Motor Sizing Calculations

This section describes certain items that must be calculated to find the optimum motor for a particular application. Selection procedures and examples are given.

Selection Procedure

1. Determine the drive mechanism component
   - First, determine certain features of the design, such as drive mechanism, rough dimensions, distances moved, and positioning period.

2. Confirm the required specifications
   - Confirm the required specifications for the drive system and equipment (stop accuracy, position holding, speed range, operating voltage, resolution, durability, etc.).

3. Calculate the speed and load
   - Calculate the value for load torque, load inertia, speed, etc. at the motor drive shaft of the mechanism. Refer to page 3 for calculating the speed, load torque and load inertia for various mechanisms.

4. Select motor type
   - Select a motor type from AC Motors, Brushless DC Motors or Stepping Motors based on the required specifications.

5. Check the selected motor
   - Make a final determination of the motor after confirming that the specifications of the selected motor/gearhead satisfy all of the requirements (mechanical strength, acceleration time, acceleration torque etc.).
Formulas for Calculating Load Torque

**Ball Screw**

\[ T_L = \frac{FP_b}{2\pi \eta} + \frac{\mu F_0 P_b}{2\pi} \times \frac{1}{i} \text{ [oz-in]} \]  

\[ F = F_A + m (\sin \alpha + \mu \cos \alpha) \text{ [oz]} \]

**Pulley**

\[ T_L = \frac{\mu F_A + m}{2\pi} \cdot \frac{\pi D}{i} \]  

\[ = \frac{(\mu F_A + m) D}{2i} \text{ [oz-in]} \]

**Wire Belt Mechanism, Rack and Pinion Mechanism**

\[ T_L = \frac{F}{2\pi \eta i} = \frac{FD}{2\pi \eta} \text{ [oz-in]} \]  

\[ F = F_A + m (\sin \alpha + \mu \cos \alpha) \text{ [oz]} \]

**By Actual Measurement**

\[ T_L = \frac{F_B D}{2} \text{ [oz-in]} \]

---

**Formulas for Calculating Moment of Inertia**

**Inertia of a Cylinder**

\[ J_x = \frac{1}{8} m D_l^2 = \frac{\pi}{32} \rho L D_l^4 \text{ [oz-in^2]} \]  

\[ J_y = \frac{1}{4} m \left( \frac{D_1^2}{4} + \frac{L^2}{3} \right) \text{ [oz-in^2]} \]

**Inertia of a Hollow Cylinder**

\[ J_x = \frac{1}{8} m \left( D_1^2 + D_2^2 \right) = \frac{\pi}{32} \rho L \left( D_1^4 - D_2^4 \right) \text{ [oz-in^2]} \]  

\[ J_y = \frac{1}{4} m \left( \frac{D_1^2 + D_2^2}{4} + \frac{L^2}{3} \right) \text{ [oz-in^2]} \]

**Inertia for Off-center Axis of Rotation**

\[ J_x = J_{co} + m l^2 = \frac{1}{12} m \left( A^2 + B^2 + 12 l^2 \right) \text{ [oz-in^2]} \]

**Inertia of a Rectangular Pillar**

\[ J_x = \frac{1}{12} m \left( A^2 + B^2 \right) = \frac{1}{12} \rho ABC \left( A^2 + B^2 \right) \text{ [oz-in^2]} \]  

\[ J_y = \frac{1}{12} m \left( B^2 + C^2 \right) = \frac{1}{12} \rho ABC \left( B^2 + C^2 \right) \text{ [oz-in^2]} \]

**Inertia of an Object in Linear Motion**

\[ J = m \left( \frac{V}{2\pi \rho} \right)^2 = m \left( \frac{A}{2\pi} \right)^2 \text{ [oz-in^2]} \]

---

**Notations**

- \( F \) = Force of moving direction [oz.]
- \( F_0 \) = Pilot pressure weight [oz.] \( (=1.3 F) \)
- \( \mu_{fr} \) = Internal friction coefficient of pilot pressure nut (0.1 to 0.3)
- \( \eta \) = Efficiency (0.85 to 0.95)
- \( i \) = Gear ratio
- \( D \) = Final pulley diameter [inch]

**Density**

- Iron \( \rho = 4.64 \text{ [oz/in}^3] \)
- Aluminum \( \rho = 1.65 \text{ [oz/in}^3] \)
- Bronze \( \rho = 5 \text{ [oz/in}^3] \)
- Nylon \( \rho = 0.65 \text{ [oz/in}^3] \)
### Stepping Motors

This section describes in detail the key concerns in the selection procedure, such as the determination of the motion profile, the calculation of the required torque and the confirmation of the selected motor.

**Operating Patterns**

There are 2 basic motion profiles. One is a start/stop operation and the other is an acceleration/deceleration operation.

Acceleration/deceleration operation is the most common. When load inertia is small, start/stop operation can be used.

![Operating Pulse Diagram](image)

#### Find the Number of Operating Pulses A [pulses]

The number of operating pulses is expressed as the number of pulse signals that adds up to the angle that the motor must move to get the work from point A to point B.

\[
\text{Operating Pulse (A) [Pulses]} = \frac{\text{Distance per Movement}}{\text{Distance per Motor Rotation}} \times \text{No. of Pulses Required for 1 Motor Rotation}
\]

\[
= \frac{l}{\text{rev}} \times 360^\circ \times \theta_s: \text{Step Angle}
\]

#### Determine the Operating Pulse Speed \( f_2 \) [Hz]

The operating pulse speed can be found from the number of operating pulses, the positioning period and the acceleration/deceleration period.

1. For Acceleration/Deceleration Operation

   Acceleration/deceleration is a method of operation in which the operating pulses of a motor being used in a medium- or high-speed region are gradually changed. It is found by the equation below. Usually, the acceleration (deceleration) period \( (t_1) \) is set at roughly 25% of the positioning periods. For gentle speed changes, the acceleration torque can be kept lower than in start-stop operations.

   When a motor is operated under an operating pattern like this, the acceleration/deceleration period needs to be calculated using the positioning period.

   \[
   \text{Acceleration/Deceleration Period [s]} = \text{Positioning Period [s]} \times 0.25
   \]

   \[
   \text{Operating Pulse Speed} \ (f_2) \ [Hz] = \frac{\text{Number of Operating Pulses [Pulses]}}{\text{Positioning Period [s]}} \times \text{Starting Pulse Speed [Hz]} \times \frac{\text{Acceleration (Deceleration) Period [s]}}{\text{Starting Pulse Speed [Hz]}}
   \]

   \[
   = \frac{A-f_1 \cdot t_1}{t_0-t_1}
   \]

2. For Start-Stop Operation

   Start-stop is a method of operation in which the operating pulse speed of a motor being used in a low-speed region is suddenly increased without an acceleration period. It is found by the following equation. Since rapid changes in speed are required, the acceleration torque is very large.

   \[
   \text{Operating Pulse Speed} \ (f_2) \ [Hz] = \frac{A}{t_0}
   \]

#### Calculate the Acceleration/Deceleration Rate \( T_a \)

Calculate the acceleration/deceleration rate from the following equation.

\[
\text{Acceleration/deceleration rate} \ (T_a) \ [\text{ms/Hz}] = \frac{\text{Acceleration (Deceleration) Period [ms]}}{\text{Operating Pulse Speed [Hz]}} - \text{Starting Pulse Speed [Hz]}
\]

* Calculate the pulse speed in full-step equivalents.

#### Calculate the Operating Speed from Operating Pulse speed

\[
\text{Operating Speed [r/min]} = \frac{\text{Operating Pulse Speed [Hz]} \times \text{Step Angle} [\text{°}] \times 60}{360^\circ}
\]

#### Calculate the Load Torque \( T_L \)

(See basic equations on pages F-3)

#### Calculate the Acceleration Torque \( T_a \)

1. For Acceleration/Deceleration Operation

   \[
   \text{Acceleration Torque} \ (T_a) \ [\text{oz-in}] = \left( \frac{\text{Inertia of Rotor [oz-in]}}{\text{[oz-in]}^2} + \frac{\text{Total Inertia [oz-in]}}{\text{[oz-in]}} \right) \times \frac{\pi \times \text{Step Angle} [\text{°}]}{180^\circ} \times \frac{\text{Operating Pulse Speed [Hz]} - \text{Starting Pulse Speed [Hz]}}{\text{Acceleration (Deceleration) Period [s]}}
   \]

   \[
   = (J_0+J_c) \times \frac{-\pi \theta_s}{180^\circ} \times \frac{f_2-f_1}{t_0}
   \]

2. For Start-Stop Operation

   \[
   \text{Acceleration Torque} \ (T_a) \ [\text{oz-in}] = \left( \frac{\text{Inertia of Rotor [oz-in]}}{\text{[oz-in]}^2} + \frac{\text{Total Inertia [oz-in]}}{\text{[oz-in]}} \right) \times \frac{\pi \times \text{Step Angle} [\text{°}] \times (\text{Operating Pulse Speed})^2 \ [\text{Hz}]}{180^\circ \times \text{Coefficient}}
   \]

   \[
   = (J_0+J_c) \times \frac{-\pi \theta_s \cdot f_2^2}{180^\circ \times n} \quad \text{n: 3.6/°s}
   \]

#### Calculate the Required Torque \( T_m \)

Required Torque = (Load Torque + Acceleration Torque) x Safety Factor

\[
T_m \ [\text{oz-in}] \times \text{Safety Factor}
\]

\[
= (T_L + T_a) \times \text{Sf}
\]
Choosing Between Standard AC Motors and Stepping Motors

Selection Considerations
There are differences in characteristics between standard AC motors and stepping motors. Shown below are some of the points you should know when sizing a motor.

Standard AC Motors

1. The speed of Induction Motors and Reversible Motors vary with the size of the load torque. So, the selection should be made between the rated speed and the synchronous speed.
2. There can be a difference of continuous and short-term ratings, due to the difference in motor specifications, despite the fact that two motors have the same output power. Motor selection should be based on the operating time (operating pattern).
3. Each gearhead has maximum permissible load inertia. When using a dynamic brake, changing direction quickly, or quick starts and stops, the total load inertia must be less than the maximum permissible load inertia.

Stepping Motors

1. Checking the Running Duty Cycle
A stepping motor is not intended to be run continuously with rated current. Lower than 50% running duty cycle is recommended.

Running Duty Cycle = \( \frac{\text{Running Time}}{\text{Running Time} + \text{Stopping Time}} \times 100 \)

2. Checking the Inertia Ratio
Large inertia ratios cause large overshooting and undershooting during starting and stopping, which can affect start-up times and settling times. Depending on the conditions of usage, operation may be impossible. Calculate the inertia ratio with the following equation and check that the values found are at or below the inertia ratios shown in the table.

\[ \text{Inertia Ratio} = \frac{J \times i^2}{J_0} \]

Inertia Ratio (Reference Values)

<table>
<thead>
<tr>
<th>Product Series</th>
<th>Inertia Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha \text{STEP} )</td>
<td>30</td>
</tr>
<tr>
<td>( RK ) Series</td>
<td>10 Maximum</td>
</tr>
</tbody>
</table>

*Except geared motor types

3. Check the Acceleration/Deceleration Rate
Most controllers, when set for acceleration or deceleration, adjust the pulse speed in steps. For that reason, operation may sometimes not be possible, even though it can be calculated. Calculate the acceleration/deceleration rate from the following equation and check that the value is at or above the acceleration/deceleration rate in the table.

\[ \text{Acceleration/Deceleration Rate} = \frac{\text{Operating Pulse Speed [Hz]} - \text{Starting Pulse Speed [Hz]}}{t_1 - f_i} \times \frac{10}{f_1} \]

Calculate the pulse speed in full-step equivalents.

\[ \frac{f_1}{t_1} \]

Acceleration Rate (Reference Values with \( \text{EMP} \) Series)

<table>
<thead>
<tr>
<th>Model</th>
<th>Motor Frame Size inch (mm)</th>
<th>Acceleration/Deceleration Rate ( \tau ) [ms/kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha \text{STEP} )</td>
<td>1.10(28), 1.65(42), 2.36(60), 3.35(85)</td>
<td>0.5 Min.</td>
</tr>
<tr>
<td>( RK ) Series</td>
<td>1.65(42), 2.36(60), 3.35(85), 3.54(90)</td>
<td>20 Min.</td>
</tr>
</tbody>
</table>

4. Checking the Required Torque
Check that the required torque falls within the pull-out torque of the speed-torque characteristics.

Safety Factor: \( S_f \) (Reference Value)

<table>
<thead>
<tr>
<th>Product Series</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha \text{STEP} )</td>
<td>1.5 – 2</td>
</tr>
<tr>
<td>( RK ) Series</td>
<td>2</td>
</tr>
</tbody>
</table>

* Except geared motor types

When these values are exceeded, we recommend a geared motor. Using a geared motor can increase the drivable inertia load.
Sizing Example

- **Ball Screw**

Using Stepping Motors ($\alpha_{\text{step}}$)

![Diagram of Ball Screw System]

- **Determine the Drive Mechanism**
  - Total mass of the table and work: $m = 90 \text{ lb. (40 kg)}$
  - Frictional coefficient of sliding surfaces: $\mu = 0.05$
  - Ball screw efficiency: $\eta = 0.9$
  - Internal frictional coefficient of pilot pressure nut: $\mu_0 = 0.3$
  - Ball screw shaft diameter: $D_b = 0.6 \text{ inch (1.5 cm)}$
  - Total length of ball screw: $L_B = 23.6 \text{ inch (60 cm)}$
  - Material of ball screw: Iron \( [\text{density } \rho = 4.64 \text{ oz/in}^3 \times (7.9 \times 10^{-3} \text{ kg/cm}^3)] \)
  - Pitch of ball screw: $P_b = 0.6 \text{ inch (1.5 cm)}$
  - Desired Resolution (feed per pulse): $\Delta f = 0.001 \text{ inch (0.03 mm)/step}$
  - Feed: $l = 7.01 \text{ inch (180 mm)}$
  - Positioning period: $t_0 = 0.8 \text{ sec}$

- **Calculate the Required Resolution**

  \[
  \text{Required Resolution } \theta_s = \frac{360^\circ \times \text{Desired Resolution } (\Delta f)}{\text{Ball Screw Pitch } (P_s)} = \frac{360^\circ \times 0.001}{15} = 0.72^\circ
  \]

$\alpha_{\text{step}}$ can be connected directly to the application.

- **Determine the Operating Pattern**

  (see page F-4, see basic equations on pages F-3)

1. **Finding the Number of Operating Pulses (A) [pulses]**

  \[
  \text{Operating pulses } A = \frac{\text{Feed per Unit } (l)}{\text{Ball Screw Pitch } (P_s)} \times \frac{360^\circ}{\text{Step Angle } (\theta_s)} = \frac{7.01}{0.6} \times \frac{360^\circ}{0.72} = 6000 \text{ pulses}
  \]

2. **Determine the Acceleration (Deceleration) Period $t_1$ [sec]**

   An acceleration (deceleration) period of 25% of the positioning period is appropriate.

   \[
   \text{Acceleration (deceleration) period } t_1 = 0.8 \times 0.25 = 0.2 \text{ sec}
   \]

- **Determine the Operating Pulse Speed $f_2$ [Hz]**

  \[
  \text{Operating pulse speed } f_2 = \frac{\text{Number of Operating Pulses } A - \text{Starting Pulses } B \times \text{Acceleration (Deceleration) Period } t_1}{\text{Positioning Period } t_0} = \frac{6000 - 0}{0.8 - 0.2} = 10000 \text{ Hz}
  \]

- **Calculate the Operating Speed N [r/min]**

  \[
  \text{Operating Speed } N = \frac{f_2 \times \theta_s}{360} = \frac{10000 \times 0.72}{360} = 1200 \text{ [r/min]}
  \]

- **Calculate the Required Torque $T_m$ [oz-in]**

  (see page F-4)

1. **Calculate the Load Torque $T_l$ [oz-in]**

   \[
   \text{Load in Shaft Direction } F = FA + m \times (\sin \alpha + \mu \cos \alpha) = 0 + 90 \times (\sin 0 + 0.05 \cos 0) = 4.5 \text{ lb.}
   \]

   \[
   \text{Pilot Pressure Load } F_p = \frac{F}{3} = \frac{4.5}{3} = 1.5 \text{ lb.}
   \]

   \[
   \text{Load Torque } T_l = \frac{F \times P_s}{2 \pi} + \mu F_p \times P_s \times \frac{2 \pi}{2 \pi} = 4.5 \times 0.6 + 0.3 \times 1.5 \times 0.6 = 0.52 \text{ lb-in} = 8.3 \text{ oz-in}
   \]

2. **Calculate the Acceleration Torque $T_a$ [oz-in]**

   \[
   \text{Inertia of Ball Screw } J_b = \frac{\pi}{32} \times 4.64 \times 23.6 \times 0.6 = 1.39 \text{ oz-in}^2
   \]

   \[
   \text{Inertia of Table and Work } J_t = \frac{\pi}{32} \times 0.6 \times \frac{2 \pi}{2 \pi} = 0.82 \text{ lb-in}^2 = 13.1 \text{ oz-in}^2
   \]

   \[
   \text{Total Inertia } J_s = J_b + J_t = 1.39 + 13.1 = 14.5 \text{ oz-in}^2
   \]

   \[
   \text{Acceleration } T_a = \frac{J_s + J_b}{9} \times \frac{\pi}{180} \times \frac{t_1 - t_2}{t_1} = \frac{1.63 \times 23.6}{180} \times \frac{10000 - 0}{0.2} = 1.63 \times 23.6 \text{ oz-in}
   \]

3. **Calculate the Required Torque $T_m$ [oz-in]**

   \[
   \text{Required torque } T_m = (T_a + T_r) \times 2 = (8.3 + 1.63 \times 23.6) \times 2 = 3.26 \times 63.8 \text{ oz-in}
   \]
Ball Screw

Using Standard AC Motors

This example demonstrates how to select an AC motor with an electromagnetic brake for use on a tabletop moving vertically on a ball screw. In this case, a motor must be selected that meets the following basic specifications.

Required and Structural Specifications

<table>
<thead>
<tr>
<th>Motor</th>
<th>Gearhead</th>
<th>Coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total weight of table and work .........................  m = 100 lb.
Table speed ..............................................  V = 0.6 in./s ± 10%
Ball screw pitch .......................................  Pb = 0.197 in.
Ball screw efficiency ..................................  η = 0.9
Ball screw friction coefficient .........................  μ0 = 0.3
Friction coefficient of sliding surface (Slide guide) ..  μ = 0.05
Motor power supply .....................................  Single-Phase 115 VAC 60 Hz
Ball screw total length ..................................  Lb = 31.5 in.
Ball screw shaft diameter ................................  Db = 0.787 in.
Ball screw material .....................................  Iron (density ρ = 4.64 oz/in.³)
Distance moved for one rotation of ball screw .......  A = 0.197 in.
External force .............................................  Fa = 0 lb.
Ball screw tilt angle ....................................  α = 90°
Movement time .......................................... 5 hours/day
Brake must provide holding torque

Determine the Gear Ratio

Speed at the gearhead output shaft:  No

\[ No = \frac{V \cdot 60}{\omega_B} = \frac{(0.6 \times 0.06) \times 60}{0.197} \]

Because the rated speed for a 4-pole motor at 60 Hz is 1450–1550 r/min, the gear ratio (i) is calculated as follows:

\[ i = \frac{1450–1550}{182 \pm 18} = 7.2–9.5 \]

From within this range a gear ratio of i = 9 is selected.

Calculate the Required Torque

F, the load weight in the direction of the ball screw shaft, is obtained as follows:

\[ F = F_A \times m \sin \alpha \pm \mu \times \cos \alpha = 0 + 100 \sin (90 + 0.05 \times 90 \cos 90) = 100 \text{ lb.} \]

Preload weight Fa:

\[ F_S = \frac{F}{3} = 33.3 \text{ lb.} \]

Load torque TL:

\[ T_L = \frac{F \times P_B}{2 \pi \eta} + \frac{\mu_0 \times F_S \times P_B}{2 \pi} = 100 \times \frac{0.197}{2 \pi \times 0.9} + 0.3 \times 33.3 \times 0.197 \]

\[ = 3.8 \text{ lb-in} \]

This value is the load torque at the gearhead drive shaft, and must be converted into load torque at the motor output shaft. The required torque at the motor output shaft (Tm) is given by:

\[ T_M = \frac{T_L}{i \times \eta_G} = \frac{3.8}{9 \times 0.81} = 0.52 \text{ [lb-in]} = 8.32 \text{ oz-in} \]

(Gearhead transmission efficiency \( \eta_G = 0.81 \))

Look for a margin of safety of 2 times.

\[ 8.32 \times 2 = 16.64 \text{ oz-in} \]

To find a motor with a start-up torque of 16.64 oz-in or more, select motor 5RK40GN-AWMU. This motor is equipped with an electromagnetic brake to hold a load. A gearhead with a gear ratio of 9:1 that can be connected to the motor 5RK40GN-AWMU is 5GN9KA.

The rated motor torque is greater than the required torque, so the speed under no-load conditions (1740 r/min) is used to confirm that the motor produces the required speed.

Load Inertia Check

Ball Screw

Moments of Inertia

\[ I_h = \frac{\pi \times \rho \times L_B \times D_b^4}{32} = \frac{\pi \times 4.64 \times 31.5 \times (0.787)^4}{32} = 5.5 \text{ oz-in}^2 \]

Table and Work

Moments of Inertia

\[ I_w = m \left( \frac{A}{2 \pi} \right)^2 = 100 \times 16 \times \left( \frac{0.197}{2 \pi} \right)^2 = 1.57 \text{ oz-in}^2 \]

Gearhead shaft total load inertia

\[ J = I_h + I_w + I_L = 5.5 + 1.57 + 7.07 \text{ [oz-in}^2] \]

Here, the 5GN9KA permitted load inertia is (see page A-12):

\[ J_S = J_M \times \omega_s^2 = 4 \times 9^2 = 324 \text{ oz-in}^2 \]

Therefore, \( J < J_S \), the load inertia is less than the permitted inertia, so there is no problem. There is margin for the torque, so the rotation rate is checked with the no-load rotation rate (about 1750 r/min).

\[ V = \frac{N_M \cdot P}{60 - \omega_s} = 0.64 \text{ in./s} \] (where \( N_M \) is the motor speed)

This confirms that the motor meets the specifications.
Belt and Pulley

Using Standard AC Motors

Here is an example of how to select an induction motor to drive a belt conveyor.

In this case, a motor must be selected that meets the following basic specifications.

**Required Specifications and Structural Specifications**

![Diagram of Belt Conveyor and Motor](image)

- Total weight of belt and work \( m_1 = 30 \text{ lb.} \)
- Friction coefficient of sliding surface \( \mu = 0.3 \)
- Drum radius \( D = 4 \text{ inch} \)
- Weight of drum \( m_2 = 35.27 \text{ oz.} \)
- Belt roller efficiency \( \eta = 0.9 \)
- Belt speed \( V = 7 \text{ inch/s} \leq 10\% \)
- Motor power supply \( \text{Single-Phase 115 VAC 60 Hz} \)

**Determine the Gear Ratio**

Speed at the gearhead output shaft:

\[
N_d = \frac{V \cdot 60}{\pi \cdot D} = \frac{(7 \pm 0.7) \times 60}{4 \times \pi} = 33.4 \pm 3.3 \text{ r/min}
\]

Because the rated speed for a 4-pole motor at 60 Hz is 1450–1550 r/min, the gear ratio \( i \) is calculated as follows:

\[
i = \frac{1450–1550}{33.4} = 43.4–46.5
\]

From within this range a gear ratio of \( i = 50 \) is selected.

**Calculate the Required Torque**

On a belt conveyor, the greatest torque is needed when starting the belt. To calculate the torque needed for start-up, the friction coefficient (\( F \)) of the sliding surface is first determined:

\[
F = \mu m_1 = 0.3 \times 30 = 9 \text{ lb.} = 144 \text{ oz.}
\]

Load torque \( (T_L) \) is then calculated by:

\[
T_L = \frac{F \cdot D}{2 \cdot \eta} = \frac{144 \times 4}{2 \times 0.9} = 320 \text{ oz-in}
\]

The load torque obtained is actually the load torque at the gearhead drive shaft, so this value must be converted into load torque at the motor output shaft. If the required torque at the motor output shaft is \( T_M \), then:

\[
T_M = \frac{T_L}{\eta_G} = \frac{320}{50 \times 0.66} = 9.7 \text{ oz-in}
\]

(Gearhead transmission efficiency \( \eta_G = 0.66 \))

Look for a margin of safety of 2 times, taking into consideration commercial power voltage fluctuation:

\[
9.7 \times 2 = 19.4 \text{ oz-in}
\]

The suitable motor is one with a starting torque of 19.4 oz-in or more. Therefore, motor 5IK40GN-AWU is the best choice. Since a gear ratio of 50:1 is required, select the gearhead 5GN50KA which may be connected to the 5IK40GN-AWU motor.

**Load Inertia**

Roller Moment of Inertia

\[
J_1 = \frac{1}{8} \times m_2 \times D^2 \times 2 = \frac{1}{8} \times 35.27 \times 4^2 \times 2 = 141 \text{ oz-in}^2
\]

Belt and Work Moment of Inertia

\[
J_2 = m_1 \left( \frac{\pi \times D}{2\pi} \right)^2 = 30 \times 16 \times \left( \frac{4}{2\pi} \right)^2 = 1920 \text{ oz-in}^2
\]

Gearhead Shaft Load Inertia

\[
J = J_1 + J_2 = 141 + 1920 = 2061 \text{ oz-in}^2
\]

Here, the 5GN50KA permitted load inertia is:

\[
J_G = 4 \times 50^2 = 10000 \text{ oz-in}^2
\]

(See page A-12)

Therefore, \( J < J_G \), the load inertia is less than the permitted inertia, so there is no problem.

Since the motor selected has a rated torque of 36.1 oz-in, which is somewhat larger than the actual load torque, the motor will run at a higher speed than the rated speed. Therefore the speed is used under no-load conditions (approximately 1740 r/min) to calculate belt speed, and thus determine whether the selected product meets the required specifications.

\[
V = \frac{N_m \cdot \pi \cdot D}{60 \cdot i} = \frac{1740 \times \pi \times 4}{60 \times 50} = 7.3 \text{ in/s}
\]

(Where \( N_m \) is the motor speed)

The motor meets the specifications.
Using Brushless DC Motors

Here is an example of how to select a speed control motor to drive a belt conveyor.

**Performance**
Belt speed \(V_l\) is 0.6 in./s \(\sim\) 40 in./s

**Specifications for belt and work**

Condition: Motor power supply ---- Single-Phase 115 VAC
Belt conveyor drive
Roller diameter ............................ \(D\) = 4 inch
Mass of roller ............................ \(m_1\) = 2.2 lb.
Total mass of belt and work ........... \(m_2\) = 33 lb.
Friction coefficient of sliding surface .... \(\mu\) = 0.3
Belt roller efficiency .................. \(\eta\) = 0.9

**Find the Required Speed Range**

For the gear ratio, select 15:1 (speed range: 2 \(\sim\) 200) from the permissible torque table for combination type on page B-14 so that the minimum/maximum speeds fall within the speed range.

\[N_o = \frac{60V_l}{\pi D}\]

**Calculate the Load Inertia \(J_g\)**

Load Inertia of Roller : \(J_{m1}\)
\[J_{m1} = \frac{1}{8} \times m_1 \times D^2 = \frac{1}{8} \times 2.2 \times 16 \times 4 = 70.4 \text{ oz-in}^2\]

Load inertia of belt and work : \(J_{m2}\)
\[J_{m2} = m_2 \times \left( \frac{\pi D}{2\pi} \right)^2 = 33 \times \left( \frac{\pi 4}{2\pi} \right)^2 = 132 \text{ oz-in}^2\]

The load inertia \(J_o\) is calculated as follows:
\[J_o = J_{m1} + J_{m2} = 70.4 + 132 = 202.4 \text{ oz-in}^2\]

From the specifications on page B-15, the permissible load inertia for BX5120A-15 is 2300 oz-in\(^2\) (4.2 \times 10^{-2} \text{ kg-m}^2)

**Calculate the Load Torque \(T_L\)**

Friction Coefficient of the Sliding Surface: \(F = \mu \times m_2 = 0.3 \times 33 = 9.9 \text{ lb.}\)

Load Torque \(T_L\)
\[T_L = \frac{F \times D}{2\pi \eta} = \frac{9.9 \times 4}{2 \times 0.9} = 22 \text{ lb-in}\]

Select BX5120A-15 from the permissible torque table on page B-14.

Since the permissible torque is 47 lb-in (5.4 N-m), the safety margin is
\[T_{m}/T_L = 50/22 = 2.3\]

Usually, a motor can operate at the safety margin of 1.5 \(\sim\) 2 or more.

Using Stepping Motors

Geared stepping motors are suitable for systems with high inertia, such as index tables.

**Determine the Drive Mechanism**

**Index Table**

Diameter of index table: \(D_T = 11.8 \text{ inch (300 mm)}\)
Index table thickness: \(L_T = 0.39 \text{ inch (10 mm)}\)
Thickness of work: \(L_W = 1.18 \text{ inch (30 mm)}\)
Diameter of work: \(D_W = 1.57 \text{ inch (40 mm)}\)
Material of table and load: Iron [density \(\rho = 4.64 \text{ oz/in}^3 = (7.9 \times 10^{-3} \text{ kg/cm}^3)]\)
Number of loads: 12 (one every 30\(^\circ\))
Distance from center of index table to center of load: \(l = 4.92 \text{ inch (125 mm)}\)
Positioning angle: \(\theta = 30^\circ\)
Positioning period: \(t_b = 0.3 \text{ [sec]}\)

The \(\Omega_{\text{STEP-PN}}\) geared (gear ratio 7.2:1) can be used.

Gear Ratio: \(i = 7.2\)
Resolution: \(\theta s = 0.05^\circ\)

Speed Range (Gear Ratio 7.2:1) is 0 \(\sim\) 416 r/min

**Determine the Operating Pattern**

(see page F-4, see basic equations on page F-3)

1. **Find the Number of Operating Pulses (A) [pulses]**

\[\text{Operating pulses}(A) = \frac{\text{Angle rotated per movement (°)}}{\text{Gear output shaft step angle (°)}}\]
\[= \frac{30^\circ}{0.05^\circ} = 600 \text{ Pulses}\]

2. **Determine the Acceleration (Deceleration) Period \(t_1\) [sec]**

An acceleration (deceleration) period of 25% of the positioning period is appropriate.

\[\text{Acceleration (deceleration) period (t1) = } t_1 \times 0.25\]
\[= 0.3 \times 0.25 = 0.075 \text{ sec}\]

3. **Calculate the Operation Speed**

\[\text{Operating N} = \frac{60 \times \theta}{360 \times t_b - t_1} = \frac{60 \times 30}{360 \times 0.3 - 0.075}\]
\[= 22.2 \text{ [r/min]}\]
(4) Determine the Operating Pulse Speed $f_2$ [Hz]

$$f_2 = \frac{N - O}{T_a}$$

$$= \frac{600 - 0}{0.3 - 0.075} = 2667 [\text{Hz}]$$

(1) Calculate the Load Torque $T_L$ [oz-in]

(See page F-3 for basic equations)

Frictional load is omitted because it is negligible. Load torque is considered 0.

(2) Calculate the Acceleration Torque $T_a$ [oz-in]

(See page F-4 for basic equations)

$$T_a = \left( J_0 \cdot i^2 + J_L \right) \frac{\pi \cdot 6560 \cdot f_1}{180 \cdot f_2}$$

$$= \left( 4.16 J_0 + 527 \right) \times 2$$

$$= 8.32 J_0 + 1054 [\text{oz-in}]$$

(3) Calculate the Required Torque $T_M$ [oz-in]

Safety Factor $S_f = 2$

$$T_M = \left( T_L + T_a \right) \times 2$$

$$= \left( 0 + 8.32 J_0 + 1054 \right) \times 2$$

$$= 8.32 J_0 + 2108 [\text{oz-in}]$$

(1) Provisional Motor Selection

<table>
<thead>
<tr>
<th>Model</th>
<th>Rotor Inertia oz-in²</th>
<th>Required Torque lb-in</th>
<th>Required Torque [N-m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS66AA-N7.2</td>
<td>2.2</td>
<td>67</td>
<td>7.6</td>
</tr>
</tbody>
</table>

(2) Determine the Motor from the Speed-Torque Characteristics

Select a motor for which the required torque falls within the pull-out torque of the speed-torque characteristics. 

PN geared type can operate inertia load up to acceleration torque less than Maximum torque.