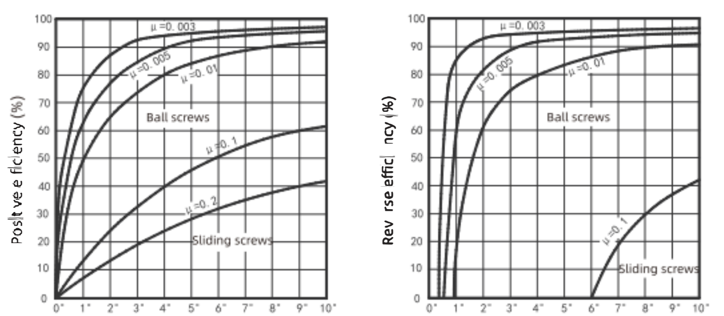
BALL SCREWS

Ball screw is a mechanical component consisting of Screw shaft, ball nut, ball and others, mainly used to convert the rotational motion into linear motion, or the linear motion into rotational motion. With the features of high efficiency and reversibility, high precision, high wear resistance, zero clearance, high stiffness transmission, etc. it has been widely used in precision high-speed CNC machine tools, precision electronic machinery, precision grinding machines and other industrial equipment. Besides, HTPM's ball screws can also meet the special use requirements in different fields.

Features of HTPM ball screws

1. High efficiency and reversibility

The transmission of the ball screws is driven by balls between the Screw shaft and ball nuts, the mechanical efficiency can reach over 90%, the friction coefficient is lower than that of the traditional screws, and the transmission torque is only 1/4 - 1/2 of the sliding screws. Therefore, it is not easy to convert the rotational motion to linear motion, and convert the linear motion to rotational motion.



Lead angle
Convert rotational motion to linear motion
μ: Friction coefficient

Lead angle
Convert linear motion to rotational motion
μ: Friction coefficient

Mechanical efficiency comparison of ball screws

2. High precision

HTPM ball screws can be manufactured according to the precision level requirement of GB/T 17587.3-2017, and the ball screws for industrial machine with higher prevision are also available to meet customer needs.

Precision machining, grinding, precision measurement and assembly of HTPM ball screws are carried out in a constant temperature room. For testing and measurement, the laser screw stroke measuring instrument, precision profile roughness tester, dynamic screw stroke error measuring instrument, ball screw friction torque measuring instrument, ball screw comprehensive performance test bench, coordinate measuring machine (CMM), rigid load test bench, Renishaw laser interferometer, vertical/horizontal projector, decibel meter and other testing equipment are configured, as well as a number of ball screw running-in machine and life test bench, in order to can meet the precision level of the ball screw test and various performance indicators.

3、Superb durability

Screw shaft and ball nuts are made of high-quality alloy steel material and manufactured using HTPM heat treatment technology that is developed for many years. Its thread raceway is hardened to HRC58 ~ 62 by quenching, so it remains high precision after long-term use, demonstrating excellent high wear resistance.

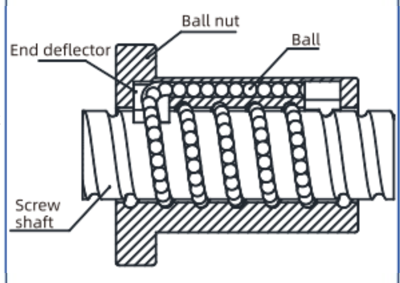
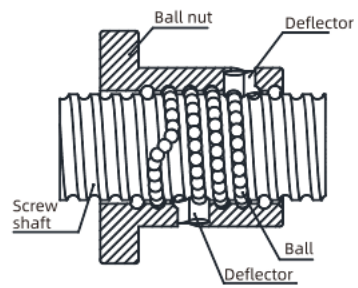
4、 Transmission with zero clearance and high stiffness

The ball screw thread raceway adopts Gothic arc tooth, the ball and thread raceway are contacted in the best way to allow flexible and convenient. Appropriate preload is applied to pre-tighten the ball screw, this is good to eliminate the axial clearance and enhance the stiffness of ball screws.

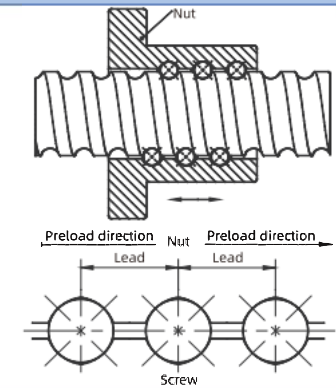
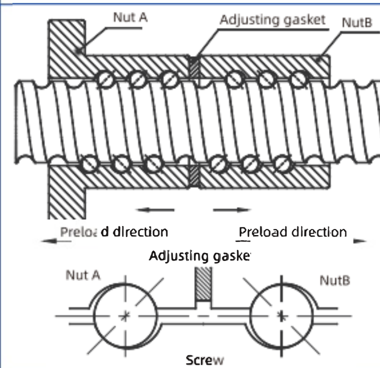
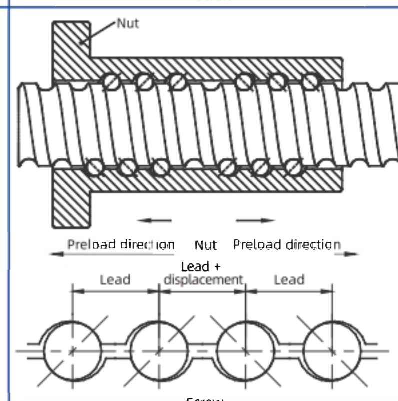
Gothic arc　　　　Single arc

Structure of HTPM ball screw

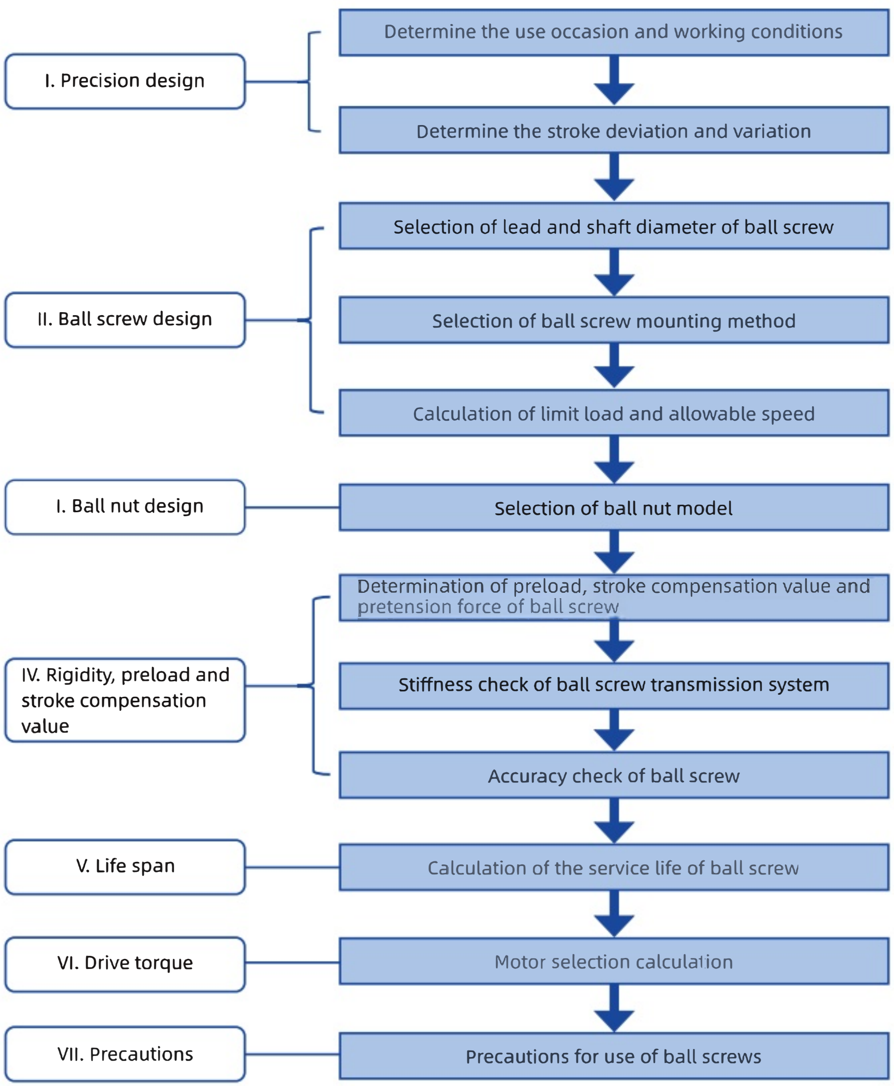
By circulation mode, HTPM ball screws are divided into external circulation and internal circulation.

Circulation mode	External circulation (C End deflector)	Internal circulation (Y Bridge Deflector)
Schematic diagram		
Structural features	The ball leaves the screw shaft surface during the reverse cycle	The ball never leaves the screw shaft surface during the cycle
Features	1. High speed, low noise; 2. Suitable for large-and-medium-sized leads; 3. The value DN is up to 120000.	1. Small cylindrical diameter for nut mounting; 2. Suitable for medium and small loads, and large-and-medium-sized leads; 3. The value DN is up to 80,000.
Applicable industry	1. High-speed industry, such as gantry-type engraving and milling machine, drill and tapping machine, etc. 2. High-speed medium load industry, such as machining centers, high-speed turning and milling composite processing.	1. Medium and low speed industry, such as CNC lathes and other equipment 2. Micro-feeding low speed machine tools, such as internal and external nut grinding machine, wire cutting machine, electric discharge machine.

By the preload, HTPM ball screws are divided into increasing ball preload (Z), double-nut gasket preload (D) and variable preload (B).

Preload mode	Schematic diagram	Features
Oversize ball preload (Z)		1. Four-point contact, simple and compact structure, short nut length, high stiffness; 2. Sound torque performance in the case of low torque; 3. Not suitable in case of excessive preload.
Double nut preload (D)		1. Two-point contact, simple form and structure, good axial performance, reliable preload and excellent manufacturability; 2. Suitable for heavy preload, high stiffness and heavy-load transmission.
Offset preload (B)		1. Two-point contact, washer-free, medium nut length, supporting miniaturized design; 2. Suitable for medium preload, good torque performance and improved stiffness.

Flow chart for selection of ball screws



Applications of ball screw precisions

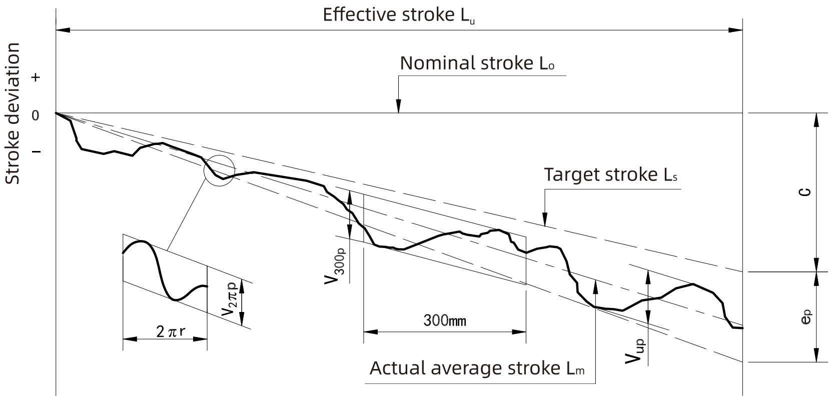
The ball screw of different prevision level are selected according to the application scenarios. From this table, the prevision level of ball screw can be can initially selected.

Application scenarios		Shaft	Precision level					
			0	1	2	3	4	5
CNC machine tool	Lathe	X	○	○	○	○	○	○
		Z			○	○	○	○
	Milling machine Boring machine	X、Y	○	○	○	○	○	○
		Z		○	○	○	○	○
	Machining center	X、Y	○	○	○	○	○	
		Z		○	○	○	○	
	Drilling machine	X、Y			○	○	○	○
		Z					○	○
	Grinders	X、Y	○	○	○	○		
		Z	○	○	○	○		
	Electrical discharge machine	X、Y	○	○	○	○		
		Z		○	○	○	○	
	Wire cutting machine	X、Y	○	○	○	○		
		Z		○	○	○	○	
	Laser processing machine	X、Y			○	○		
		Z			○	○		
	Punch press	X、Y			○	○		
	Woodworking machine	—				○	○	○
	General machineries	—			○	○	○	○

BALL SCREWS

Stroke deviation and variation of ball screws

The stroke deviation and variation of ball screws are based on GB/T 17587.3-2017. According to the provisions on 4 characteristic indicators, such as e_p、V_{up}、V_{300p} and $V_{2\pi p}$,the definitions and allowable value range are as follows:



Stroke deviation and variation terms

Name	Symbol	Definition
Stroke compensation value	C	The difference between the target stroke and the nominal stroke within the effective stroke
Target stroke tolerance	e_p	Half the difference between the maximum and minimum allowed actual average strokes $2e_p$
Stroke variation	V_{up}	The bandwidth value that is parallel to the actual average stroke L_m and contains the actual stroke deviation curve within the effective stroke
	V_{300p}	The bandwidth value that is parallel to the actual average stroke L_{300} and accommodates the deviation from actual stroke curve over a 300mm stroke
	$V_{2\pi p}$	The bandwidth value of rotation 2πrad that is parallel to the actual average stroke $L_{2\pi}$ and containing the deviation of actual stroke curve

Target stroke e_p tolerance of effective stroke L_u

Effective stroke L_u (mm)		Target stroke tolerance e_p (μm) Standard class of tolerance					
>	⩽	0	1	2	3	4	5
0	315	4	6	8	12	16	23
315	400	5	7	9	13	18	25
400	500	6	8	10	15	20	27
500	630	6	9	11	16	22	32
630	800	7	10	13	18	25	36
800	1000	8	11	15	21	29	40
1000	1250	9	13	18	24	34	47
1250	1600	11	15	21	29	40	55
1600	2000	—	18	25	35	48	65
2000	2500	—	22	30	41	57	78
2500	3150	—	26	36	50	69	96
3150	4000	—	32	45	62	86	115
4000	5000	—	—	—	76	110	140
5000	6300	—	—	—	—	—	170

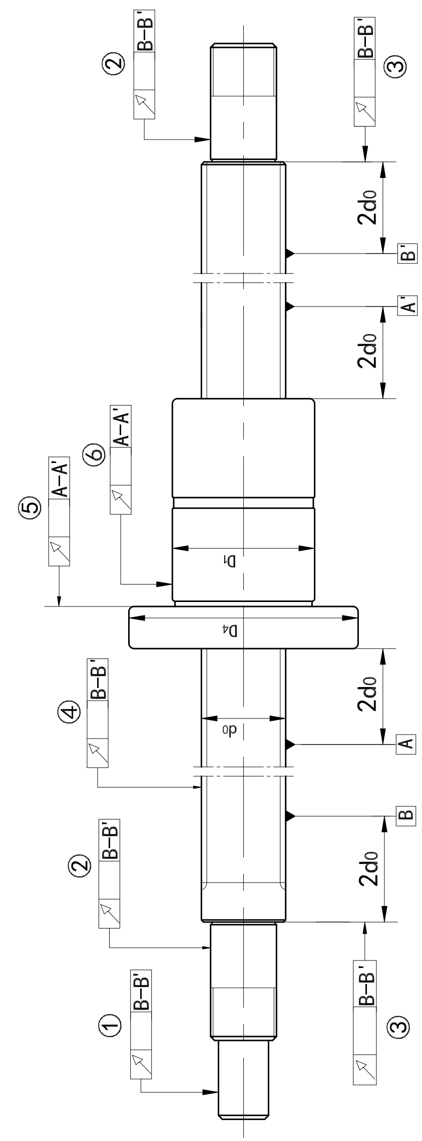
Stroke variation L_u within effective stroke V_{300p} and $V_{2\pi p}$ Unit: μm

Stroke variation		Standard class of tolerance							
V_{300p}	GB	P0		P1	P2	P3	P4		P5
		3.5		6	8	12	16		23
	JIS	C0	C1		C3			C5	
		3.5	5		8			18	
$V_{2\pi p}$	GB	P0		P1	P2	P3	P4		P5
		3		4	5	6	7		8
	JIS	C0	C1		C3			C5	
		2.5	4		6			8	

Stroke variation V_{up} within the effective stroke L_u

Effective stroke L_u (mm)		Stroke variation V_{up} (μm) Standard class of tolerance					
>	⩽	0	1	2	3	4	5
0	315	3.5	6	8	12	16	23
315	400	3.5	6	9	12	18	25
400	500	4	7	9	13	19	26
500	630	4	7	10	14	20	29
630	800	5	8	11	16	22	31
800	1000	6	9	12	17	24	34
1000	1250	6	10	14	19	27	39
1250	1600	7	11	16	22	31	44
1600	2000	—	13	18	25	36	51
2000	2500	—	15	21	29	41	59
2500	3150	—	17	24	34	49	69
3150	4000	—	21	29	41	58	82
4000	5000	—	—	—	49	70	99
5000	6300	—	—	—	—	—	119

● Runout and position tolerance of the mounting part of the ball screw



Note:
① Runout of the journal relative to the ball screw outside diameter BB';
② Runout of the bearing journal relative to the ball screw outside diameter BB';
③ Runout of the bearing journal shoulder relative to the ball screw outside diameter BB';
④ Radial runout of ball screw outside diameter;
⑤ Runout of the ball nut mounting surface relative to the ball screw outside diameter AA'.
⑥ Runout of the outer mounting circle of ball nut relative to the ball screw outside diameter AA';

Test item 1 (Q/HTPM 005-2023 G1 Term)

Test items	Tolerance
At each length l_5 of the ball screw, the radial runout of ball screw outside diameter t_5 is used to determine the straightness relative to AA'	

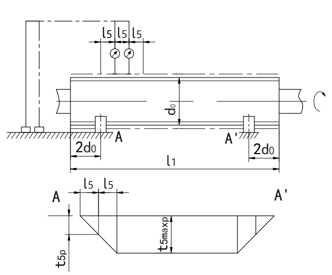
Test method

Place the ball screw on two V-shaped iron of equal heights at AA', adjust the indicator so that its probe vertically touches the cylindrical surface at the specified measurement interval l_5 ,slowly turn the ball screw, record the change in the indicator reading, and repeat the test at each point l_5 in the specified measurement interval.

Nominal diameter d_0 (mm)		l_5 (mm)	Standard class of tolerance					
			0	1	2	3	4	5
>	⩽		l_5 on $t_{5p}(\mu m)$					
6	12	80	14	16	20	22	25	25
12	25	160						
25	50	315						
50	100	630						
100	200	1250						

l_1/d_0		$l_1 > 4l_5$ on $t_{5\,\max p}$ (μm)					
>	⩽						
—	40	28	32	40	45	50	57
40	60	45	53	63	67	75	85
60	80	75	85	100	112	125	140
80	100	112	123	142	160	180	200

Schematic diagram



Note 1: Optional. It is agreed to allow the ball screw to be measured on the center hole, at this time the l_1 is at ball screw's total length.
Note 2: If $l_1 < 2l_5$, it is allowed to measure at $l_1/2$.

Test item 2 (Q/HTPM 005-2023 G2 Term)

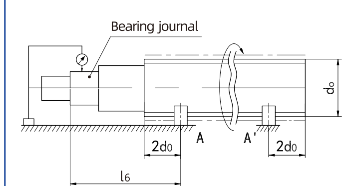
Test items	Tolerance
The radial runout of the ball screw bearing journal relative to AA' $t_{6.1}$ When $l_6 \leq l$ (l see table); When $l_6 > l$, the measured value $t_{6.1a} \leq t_{6.1p}\frac{l_6}{l}$	

Test method

Place the ball screw on two V-shaped iron of equal heights at AA', let the indicator's probe vertically touch the cylindrical surface at a distance of l_6 , slowly turn the ball screw and record the change in the indicator reading.

Nominal diameter d_0 (mm)		l (mm)	Standard class of tolerance					
			0	1	2	3	4	5
>	⩽		l on $t_{6.1p}(\mu m)$					
6	20	80	8	9	10	11	12	16
20	50	125	9	10	12	14	16	20
50	125	200	12	14	16	18	20	25
125	200	315	—	16	18	20	25	32

Schematic diagram



Note: It is agreed to allow the ball screw to be measured on the center hole (at this time l_6 indicates the distance from the measurement point to shaft end.)

BALL SCREWS

Test item 3 (Q/HTPM 005-2023 G3 Term)

Test items	Tolerance

The radial runout of the journal of ball screw relative to the bearing journal $t_{7.1}$

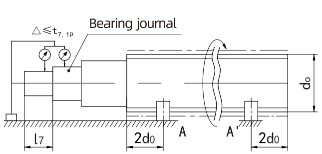
When $l_7 \le l$ (l see table);

When $l_7 > l$, the measured value $t_{7.1a} \le t_{7.1p}\frac{l_7}{l}$

Test method

Place the ball screw on two V-shaped iron of equal heights at AA', let the indicator's probe vertically touch the cylindrical surface at a distance of l_7 , turn the ball screw for a circle and record the change in indicator reading.

Schematic diagram



Tolerance

Nominal diameter d_0 (mm)		l (mm)	Standard class of tolerance					
			0	1	2	3	4	5
>	⩽		l on $t_{7.1p}(\mu m)$					
6	20	80	3	4	5	6	7	7
20	50	125	4	5	6	7	8	8
50	125	200	5	6	7	8	10	10
125	200	315	—	7	8	10	12	14

Note: It is agreed to allow the ball screw to be measured on the center hole through negotiation.

Test item 4 (Q/HTPM 005-2023 G4 Term)

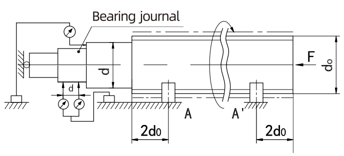
Test items	Tolerance

End-face runout of bearing journal shoulder of the ball screw with relative to AA' $t_{8.1}$

Test method

Place the ball screw on two V-shaped iron of equal heights at AA' to prevent the axial movement of ball screws (a ball may be placed between the center hole of ball screws and the fixed surface), and let the indicator probe vertically touch the shoulder surface and cylindrical surface of the bearing journal. Turn the ball screw for a circle, and record the change in the indicator reading.

Schematic diagram



Tolerance

Nominal diameter d_0 (mm)		Standard class of tolerance					
		0	1	2	3	4	5
>	⩽	$t_{8.1p}(\mu m)$					
6	63	3	3	3	4	4	4
63	125	3	4	4	5	5	6
125	200	—	5	5	6	7	7

Note: It is agreed to allow the ball screw to be measured on the center hole through negotiation.

Test item 5 (Q/HTPM 005-2023 G5 Term)

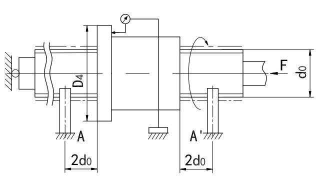
Test items

End-face runout of ball nut mounting surface of ball screw relative to AA' end face t_9
(only for ball nuts with preload)

Test method

Place the preloaded ball screw on two high V-shaped iron of equal heights at AA' to prevent the axial movement of ball screws (a ball may be placed between the center hole of ball screw and the fixed surface), so that the indicator probe vertically touches the mounting end surface at the outer edge of the ball nut diameter D_4 to prevent the ball nut from rotating relative to the ball screw, then turn the ball screw and record the change in indicator reading.

Schematic diagram



Tolerance

Nut mounting end face diameter D_4 (mm)		Standard class of tolerance					
		0	1	2	3	4	5
>	⩽	$t_{9p}(\mu m)$					
16	32	6	8	10	10	12	14
32	63	8	10	12	14	16	16
63	125	10	12	14	15	16	18
125	250	14	15	16	18	20	25
250	500	—	20	25	28	32	36

Test item 6 (Q/HTPM 005-2023 G6 Term)

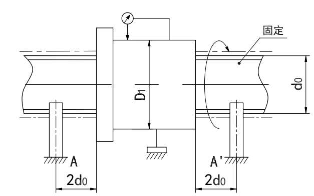
Test items

End-face runout of the outer mounting circle of ball nut relative to AA' t_{10}
(only for ball nuts with preload and rotatory body)

Test method

Place the preloaded ball screw on two high V-shaped iron of equal heights at AA' so that the indicator probe vertically touches the cylindrical surface of the nut outer mounting circle D_1 to prevent the ball screw shaft from rotating, slowly turn the ball nut and record the change in indicator reading.

Schematic diagram



Tolerance

Nut mounting end face diameter D_1 (mm)		Standard class of tolerance					
		0	1	2	3	4	5
>	⩽	$t_{10p}(\mu m)$					
16	32	6	8	10	11	12	14
32	63	8	10	12	14	15	16
63	125	10	12	14	15	18	20
125	250	14	16	18	20	22	25
250	500	—	22	25	28	32	36

Parameter design and selection of HTPM ball screws

1. Selection of the lead of ball screw

P_h: The stroke of ball nut when it rotates 2πrad (one revolution)relative to the ball screw

As shown in the transmission relationship diagram, determine the lead of ball screw by the highest moving speed of workbench V_{max} , the highest motor speed n_{max} and the transmission ratio P_h .

$$P_h = \frac{V_{max}}{n \times i_{max}}$$

When the motor is directly connected to the ball screw $i = 1$

$$P_h = \frac{V_{max}}{n_{max}}$$

The value P_h (rounded up) calculated.

2. Selection of ball screw shaft diameter

2.1 Calculation of expected dynamic axial load rating

Dynamic axial load rating C_a the constant axial load that the ball screw theoretically can withstand at the rated life span of 106 RPM.

Expected dynamic axial load rating C_{am} according to the design requirements of machine tool, it is necessary to estimate a minimum dynamic load rating, which is called the expected dynamic axial load rating C_{am} .The value can be determined by calculating the equivalent speed n_m and equivalent load F_m.

2.1.1 Equivalent speed n_m and equivalent load F_m

Ball screws in various rotational speed such as n_1、n_2、⋯、n_n the working time of various rotational speeds is $t_{1\%}$、$t_{2\%}$、⋯, $t_{n\%}$, the load is respectively F_1、F_2、⋯、F_n, and its corresponding equivalent speed and equivalent load are:

$$n_m = n_1\frac{t_1}{100} + n_2\frac{t_2}{100} + \dots + n_n\frac{t_n}{100}$$

$$F_m = \sqrt[3]{\frac{F_1^3 n_1 \frac{t_1}{100} + F_2^3 n_2 \frac{t_2}{100} + \dots + F_3^3 n_3 \frac{t_3}{100}}{n_m}}$$

In the Formula: n_m — Equivalent speed (r/min)

F_m — Equivalent load (N)

When the speed is given, the load changes linearly with time, and the equivalent load can be estimated by the following formula:

$$F_m = \frac{F_{min} + 2F_{max}}{3}$$

In the Formula: F_{min} — Minimum axial load (N)

F_{max} — Maximum axial load (N)

2.1.2 Expected dynamic axial load rating C_{am}

①Calculated according to the expected working hours of ball screws:

$$C_{am} = \sqrt[3]{60 n_m L_h} \times \frac{F_m f_w}{100 f_a f_c}$$

In the Formula:

C_{am} — Expected dynamic axial load rating (N)

L_h — Expected working hours (h)

f_w — Loading coefficient (see Table 1)

f_a — Accuracy coefficient (see Table 2)

f_c — Reliability coefficient (see Table 3)

②Calculated according to the expected operating distance of ball screws:

$$C_{am} = \sqrt[3]{\frac{L_s}{P_h}} \times \frac{F_m f_w}{f_a f_c}$$

In the Formula:

L_s — Expected operating distance (km)

③Calculated according to the maximum axial load in the case of preloading:

$$C_{am} = f_e F_{max}$$

In the Formula:

f_e — Preload coefficient(see Table 4)

Table 1 Loading coefficient

Load	No impact, stable	Slight	Impact
Loading f_w	1.0～1.2	1.2～1.5	1.5～2.0

Table 2 Precision coefficient

Precision	0～3	4～5	7	10
Precision	1.0	0.9	0.8	0.7

Table 3 Reliability coefficient

High (%)	90	95	96	97	98	99
Precision f_c	1.0	0.62	0.53	0.44	0.33	0.21

Table 4 Preload coefficient

Preload type	Light	Medium	Heavy
Loading f_e	6.7	4.5	3.4

2.2 Determination of the minimum base diameter of ball screw

The minimum base diameter of ball screw has a direct impact on its own rigidity, rated axial dynamic and static loads as well as other performance parameters. For calculation of the minimum base diameter, it is necessary to consider the maximum allowable axial deformation of and installation mode of ball screws.

2.2.1 Maximum allowable axial deformation

① Calculated according to repeated positioning accuracy:

$$\delta_{m1} = K_1\delta_1$$

In the Formula: δ_{m1} — Maximum allowable axial deformation（μm）

δ_1 — Repeated positioning accuracy (μm)

K_1 — Deformation parameter (the value ranges from 1/3 - 1/4)

② Calculated according to positioning accuracy:

$$\delta_{m2} = K_2\delta_2$$

In the Formula: δ_{m2} — Maximum allowable axial deformation（μm）

δ_2 — Positioning accuracy（μm）

K_2 — Deformation parameter (the value ranges from 1/4 - 1/5)

During the selection calculation of ball screws, the value, which is smaller is generally selected as the maximum axial deformation to ensure reliability.

2.2.2 Minimum base diameter of the ball screw

①When the ball screw is installed in a fixed-supported or fixed-free way, the minimum base diameter is calculated by the following formula:

$$d_{2min} = 2 \times 10\sqrt{\frac{10F_J l_s}{\pi\delta_m E}} = 0.078 \times \sqrt{\frac{\mu_0 mgl_s}{\delta_m}}$$

In the Formula: d_{2min} — Minimum base diameter（mm）

F_J — Static friction（N）

l_s — Maximum distance from the nut to the bearing at the fixed end of the lead（mm）

Recommended value $l_s = (1.05\text{~}1.1)L_u + (10\text{~}14)P_h$

E — Elastic modulus（$E = 2.1 \times 10^5 N/mm^2$）

μ_0 — Static friction coefficient. (Slide guide $\mu_0 = 0.1\text{~}0.2$, rolling guide $\mu_0 = 0.01\text{~}0.02$

②When the ball screw is installed in a fixed-fixed way, the minimum base diameter is calculated by the following formula:

$$d_{2min} = 10\sqrt{\frac{10F_J l_s}{\pi\delta_m E}} = 0.039 \times \sqrt{\frac{\mu_0 mgl_s}{\delta_m}}$$

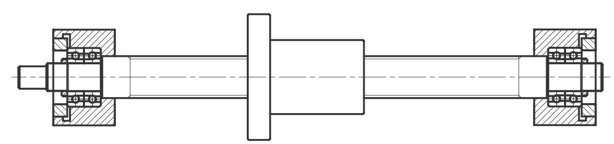
In the Formula: l_s — Distance between the two fixed bearings（mm）

3. Selection of ball screw mounting method

The installation method has great impact on the bearing capacity, rigidity and maximum speed of the ball screw. The below shows three most commonly used installation modes:

(1) Fixed - Fixed

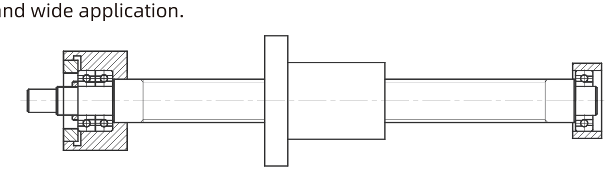
This installation mode is applicable for the circumstances with high speed and high precision. In this mode, the axial and radial degrees of freedom are restricted by a pair of bearings, and the load is shared by two sets of bearings; or the bearings at both ends are made to withstand the reverse pretension force, thereby improving the transmission rigidity. In the case of high positioning requirements, the target stroke compensation value is set according to the stress condition and the thermal deformation trend of lead screw to further improve the positioning accuracy. This involves more complex structure which is difficult to adjust, so it is often used when there is high requirement for positioning accuracy.



(1) Fixed - Fixed

(2) Fixed - Supported

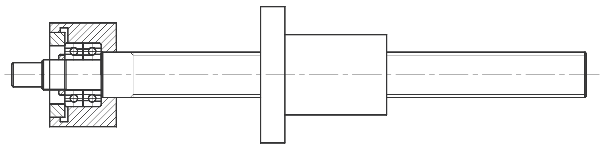
It is suitable for the occasions with medium speed, high precision. In this installation mode, a pair of bearings are used to constrain the axial and radial degrees of freedom at one end, a single bearing is used to constrain the radial degree of freedom at the other end, the load is borne by a bearing pair, and the running single bearing can prevent the cantilever deflection and eliminate the stress caused by thermal deformation. This mode features simple structure, good effect and wide application.



(2) Fixed - Supported

(3) Fixed - Free

It is suitable for the occasions involving low speed, medium accuracy, and short axial length. In this installation mode, the axial and radial degrees of freedom are constrained by a diagonal contact ball bearing at one end, and the other end is in suspended free state. The fixed end can withstand axial and radial forces, and the load is borne by a pair of bearings, and it needs to overcome the bending moment caused by gravity during horizontal installation. It features simple structure, convenient installation and commissioning, small bearing capacity, low axial rigidity and less reliable positioning accuracy.



(3) Fixed - Free

4. Calculation of limit load

Having a long and thin shape, the ball screw basically only receives the axial load according to its function, so the axial load should be analyzed. The common three main situations are listed below:

- Bending strength of the ball screw
- Yield stress of the ball screw caused by tensile and compressive stress
- Permanent deformation of the ball contact area

4.1 Bending strength of ball screw

Due to the compressive load of the ball screw resulted from the load of workpiece itself, work bench and others, i.e. axial allowable compressive load，$P$the calculation formula below is used:

$$P = \alpha \frac{\pi^2 NEI}{L^2} = m \frac{d_2^4}{L^2} x10^4$$

In the Formula: P — Axial allowable compressive load（N）

α — Safety factor（Value α =0.5）

E — Elastic modulus（$E = 2.1 \times 10^5 N/mm^2$）

I — Minimum secondary moment of lead screw section（$I = \frac{\pi d_2^4}{64} mm^4$）

d_2 — Minimum base diameter of lead screw（mm）

L — Mounting distance（mm）

m、N — The coefficient decided by the installation mode of ball screw

Installation method	m	N
Fixed - Fixed	19.9	4
Fixed - Supported	10	2
Fixed - Free	1.25	1/4

4.2 Yield due to tension and compression

The allowable load P for tensile or compressive stress of the ball screw is calculated by the following formula:

$$P = \sigma \times A = \sigma \times \frac{\pi}{4} d_2^2$$

In the Formula: P — Allowable load for tensile or compressive stress（N）

σ — Allowable stress（$\sigma = 147N/mm^2$）

A — Area of the lead screw section（$A = \frac{\pi}{4} d_2^2 (mm^2)$）

d_2— Minimum base diameter of lead screw（mm）

4.3 Permanent deformation of the ball contact area

If the axial load on the ball contact part is excessive, the ball will be squashed, causing the rolling surface of the ball to sink. After that, even if the load is removed, it cannot fully recover to the original state, but forming permanent deformation. During selection, it is important to ensure that the maximum axial load is much smaller than the rated axial static load.

(1) Axial static load rating（C_{oa}）:

The static axial load applied when the maximum contact stress point between the ball and raceway produces a total permanent deformation of 0.0001 times the ball diameter.

(2) Maximum axial load（F_{max}）:

The relationship between the rated static load and the maximum axial load is as below:

$$F_{max} = \frac{C_{oa}}{f_s}$$

In the Formula: f_s — Safety factor

General value	1.2 ~ 2
Impact vibration	1.5 ~ 3

5. Calculation of allowable speed

The rotation speed of the ball screw is determined by the moving speed and the screw lead. The allowable speed can be analyzed from the following two aspects, and the lower one of the two allowable speeds is the allowable speed of ball screw.

- The rotation speed of the ball nut or ball screw that resonates with the ball screw
- Value DN of ball screw

5.1 Critical speed

n_c :The allowable speed is below 80% of the critical speed.

n_{cr} : The rotation speed of the ball nut or ball screw that resonates with the ball screw

The number of revolutions of the ball screw is determined by the necessary transfer speed and the screw lead. Resonance will occur in case of excessive speed of the ball screw, which may affect the normal operation of equipment. In order to ensure the normal use of equipment and make $n_{max} \le n_c$, the calculation formula below is used:

$$n_c = \alpha \times \frac{60\lambda^2}{2\pi L^2} \times \sqrt{\frac{EI * 10^3}{\rho A}} = f * \frac{d_2}{L^2} * 10^7$$

In the Formula: n_c — Allowable speed（r/min）

α — Safety factor（Value α =0. 8）

E — Elastic modulus（$\mathrm{E} = 2.1 \times 10^5 N/mm^2$）

I — Minimum secondary moment of the lead screw section $(\mathrm{I} = \frac{\pi d_2^4}{64}(mm^4))$

d_2 — Minimum base diameter of lead screw（mm）

L — Mounting distance（mm）

ρ — Material density（$\rho = 7.65 \times 10^{-6} kg/mm^3$）

A — Area of the lead screw section $(A = \frac{\pi}{4} d_2^2 (mm^2))$

f，λ：The coefficient determined by the mounting mode of ball screw、Critical speed coefficient

Installation mode	f	λ
Fixed - Fixed	21.9	4.730
Fixed-supported	15.1	3.927
fixed-free	3.4	1.875

5.2 Value DN of ball screw

At the highest speed n_{max}, the pitch diameter $d_m \times n_{max}$ of ball screw, i.e. the value DN mainly affects the noise, working temperature, life span and circulation system of the ball screw.

$$d_m \times n_{max} \le DN \quad \text{(Acceptable value)}$$

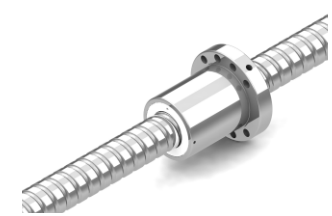
In the Formula: d_m — Pitch diameter of ball screw（mm）

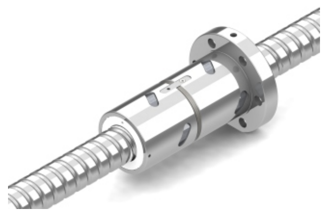
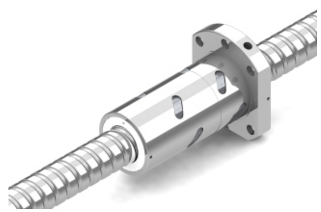
n_{max} — Maximum speed of ball screw（r/min）

Circulation mode	Allowable value DN
Internal circulation (Y type)	80000
External circulation (Type C)	120000

6. Selection of ball nut model

The type and model of nut may be determined by selecting the accuracy, guide, expected dynamic axial load and the minimum base diameter of the ball screw.

Circulation mode	Model	Preload mode	Schematic diagram
External circulation (end-back)	FC	Without preload	
	FCZ	Oversize ball preload	
	FCD	Double nut preload	

<table>
<tr><th>Circulation mode</th><th>Model</th><th>Preload mode</th><th>Schematic diagram</th></tr>
<tr><td rowspan="4">Internal circulation (waist-back)</td><td>FY</td><td>Without preload</td><td rowspan="2"></td></tr>
<tr><td>FYZ</td><td>Oversize ball preload</td></tr>
<tr><td>FYD</td><td>Double nut preload</td><td></td></tr>
<tr><td>FYB</td><td>Offset preload</td><td></td></tr>
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7. Determination of preload, stroke compensation value and pretension force of ball screw

7.1 Determination of preload of the ball screw

The preload of ball screw can increase its own axial stiffness and positioning accuracy, and the large preload can effectively reduce the axial clearance caused by elastic deformation. However, if excessive preload may also lead to increased driving torque, reduced transmission efficiency, and reduced life of ball screws.

Calculation method of preload of ball screw:

$$F_P = \epsilon C_a$$

In the Formula: F_p — Preload（N）

ϵ — Preload percentage (see the table)

C_a — Dynamic axial load rating（N）

Table of preload coefficients

Preload type	Light preload	Medium preload	Heavy preload
Preload percentage ϵ	3~5%	5~7%	7~10%

7.2 Determination of stroke compensation value of the ball screw

Stroke compensation value: the difference between the target stroke and the nominal stroke, within the effective stroke.

When the ball screw adopts fixed - fixed installation mode, the calculation formula of the stroke compensation value is as follows:

$$C = \rho \Delta t L$$

In the Formula: C — Stroke compensation value（mm）

ρ — Linear thermal expansion coefficient（general value $\rho = 12 \times 10^{-6}/°C$）

Δt — Temperature rise of lead screw shaft（°C）

L — Lead screw shaft length（mm）

7.3 Determination of pretensile force of ball screw

When the ball screw runs at a high speed, the heat produced will also increase, and the thermal displacement due to the temperature rise will lead to the failure to meet the high-precision requirements, so it needs to be pre-stretched.

When the ball screw adopts fixed - fixed installation mode, the calculation formula of pretensile force is as follows:

$$F_t = \rho \Delta t \frac{\pi d_2^2 E}{4} = 1.95 \Delta t d_2^2$$

In the Formula: F_t — Pretensile force（N）

d_2 — Base diameter of ball screw thread（mm）

E — Elastic modulus（$E = 2.1 \times 10^5 N/mm^2$）

8. Stiffness check of ball screw transmission system

The stiffness of transmission system refers to the ratio of axial load to axial displacement of ball screw. Good stiffness is favorable for effectively improving the performance characteristics of ball screw.

For checking the stiffness of transmission system, the following steps are to be followed: the axial stiffness of ball screw, the estimated stiffness of transmission system, determination of axial static stiffness R_0,according to the design requirements, check of the stiffness of transmission system.

8.1 Axial stiffness of ball screw R_s

Axial stiffness: the ability of the ball screw to resist axial deformation (the load required per unit of deformation).

In different installation modes, the calculation methods vary accordingly:

8.1.1 When installation mode is Fixed - Fixed

The calculation formula is as follows:

$$R_{s1}=\frac{\pi d_2^2 E}{4l_{s1}10^3}\times\frac{l_s}{l_s-l_{s1}}$$

In the Formula: R_{s1} — Tensile stiffness of ball screw（$N/\mu m$）

l_s — Distance between bearing points（mm）

l_{s1} — Distance between the nut and fixed end

E — Elastic modulus（$E=2.1\times10^5 N/mm^2$）

Among them, the maximum rigidity appears when the ball nut is located at both ends of the stroke:

$$R_{s1max}=\frac{\pi d_2^2 E}{4l_{s1min}10^3}\times\frac{l_s}{l_s-l_{s1min}}$$

The minimum rigidity appears when the ball nut position supports the midpoint $l_{s2}=\frac{l_s}{2}$：

$$R_{s1min}=\frac{\pi d_2^2 E}{l_s 10^3}=660\frac{d_2^2}{l_s}$$

8.1.2 When the installation mode is fixed-supported or fixed-free

The calculation formula is as follows:

$$R_{s2}=\frac{\pi d_2^2 E}{4l_{s2}10^3}$$

Among them, the maximum rigidity appears when the ball nut is located at the starting point of the effective stroke of the fixed end:

$$R_{s2max}=\frac{\pi d_2^2 E}{4l_{s2min}10^3}$$

The minimum rigidity appears when the distance between the ball nut and the fixed bearing end:

$$R_{s2min}=\frac{\pi d_2^2 E}{4l_s 10^3}=165\frac{d_2^2}{l_s}$$

8.2 Estimate stiffness of the transmission system R

The stiffness of the transmission system is a comprehensive parameter to measure the stiffness of a ball screw, which is determined by a number of specific stiffness values. The calculation formula is as follows:

$$\frac{1}{R}=\frac{1}{R_s}+\frac{1}{R_{nu}}+\frac{1}{R_b}+\frac{1}{R_h}$$

In the Formula: R — Stiffness of the transmission system（$N/\mu m$）

R_s — Axial stiffness of ball screw（$N/\mu m$）, according to installation modeDivide into R_{s1} or R_{s2}

R_{nu} — Axial static stiffness of ball nut（$N/\mu m$）, calculation methodIs available in GB/T 17587.4-2008

R_b — Axial stiffness of supporting bearing（$N/\mu m$）, bearing sample can be queried， This and related information

R_h — Stiffness of nut seat and bearing support seat（$N/\mu m$）, which is generally ignored

In the actual calculation process, only the first three items have the greatest impact on the transmission stiffness, while the others can be ignored. The calculation formula is simplified as follows:

$$\frac{1}{R}=\frac{1}{R_s}+\frac{1}{R_{nu}}+\frac{1}{R_b}$$

8.3 Determination of the axial static stiffness R_0 to the design requirements

As for the feeding transmission system of the CNC machine tool, the comprehensive stiffness must be designed to meet the machining accuracy of the machine tool. The reverse difference of the CNC machine is largely determined by the friction dead zone error, which is smaller than the reverse difference required by the feeding transmission system and the repeated positioning accuracy of machine tool. In this case, the calculation formula of the axial static stiffness is as follows:

$$R_0=\frac{1.6F_0}{\delta_1}=\frac{1.6\mu_0 mg}{\delta_1}$$

In the Formula: R_0 — Stiffness required by design（$N/\mu m$）

F_0 — Static friction force of feeding system axial starting guide（N）

δ_1 — Repeated positioning accuracy of machine tools（μm）

8.4 Stiffness check of the transmission system

The estimated stiffness of the transmission system R is compared with the axial static stiffness required by the design R_0. The stiffness is checked to be qualified when $R \geq R_0$; while it is considered as unqualified when $R < R_0$.

9、Accuracy check of ball screw

The installation mode of the ball screw and the position of the ball nut are different. When the axial stiffness of ball screw is different, the transmission system stiffness of the ball screw will also change. For the accuracy check of the ball screw, the following steps should be followed: first determine the maximum and minimum stiffness of the ball screw transmission system to calculate the positioning error, and then determine the required accuracy parameters according to the type of its control system, and finally determine the accuracy according to GB/T 17587.3-2017.

The calculation formula of the positioning error caused by the change of transmission stiffness is as follows:

$$\delta_k = F_0\left(\frac{1}{R_{min}} - \frac{1}{R_{max}}\right)$$

In the Formula: δ_k — Positioning error（mm）

9.1 For the ball screws controlled by the open loop control system

The accuracy parameters are calculated as follows:

$$e_p + V_{up} \leq 0.8\ (\delta_d - \delta_k)$$

$$e_p + V_{300p} \leq 0.8\ (\delta_{300} - \delta_k)$$

9.2 For the semi-closed loop control systems

The accuracy parameters are calculated as follows:

$$V_{up} \leq 0.8(\delta_d - \delta_k)$$

$$V_{300p} \leq 0.8(\delta_{300} - \delta_k)$$

In the Formula: δ_d — Positioning accuracy（mm）

δ_{300} — $300mm$ Positioning accuracy（mm）

9.3 For closed-loop control systems

It depends on the grating, numerical control system, ball screw contact stiffness, torsional stiffness and other parameters, and the positioning accuracy after system compensation is greatly improved.

10、Calculation of life span of ball screw

Life span of ball screw L: in a set of ball screws, the number of revolutions that the ball nut can rotate relative to the ball screw before the first fatigue of the material of ball screw, ball nut or ball.

Rated life span of ball screw L_{10}: for a set of ball screws operating under the same conditions for approximately the same set of ball screws, the specified life span that can be achieved when the probability of no fatigue is 90%.

The calculation formula of the life span L and rated life L_{10} is as follows:

$$L = \left(\frac{C_a}{F_a f_w}\right)^3 \times 10^6$$

$$L_t = \frac{L}{60n}$$

In the Formula: C_a — Dynamic axial load rating（N）

F_a — Axial load（N）

L_t — Lifetime（h）

f_w — Load factor (see table)

n — Number of revolutions（r/min）

Load factor f_w

Smooth operation, without impact	General operation	Operation with vibration, with impact
1.0~1.2	1.2~1.5	1.5~3.0

11、Model selection and calculation of motor

11.1 Calculation of dynamic preload torque (reference torque) T_{p0}

Dynamic preload torque T_{p0}: the torque required to rotate the ball nut relative to the ball screw, for the preloaded ball screw under no external load, regardless of the friction torque of sealing element, the calculation formula is as follows:

$$T_{p0} = k\frac{F_{a0} P_h}{2\pi} \approx 0.014 F_{a0}\sqrt{d_m P_h}$$

In the Formula: T_{p0} — Dynamic preload torque（$N \cdot m$）

F_{a0} — Preload（kN）

d_m — Pitch diameter（mm）

φ — Lead angle（°）

k — Torque coefficient of ball screw, $k = \frac{0.05}{\sqrt{tan\varphi}}$

11.2 Calculation of maximum dynamic preload torque T_{pmax}

Variation of dynamic preload torque ΔT_p :when the ball screw rotates continuously relative to the ball nut, the actual dynamic preload torque will experience fluctuation at the theoretical dynamic preload torque, the allowed fluctuation range is called the variation of dynamic preload torque ΔT_p. The specific value is shown in the table, wherein L_u/d_0 refers to the length/diameter ratio.

Variation of dynamic preload torque of the ball screw ΔT_{p0}

Ball screws							
$T_{p0}(N\cdot m)$		Standard class of tolerance					
		0	1	2	3	4	5
>	⩽	ΔT_{pp}(% value of T_{p0}) $\frac{L_u}{d_0} \le 40$, $L_u \le 4000mm$					
0.2	0.4	30	35	37	40	45	50
0.4	0.6	25	30	32	35	37	40
0.6	1.0	20	25	27	30	32	35
1.0	2.5	15	20	22	25	27	30
2.5	6.3	10	15	17	20	22	25
6.3	10	—	—	—	15	17	20
>	⩽	ΔT_{pp}(% value of T_{p0}) $40 < \frac{L_u}{d_0} \le 60$, $L_u \le 4000mm$					
0.2	0.4	40	40	45	50	55	60
0.4	0.6	35	35	37	40	42	45
0.6	1.0	30	30	32	35	37	40
1.0	2.5	25	25	27	30	32	35
2.5	6.3	20	20	22	25	27	30
6.3	10	—	—	—	20	22	25

*（GB/T 17587.3-2017 E12）

The maximum dynamic preload torque is the dynamic preload torque when the fluctuation value is the maximum, and its calculation formula is as follows:

$$T_{pmax} = (1 + \Delta T_{pp})T_{p0}$$

11.3 Calculation of driving torque T

Driving torque T :the torques required for the ball screw to overcome the axial load generated by the workbench mass and to drive the reciprocating movement of drive nut. The calculation formula can be divided into the following two circumstance:

11.3.1 Drive torque at uniform speed T_1

（1） Converting from rotational motion to linear motion is positive transmission,The drive torque T_1 is calculated as follows:

$$T_1 = \frac{F_a P_h}{2\pi\eta_p} \times 10^{-3}$$

$$\eta_p = \frac{tan\varphi}{tan(\varphi + arctan\mu')}$$

In the Formula: F_a — Axial working load（kN）; $F_a = F + F_b$

F_b — Axial force of the work bench; $F_b = \mu mg$

η_p — Positive drive efficiency

φ — Lead angle

μ' — Equivalent friction coefficient, $\mu' = 0.0025 \sim 0.0035$

（2）Converting from linear motion to rotational motion is positive transmission,The drive torque T_1' is calculated as follows:

$$T_1' = \frac{F_a P_h \eta_p'}{2\pi} \times 10^{-3}$$

$$\eta_p' = \frac{tan(\varphi - arctan\mu')}{tan\varphi}$$

11.3.2 Drive torque for acceleration T_2

The maximum torque required for accelerating the drive of ball screw can be derived from the following formula:

1) During horizontal use:

$$T_2 = J_L \cdot \dot{\omega} + \frac{F_b P_h}{2\pi\eta_p} \times 10^{-3}$$

2) During vertical use:

$$T_2 = J_L \cdot \dot{\omega} + \frac{(F_b + mg)P_h}{2\pi\eta_p} \times 10^{-3}$$

$$J_L = \frac{\lambda}{\lambda - 1} J_{G1} i^2 \left[J_{G2} + J_s + J_u + m\left(\frac{P_h}{2\pi}\right)^2\right]$$

In the Formula: $\dot{\omega}$ — Angular acceleration of the motor (rad/s^2)

J_L — Inertia torque applied to the motor (kg/m^2)

J_{G1} — Inertia torque of gear 1 (kg/m^2)

J_{G2} — Inertia torque of gear 2 (kg/m^2)

J_s — Inertia torque of ball screw (kg/m^2)

J_u — Inertia torque of coupling (kg/m^2)

λ — Safety factor of inertia ratio, value 2~8(for precision machine tools, it is recommended to beless than 3)

11.3.3 Inertia torque of ball screw, gear and other cylinders

The calculation formula is as follows:

$$J_b = \frac{\pi \cdot \rho}{32} D^4 \cdot L$$

In the Formula: J_b — Cylinder moment of inertia $(kg \cdot cm^2)$

ρ — Material density (kg/cm^3)

D — Cylinder diameter (cm)

L — Cylinder length (cm)

11.4 Selection of motor

(1) The rated speed of the motor is greater than or equal to the maximum working speed of the motor, $N_m \geq N$;

(2) The rated torque of the motor is greater than or equal to the driving torque at constant speed, $T_N \geq (T_{pmax} + T_1 + T_u)i$;

(3) The peak motor torque is greater than or equal to the driving torque for acceleration $T_{Nmax} \geq (T_{pmax} + T_2 + T_u)i$;

(4) Motor moment of inertia $J_m \geq \frac{J_L}{\lambda}$.

Note: T_u is the friction torque of the supporting bearing, the specific data can be consulted by the relevant manufacturers.

12、Notes for use of ball screws

12.1 Lubrication

Lubrication is to apply lubricant between the contacted surfaces to form a lubricant film, reducing the friction and wear. The lubrication effect will directly affect the temperature rise of lead screw. The commonly used lubricants are divided into two main categories: lubricants and greases.

(1) Lubricants

In the case of high speed light and medium load, the ball screw usually use the lubricants with a viscosity index range of 32~68cst at 40℃; in the case of low speed and heavy load, it usually uses the lubricants with a viscosity index range of 90cst if the temperature is above 40℃. When the equipment is working, the centralized lubrication oil supply system is used to inject certain amount of lubricating oil into the ball screw regularly, so that the ball screw has reliable lubrication and small friction coefficient, and demonstrates good cooling and cleaning effect.

(2) Grease

Before delivery, the nuts of HTPM ball screws are pre-injected with No.2 lithium base grease, showing good adhesion and retention. It is advised to apply 00, 0 or 1 lithium base grease to the running equipment through a centralized lubrication oil supply system. Important Note: The grease used must not contain graphite, molybdenum disulfide and other solid lubrication components.

12.2 Sealing

If there is entry of dirt or foreign matter into the ball nut, it will lead to serious wear of ball screw, resulting in reduced life span of the ball screw. HTPM ball screws is equipped with labyrinth seal ring as standard parts before delivery. Users are recommended to provide screw protective cover, armor shield, airtight protection and other measures in the operating environment to prevent the entry of dirt or foreign matters.

12.3 Precautions for installation and use

(1) When installing the ball screws, the bearing support seat holes at both ends need to be concentric with the nut seat holes. Forced installation without alignment is prohibited. Keeping them in natural concentric state can ensure that the ball screws are evenly stressed to prevent production of tipping moment.

(2) The ball nuts should be kept close to the supporting bearing as possible during installation;

(3) When the ball nuts are running within the effective stroke, a limiting device needs to be provided at both ends of the stroke to avoid the nut getting out of the ball screw and resulting in ball falling. Where the nut is out of the ball screw or the ball falls, please contact us at the first time.

Order number of HTPM ball screw

F Y D 50 10 K5 − 2280 − 1856 − 0.008

- F — Identification of nut flange: F: Flange type; R: Round type
- Y — Recirculation code: Y: Bridge Deflector; C: End Deflector; W: Tube
- D — Preload system: Z: Oversize ball preload; D: Double nut preload; B: Offset preload
- 50 — Screw shaft diameter
- 10 — Lead
- K5 — Effective ball turns
- 2280 — Total length
- 1856 — Thread length
- 0.008 — Accuracy grade: V_{300p} Lead deviation in random 300mm travel path thread length

Note: 1. We can supply P2 and above ball screws in batches;

2. Right screw is defaulted;

3. In case of special customized needs, please contact our company.

HTPM ball screw series products

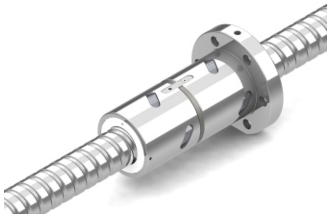
1.External circulation(End Deflector) ball screw

FCZ

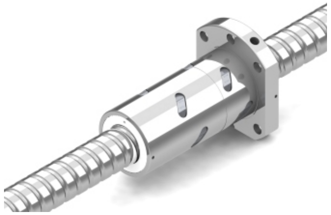
FCD

2. Internal circulation (Bridge Deflector) ball screw

FYZ

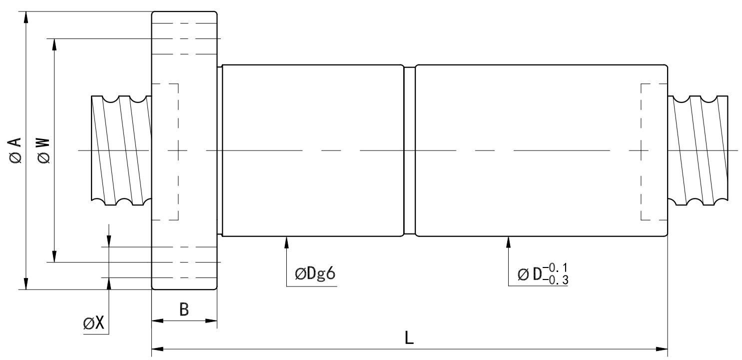


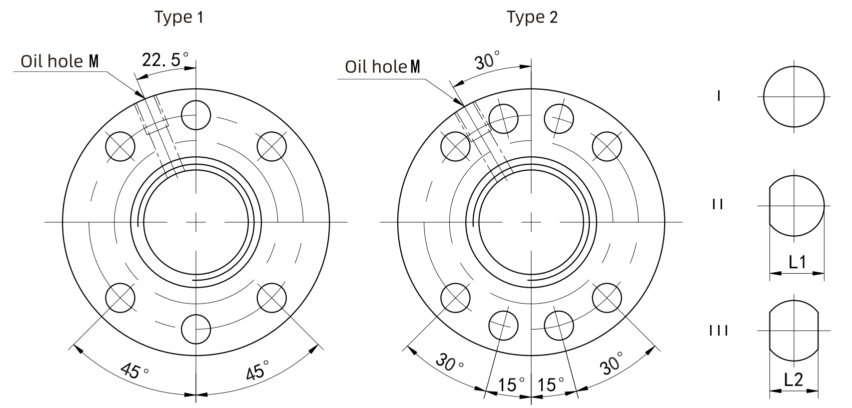
FYD



FYB

FCD series External circulation(end deflector) double nut preload ball screw



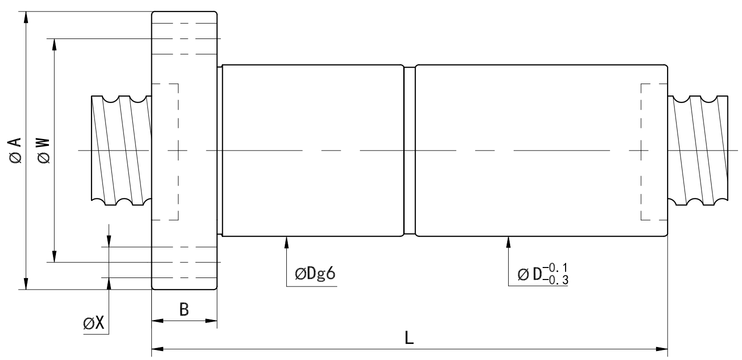


Unit: mm

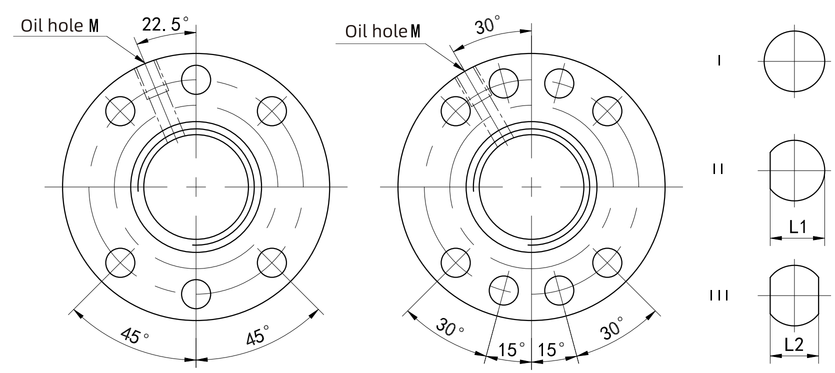
Model	Nominal diameter	Lead	Ball diameter	Ball circle diameter	Root diameter	Effective ball turns	Mounting dimensions of nuts										Dynamic load $c_a(kgf)$	Static load $c_{0a}(kgf)$	Stiffness $(kgf/\mu m)$
							D	L	Type	I (A)	II (L1)	III (L2)	B	W	X	M			
2505 K4	25	5	3.175	25.75	22.26	4	40	76	1	62	55	48	12	51	6.6	M6X1	1560	4380	61
2505 K5						5		86									1940	5465	76
2510 K3		10		25.6	22.11	3		103									1186	3200	47
2510 K4						4		123									1484	3983	58
2812 K4	28	12	4.763	29	23.76	4	50	144		80	71	62	16	65	9		2910	7600	80
2812 K5						5		168									3635	9490	100
2816 K4		16				4		146					12		6.6		2820	7370	78
2816 K5						5		178									2520	9215	98
3210 K3	32	10	3.969	32.8	28.43	3	50	105		80	71	62	16	65	9		1935	5700	72
3210 K4						4		125									2420	7125	90
3210 K5						5		145									2925	8975	106
3210 K3			4.763	33	27.76	3	54	105		87	75.5	65		71			2320	6574	68
3210 K4						4		125									2914	8244	85
3210 K5						5		145									3648	10316	106
3210 K3			6.35	33.4	26.42	3	57	118			78	69		72		M8X1	3395	8752	71
3210 K4						4		138									4258	10061	90
3210 K5						5		158									5329	13684	111
3216 K3		16				3	60	147		92	83	74		77			3452	8636	72
3216 K4						4		179									4320	10796	90
3216 K5						5		211									5415	13500	112

Note: The stiffness values are listed in the table, which are calculated when the pre-stress is 10% of the dynamic load.

FCD series External circulation(end deflector) double nut preload ball screw



Type 1 Type 2



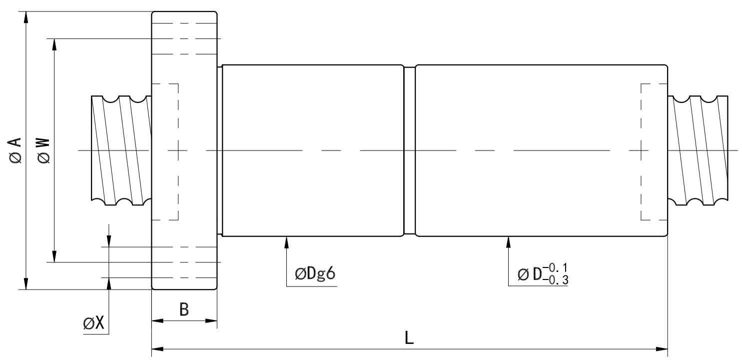
Unit: mm

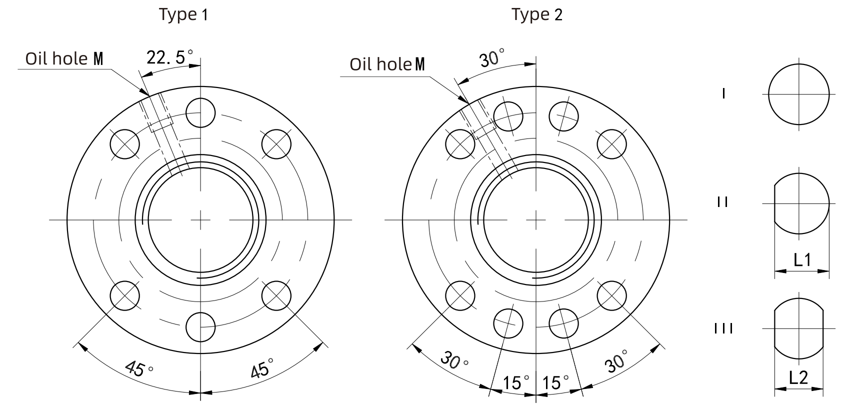
Model	Nominal diameter	Lead	Ball diameter	Ball circle diameter	Root diameter	Effective ball turns	Mounting dimensions of nuts											Dynamic load $c_a(kgf)$	Static load $c_{0a}(kgf)$	Stiffness $(kgf/\mu m)$
							D	L		Type	I (A)	II (L1)	III (L2)	B	W	X	M			
3616 K4	36	16	6.35	37.4	30.42	4	66	189		2	96	84.5	73	16	81	9	M8X1	4520	12416	100
3616 K5						5		221										5642	15513	123
3816 K5	38	16	6.35	39	32.02	5	63	189			93	81.5	70	18	78			5830	16470	127
4010 K3	40	10	6.35	41.4	34.42	3	70	118			100	87.5	75		85			3840	11165	85
4010 K4						4		138										4815	13954	106
4010 K5						5		158										5994	17460	135
4010 K6						6		178										7520	21830	166
4012 K3		12				3		124										3820	11162	84
4012 K4						4		148										4791	13940	104
4012 K5						5		172										5983	17430	133
4016 K3		16				3		157										3816	11126	83
4016 K4						4		189										4748	13893	103
4016 K5						5		221										5965	17385	134
4020 K3		20				3		181										3885	10950	85
4020 K4						4		221										4860	13710	107

Note: The stiffness values are listed in the table, which are calculated when the pre-stress is 10% of the dynamic load.

BALL SCREWS

FCD series External circulation(end deflector) double nut preload ball screw





Unit: mm

Model	Nominal diameter	Lead	Ball diameter	Ball circle diameter	Root diameter	Effective ball turns	Mounting dimensions of nuts											Dynamic load $c_a(kgf)$	Static load $c_{0a}(kgf)$	Stiffness $(kgf/\mu m)$
							D	L		Type	I (A)	II (L1)	III (L2)	B	W	X	M			
5010 K3	50	10	6.35	51.4	44.42	3	82	120		2	118	105	92	18	100	11	M8X1	4266	14162	99
5010 K4						4		140										5348	17480	124
5010 K5						5		160										6674	22110	156
5010 K6						6		180										8351	27626	195
5012 K4		12				4		148										5345	17690	129
5012 K5						5		172										6685	22110	162
5016 K3		16				3		159										4244	14110	103
5016 K4						4		191										5325	17638	128
5016 K5						5		223										6666	22044	161
5020 K3		20				3		177										4320	13926	104
5020 K4						4		217										5414	17420	130
8010 K4	80	10	6.35	81.4	74.42	4	105	140			150	132.5	115	22	130	13.5		6897	29170	168
8010 K5						5		160										8278	36462	211
8010 K6						6		180										9932	43754	264

Note: The stiffness values are listed in the table, which are calculated when the pre-stress is 10% of the dynamic load.