1 Introduction

Ballscrews, also called a ball bearing screws, recirculating ballscrews, etc., consist of a screw spindle and a nut integrated with balls and the balls’ return mechanism, return tubes or return caps. Ballscrews are the most common type of screws used in industrial machinery and precision machines. The primary function of a ballscrew is to convert rotary motion to linear motion or torque to thrust, and vice versa, with the features of high accuracy, reversibility and efficiency. HIWIN provides a wide range of ballscrews to satisfy your special requirements.

The combination of state-of-the-art machining technology, manufacturing experiences, and engineering expertise makes HIWIN ballscrew users “High-Tech Winners”. HIWIN uses precise procedures to create exact groove profiles, either by grinding or precision rolling. Accurate heat treatment is also used to ensure the hardness of our ballscrews. These result in maximum load capacity and service life.

HIWIN precision ballscrews provide the most smooth and accurate movement, together with low drive torque, high stiffness and quiet motion with predictable lengthened service life. HIWIN rolled ballscrews also provide smooth movement and long life for general applications with less precision in lower price. HIWIN has modern facilities, highly skilled engineers, quality manufacturing and assembly processes, and uses quality materials to meet your special requirements.

It is our pleasure to provide you with the technical information and selection procedure to choose the right ballscrews for your applications through this catalogue.

2 Technological Features of HIWIN Ballscrews

2.1 Characteristics of HIWIN Ballscrews

There are many benefits in using HIWIN ballscrews, such as high efficiency and reversibility, backlash elimination, high stiffness, high lead accuracy, and many other advantages. Compared with the contact thread lead screws as shown in Fig. 2.1, a ballscrew add balls between the nut and spindle. The sliding friction of the conventional screws is thus replaced by the rolling motion of the balls. The basic characteristics and resultant benefits of HIWIN ballscrews are listed in more details as follows:

![Fig 2.1 Basic configuration of ballscrews and contact thread lead screws](www.zetek.ru)
[1] High efficiency and reversibility

Ball screws can reach an efficiency as high as 90% because of the rolling contact between the screw and the nut. Therefore, the torque requirement is approximately one third of that of conventional screws. It can be seen from Fig. 2.2 that the mechanical efficiency of ball screws are much higher than conventional lead screws.

HIWIN ball screws have super surface finish in the ball tracks which reduce the contact friction between the balls and the ball tracks. Through even contact and the rolling motion of the balls in the ball tracks, a low friction force is achieved and the efficiency of the ball screw is increased. High efficiency renders low drive torque during ball screw motion. Hence, less drive motor power is needed in operation resulting in lower operation cost.

HIWIN uses a series of test equipment and testing procedures to guarantee the efficiency.

![Fig 2.2 Mechanical efficiency of ball screws](image)

[2] Backlash elimination and high stiffness

Computer Numerically Controlled (CNC) machine tools require ball screws with zero axial backlash and minimal elastic deformation (high stiffness). Backlash is eliminated by our special designed Gothic arch form balltrack (Fig. 2.3) and preload.

In order to achieve high overall stiffness and repeatable positioning in CNC machines, preloading of the ball screws is commonly used. However, excessive preload increases friction torque in operation. This induced friction torque will generate heat and reduce the life expectancy. With our special design and fabrication process, we provide optimized ball screws with no backlash and less heat losses for your application.

![Fig 2.3 Typical contact types for ball screws](image)

[3] High lead accuracy

For applications where high accuracy is required, HIWIN modern facilities permit the achievement of ISO, JIS and DIN standards or specific customer requirements.

This accuracy is guaranteed by our precise laser measurement equipment and reported to each customer.

[4] Predictable life expectancy

Unlike the useful life of conventional screws which is governed by the wear on the contact surfaces, HIWIN’s ball screws can usually be used till the metal fatigue. By careful attention to design, quality of materials, heat treatment and manufacture, HIWIN’s ball screws have proved to be reliable and trouble free during the period of expected service.
life. The life achieved by any ballscrew depends upon several factors including design, quality, maintenance, and the major factor, dynamic axial load \([C]\).

Profile accuracy, material characteristics and the surface hardness are the basic factors which influence the dynamic axial load.

It is recommended that the life at average axial load should be a minimum of \(1 \times 10^6\) revs. High quality ballscrews are designed to conform with the B rating [i.e. 90% probability of achieving the design life]. Fifty percent of the ballscrews can exceed 2 to 4 times of the design life.

(5) Low starting torque and smooth running

Due to metal to metal contact, conventional contact thread lead screws require high starting force to overcome the starting friction. However, due to rolling ball contact, ballscrews need only a small starting force to overcome their starting friction.

HIWIN uses a special design factor in the balltrack (conformance factor) and manufacturing technique to achieve a true balltrack. This guarantees the required motor torque to stay in the specified torque range.

HIWIN has special balltrack profile tracing equipment to check each balltrack profile during the manufacturing process. A sample trace is shown in Fig. 2.4.

HIWIN also uses computer measurement equipment to accurately measure the friction torque of ballscrews. A typical distance-torque diagram is shown in Fig. 2.5.

![Balltrack checking by HIWIN profile tracer](image)

![HIWIN Ball Screw Torque Test Report](image)
[6] Quietness

High quality machine tools require low noise during fast feeding and heavy load conditions. HIWIN achieves this by virtue of its return system, balltrack designs, assembly technique, and careful control of surface finish and dimensions.

[7] Short lead time

HIWIN has a fast production line and can stock ballscrews to meet short lead times.

[8] Advantages over hydraulic and pneumatic actuators

The ballscrew used in an actuator to replace the traditional hydraulic or pneumatic actuator has many advantages, i.e. fast response, no leakage, no filtering, energy savings and good repeatability.

---

2.2 Applications for Ballscrews

HIWIN ballscrews are used in the following fields and the recommended application grade can be found in Table 4.5.

1. **CNC machinery**: CNC machine center, CNC lathe, CNC milling machine, CNC EDM, CNC grinder, wire cutting machine, boring machine, etc.

2. **Precision machine tools**: Milling machine, grinder, EDM, tool grinder, gear manufacturing machine, drilling machine, planer, etc.

3. **Industrial machinery**: Printing machine, paper-processing machine, automatic machine, textile machine, drawing machine, special purpose machine, injection molding machine, etc.

4. **Electronic machinery**: Robot measuring instrument, X-Y table, medical equipment, surface mounting device, semi-conductor equipment, factory automation equipment, etc.

5. **Transport machinery**: Material handling equipment, elevated actuator, etc.

6. **Aerospace industry**: Aircraft flaps, thrust open-close reverser, airport loading equipment, fin actuator, etc.

7. **Miscellaneous**: Antenna leg actuator, valve operator, etc.
3 Classification of Standard Ballscrews

3.1 Standard Ballscrew Spindle

HIWIN recommends our standard regular ballscrews for your design. However, high lead, miniature or other special types of ballscrews, may also be available upon your request. Table 3.1 shows the standard ballscrew spindles which are available.

3.2 Nut Configuration

The circuiting systems of nut of HIWIN ball screw can be divided into: external circuit, internal circuit, end caps, and Super S. For each circuiting way the features are as follows: external recirculation type, internal recirculation type, endcap recirculation type, and Super S. The features of these types are specified below.

3.2.1 Type of return tube design

(1) External recirculation type
   a. structure
   The first, called the external recirculation type ballscrew, consists of the screw shaft, the ball nut, the steel balls, the return tubes and the fixing plate. The steel balls are introduced into the space between the screw shaft and the ball nut. The balls are diverted from the ball tracks and carried back by the ball guide return tube form a loop. Since the return tubes are located outside the nut body, this type is called the external recirculation type ball screw Fig. 3.1.
   b. features
      (a) Adapted to wide kinds of shaft diameters and leads of ball screw
      (b) Complete specifications

(2) Internal recirculation type
   a. structure
   The second design, called the internal recirculation type ballscrew, consists of the screw spindle, the ball nut, the steel balls and the ball return caps. The steel balls make only one revolution around the screw spindle. The circuit is closed by a ball return cap in the nut allowing the balls to cross over adjacent ball tracks. Since the ball return caps are located inside the nut body, this is called the internal recirculation type ballscrew Fig. 3.2.
   b. features
      (a) Adapted to normal leads
      (b) Outer diameter of nut is small

(3) Endcap recirculation type
   a. structure
   The third design is called endcap recirculation type ball screw Fig. 3.3. The basic design of this return system is the same as the external recirculation type nut Fig. 3.5 except that the return tube is made inside the nut body as a through hole. The balls in this design traverse the whole circuit of the ball tracks within the nut length. Therefore, a short nut with the same load capacity as the conventional design can be used.
b. features
(a) Adapted to high lead
(b) Outer diameter of nut is middle
(c) Single nut only

(4) Super S
a. structure
The forth design is called Super S recirculation type ballscrew which consists of screw shaft, the ball nut, the steel balls and the cassette (Fig.3.4). The basic design of this return system is the same as the endcap recirculation type. Instead of using endcap, cassette is used in the recirculation. The balls in this design traverse the whole circuit of the ball tracks by passing through the cassette within the nut length.

b. features
(a) Quietness
(b) Compact and lightweight
(c) High acceleration and deceleration

(5) Super T
a. structure
The Super T Series recirculation path is connected in tangent, formed between the tunnel of the recirculation component and the screws raceway. This tangential recirculation path greatly reduces the drag force, resulting in smoother rotational motion of the ball nut to shaft and having the ballscrew being able to reach it’s maximum rotational speed.

b. features
(a) Smooth and high-speed motion
(b) Low noise
(c) Long service life

Table 3.1: The comparison chart of ball screw diameter vs lead and recirculation

| lead dia. | 1 | 1.5 | 2 | 2.5 | 3 | 3.175 | 4 | 4.23 | 5 | 5.08 | 6 | 6.35 | 8 | 10 | 12 | 12.7 | 15 | 16 | 20 | 24 | 25 | 25.4 | 28 | 30 | 32 | 35 | 36 | 40 | 50 | 60 | 64 | 80 |
|-----------|---|-----|---|-----|---|-------|---|------|---|------|---|------|---|-----|---|------|---|-----|---|-----|---|------|---|-----|---|------|---|-----|---|-----|---|-----|---|-----|---|-----|---|-----|---|
| 6         | I | I   | I | I   | I | I     |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |
| 8         | I | I   | I | I   | I | I     | I | I    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |   | H    |
| 18        | I | I   | I | I   | I | I     | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I |
| 20        | I | T   | T | I   | T | I     | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T |
| 22        | T | T   | T | T   | T | T     | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T |
| 24        | I | T   | T | I   | T | T     | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T |
| 25        | T | I   | I | I   | I | I     | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I |
| 26        | T | I   | I | I   | I | I     | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I | I    | I |
| 28        | I | T   | T | I   | T | I     | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T |
| 30        | T | T   | T | I   | T | I     | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T |
| 32        | I | T   | T | I   | T | I     | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T |
| 34        | T | T   | T | I   | T | I     | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T | T    | T |

Fig. 3.4 Cassette recirculation type nut with return system
[2] Type of nuts

The type of nuts to select depends on the application requirements. HIWIN standard nuts are classified by three letters as follows (see also Chapter 5 for details):

- **Flange Type (F)**
- **Round Type (R)**

```
<table>
<thead>
<tr>
<th>Flange Type</th>
<th>Round Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Nut (S)</td>
<td>Double-Nut (D)</td>
</tr>
<tr>
<td>External Return Tube</td>
<td>Internal Return Cap (I)</td>
</tr>
<tr>
<td>Super S (C)</td>
<td></td>
</tr>
</tbody>
</table>
```

* Other types of nut shape can also be made upon your design.
  - The special high-lead double-start nut is classified by adding D in front of the above three letters.
  - The compression preload nut is classified by adding P in front of the above three letters.
  - The offset pitch preload single nut is classified by adding O in front of the above letters.

Examples:
- RDI means round type, double nut with internal return caps.
- FSW means flange type, single nut with external return tube within the nut diameter.
- DFSV means two-start, flange, single nut with external return tube above the nut diameter.

[3] Number of circuits

The HIWIN nomenclature for the number of circuits in the ballnut is described as follows:

- **For the external type design:**
  - A : 1.5 turns per circuit
  - B : 2.5 turns per circuit
  - C : 3.5 turns per circuit
  - D : 4.5 turns per circuit
  - E : 5.5 turns per circuit

- **For the internal type design:**
  - T : 1.0 turn per circuit

- **For end cap type design:**
  - U : 2.8 turns per circuit (high lead)
  - S : 1.8 turns per circuit (super high lead)
  - V : 0.8 turns per circuit (extra high lead)
For Super S Series:
- K : 1 turn per circuit

Example:
- B2 : designates 2 external return tube ball circuits. Each circuit has 2.5 turns.
- T3 : designates 3 internal return ball circuits. Each circuit has a maximum of 1 turn.
- S4 : designates 4 internal return ball circuits. Each circuit has 1.8 turns.
- K5 : designates 5 internal return ball circuits. Each circuit has 1 turn.

HIWIN recommends that number of circuits for the external type design be 2 for 2.5 or 3.5 turns (that is, B2 or C2), and 3, 4 or 6 circuits for the internal type. Those shapes are shown in Fig. 3.5 and Fig. 3.6.

### 3.3 Spindle End and Journal Configuration

#### Mounting methods

Bearing mounting methods on the end journals of ballscrews are crucial for stiffness, critical speed and column buckling load. Careful consideration is required when designing the mounting method. The basic mounting configuration are shown as follows Fig. 3.9.

#### Spindle end journal configurations

The most popular journal configurations are shown in Fig. 3.10.

Table 3.2 lists the recommended dimensions and the bearings for the configurations of Fig. 3.10.

| Model | d1 | d5 | d6 | d7 | E | L3 | L4 | L5 | L6 | L7 | L8 | L9 | L10 | L11 | L12 | L13 | bt1 | Recommended Bearing |
|-------|----|----|----|----|---|----|----|----|----|----|----|----|-----|-----|-----|-----|---------------------|
| 10    | 10 | 8  | 7.6| M8x0.75 | 6 | 6  | 16 | 7  | 29 | 26 | 0.9 | 39 | 50 | 56 | 18 | 10 | 12 | 3.0x1.8 | DIN625          |
| 12    | 12 | 8  | 7.6| M8x0.75 | 6 | 6  | 16 | 7  | 29 | 26 | 0.9 | 39 | 50 | 56 | 18 | 10 | 12 | 3.0x1.8 | DIN625          |
| 14    | 14 | 10 | 9.6| M10x0.75| 8 | 8  | 20 | 9  | 37 | 34 | 1.15 | 45 | 54 | 62 | 20 | 10 | 14 | 3.0x1.8 | DIN625          |
| 16    | 16 | 12 | 11.5| M12x1 | 10 | 8  | 21 | 10 | 41 | 38 | 1.15 | 44 | 56 | 66 | 20 | 10 | 14 | 4.0x2.5 | DIN625          |
| 20    | 20 | 15 | 14.3| M15x1 | 12 | -  | 22 | 11 | 47 | 44 | 1.15 | 55 | 70 | 84 | 25 | 13 | 16 | 5.0x3.0 | DIN625          |
| 25    | 25 | 17 | 16.2| M17x1 | 15 | -  | 23 | 12 | 49 | 44 | 1.15 | 56 | 72 | 86 | 25 | 13 | 16 | 5.0x3.0 | DIN625          |
| 28    | 28 | 20 | 19  | M20x1 | 16 | -  | 26 | 14 | 58 | 54 | 1.35 | 68 | 82 | 100 | 28 | 20 | 18 | 6.0x3.5 | DIN625          |
| 32    | 32 | 25 | 23.9| M25x1.5 | 20 | -  | 27 | 15 | 64 | 60 | 1.35 | 79 | 94 | 116 | 36 | 22 | 26 | 7.0x4.0 | DIN625          |
| 36    | 36 | 25 | 23.9| M25x1.5 | 20 | -  | 27 | 15 | 64 | 60 | 1.35 | 79 | 94 | 116 | 36 | 22 | 26 | 7.0x4.0 | DIN625          |
| 40    | 40 | 30 | 28.6| M30x1.5 | 25 | -  | 28 | 16 | 68 | 64 | 1.65 | 86 | 102 | 126 | 42 | 22 | 32 | 8.0x4.0 | DIN625          |
| 45    | 45 | 35 | 33.3| M35x1.5 | 30 | -  | 29 | 17 | 80 | 76 | 1.65 | 97 | 114 | 148 | 50 | 24 | 40 | 10.0x5.0 | DIN625         |
| 50    | 50 | 40 | 38  | M40x1.5 | 35 | -  | 36 | 23 | 93 | 88 | 1.95 | 113 | 126 | 160 | 60 | 24 | 45 | 12.0x5.0 | DIN625         |
| 55    | 55 | 45 | 42.5| M45x1.5 | 40 | -  | 38 | 25 | 93 | 88 | 1.95 | 125 | 138 | 168 | 70 | 24 | 50 | 14.0x5.5 | DIN625         |
| 63    | 63 | 50 | 47  | M50x1.5 | 45 | -  | 33 | 27 | 102 | 97 | 2.2 | 140 | 153 | 188 | 80 | 27 | 60 | 14.0x5.5 | DIN625         |
| 70    | 70 | 55 | 52  | M55x2.0 | 50 | 10 | 46 | 29 | 118 | 113 | 2.2 | 154 | 167 | 212 | 90 | 27 | 70 | 16.0x6.0 | DIN625         |
| 80    | 80 | 65 | 62  | M65x2.0 | 60 | 10 | 49 | 33 | 132 | 126 | 2.7 | 171 | 184 | 234 | 100 | 30 | 80 | 18.0x7.0 | DIN625         |
| 100   | 100 | 75 | 72  | M75x2.0 | 70 | 10 | 53 | 37 | 140 | 134 | 2.7 | 195 | 208 | 258 | 120 | 30 | 90 | 20.0x7.5 | DIN625         |

For Super S Series:  
- K : 1 turn per circuit
- Example:
  - B2 : designates 2 external return tube ball circuits. Each circuit has 2.5 turns.
  - T3 : designates 3 internal return ball circuits. Each circuit has a maximum of 1 turn.
  - S4 : designates 4 internal return ball circuits. Each circuit has 1.8 turns.
  - K5 : designates 5 internal return ball circuits. Each circuit has 1 turn.

HIWIN recommends that number of circuits for the external type design be 2 for 2.5 or 3.5 turns (that is, B2 or C2), and 3, 4 or 6 circuits for the internal type. Those shapes are shown in Fig. 3.5 and Fig. 3.6.

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#### Spindle end journal configurations

The most popular journal configurations are shown in Fig. 3.10.

Table 3.2 lists the recommended dimensions and the bearings for the configurations of Fig. 3.10.

www.zetek.ru
A. Both ends fixed.

B. One end fixed other end supported.

C. Both ends supported.

D. One end fixed other end free.

Fig 3.9 Recommended mounting methods for the ballscrew end journals

Fig 3.10 Configurations of spindle ends
4.1 Fundamental Concepts for Selection & Installation

[1] A ballscrew must be thoroughly cleaned in white spirit and oil to protect against corrosion. Trichloroethylene is an acceptable degreasing agent, ensuring the ball track free from dirt and damage (paraffin is not satisfactory). Great care must be taken to ensure that the ball track is not struck by a sharp edged component or tool, and metallic debris does not enter the ball nut (Fig. 4.1).

[2] Select a suitable grade ballscrew for the application (ref. Table 4.5). Install with corresponding mounting disciplines. That is, precision ground ballscrews for CNC machine tools demand accurate alignment and precision bearing arrangement, where the rolled ballscrews for less precision applications, such as packaging machinery, require less precise support bearing arrangement.

It is especially important to eliminate misalignment between the bearing housing center and the ballnut center, which would result in unbalanced loads (Fig. 4.2). Unbalanced loads include radial loads and moment loads (Fig. 4.2a). These can cause malfunction and reduce service life (Fig. 4.2b).

---

Fig 4.1 Carefully clean and protect
Fig 4.2 Oil lubrication method.
Fig 4.3 Carefully protect the nut

---

Fig 4.2(a) Unbalance load caused by misalignment of the support bearings and nut brackets, inaccurate alignment of the guide surface, inaccurate angle or alignment of the nut mounting surface

---

Fig 4.2(b) The effect on service life of a radial load caused by misalignment
(3) To achieve the ballscrews’ maximum life, recommend the use of antifriction bearing oils. Oil with graphite and MoS₂ additives must not be used. The oil should be maintained over the balls and the balltracks.

(4) Oil mist bath or drip feeds are acceptable. However, direct application to the ball nut is recommended (Fig. 4.3).

(5) Select a suitable support bearing arrangement for the screw spindle. Angular contact ball bearings (angle=60°) are recommended for CNC machinery. Because of higher axial load capacity and ability to provide a clearance-free or preloaded assembly (Fig. 4.4).

(6) A dog stopper should be installed at the end to prevent the nut from over-travelling which results in damage to ballscrew assembly (Fig 4.5).

(7) In environments contaminated by dust or metallic debris, ballscrews should be protected using telescopic or bellow-type covers. The service life of a ballscrew will be reduced to about one-tenth normal condition if debris or chips enter the nut. The bellow type covers may need to have a threaded hole in the flange to fix the cover. Please contact engineers when special modifications are needed (Fig 4.6).

(8) If you select an internal recirculation type or an endcap recirculation type ballscrew, one end of the ball thread must be cut through to the end surface. The adjacent diameter on the end journal must be 0.5 ~ 1.0 mm less than the root diameter of the balltracks (Fig 4.7).

(9) After heat treating the ballscrew spindle, both ends of the balltracks adjacent to the journal have about 2 to 3 leads left soft, for the purpose of machining. These regions are shown in (Fig. 4.8) with the mark “○” on HIWIN drawings. Please contact engineers if special requirements are needed in these regions.

---

Fig 4.4 Different arrangement of ballscrew support bearings

Fig 4.5 A dog stopper to prevent the nut from over travelling

Fig 4.6 Ballscrew protection by telescopic or bellow type covers

Fig 4.7 Special arrangement for the end journal of an internal recirculation screw

Fig 4.8 The heat treatment range of the ballscrew spindle
(10) Excessive preload increases the friction torque and generates heat which reduces the life expectancy. But insufficient preload reduces stiffness and increases the possibility of lost motion. Recommends that the maximum preload used for CNC machine tools should not exceed 8% of the basic dynamic load C.

(11) When the nut needs to be disassembled from/assembled to the screw spindle, a tube with an outer dia. 0.2 to 0.4 mm less than the root diameter [ref. M37] of the balltracks should be used to release/connect the nut to/from to the screw spindle via one end of the screw spindle shown in Fig. 4.9.

(12) As shown in Fig 4.10, the support bearing must have a chamfer to allow it to seat properly and maintain proper alignment. HIWIN suggests the DIN 509 chamfer as the standard construction for this design [Fig. 4.11].
4.2 Ballscrews Selection Procedure

The selection procedure for ballscrews is shown in Table 4.1. From the known design operation condition, (A) select the appropriate parameter of ballscrew, (B) follow the selection procedure step by step via the reference formula, and (C) find the best ballscrew parameters which can be met for the design requirements.

Table 4.1 Ballscrew selection procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Design operation condition (A)</th>
<th>Ballscrew parameter (B)</th>
<th>Reference formula(C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Positioning accuracy</td>
<td>Lead accuracy</td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td>(1) Max. speed of DC motor (N_{\text{max}}) (2) Rapid feed rate (v_{\text{max}})</td>
<td>Ballscrew lead</td>
<td>( \epsilon \geq \frac{v_{\text{max}}}{N_{\text{max}}} )</td>
</tr>
<tr>
<td>Step 3</td>
<td>Total travel distance</td>
<td>Total thread length</td>
<td>Total length = thread length + journal end length</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thread length = stroke + nut length + 100 mm (unused thread)</td>
</tr>
<tr>
<td>Step 4</td>
<td>(1) Load condition [%] (2) Speed condition [%]</td>
<td>Mean axial load Mean speed</td>
<td>M7-M10</td>
</tr>
<tr>
<td>Step 5</td>
<td>Mean axial force (s1/5 C is the best)</td>
<td>Preload</td>
<td>M1</td>
</tr>
<tr>
<td>Step 6</td>
<td>(1) Service life expectancy (2) Mean axial load (3) Mean speed</td>
<td>Basic dynamic load</td>
<td>M13-M14</td>
</tr>
<tr>
<td>Step 7</td>
<td>(1) Basic dynamic load (2) Ballscrew lead (3) Critical speed (4) Speed limited by Dm-N value</td>
<td>Screw diameter and nut type (select some range)</td>
<td>M31-M33 and dimension table</td>
</tr>
<tr>
<td>Step 8</td>
<td>(1) Ballscrew diameter (2) Nut type (3) Preload (4) Dynamic load</td>
<td>Stiffness (check the best one via lost motion value)</td>
<td>M34-M40</td>
</tr>
<tr>
<td>Step 9</td>
<td>(1) Surrounding temperature (2) Ballscrew length</td>
<td>Thermal displacement and target value of cumulative lead (T)</td>
<td>M41 and 4.6 temperature rising effect</td>
</tr>
<tr>
<td>Step 10</td>
<td>(1) Stiffness of screw spindle (2) Thermal displacement</td>
<td>Pretension force</td>
<td>M45</td>
</tr>
<tr>
<td>Step 11</td>
<td>(1) Max. table speed (2) Max. rising time (3) Ballscrew specification</td>
<td>Motor drive torque and motor specification</td>
<td>M19-M28</td>
</tr>
</tbody>
</table>

4.3 Accuracy Grade of HIWIN Ballscrews

Precision ground ballscrews are used in applications requiring high positioning accuracy and repeatability, smooth movement and long service life. Ordinary rolled ballscrews are used for application grade less accurate but still requiring high efficiency and long service life. Precision grade rolled ballscrews have an accuracy between that of the ordinary grade rolled ballscrews and the higher grade precision ground ballscrews. They can be used to replace certain precision ground ballscrews with the same grade in many applications.

HIWIN makes precision grade rolled ball screw up to C6 grade. Geometric tolerances are different from those of precision ground screws (See Chapter 6). Since the outside diameter of the screw spindle is not ground, the set-up procedure for assembling precision rolled ballscrews into the machine is different from that of ground ones. Chapter 7 contains the entire description of rolled ballscrews.

(1) Accuracy grade

There are numerous applications for ballscrews from high precision grade ballscrews, used in precision measurement and aerospace equipment, to transport grade ballscrews used in packaging equipment. The quality and accuracy classifications are described as follows: lead deviation, surface roughness, geometrical tolerance, backlash, drag torque variation, heat generation and noise level.
HIWIN precision ground ballscrews are classified to 7 classes. In general, HIWIN precision grade ballscrews are defined by the so-called $V_{300p}$ value see Fig 4.12 and rolled grade ballscrews are defined differently as shown in Chapter 7.

Fig. 4.12 is the lead measuring chart according to the accuracy grade of the ballscrews. The same chart by the DIN system is illustrated in Fig. 4.13. From this diagram, the accuracy grade can be determined by selecting the suitable tolerance in Table 4.2. Fig. 4.14 shows HIWIN’s measurement result according to the DIN standard. Table 4.2 shows the accuracy grade of precision grade ballscrews in HIWIN’s specification. The relative international standard is shown in Table 4.3.

The positioning accuracy of machine tools is selected by $e_p$ value with the $V_{300p}$ variation. The recommended accuracy grade for machine applications is shown in Table 4.5. This is the reference chart for selecting the suitable ballscrews in different application fields.

(2) Axial play (Backlash)

If zero axial play ballscrews (no backlash) are needed, preload should be added and the preload drag torque is specified for testing purpose. The standard axial play of HIWIN ballscrews is shown in Table 4.4. For CNC machine tools, lost motion can occur in zero-backlash ballscrews through incorrect stiffness. Please consult our engineers when determining stiffness and backlash requirements.

(3) Geometrical tolerance

It is crucial to select the ballscrew of the correct grade to meet machinery requirements. Table 4.6 and Fig 4.15 are helpful for you to determine the tolerance factors, which are based on certain required accuracy grades.

Table 4.2 HIWIN accuracy grade of precision ballscrew

<table>
<thead>
<tr>
<th>Accuracy Grade</th>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{300p}$</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>$V_{300p}$</td>
<td>3.5</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>18</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 4.3 International standard of accuracy grade for ballscrews

<table>
<thead>
<tr>
<th>Grade</th>
<th>ISO, DIN</th>
<th>JIS</th>
<th>HIWIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{300p}$</td>
<td>6</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 4.4 Standard combination of grade and axial play

<table>
<thead>
<tr>
<th>Grade</th>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Play</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>
Table 4.5 Recommended accuracy grade for machine applications

<table>
<thead>
<tr>
<th>Application grade</th>
<th>AXIS</th>
<th>Accuracy grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Lathes</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>•</td>
</tr>
<tr>
<td>Milling machines</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td>Boring machines</td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>•</td>
</tr>
<tr>
<td>Machine Center</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>•</td>
</tr>
<tr>
<td>Jig borers</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>•</td>
</tr>
<tr>
<td>Drilling machines</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>•</td>
</tr>
<tr>
<td>Grinders</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td>EDM</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>•</td>
</tr>
<tr>
<td>Wire cut EDM</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>•</td>
</tr>
<tr>
<td>Laser Cutting Machine</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>•</td>
</tr>
<tr>
<td>Punching Press</td>
<td>X</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>•</td>
</tr>
<tr>
<td>Single Purpose Machines</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Wood working Machines</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Industrial Robot (Precision)</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Industrial Robot (General)</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Coordinate Measuring Machine</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Non-CNC Machine</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Transport Equipment</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>X-Y Table</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Linear Actuator</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Aircraft Landing Gear</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Airfoil Control</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Gate Valve</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Power steering</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Glass Grinder</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Surface Grinder</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Induction Hardening Machine</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Electromachine</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>All-electric injection molding machine</td>
<td></td>
<td>•</td>
</tr>
</tbody>
</table>
**Fig 4.12 HIWIN lead measuring curve of precision ball screw**

- \( T_p \): Target point of accumulated lead. This value is determined by customers' different application requirements.
- \( e_p \): Total reference lead deviation. Maximum deviation for accumulated reference lead line over the full length.
- \( V_{2\pi\pi} \): Single lead variation.
- \( e_a \): Real accumulated reference lead measured by laser system.
- \( V_u \): Total relative lead deviation. Maximum deviation of the real accumulated lead from the real accumulated reference lead in the corresponding range.
- \( V_{300p} \): Lead deviation over path of 300mm. The above deviation in random 300 mm within thread length.

- \( e_oa \): Average lead deviation over useful path \( L_u \). A straight line representing the tendency of the cumulative actual lead. This is obtained by the least square method and measured by the laser system. The value is added by path compensation over the useful path and the mean travel deviation.
- \( C \): Path compensation over useful path \( L_u \). Selection parameter: This value is determined by customer and maker as it depends on different application requirements.
- \( e_o \): Mean travel deviation.
- \( V_{us} \): Lead variation over useful path \( L_u \).
- \( V_{300u} \): Lead variation over path of 300 mm.
- \( V_{2\pi\pi} \): Lead variation over 1 rotation.

**Fig 4.13 DIN lead measuring curve of precision ball screw**
**Fig 4.14** Lead accuracy measuring chart from dynamic laser measurement equipment according to DIN 69051 standard

- $e_{oa}(Ea)$: Lead deviation over useful thread length relative to the nominal deviation. (This measurement is made according to DIN standard 69051-3-1).
  
  $C(T) - e_{oa}(Ep) \leq e_{oa}(Ea) \leq C(T) + e_{oa}(Ep)$

- $V_{ua}(ea)$: Total relative lead variation over useful thread length. (This measurement is made according to DIN standard 69051-3-2).
  
  $V_{ua}(ea) \leq V_{up}(ep)$

- $V_{300a}(e_{300a})$: Relative lead variation in random 300mm length within thread length. (This measurement is made according to DIN standard 69051-3-3).
  
  $V_{300a}(e_{300a}) \leq V_{300p}(e_{300p})$

- $V_{2\pi}(e_{2\pi})$: Single lead variation over 2p. (This measurement is made according to DIN standard 69051-3-4).
  
  $V_{2\pi}(e_{2\pi}) \leq V_{2\pi p}(e_{2\pi p})$

**Fig 4.15** Geometrical tolerance of HIWIN precision ground ballscrew

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Table 4.6 Tolerance table and measurement method for HIWIN precision ballscrews

### T1: True running deviation of external diameter relative to AA' (This measurement is made according to DIN 69051 and JIS B1192)

<table>
<thead>
<tr>
<th>Nominal Diameter do (mm)</th>
<th>Reference length Lt/do</th>
<th>T1P [μm] for HIWIN tolerance class above up to Lt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>80</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
<td>160</td>
</tr>
<tr>
<td>25</td>
<td>50</td>
<td>315</td>
</tr>
<tr>
<td>50</td>
<td>100</td>
<td>630</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>1250</td>
</tr>
</tbody>
</table>

### T2: Run out deviation of bearing relative to AA' (This measurement is made according to DIN 69051 and JIS B1192)

<table>
<thead>
<tr>
<th>Nominal Diameter do (mm)</th>
<th>Reference length Lr</th>
<th>T2P [μm] for HIWIN tolerance class above up to Lr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>125</td>
</tr>
<tr>
<td>50</td>
<td>125</td>
<td>200</td>
</tr>
<tr>
<td>125</td>
<td>200</td>
<td>315</td>
</tr>
</tbody>
</table>

if \( L_{r1} > L_{r2} \), then \( T_{2a} \leq T_{2p} \)

### T3: Coaxial deviation relative to AA' (This measurement is made according to DIN 69051 and JIS B1192)

<table>
<thead>
<tr>
<th>Nominal Diameter do (mm)</th>
<th>Reference length Lr</th>
<th>T3P [μm] for HIWIN tolerance class above up to Lr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>125</td>
</tr>
<tr>
<td>50</td>
<td>125</td>
<td>200</td>
</tr>
<tr>
<td>125</td>
<td>200</td>
<td>315</td>
</tr>
</tbody>
</table>

if \( L_{r1} > L_{r2} \), then \( T_{3a} \leq T_{3p} \)
Table 4.6 Tolerance table and measurement method for HIWIN precision ballscrews

**T4**: Run-out deviation of bearing end shoulder relative to AA’ [This measurement is made according to DIN 69051 and JIS B1192]

<table>
<thead>
<tr>
<th>Nominal Diameter do (mm)</th>
<th>T4P [μm] for HIWIN tolerance class</th>
</tr>
</thead>
<tbody>
<tr>
<td>above up to</td>
<td>0  1  2  3  4  5  6  7</td>
</tr>
<tr>
<td>6</td>
<td>3  3  3  4  4  5  6  6</td>
</tr>
<tr>
<td>63</td>
<td>3  4  4  5  6  7  7  7</td>
</tr>
<tr>
<td>125</td>
<td>-  -  -  -  -  6  8  8</td>
</tr>
</tbody>
</table>

**T5**: Face running deviation of locating face [only for nut] relative to BB’ [This measurement is made according to DIN 69051 and JIS B1192]

<table>
<thead>
<tr>
<th>Nut Flange Diameter Df (mm)</th>
<th>T5P [μm] for HIWIN tolerance class</th>
</tr>
</thead>
<tbody>
<tr>
<td>above up to</td>
<td>0  1  2  3  4  5  6  7</td>
</tr>
<tr>
<td>20</td>
<td>5  6  7  8  9  10 12 14</td>
</tr>
<tr>
<td>32</td>
<td>5  6  7  8  9  10 12 14</td>
</tr>
<tr>
<td>50</td>
<td>6  7  8  9  10 12 13 16</td>
</tr>
<tr>
<td>80</td>
<td>7  9  10 12 14 15 16 18</td>
</tr>
<tr>
<td>125</td>
<td>8  10 11 13 15 17 19 20</td>
</tr>
<tr>
<td>160</td>
<td>10 11 13 15 17 22 25 30</td>
</tr>
<tr>
<td>200</td>
<td>12 14 15 18 20 25 30</td>
</tr>
</tbody>
</table>

**T6**: Run-out deviation of external diameter [only for nut] relative to BB’ [This measurement is made according to DIN 69051 and JIS B1192]

<table>
<thead>
<tr>
<th>Nut Diameter Diameter D (mm)</th>
<th>T6P [μm] for HIWIN tolerance class</th>
</tr>
</thead>
<tbody>
<tr>
<td>above up to</td>
<td>0  1  2  3  4  5  6  7</td>
</tr>
<tr>
<td>20</td>
<td>5  6  7  9  10 12 16 20</td>
</tr>
<tr>
<td>32</td>
<td>6  7  8  10 11 12 16 20</td>
</tr>
<tr>
<td>50</td>
<td>7  8  10 12 14 15 17 20</td>
</tr>
<tr>
<td>80</td>
<td>8  10 12 15 17 19 25 30</td>
</tr>
<tr>
<td>125</td>
<td>9  12 16 20 24 22 25 40</td>
</tr>
<tr>
<td>160</td>
<td>10 13 17 22 25 28 32 40</td>
</tr>
<tr>
<td>200</td>
<td>12 16 20 22 25 28 32 40</td>
</tr>
</tbody>
</table>

**T7**: Deviation of parallelism [only for nut] relative to BB’ [This measurement is made according to DIN 69051 and JIS B1192]

<table>
<thead>
<tr>
<th>Mounting basic length (mm) Lr</th>
<th>T7P [μm] / 100mm for HIWIN tolerance class</th>
</tr>
</thead>
<tbody>
<tr>
<td>above up to</td>
<td>0  1  2  3  4  5  6  7</td>
</tr>
<tr>
<td>50</td>
<td>5  6  7  8  9  10 14 17</td>
</tr>
<tr>
<td>100</td>
<td>7  8  9  10 12 13 15 17</td>
</tr>
<tr>
<td>200</td>
<td>7  10 10 11 13 17 24 30</td>
</tr>
</tbody>
</table>
4.4 Preload Methods

The specially designed Gothic ball track can make the ball contact angle around 45°. The axial force \( F_a \) which comes from an outside drive force or inside preload force, causes two kinds of backlash. One is the normal backlash, \( S_a \) caused by the manufacturing clearance between ball track and ball. The other is the deflection backlash, \( \Delta l \) caused by the normal force \( F_n \) which is perpendicular to the contact point.

The clearance backlash can be eliminated by the use of an preload internal force \( P \). This preload can be obtained via a double nut, an offset pitch single nut, or by adjusting the ball size for preloaded single nuts.

The deflection backlash is caused by the preload internal force and the external loading force and is related to that of the effect of lost motion.

(1) Double nut preloading

Preload is obtained by inserting a spacer between the 2 nuts [Fig. 4.17]. "Tension preload" is created by inserting an oversize spacer and effectively pushing the nuts apart. "Compression pre-load" is created by inserting an undersize spacer and correspondingly pulling nuts together. Tension preload is primarily used for precision ballscrews. However, compression preload type ballscrews are also available upon your request. If pretension is necessary to increase stiffness, please contact us for the amount of pretension to be used in the ballscrew journal ends. \( 0.02\text{mm} \) to \( 0.03\text{mm} \) per meter is recommended, but the \( T \) value should be selected according to the compensation purpose.

(2) Single nut preloading

There are two ways of preloading a single nut. One is called "the oversized-ball preloading method". The method is to insert balls slightly larger than the ball groove space (oversized balls) to allow balls to contact at four points [Fig. 4.18].

The other way is called "The offset pitch preloading method" as shown in Fig. 4.19. The nut is ground to have a \( \delta \) value offset on the center pitch. This method is used to replace the traditional double nut preloading method and has the benefit of a compact single nut with high stiffness via small preload force. However, it should not be used in heavy duty preloading. The best preload force is below 5% of dynamic load \( C \).
# 3 Preload calculation

\[ p = \frac{F_{\text{mean}}}{2.8} \]

- \( p \): preload force (kgf)
- \( F_{\text{mean}} \): Mean operating load (kgf)

(Ref. M8–M10)

\[ T_d = \frac{K_p \times P \times \ell}{2\pi} \]

Preload drag torque (Fig. 4.20)

- \( T_d \): preload drag torque (kgf-mm)
- \( P \): preload (kgf)
- \( \ell \): lead (mm)
- \( K_p \): preload torque coefficient

\[ K_p = 0.05 \tan \alpha \]

\( \eta_1, \eta_2 \) are the mechanical efficiencies of the ballscrew.

## (1) For common transmission (to convert rotary motion to linear motion)

\[ \eta_1 = \frac{\tan(\alpha)}{\tan(\alpha + \beta)} = \frac{1 - \mu \tan \alpha}{1 + \mu \tan \alpha} \]

## (2) For reverse transmission (to convert linear rotary motion to rotary motion)

\[ \eta_2 = \frac{\tan(\alpha - \beta)}{\tan(\alpha)} = \frac{1 - \mu / \tan \alpha}{1 + \mu / \tan \alpha} \]

\[ \alpha = \tan^{-1} \frac{\ell}{\pi D_m} \]

\[ \beta = \tan^{-1} \mu \]

- \( \alpha \): lead angle (degrees)
- \( D_m \): pitch circle diameter of screw shaft (mm)
- \( \ell \): lead (mm)
- \( \beta \): friction angle (0.17°~0.57°)
- \( \mu \): friction coefficient (0.003~0.01)

## (4) Uniformity of preload drag torque

### (1) Measuring method

Preload creates drag torque between the nut and screw. It is measured by rotating the screw spindle at constant speed while restraining the nut with a special fixture as shown in Fig. 4.20. The load cell reading force \( F_p \) is used to calculate the preload drag torque of the ballscrew.

HIWIN has developed a computerized drag torque measuring machine which can accurately monitor the drag torque during screw rotation. Therefore, the drag torque can be adjusted to meet customer requirements (Fig. 2.5). The measurement standard for preload drag torque is shown in Fig. 4.21 and Table 4.7.

### (2) Measuring conditions

1. Without wiper.
2. The rotating speed, 100 rpm.
3. The dynamic viscosity of lubricant, 61.2 ~74.8 cSt (mm/s) 40°C, that is, ISO VG 68 or JIS K2001.
4. The return tube up.

### (3) The measurement result is illustrated by the standard drag torque chart. Its nomenclature is shown in Fig. 4.21.

### (4) The allowable preload drag torque variation as a function of accuracy grade is shown in Table 4.7.
Table 4.7: Variation range for preload drag torque (According to JIS B1192)

<table>
<thead>
<tr>
<th>Slender ratio ≤ 40</th>
<th>40 &lt; Slender ratio &lt; 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy grade</td>
<td>Accuracy grade</td>
</tr>
<tr>
<td>Above Up To</td>
<td>0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7</td>
</tr>
<tr>
<td></td>
<td>2 4 6 8 10 12 14 16 18 20 22 24 26 28 30</td>
</tr>
<tr>
<td></td>
<td>4 6 8 10 12 14 16 18 20 22 24 26 28 30 32</td>
</tr>
<tr>
<td></td>
<td>6 8 10 12 14 16 18 20 22 24 26 28 30 32 34</td>
</tr>
<tr>
<td></td>
<td>10 12 14 16 18 20 22 24 26 28 30 32 34 36 38</td>
</tr>
<tr>
<td></td>
<td>25 30 35 40 45 50 55 60 65 70 75 80 85 90 95</td>
</tr>
<tr>
<td></td>
<td>63 85 100 125 150 175 200 225 250 275 300 325 350 375 400</td>
</tr>
</tbody>
</table>

Note:
1. Slender ratio = Thread length of spindle / Nominal spindle O.D. (mm)
2. Refer to the designing section of the manual to determine the basic preload drag torque.
3. Table 4.9 shows the conversion table for Nm.
4. For more information, please contact our engineering department.

4.5 Calculation Formulas

Service life

- The average number of rpm, \( n_u \)

\[
n_u = n_1 \times \frac{t_1}{100} + n_2 \times \frac{t_2}{100} + n_3 \times \frac{t_3}{100} + \ldots
\]

\( n_u \): average speed (rpm)
\( n \): speed (rpm)
\( t_1 \): % of time at speed \( n_1 \), etc.
• The average operating load $F_{bm}$

(1) With variable load and constant speed

$$F_{bm} = \sqrt{\left(F_{b1} \times \frac{t_1}{100} \times f_{p1}^3 + F_{b2} \times \frac{t_2}{100} \times f_{p2}^3 + F_{b3} \times \frac{t_3}{100} \times f_{p3}^3 \right)^2} \quad \text{M8}$$

$F_{bm}$: average operating load (kgf); $F_b$: working axial load

$f_{p}$: operation condition factor

- $1.1 \sim 1.2$ when running without impact
- $1.3 \sim 1.8$ when running in the normal condition
- $2.0 \sim 3.0$ when running with heavy impact and vibration

(2) With variable load and variable speed

$$F_{bm} = \sqrt{\left(F_{b1} \times \frac{n_1}{n_{av}} \times \frac{t_1}{100} \times f_{p1}^3 + F_{b2} \times \frac{n_2}{n_{av}} \times \frac{t_2}{100} \times f_{p2}^3 + F_{b3} \times \frac{n_3}{n_{av}} \times \frac{t_3}{100} \times f_{p3}^3 \right)^2} \quad \text{M9}$$

(3) With linear variable load and constant speed

$$F_{bm} = \frac{F_{b_{min}} \times f_{p} + 2 \times F_{b_{max}} \times f_{p}^2}{3} \quad \text{M10}$$

**Example 4.5 - 1**

A HIWIN ballscrew is subjected to the following operating conditions. Calculate the average running speed and operating load.

**Operating Condition:**

- For smooth running without impact $f_p = 1.1$

<table>
<thead>
<tr>
<th>Condition</th>
<th>Axial load [kgf]</th>
<th>Revolution [rpm]</th>
<th>Loading time ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>1000</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td>800</td>
<td>100</td>
<td>20</td>
</tr>
</tbody>
</table>

Calculation

$$n_{av} = 1000 \times \frac{45}{100} + 50 \times \frac{35}{100} + 100 \times \frac{20}{100} = 487.5 \text{rpm} \quad \text{[ref.M7]}$$

$$F_{bm} = \sqrt{\left(100^3 \times \frac{1000}{487.5} \times 45 \times 487.5 \times 1.1^3 + 100^3 \times \frac{50}{487.5} \times \frac{35}{100} \times 1.1^3 + 800^3 \times \frac{100}{487.5} \times \frac{20}{100} \times 1.1^3 \right)^2} = 318.5 \text{ kgf}$$

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The resultant axial force, $F_a$

For a single nut without preload
\[ F_a = F_{bm} \]  

For a single nut with preload $P$
\[ F_a \leq F_{bm} + P \]

Expected service life

For single nut
- Service life represented in revolutions :
\[ L = \left( \frac{C}{F_a} \right)^3 \times 10^6 \]

$L$: Service life in running revolution (revolutions)

$C$: dynamic load rating (kgf) ($10^6$ rev)

For symmetrical preload double nut arrangement

(a) Service life represented in revolutions :
\[ F_{bm} (1) = P \left( 1 + \frac{F_{bm}}{3P} \right)^{1/2} \]
\[ L (1) = \left( \frac{C}{F_{bm} (1)} \right)^3 \times 10^6 \]
\[ F_{bm} (2) = F_{bm} (1) - F_{bw} \]
\[ L (2) = \left( \frac{C}{F_{bw} (2)} \right)^3 \times 10^6 \]
\[ L = \left[ L(1)^{10/9} + L(2)^{10/9} \right]^{9/10} \]

$L$: Service life in running revolution (revolutions)

$P$: Preload force (kgf)

(b) conversion from revolutions to hours :
\[ L_h = \frac{L}{n_{av} \times 60} \]

$L_h$: Service life in hours (hours)

$n_{av}$: Average speed (rpm, Ref. M7)

(c) Conversion from travel distance to hours:
\[ L_h = \left( \frac{L_d \times 10^6}{l} \right) \times \frac{1}{n_{av} \times 60} \]

$L_h$: Running life (in hours)

$L_d$: Running life (in distance, Km)

$l$: Ballscrew lead (mm per rev)

$n_{av}$: Average running speed (rpm)
(d) The modified service life for different reliability factors is calculated by

\[ L_m = L \times f_r \]

\[ L_{hm} = L_h \times f_r \]

with the reliability factor \( f_r \) (Table 4.8)

Table 4.8 Reliability factor for service life

<table>
<thead>
<tr>
<th>Reliability %</th>
<th>( f_r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1</td>
</tr>
<tr>
<td>95</td>
<td>0.63</td>
</tr>
<tr>
<td>96</td>
<td>0.53</td>
</tr>
<tr>
<td>97</td>
<td>0.44</td>
</tr>
<tr>
<td>98</td>
<td>0.33</td>
</tr>
<tr>
<td>99</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Example 4.5 - 2

By the example 4.5-1, if the design service life of the ballscrew is 3500 hours, lead = 10 mm, single nut with zero backlash, find the nominal diameter of the HIWIN ballscrew.

Calculation

\[ P = \frac{F_{bm}}{2.8} = \frac{318.5}{2.8} = 114 \text{ kgf} \] (Assume zero backlash when \( F_{bm} = 318.5 \text{ kgf} \))

\[ F_a = F_{bm} + P = 318.5 + 114 = 432.5 \text{ kgf} \] (Ref formula M1)

\[ L = L_h \times n_a \times 60 = 3500 \times 487.5 \times 60 = 1.02375 \times 10^8 \] (revolutions)

\[ C' = F_a \left( \frac{L}{10^6} \right)^{1/3} = 432.5 \times \left( \frac{1.02375 \times 10^8}{10^6} \right)^{1/3} = 2023 \text{ kgf} \]

\( C' \leq \text{rating} \)

So, from the dimensions table of HIWIN ballscrews, select FSV type nut with spindle nominal diameters equals 32 mm and C1 circuits which can satisfy this application.

Example 4.5 - 3

If the ballscrew nominal diameter = 50 mm, lead = 8 mm, and service life \( L = 7 \times 10^6 \) revolutions, find the permissible load on the screw spindle.

Calculation

From the dimensions table of HIWIN ballscrew, the FSV type ballscrew with nominal diameter = 50 mm, lead = 8 mm and B3 type return tube has the dynamic load rating \( C = 5674 \).

\[ F_a = C \div \left( \frac{L}{10^6} \right)^{1/3} = 5674 \div \left( \frac{7 \times 10^6}{10^6} \right)^{1/3} = 2966 \text{ kgf} \]

Drive torque and drive power for the motor

Fig 4.23 Load operation by ballscrew
Fig. 4.23 shows the terms for a feed system operated by ballscrew. The formula for motor drive torque is given below:

(a) Common transmission (to convert rotary motion to linear motion)

\[ T_a = \frac{F_b \times \ell}{2\pi \eta_1} \]

- \( T_a \) = Drive torque for common transmission (kgf-mm)
- \( F_b \) = Axial load (kgf)
- \( F_b = F_{bm} + \mu \times W \) (for horizontal motion)
- \( \ell \) = Lead (mm)
- \( \eta_1 \) = Mechanical efficiency (0.9~0.95, Ref. M3)
- \( W \) = Table weight + Work piece weight (kgf)
- \( \mu \) = Friction coefficient of table guide way

(b) Reverse transmission (to convert linear motion to rotary motion)

\[ T_c = \frac{F_b \times \ell \times \eta_2}{2\pi} \]

- \( \eta_2 \) = Mechanical efficiency (0.9~0.95, Ref. M4)
- \( T_c \) = Torque for reverse transmission (kgf-mm)

(c) Motor drive torque

For normal operation:

\[ T_m = (T_a + T_b + T_d) \times \frac{N_1}{N_2} \]

- \( T_m \) = Motor drive torque (kgf-mm)
- \( T_b \) = Friction torque of supporting bearing (kgf-mm)
- \( T_d \) = Preload drag torque (kgf-mm, Ref. M2)
- \( N_1 \) = Number of teeth for driver gear
- \( N_2 \) = Number of teeth for driven gear

For acceleration operation:

\[ T'a = J\alpha \]

- \( T'a \) = Motor drive torque during acceleration (kgf)
- \( J \) = System inertia (kgf-mm-sec²)
- \( \alpha \) = Angular acceleration (rad/sec²)

\[ \alpha = \frac{2\pi N_{adi}}{60t_a} \]

- \( N_{adi} \) = \( rpm_{stage2} \) - \( rpm_{stage1} \)
- \( t_a \) = acceleration rising time (sec)

\[ J = J_m + J_{adi} + J_{d2} \left( \frac{N_1}{N_2} \right)^2 + \frac{1}{2 g} W \left( \frac{D_o}{2} \right)^2 \left( \frac{N_1}{N_2} \right)^2 + \frac{W}{g} \left( \frac{\ell}{2\pi} \right)^2 \left( \frac{N_1}{N_2} \right)^2 \]

- \( W_s \) = Ballscrew weight (kgf)
- \( D_o \) = Ballscrew nominal diameter (mm)
- \( g \) = Gravity coefficient (9800 mm/sec²)
- \( J_m \) = Inertia of motor (kgf-mm-sec²)
- \( J_{adi} \) = Inertia of driver gear (kgf-mm-sec²)
- \( J_{d2} \) = Inertia of driver gear (kgf-mm-sec²)
Total operating torque:

\[ T_{Mo} = T_M + T'a \]

\[ T_{Mo} = \text{Total operating torque (kgf)} \]

The inertia of a disc is calculated as following:

For disc with concentric O.D.

\[ J = \frac{1}{2g} \pi \rho_d R^4 L \]

\[ J : \text{Disc inertia (kgf} \cdot \text{mm} \cdot \text{sec}^2) \]
\[ \rho_d : \text{Disc specific weight (7.8 \times 10^{-6} \text{ kgf/mm}^3) for steel} \]
\[ R : \text{Disc radius (mm)} \]
\[ L : \text{Disc length (mm)} \]
\[ g : \text{Gravity coefficient (9800 mm/sec}^2) \]

\[ \text{[d] Drive power} \]

\[ P_d = \frac{T_{pmax} \times N_{max}}{974} \]

\[ P_d : \text{Maximum drive power (watt) safety} \]
\[ T_{pmax} : \text{Maximum drive torque (safety factor} \times T_{ma}, \text{kgf-mm) } \]
\[ T_{max} : \text{Maximum rotation speed (rpm)} \]

\[ \text{[e] Check the acceleration time} \]

\[ t_a = \frac{J}{T_{Mo} - TL} \times \frac{2\pi N_{max}}{60} \cdot f \]

\[ t_a : \text{Acceleration rising time} \]
\[ J : \text{Total inertia moment} \]
\[ T_{Mo} = 2 \times T_{mr} \]
\[ T_{Mr} : \text{Motor rated torque} \]
\[ TL : \text{Drive torque at rated feed} \]
\[ f : \text{Safety factor} = 1.5 \]

Table 4.9: Shows the conversion relationship of different measurement units for the motor torque or preload drag torque.

<table>
<thead>
<tr>
<th>kgf - cm</th>
<th>kgf - mm</th>
<th>Nm</th>
<th>kpm ( kgf - m )</th>
<th>OZ - in</th>
<th>ft - l bf</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>9.8x10^{-2}</td>
<td>10^{-2}</td>
<td>13.8874</td>
<td>7.23301x10^{-2}</td>
</tr>
<tr>
<td>0.1</td>
<td>1</td>
<td>9.8x10^{-3}</td>
<td>1.0x10^{-3}</td>
<td>1.38874</td>
<td>7.23301x10^{-3}</td>
</tr>
<tr>
<td>10.19716</td>
<td>1.019716x10^2</td>
<td>1</td>
<td>0.1019716</td>
<td>1.41612x10^2</td>
<td>0.737562</td>
</tr>
<tr>
<td>10^2</td>
<td>10^2</td>
<td>9.80665</td>
<td>1</td>
<td>1.38874x10^3</td>
<td>7.23301</td>
</tr>
<tr>
<td>7.20077x10^{-2}</td>
<td>0.720077</td>
<td>7.06155x10^{-3}</td>
<td>7.20077x10^{-4}</td>
<td>1</td>
<td>5.20833x10^{-1}</td>
</tr>
<tr>
<td>13.82548</td>
<td>1.382548x10^3</td>
<td>1.35582</td>
<td>0.1382548</td>
<td>1.92x10^2</td>
<td>1</td>
</tr>
</tbody>
</table>

Example 4.5 - 4

Consider the machining process driven by the motor and ballscrew as Fig. 4.24.

Table weight \( W_1 = 200 \text{ kgf} \)

Work weight \( W_2 = 100 \text{ kgf} \)

Friction coefficient of slider \( \mu = 0.02 \)
Operating condition: Smooth running without impact

<table>
<thead>
<tr>
<th>Axial feed force (kgf)</th>
<th>Revolution (rpm)</th>
<th>Loading time ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>500</td>
<td>20</td>
</tr>
<tr>
<td>300</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>500</td>
<td>50</td>
<td>30</td>
</tr>
</tbody>
</table>

Acceleration speed: 100 rad/sec²
Motor Condition: Motor diameter: 50 mm, Motor length: 200 mm,
Gear condition:
- Driver gear diameter G1: 80 mm, Thickness: 20 mm, Teeth: 30
- Driven gear diameter G2: 240 mm, Thickness: 20 mm, Teeth: 90
Ballscrew condition:
- Nominal diameter: 50 mm, Pitch: 10 mm
- Length: 1200 mm, Weight: 18 kgf
No backlash when axial feed force = 300 kgf
Bearing torque $T_b = 10$ kgf-mm
Mechanical efficiency $\eta_1 = 0.80$

![Fig 4.24 Milling process in the machine](www.zetek.ru)

Calculation

1) Motor drive torque in normal rating condition:

$$n_{av} = 500 \times \frac{20}{100} + 100 \times \frac{20}{100} + 50 \times \frac{20}{100} = 165 \text{ rpm} \quad \text{(Ref. M7)}$$

$$F_1 = 100, \ F_2 = 300, \ F_3 = 500$$

$$F_{bew} = \sqrt{100^3 \times 1 \times \frac{20}{100} + 500^3 \times 1 \times \frac{20}{100} + 300^3 \times 1 \times \frac{20}{100}} = 272 \text{ kgf} \quad \text{(Ref. M9)}$$

$$P = \frac{300}{2.8} \approx 110 \text{ kgf} \quad \text{(axial feed force = 300 kgf, Ref. M1)}$$

$$F_b = F_{bew} + \mu W = 270 + (200 + 100) \times \frac{0.02}{2} = 278 \text{ kgf}$$

$$T_e = \frac{F_e \times L}{2\pi \eta_1} = \frac{278 \times \frac{10}{2}}{2\pi \times 0.80} = 553 \text{ kgf} \cdot \text{mm} \quad \text{(Ref. M19)}$$

$$T_o = 0.2 \times \frac{P \times L}{2\pi} = \frac{0.2 \times 110 \times \frac{10}{2}}{2\pi} = 35 \text{ kgf} \cdot \text{mm} \quad \text{(Ref. M2)}$$

$$T_M = (T_e + T_b + T_o) \times \frac{N_1}{N_2} = (535 + 10 + 35) \times \frac{30}{90} = 199 \text{ kgf} \cdot \text{mm} \quad \text{(Ref. M21)}$$
(2) Motor torque in acceleration operation:

(I) Inertia of motor

\[ J_M = \frac{1}{2} \times 9800 \times \pi \times 7.8 \times 10^{-6} \times (25)^4 \times 200 = 0.1 \text{ kgf} \cdot \text{mm} \cdot \text{sec}^2 \]

(II) Inertia of gear

\[ J_{\text{Gear(eq)}} = J_{G1} + J_{G2} \times \frac{N_1}{N_2} \]

\[ J_{G1} = \frac{1}{2} \times 9800 \times \pi \times 7.8 \times 10^{-6} \times \frac{80}{2}^4 \times 20 = 0.064 \text{ kgf} \cdot \text{mm} \cdot \text{sec}^2 \]

\[ J_{G2} = \frac{1}{2} \times 9800 \times \pi \times 7.8 \times 10^{-6} \times \frac{240}{2}^4 \times 20 = 5.18 \text{ kgf} \cdot \text{mm} \cdot \text{sec}^2 \]

\[ J_{\text{Gear(eq)}} = 0.064 + 5.18 \times \left( \frac{30}{90} \right)^2 = 0.640 \text{ kgf} \cdot \text{mm} \cdot \text{sec}^2 \]

(III) Inertia of ballscrew

\[ J_{\text{ballscrew}} = \frac{1}{2} \times 9800 \times 18 \times \left( \frac{50}{2} \right)^2 \left( \frac{30}{90} \right)^2 = 0.064 \text{ kgf} \cdot \text{mm} \cdot \text{sec}^2 \]

(IV) Inertia of load

\[ J_{\text{load}} = \frac{300}{9800} \times \left( \frac{10}{2 \times \pi} \right)^2 \left( \frac{30}{90} \right)^2 = 0.009 \text{ kgf} \cdot \text{mm} \cdot \text{sec}^2 \]

(V) Total inertia

\[ J = 0.1 + 0.64 + 0.064 + 0.009 = 0.813 \text{ kgf} \cdot \text{mm} \cdot \text{sec}^2 \]

(3) Total motor torque:

\[ T'_a = J \cdot \alpha = 0.813 \times 100 = 81.3 \text{ kgf} \cdot \text{mm} \]

\[ T_{\text{ma}} = T_M + T'_a = 199 + 81.3 = 280 \text{ kgf} \cdot \text{mm} \]

(4) Drive power:

\[ T_{p_{\text{max}}} = 2 \times 280 = 560 \text{ kgf} \cdot \text{mm} \] (safety factor = 2)

\[ P_d = \frac{560 \times 1500}{974} = 862 \text{ W} = 1.16 \text{ Hp} \]

(5) Selection motor:

Select the DC motor rated torque : \( T_{M_r} > 1.5T_M \), and maximum motor torque : \( T_{\text{Max}} > 1.5T_{\text{ma}} \)

Thus the DC servo motor with following specification can be chosen.

- Rated output : 950 w
- Rated torque : 30 kgf-cm [300 kgf • mm]
- Rated rotational speed : 2000 rpm
- Maximum torque : 65 kgf x cm [650 kgf • mm]
- Moment of inertia of motor : 0.20 kgf • mm • sec^2

(6) Check the acceleration time:

\[ T_s = \left( \frac{F_s \times t}{2\pi \eta_i} + T_s + T_s \right) \left( \frac{N_i}{N_f} \right) \]

\[ T_s = \left( \frac{100 \times 10 + 10 + 35}{2\pi \times 0.8} \times \frac{30}{90} \right) = 81.3 \text{ kgf} \cdot \text{mm} \]

\[ t_a \geq \left( \frac{0.879}{300 \times 2 - 81.3} \right) \times \frac{2\pi \times 2000}{60} \times 1.5 = 0.53 \text{ sec} \]
**Buckling load**

The ballscrew shaft when subjected to an axial compressive force may undergo visibly large deflection. The axial force is called the buckling load.

\[ F_k = 40720 \left( \frac{N_d}{L_t^2} \right)^2 \]

F	ext{p} = 0.5 \times F_k \hspace{1cm} M29

F_k = Permissible load (kgf) \hspace{1cm} \text{fixed - fixed} \hspace{1cm} N_k = 1.0

F_p = Maximum permissible speed (kgf) \hspace{1cm} \text{fixed - supported} \hspace{1cm} N_k = 0.5

d_r = Root diameter of screw shaft (mm) \hspace{1cm} \text{supported - supported} \hspace{1cm} N_k = 0.25

L_t = distance between support bearing (mm) \hspace{1cm} \text{fixed - free} \hspace{1cm} N_k = 0.0625

N_k = Factor for different mounting types

\*1kgf = 9.8N; 1daN = 10N

The buckling load diagram for different spindle diameter and support method is shown in Fig 4.25.

**Critical speed**

The critical speed is said to exist when the rotational frequency of a shaft equals the first natural frequency of the shaft. This will cause the ball screw to bend under the stress of vibration coupled with the centrifugal forces due to the rotation and cause the shaft to vibrate violently. Therefore, the rotational speed of the ball screw should be set to below the value indicated by critical speed.

\[ N_c = 2.71 \times 10^8 \times \frac{M_t d_r}{L_t^2} \]

N_c = critical speed (rpm) \hspace{1cm} \text{fixed - fixed} \hspace{1cm} M_t = 1

N_c = Maximum permissible load (rpm) \hspace{1cm} \text{fixed - supported} \hspace{1cm} M_t = 0.689

d_r = Root diameter of screw shaft (mm) \hspace{1cm} \text{supported - supported} \hspace{1cm} M_t = 0.441

L_t = distance between support bearing (mm) \hspace{1cm} \text{fixed - free} \hspace{1cm} M_t = 0.157

M_t = Factor for different mounting types

The critical speed for different spindle and support method is shown in Fig 4.26.

---

**Fig 4.25** Shows the buckling load for different screw spindle diameter and length

**Fig 4.26** Shows the critical speed for different screw spindle diameter and length
Supporting Conditions for Calculation of Buckling Load and Critical Speed

1. Critical Speed: fixed-fixed
   Buckling Load: fixed-fixed

2. Critical Speed: fixed-supported
   Buckling Load: fixed-fixed

3. Critical Speed: fixed-supported
   Buckling Load: fixed-supported

4. Critical Speed: fixed-free
   Buckling Load: fixed-fixed

Fig 4.27 Supporting conditions for screw shaft ball nut
**D_m-N value for ballscrew surface speed**

- D_m-N value has a strong influence over ballscrew noise, working temperature and service life of return system.
- For HIWIN ballscrew,
  - \( D_m \times N \leq 70,000 \)
  - \( D_m \): Pitch circle diameter (mm)
  - \( N \): Maximum speed (rpm)
- Ball screw structure enhancement designed by HIWIN when D_m-N value ranges from 70,000 to 180,000. If D_m-N value above 180,000, please consult our company.

**Stiffness**

- Stiffness is an indication of the rigidity of a machine. The stiffness of the ballscrew is determined by nut-spindle rigidity via axial load, ball track contact rigidity and screw spindle rigidity. When assembling the ballscrew in the machine, the stiffness of support bearing, mounting condition of nut with machine table etc. also should be considered. Fig 4.28 shows the relation of total stiffness of the machine feed system.
- From testing, the stiffness of nut-spindle relation and ball and ball track relation can be combined into the stiffness of nut, \( K_n \), and listed in dimension table of different nut type. The stiffness of the ballscrew is shown as:

  \[
  \frac{1}{K_{bs}} = \frac{1}{K_s} + \frac{1}{K_n}
  \]

  - \( K_{bs} \): Total stiffness of ballscrew (kgf/µm)
  - \( K_s \): Screw spindle stiffness (kgf/µm)
  - \( K_n \): Nut stiffness (kgf/µm)

  The stiffness of the screw spindle is shown as:

  \[
  K_s = \frac{67.4 \times d_r^2}{L_1} \quad \text{(Fixed-Fixed)}
  \]

  \[
  K_s = \frac{16.8 \times d_r^2}{L_1} \quad \text{(Fixed-Free)}
  \]

  The stiffness chart is shown in Fig 4.29

  - \( d_r \): Root diameter of screw spindle (mm) = \( D_m - D_b \)
  - \( L_1 \): Diameter of ball (mm)
  - \( K_s \): Screw spindle stiffness (kgf/µm)
  - \( K_n \): Nut stiffness (kgf/µm)

  The stiffness of the nut is tested using an axial force equal to the highest possible preload of 10% dynamic load \( C \) and is shown in the dimension table of each nut. When the preload is less than this value, the stiffness of the nut is calculated by extrapolation method as:

  \[
  K_n = 0.8 \times K \left( \frac{P}{0.1C} \right)^{1/3}
  \]

  - \( K_n \): Stiffness of nut
  - \( K \): Stiffness in the dimension table
  - \( P \): Preload
  - \( C \): Dynamic load on dimension table

  Single nut with backlash is calculated when the external axial force is equal to 0.28 C, thus:

  \[
  K_n = 0.8 \times K \left( \frac{F_b}{2.8 \times 0.1C} \right)^{1/3}
  \]
The axial stiffness of the whole feed system includes the stiffness of support bearings and nut mounting table. The designer should consider the total stiffness carefully.

**Thermal expansion**

\[ \Delta L = 11.6 \times 10^{-6} \times \Delta T \times L_s \]

- \( \Delta L \): Thermal expansion of screw spindle (mm)
- \( \Delta L \): (°C) Temperature rise at screw spindle
- \( L_s \): Total length of screw spindle (mm)

The \( T \) value should be chosen to compensate for the temperature rise of the ballscrew. HIWIN recommends a \( T \) value of -0.02 ~ -0.03 per meter for CNC machine tools.

**Basic dynamic axial load rating \( C \) (theoretical)**

The dynamic load is the load at which 90% of the ballscrews will achieve the service life of \( 1 \times 10^6 \) rev. The reliability factor can be adjusted by Table 4.8. The dynamic load is shown on the dimension table of each nut type.

**Basic static axial load rating \( C_0 \) (theoretical)**

The static load is the load which will cause the balltrack to have a plastic deformation exceeding 0.0001x ball diameter. To calculate the maximum static load of a ballscrew, the static safety factor \( S_f \) of the application condition should be considered.

\[ S_f \times F_{a(max)} < C_0 \]

- \( S_f \): Static factor = 2.5 max
- \( C_0 \): Static load from the dimension table of the nut type
- \( F_{a(max)} \): Maximum static axial load
Example 4.5 - 5

Ballscrew specification: 1R40-10B2-FSW-1000-1200-0.012
Lead \( \ell = 10 \text{ mm} \)
Pitch circle diameter \( D_m = 41.4 \text{ mm} \)
Ball diameter : 6.35 mm
Turns = 2.5x2
Root diameter \( d_r = 34.91 \text{ mm} \)
Lead angle \( \alpha = 4.4^\circ \)
Column load : fixed - supported
Friction angle \( \beta = 0.286^\circ \)
Critical speed : fixed - supported
Mean axial force \( F_b = 700 \text{ kgf} \)
Preload \( P = 250 \text{ kgf} \)

Stiffness of bearing \( K_b = 105 \text{ kgf}/\mu \text{m} \)

Calculation

1. Buckling load \( F_p \)

\[
F_p = 40720 \times \frac{N_f d_r^4}{L_t^2} = 40720 \times \frac{0.5 \times 34.91^4}{1000^2} = 30240 \text{ kgf} \quad \text{(Ref. M29)}
\]

\[
F_p = 0.5 \times F_k = 0.5 \times 30240 = 15120 \text{ kgf}
\]

2. Critical speed \( N_c \)

\[
N_c = 2.71 \times 10^8 \times \frac{0.689 \times 34.90}{1000^2} = 6516 \text{ rpm}
\]

\[
N_c = 0.8 \times N_c = 0.8 \times 6516 = 5213 \text{ rpm}
\]

3. Mechanical efficiency \( \eta \) [theoretical]

I. Common transmission

\[
\eta_1 = \frac{\tan \alpha}{\tan(\alpha + \beta)} = \frac{\tan(4.4^\circ)}{\tan(4.4^\circ + 0.286^\circ)} = 0.938 \quad \text{(Ref. M3)}
\]

II. Reverse transmission

\[
\eta_2 = \frac{\tan(\alpha + \beta)}{\tan \alpha} = \frac{\tan(4.396^\circ + 0.286^\circ)}{\tan(4.396^\circ)} = 0.934 \quad \text{(Ref. M4)}
\]

4. Stiffness \( K \)

\[
K_s = 16.8 \times \frac{d_r^2}{L_t} = 16.8 \times \frac{34.91^2}{1000} = 20.5 \text{ kgf}/\mu \text{m}
\]

\[ p = 250 < 0.1C(=537) \]

\[ \therefore K_s = 0.8 \times \left( \frac{P}{0.1C} \right)^{1/3} = 0.8 \times 74 \times \left( \frac{250}{0.1 \times 537} \right)^{1/3} = 46 \text{ kgf}/\mu \text{m} \]

\[
\frac{1}{K} = \frac{1}{K_s} + \frac{1}{K_b} = \frac{1}{20.5} + \frac{1}{46} = 14.18 \text{ kgf}/\mu \text{m}
\]

5. Lost motion during axial force \( F_b = 700 \text{ kgf} \)

\[
\delta / 2 = \frac{F_b}{K} = \frac{700}{14.24} = 50 \mu \text{m} = 0.056 \text{ mm} \quad \text{(each way)} \quad \text{Total lost motion} \ \delta = 2 \times 0.056 = 0.112 \text{ mm}
\]

If the preload increases to \( 2 \times 250 = 500 \text{ kgf} \) then \( K_s = 58 \text{ kgf}/\mu \text{m} \) and \( K = 15.1 \text{ kgf}/\mu \text{m} \). Total stiffness \( K = 13.2 \text{ kgf}/\mu \text{m} \) and total lost motion \( \delta = 0.106 \text{ mm} \). The difference is only \( 0.6 \mu \text{m} \) (5% change). Comparing with 250 kgf, preload, but the temperature rise caused by 500 kgf preload is heavy. The spindle stiffness is sometimes more important than the nut stiffness. The best way to increase the stiffness of the system is not in the heavy preloading of the ballscrew nut. If the support method changes to fixed-fixed, then \( K_s = 82 \text{ kgf}/\mu \text{m} \) and \( K \) becomes 23 kgf/\mu m. The total lost motion \( \delta = 0.061 \text{ mm} \). The difference is 51\mu m (45%).
Manufacturing range

The maximum length to which a ballscrew can be manufactured depends on spindle diameter and accuracy grade (Table 4.10). Since high accuracy ballscrews require a high degree of straightness to the screw spindle, the higher the slender ratio [length/diameter], the more difficult to manufacture and the less the spindle stiffness.

HIWIN recommends the maximum lengths shown in Table 4.10.

If a longer length is required, please contact with HIWIN engineer.

Table 4.10 General manufacturing range of HIWIN screw spindle vs. diameter and accuracy grade

| Total length Grade | 6  | 8  | 10 | 12 | 16 | 20 | 25 | 30 | 36 | 40 | 50 | 55 | 63 | 70 | 80 | 100 |
|--------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| C0                 | 110| 170| 300| 400| 600| 700| 1000|1000|1200|1300|1500|1600|1800|2000|2000|2000|
| C1                 | 110| 170| 400| 500| 720| 950| 1300|1500|1800|2000|2300|2500|3100|3500|4000|4000|
| C2                 | 140| 200| 500| 630| 900|1300|1700|1800|2200|2200|2900|3200|4000|5000|5500|6000|
| C3                 | 170| 250| 500| 630|1000|1400|1800|2000|2500|2500|3200|3500|4000|4500|5000|6000|
| C4                 | 170| 250| 500| 630|1000|1400|1800|2000|2500|2500|3200|3500|4000|4500|5000|6000|
| C5                 | 170| 250| 500| 630|1410|1700|2400|2500|3000|3000|3800|4000|5000|5500|6000|7000|
| C6                 | 400| 800|1000|1200|1500|1800|2500|3000|3000|4000|4000|5600|5600|5600|6900|7100|
| C7                 | 400| 800|1000|1200|1500|1800|2500|3000|4000|4500|4500|5000|5000|6000|7100|10000|

Heat treatment

HIWIN’s homogenous heat treatment technique gives the ballscrew maximum life capability. Table 4.11 shows the hardness value of hardness in each component of HIWIN ballscrews. The surface hardness of the ballscrew affects both dynamic and static load value. The dynamic and static values shown in the dimension table are the values for a surface hardness equal to HRC 60. If the surface hardness is lower than this value, the following formula will give you the calibration result.

\[
C'_{o} = C_{o} \times f_{H0} \quad f_{H0} = \left( \frac{\text{Real Hardness (HRC)}}{60} \right)^3 \leq 1
\]

\[
C' = C \times f_{H} \quad f_{H} = \left( \frac{\text{Real Hardness (HRC)}}{60} \right)^2 \leq 1
\]

Where \( f_{H} \) and \( f_{H0} \) are the hardness factor.

\( C'_{o} \): Calibrated static load
\( C_{o} \): Static load
\( C' \): Calibrated dynamic load
\( C \): Dynamic load

Table 4.11 Hardness of each component of HIWIN ballscrew

<table>
<thead>
<tr>
<th>Item</th>
<th>Treat Method</th>
<th>Hardness [HRC]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle</td>
<td>Carburizing or Induction Hardening</td>
<td>58 - 62</td>
</tr>
<tr>
<td>Nut</td>
<td>Carburizing</td>
<td>58 - 62</td>
</tr>
<tr>
<td>Ball</td>
<td></td>
<td>62 - 66</td>
</tr>
</tbody>
</table>
4.6 Temperature Rise Effect on Ballscrews

The temperature rise of ballscrew during the working period will influence the accuracy of the machine feed system, especially in a machine designed for high speed and high accuracy.

The following factors have the effect of raising the temperature in a ballscrew.

1. Preload
2. Lubrication
3. Pretension

Fig 4.30 shows the relation of working speed, preload and temperature rise. Fig 4.31 shows the relation of nut temperature rise to preload friction torque. From Fig 4.30, Fig 4.31 and example 4.5-5, doubling the preload of the nut will increase the temperature about 5 degrees, but the stiffness increase only by about 5% (few μm).

[1] Preload effect

To avoid any lost motion in the machine feed system, increasing the rigidity of the ballscrew nut is important. However, to increase the rigidity of the ballscrew nut, it is necessary to preload the nut to a certain level.

Preloading the nut will increase the friction torque of the screw, making it more sensitive to an increase in temperature during working period.

HIWIN recommends using a preload of 8% of the dynamic load for medium and heavy preload, 6% ~ 8% for medium preload, 4% ~ 6% for light and medium and below 4% for light preload.

The heaviest preload should not exceed 10% of the dynamic load for best service life and a low temperature rise effect.

[2] Lubrication effect

The selection of lubricant will directly influence the temperature rise of the ballscrew.

HIWIN ballscrews require appropriate lubrication either by greasing or oiling. Antifriction bearing oil is recommended for ballscrew oil lubrication. Lithium soap based grease is recommended for ballscrew greasing. The basic oil viscosity requirement depends on the speed, working temperature and load condition of the application. [Fig 4.32] shows the relation of oil viscosity, working speed and rise in temperature.

When the working speed is higher and the working load is lower, a low viscosity oil is better. When the working speed is lower and the working load is heavy, a high viscosity oil is preferred.

Generally speaking, oil with a viscosity of 32 ~ 68 cSt at 40°C [ISO VG 32-68] is recommended for high speed lubrication [DIN 51159] and viscosity above 90 cSt at 40°C [ISO VG 90] is recommended for low speed lubrication.

In high speed and heavy load applications the use of a forced coolant is necessary to lessen the temperature. The forced lubrication of coolant can be done by a hollow ballscrew.

Fig 4.33 shows the comparison of a ballscrew applied with coolant and without coolant. Fig 4.34 shows a typical application for hollow ballscrew in machine tools. The inspection and replenishing of the ballscrew lubricant is listed in Table 4.12.
(3) Pretension effect

When the temperature rises in the ballscrew, the effect of thermal stress will elongate the screw spindle. It can make the spindle length unstable.

The elongating relationship can be calculated according to M41. This elongation can be compensated via the pretension force. For the purpose of pretension, there is a negative $T$ value indicated in the design drawing to compensate the pretension value.

Since a large pretension force will cause the burn down of the supporting bearing, HIWIN recommends using pretension when the temperature rise is below $5^\circ$C. Also, if the diameter of the screw spindle is greater than 50 mm, it is not suitable for pretension. A large spindle diameter requires a high pretension force, causing burn down of the supporting bearing.

HIWIN recommends a $T$ compensation value of about 3°, (about -0.02~0.03 for each 1000 mm screw spindle).

Since different applications require different $T$ values, please contact HIWIN engineer.

The pretension force is calculated as:

$$P_f = K_s \times \Delta L$$

Where:
- $K_s$: Stiffness of screw spindle (kgf/µm)
- $P_f$: Pretension force (kgf)
- $\Delta L$: Pretension value (µm)

Table 4.12: Inspection and replenishment of Lubricant

<table>
<thead>
<tr>
<th>Lubrication Method</th>
<th>Inspection &amp; Replenishent Guide</th>
</tr>
</thead>
</table>
| Oil                | - Check the oil level and clean the contamination once a week.  
|                    | - When contamination happens, replacing the oil is recommended.  
|                    | - Lubrication suggestion:  
|                    |  
|                    |  
| Grease             | - Inspect for contamination of chips every 2 or 3 months.  
|                    | - If contamination happens, remove old grease and replace with new grease.  
|                    | - Injection amount is about half of internal space within nut every 2 months or 100 km stroke.  

Fig 4.33 Ball screw temperature rise with the coolant and without the coolant

Fig 4.34 High accuracy machine tools with hollow ball screw lubrication

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HIWIN manufactures ballscrews according to customers’ blueprints or specifications. Please read the following information for understanding ballscrew designing.

1. Nominal diameter.  
2. Thread lead.  
3. Thread length, total length.  
4. End journal configuration.  
5. Nut configuration  
6. Accuracy grade (lead deviation, geometrical tolerance).  
7. Working speed.  
8. Maximum static load, working load, preload drag torque.  
9. Nut safety requirements.  
10. Lubrication hole position.

**HIWIN Ballscrew Nomenclature**

HIWIN ballscrews can be specified as follows:

1R40 - 10B2 - PFDWE2 - 800 - 1000 - 0.0035 - M

- **Start type**
  1. Single start  
  2. Double start  
  3. Triple start  
  4. Four start  
  5. Five Start
- **Right hand screw**
- **Nominal diameter**
- **Lead**
- **Number of turns**
- **Preload type**
  - P: Compression type  
  - O: Offset type  
  - D: High lead double start  
  - T: High lead triple start  
  - Q: High lead quatemary start  
  - V: High lead five start
- **Nut shape**
  - S: Square nut  
  - R: Round  
  - F: Nut with flange
- **Note:**
  - M: Stainless  
  - H: Hollow Shaft  
  - L: heavy load

- **Optional Functions:**
  - E2: Self-lubrication  
  - R1: Rotating Nut  
  - C1, C2: Cool Type
- **Circulation type**
  - W: Tubes within nut body  
  - V: Tubes above nut body  
  - B: Bonded tube  
  - I: Internal cap  
  - H: End cap  
  - C: Super S series
- **Nut type**
  - S: Single nut  
  - D: Double nut

**Number of turns**

<table>
<thead>
<tr>
<th>Type</th>
<th>A : 1.5, B : 2.5, C : 3.5</th>
<th>T3 : 3</th>
<th>S1 : 1.8x1</th>
<th>U1 : 2.8x1</th>
<th>K2 : 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>1.5x2</td>
<td>T4 : 4</td>
<td>S2 : 1.8x2</td>
<td>U2 : 2.8x2</td>
<td>K3 : 3</td>
</tr>
<tr>
<td>B2</td>
<td>2.5x2</td>
<td>T5 : 5</td>
<td>S4 : 1.8x4</td>
<td>V2 : 0.8x2</td>
<td>K4 : 4</td>
</tr>
<tr>
<td>C1</td>
<td>3.5x1</td>
<td>T6 : 6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

1. Different diameters and leads are available upon request.
2. Right hand thread is standard, left hand thread is available upon request.
3. Longer lengths are available upon request.
4. Stainless steel is available upon request, only if the ball size is less than 2.381 mm.
5. Complete questionnaire on page 173~174 and consult with HIWIN engineers.
6. If you need to order DIN 69051 type, please mark “DIN”.
7. Number of turns = turns per circuit x number of circuits.

Please refer to page 6 for detailed illustration.

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