[Technical Data]

Selection of Ball Screws 1

1. Ball Screw Selection Procedure
Basic ball screw selection procedure and required evaluation items are shown below.

- Determine the application parameters
- Select the application parameters
- Evaluate various parameter values
- Select the application parameters

Moving mass, feed speed, motion pattern, screw shaft rotational speed, stroke, mounting orientation (horizontal or vertical), life, positioning accuracy

Temporary selection of ball screw lead accuracy grade (C3 – C10), shaft diameter, leads, and length.

- Axial Lead Capacity
  Confirm that the applied axial load is within the ball screw’s axial load capacity rating.

- Allowable Rotational Speed
  Confirm that the intended shaft rotational speed is within the ball screw’s allowable rotational speed rating.

- Life
  Confirm that the ball screw satisfies the life requirement.

If higher positioning accuracy and/or improved responsiveness is needed, below parameters need to be evaluated.

- Screw shaft rigidity
- Effects of temperature variation on life
- Effects of temperature variation on life

2. Ball Screw Lead Accuracy
Ball screw lead accuracy is defined by ISO Standard property parameters (ep, u, v, w, x, y, z).

Parameter definitions and allowable values are shown below.

In general, a ball screw lead accuracy grade is selected by evaluating if the Actual Mean Travel Error of a candidate is within the allowable positioning error.

Parameter Definitions:
- ep: V = Effective Travel (User) – Nominal Travel (Standard)
- 0.20 or less
- v: "V = Mean Travel (User) – Actual Travel (User)"
- 0.12 or less
- w: "V = Standard Actual Travel – Actual Travel (User)"
- 0.05 or less
- x: "V = Actual Travel (User) – Standard Travel (User)"
- 0.07 or less
- y: "V = Actual Travel (User) – Standard Travel (User)"
- 0.05 or less
- z: "V = Actual Travel (User) – Nominal Travel (Standard)"
- 0.05 or less

3. Axial Clearances of Ball Screws
Axial clearance does not affect positioning accuracy if the feed is unidirectional, but will generate backlash and negatively affect on positioning accuracy if the direction or the axial load is reversed.

Selection Example of Axial Clearances
From Table 5, it can be determined that C5 grade with 0.005mm or less axial clearance satisfies the allowable backlash amount of 0.01mm for the B15 group.

Selection Example of Axial Clearance
- Requirements:
  Ball screw diameter Ø15, lead 5.
  Allowable backlash ≤0.01mm

- Selection Details:
  Select an appropriate lead accuracy grade based on the application requirements.

1. Evaluating the screw thread length:
   - Stroke = Lead × Length = (16.5 + 1.0) × 20

2. Evaluating the lead accuracy:
   - Actual Mean Travel Error ≤ ±0.001mm

3. Determining the lead accuracy:
   - It can be determined that a C5 grade (±0.040/800 ~ 1000mm) ball screw can satisfy the required positioning accuracy of ±0.05/720mm.
4. Allowable Axial Load

Allowable Axial Load is a load with a safety margin built-in against a shaft buckling load. Axial load that applies to a ball screw needs to be less than Allowable Maximum Axial Load. Allowable Axial Load can be obtained by the following formula. Additionally, approximate Allowable Axial Load can be obtained from Table 1. Allowable Axial Load Graph.

\[ P = \frac{\pi^2 EI}{d^4} \times 10^7 \text{min}^{-1} \]

Where:
- \( P \): Allowable Axial Load (N)
- \( n \): Coefficient Determined by Method of Screw Support
- \( d \): Thread Root Diameter (mm)
- \( I \): Min. Geometrical Moment of Inertia of Across Root Thread Area (mm\(^4\))
- \( E \): Young’s Modulus (2.06×10^5 N/mm\(^2\))
- \( \ell \): Distance between Points of Buckling Load (mm)
- \( g \): Operating Factor

For higher safety, a higher safety factor should be required.

5. Allowable Rotational Speed

Ball screw rotational speed is determined by required feed speed and the given screw lead, and needs to be less than the Allowable Maximum Rotational Speed. Ball screw rotational speed is evaluated based on the shaft’s critical speed and ball recirculation speed limitation (DmN value).

5-1. Critical Speed

Allowable rotational speed is defined as a speed 90% or less of the Critical Speed where the rotational speed coincides with a natural resonant frequency of the screw shaft. The Allowable Critical Speed can be obtained by the following formula.

\[ N_c = \frac{60 \pi^2 EI}{d^4} \times g \times 10^7 \text{min}^{-1} \]

Where:
- \( N_c \): Allowable Rotational Speed (min\(^{-1}\))
- \( d \): Thread Root Diameter (mm)
- \( I \): Min. Geometrical Moment of Inertia of Across Root Thread Area (mm\(^4\))
- \( E \): Young’s Modulus (2.06×10^5 N/mm\(^2\))
- \( g \): Operating Factor

For higher safety, a higher safety factor should be required.

5-2. DmN Value

The DmN value represents a ball recirculation (orbit) speed limit within a ball nut. If this value is exceeded, the recirculation components will be damaged.

### Table 1

<table>
<thead>
<tr>
<th>Ball Dia.</th>
<th>A Value</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>3.5</th>
<th>4.0</th>
<th>4.5</th>
<th>5.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø15</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Ø20</td>
<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
<td>1.4</td>
<td>1.6</td>
<td>1.8</td>
<td>2.0</td>
<td>2.2</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Balance of Supports (Critical Speed: Fixed-Support)</th>
<th>1000min(^{-1})</th>
<th>2000min(^{-1})</th>
<th>4000min(^{-1})</th>
<th>6000min(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-Support</td>
<td>1.5</td>
<td>3.0</td>
<td>6.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Fixed-Free</td>
<td>1.8</td>
<td>3.5</td>
<td>6.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Support-Support</td>
<td>2.1</td>
<td>4.2</td>
<td>7.4</td>
<td>10.6</td>
</tr>
<tr>
<td>Support-Fixed</td>
<td>2.4</td>
<td>4.9</td>
<td>9.8</td>
<td>15.6</td>
</tr>
<tr>
<td>Fixed-Free</td>
<td>2.4</td>
<td>4.9</td>
<td>9.8</td>
<td>15.6</td>
</tr>
</tbody>
</table>

### Figure 1. Allowable Axial Load Curve

- **How to use**
  - Find the intersection on the graph where the axis of variable distance (mm) and the fixed line of variable load (N) intersect.
  - The intersection of (1) above is the Allowable Axial Load.

### Figure 2. Allowable Rotational Speed Graph

- **How to use**
  - Find the intersection on the graph where the axis of variable distance (mm) and the fixed line of variable speed (min\(^{-1}\)) intersect.
  - The intersection of (1) above is the Allowable Rotational Speed.
6. Life Span

Ball screws' life is defined as: Total number of rotations, time, or distance where either the ball rolling surfaces or the balls begin to exhibit repetitive stress caused flaking. Ball screw's life can be calculated based on Basic Dynamic Load Rating with the following formula.

6-1. Life Hours (Lh)

\[ L_h = \frac{10^6}{60 \times N_m \times F_w} \times \frac{C}{P_m f_w} \] (hrs)

Where:
- \( L_h \): Life Hours (hrs)
- \( N_m \): Basic Dynamic Load Rating (N)
- \( F_w \): Mean Axial Load (N)
- \( v \): Work Factor
  - Impulse Run: \( v \) = 1.0 ~ 1.2
  - Normal Run: \( v \) = 1.2 ~ 1.5
  - Run with impact: \( v \) = 1.5 ~ 2.0

(Basic Dynamic Load Rating : C

Basic Dynamic Load Rating (C) is defined as an axial load which a group of same ball screws are subjected and 90% of the specimen will reach 1 million rotating (10^6) without experiencing any flaking of the rolling surfaces. See product catalog pages for the Basic Dynamic Load Ratings.

Setting life span hours longer than what is actually necessary not only requires a larger ball screw, but also increases the price.

In general, the following standards are used for life span hours:
- Machine Tools: 20,000hrs
- Automatic Control Equipment: 15,000hrs
- Industrial Machinery: 10,000hrs
- Measuring Instruments: 15,000hrs

6-2. Axial Load

Axial loads that apply on the screw shafts will vary depending on applicable motion profile such as acceleration, constant velocity, and deceleration phases. Following formula can be used.

Axial Load Formula:
Constant Velocity : Axial Load \( (P_a) = \mu W_g \)
- Acceleration : Axial Load \( (P_a) = \frac{W_a}{2} \) ...
- Deceleration : Axial Load \( (P_a) = \frac{W_d}{2} \)

* The basic dynamic load rating that satisfies the sat life span hours is expressed by the following formula.

\[ C = \frac{P_{mfw}(N)}{10^6} \]

6-3. Formulas for Average Axial Load and Average Rotational Speed

Average Axial Load and Average Rotational Speed are calculated based on proportions of motion profiles. Average Axial Load and Average Rotational Speed for Motion profiles in Table 1. can be calculated with the formulas 2.

Average Axial Load and Average Rotational Speed Calculation Example

(Tables 1-2)

Average Axial Load and Average Rotational Seed Calculation Example

(Tables 3-4)

7. Screw Shaft Mounting Arrangements

Representative ball screw mounting arrangements are shown below.

8. Temperature and Life

When ball screws are continuously used at 100°C or higher, or used momentarily at very high temperatures, Basic Dynamic/Static Load Ratings will be reduced according to the temperature rise due to changes in material compositions.

However, there will be no effects up to 100°C. Basic Dynamic Load Rating \( C^* \) and Basic Static Load Rating \( G^* \) at 100°C or higher with the temperature factors \( f^* \) and \( f^* \) can be expressed with the following formula.

\[ C^* = f^* C \]

\[ G^* = f^* G \]

Where:
- \( f^* \): Axial Load Factor
- \( f^* \): Axial Load Factor

The expansion and contraction are expressed in the following formula. The expansion and contraction will directly appear as ball screw backlash.

(1) Fixed-Free Arrangement
\[ \ell = 4P \ell \]

Where:
- \( P \): Axial Load (N)
- \( \ell \): Screw Shaft Expansion/Contraction (mm)

(2) Fixed-Fixed Arrangement
\[ \ell = \frac{4P \ell}{E \pi d^2} \]

Where:
- \( P \): Axial Load (N)
- \( \ell \): Screw Shaft Expansion/Contraction (mm)
- \( E \): Young's Modulus (2.06x10^5N/mm²)
- \( d \): Screw Shaft Root Diameter (mm)

9. Rigidity

In order to improve accuracies and system response of precision machinery and equipment, feed screw related component rigidity must be evaluated. Rigidity of feed screw system can be expressed with the following formula.

\[ \frac{P}{\ell} = \frac{K}{E} \]

Where:
- \( P \): Axial Load (N)
- \( \ell \): Screw Shaft Expansion/Contraction (mm)
- \( E \): Young's Modulus (2.06x10^5N/mm²)
- \( d \): Screw Shaft Root Diameter (mm)
- \( L \): Mounting Span Distance (mm)

The formula produces the max. value when \( \ell = \ell' = L \) and other various construction element rigidity.

**Technical Data**
Selection of Ball Screws 3
10. Driving Torque

This selection provides a guide for selecting ball screw frictional properties and the driving motor.

10-1. Friction and Efficiency

Ball screw efficiency can be expressed in the following formulas, wherein μ is the coefficient of friction and g is the screw's lead angle. Variables are determined through analysis of a dynamic model.

When rotational force is converted into axial force (Forward Action)

\[
T_f = \frac{P \cdot \mu}{\pi \cdot D \cdot l} \times \frac{g}{\sin g} \times \frac{1}{\cos g}
\]

When axial force is converted into rotational force (Reverse Action)

\[
T_r = \frac{P \cdot \mu}{\pi \cdot D \cdot l} \times \frac{g}{\sin g} \times \frac{1}{\cos g}
\]

10-2. Load Torque

The load torque (constant speed driving torque) required in drive source design/selection is calculated as follows.

(1) Driving Torque at Constant Speed (N·cm)

\[
T_1 = \frac{2\pi \cdot N}{60} \cdot T_2
\]

(2) Acceleration Torque Exercised on the Motor Output Thread

\[
T_2 = \frac{2\pi \cdot N}{60} \cdot (J_1 + J_2 + J_3 + J_4 + J_5 + J_6) \times \frac{10^{-3}}{2\pi}
\]

(3) Deceleration Torque Exercised on the Motor Output Thread

\[
T_3 = \frac{2\pi \cdot N}{60} \cdot (J_1 + J_2 + J_3 + J_4 + J_5 + J_6) \times \frac{10^{-3}}{2\pi}
\]

11. Selecting the Driving Motors

When selecting a driving motor, it is necessary to satisfy the following conditions:

1. Ensure a sufficient torque to counter the load torque exerted on the motor's output thread.
2. Ensure the prescribed acceleration and deceleration constants, sufficient to counter the moment of inertia exerted on the motor's output thread.

12. Example of Selection of Ball Screws

(1) Constant Speed Torque Exercised on the Motor Output Thread

This is the amount of torque required in the input shaft during acceleration.

\[
T_1 = \frac{2\pi \cdot N}{60} \cdot (J_1 + J_2 + J_3 + J_4 + J_5 + J_6) \times \frac{10^{-3}}{2\pi}
\]

(2) Acceleration Torque Exercised on the Motor Output Thread

This is the amount of torque required to drive the output shaft against the external load, at a constant speed.

\[
T_2 = \frac{2\pi \cdot N}{60} \cdot (J_1 + J_2 + J_3 + J_4 + J_5 + J_6) \times \frac{10^{-3}}{2\pi}
\]

(3) Deceleration Torque Exercised on the Motor Output Thread

This is the amount of torque required to drive the output shaft against the external load during deceleration.

\[
T_3 = \frac{2\pi \cdot N}{60} \cdot (J_1 + J_2 + J_3 + J_4 + J_5 + J_6) \times \frac{10^{-3}}{2\pi}
\]

13. Selection Result

5. Selection Result

From the above, it is determined that a suitable ball screw model is BSS1520-914.