selected as direct drive.

3

Calculate inertia (assume no friction or load torque).
Hint: The density of aluminum can be found on page K-47.

$$W = \rho\pi L_S R^2 = 3.14 \bullet 0.40 \bullet 1.57 \bullet 5.0^2 = 49.3 \text{ oz}$$

$$J_L = \frac{1}{2} \bullet \frac{w}{g} \bullet R^2 = \frac{1}{2} \bullet \frac{49.3}{386} \bullet 5^2 = 1.6 \text{ oz-in sec}^2$$

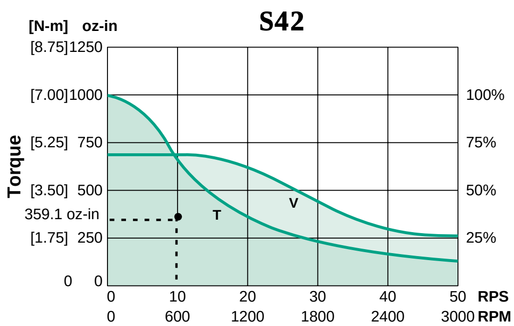
$$J_{Total} = J_{Load} + J_{Motor} \quad \left(\text{Assume motor is S42, rotor inertia is 0.114 oz-in-sec}^2\right)$$

$$= 1.6 + 0.114 = 1.71 \text{ oz-in-sec}^2$$

4

Determine peak and continuous torque requirements.

$$T_A = T_{RL} + \left[\frac{J_T\alpha}{e}\right] = 0 + \frac{1.71 \bullet 210}{1.0} = 359.1 \text{ oz-in}$$



Plotting the required torque on the S42 speed torque curve shows sufficient torque is present with a safety margin of 80%.

EXAMPLE 2–SERVO: Select a motor which will move a 500 lb load 10 inches in 1 second using a 2 pitch leadscrew 24 inches in length, and 1 inch in diameter. The load is externally supported by plastic bushings sliding on steel supports. There is a 125 lb applied force. There will be 1.0 second dwell between moves. The orientation of the leadscrew is horizontal.

1

Calculate distance the motor must rotate, acceleration, deceleration and maximum velocity using a 1/3, 1/3, 1/3 trapezoidal move profile.

$$D = 2\pi \bullet p \bullet d = 2\pi\,\frac{rad}{rev} \bullet 2\,\frac{rev}{in} \bullet 10 \text{ in} = 126 \text{ rad}$$

$$\omega = \frac{1.5D}{T} = \frac{1.5 \bullet 126}{1.0} = 189\,\frac{rad}{sec}$$

$$\alpha = \frac{4.5D}{T} = \frac{4.5 \bullet 126}{1.0^2} = 567\,\frac{rad}{sec^2}$$

$$t_A = t_D = t_R = t/_3 = 0.33 \text{ sec.}$$

2

Select mechanical drive mechanism as a leadscrew.

3

Calculate inertia, friction and load torque. A B32 motor was chosen to see if it will meet the requirements of the application. The friction coefficient of plastic on steel is 0.2.

$$J_{RL} = \frac{W_L}{g}\left[\frac{1}{2\pi p}\right]^2 = \frac{500 \text{ lb} \bullet 16\,\frac{oz}{lb}}{386 \text{ in/sec}^2}\left[\frac{1}{2\pi \bullet 2\,\frac{rev}{in}}\right]^2 = 0.131 \text{ oz-in sec}^2$$

$$J_S = 0.0012 \bullet L_S \bullet D^4 = 0.0012 \bullet 24 \bullet 1^4 = 0.0288 \text{ oz-in sec}^2$$

$$J_{Total} = J_{Motor} + J_{RL} + J_S = 0.016 + 0.131 + 0.029 = 0.176 \text{ oz-in sec}^2$$

$$F_t = W_L \bullet \mu_S + F_{Applied} = 500 \text{ lbs} \bullet 16\,\frac{oz}{lb} \bullet 0.2 + 125 \text{ lbs x } 16\,\frac{oz}{lb}$$

$$+ 2000 = 3600 \text{ oz}$$

$$T_{RL} = \frac{F_t}{2\pi p e} + T_{PL} = \frac{3600}{2\pi \bullet 2 \bullet 0.9} + 0 = 318 \text{ oz-in}$$

4

Determine peak and continuous torque requirements.

$$T_A = T_{RL} + \frac{J_T\alpha}{e} = 318 + \frac{0.176 \bullet 567}{0.9} = 429 \text{ oz-in}$$

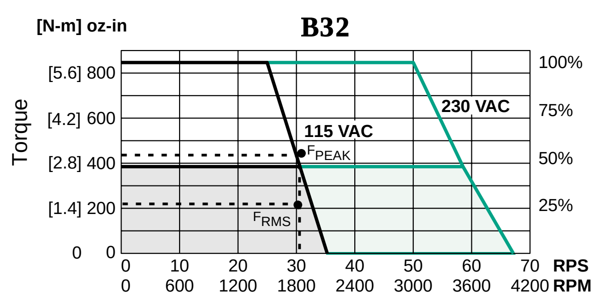
$$T_D = T_{RL} - \frac{J_T\alpha}{e} = 318 - \frac{0.176 \bullet 567}{0.9} = 207 \text{ oz-in}$$

If the dwell time between moves is 1.0 second, the total cycle time becomes 2.0 seconds.

$$T_{RMS} = \sqrt{\frac{T_A{}^2 t_A + T_R{}^2 t_R + T_D{}^2 t_D}{t_c}}$$

$$= \sqrt{\frac{(429)^2 \bullet 0.33 + (318)^2 \bullet 0.33 + (207)^2 \bullet 0.33}{2.0}}$$

$$= 233 \text{ oz-in}$$



The maximum torque required by the application is 429 oz-in. This falls within the speed/torque curve of the B32 motor, but it falls in the peak region. In order to have adequate torque margin in this application the B8000 Series drive used with the B32 motor would need to be run off of 230 VAC. Assuming the B8000 Series drive is run off of 230 VAC, the peak torque safety margin is 98.1%