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Research Paper

RECIRCULATING BALL SCREW

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The demand for higher productivity and tight part tolerances requires machine tools to have faster and more accurate feed drive systems. As tried and tested technology, ball screw drive systems are still used in a majority of machine tools due to their low cost and high degree of stiffness. A high-speed ball screw drive system generates more heat and results in greater positioning error, adversely affecting the accuracy of machined parts.

Keywords: Ball screw, Selection of ball screw, Preloading of ball screw, Calculations, Design of recirculating ball screw advantages, Disadvantages, Applications

INTRODUCTION

Recirculating ball screw consists of screw and nut, the surfaces of which are separated by series of balls. The screw and the nut have approximately semi-circular thread profiles instead of conventional square or trapezoidal shape. As the screw is rotated, the balls advance in the grooves in the nut and the screw. They are collected at the end of the nut and returned back. The re-circulating ball screw is also called as ball bearing screw. Such screws are preloaded and give accurate motion due to elimination of backlash. There is no heat generation due to negligible friction. This can be used for high speeds even up to 10 m/min. The balls, screw and nut are subjected to contact stresses. The primary function of ballscrew is to convert rotary motion into linear motion or torque to thrust,and vice versa with the features of high accuracy,reversibility and efficiency

Characteristics

1. High mechanical efficiency: Most of the force used to rotate the screw shaft can be converted to the force to move the ball nut.
2. Low in wear: Because of rolling contact, wear is far less than that of sliding contact. Thus, deterioration of accuracy is extremely low.
3. Low in tear: Ball screws move smoothly enough under very slow speed. They run smoothly even under a load.

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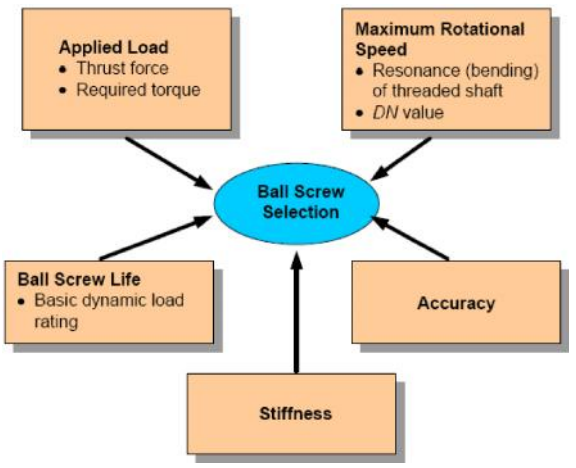
Figure 1: Ball Screw Selection Criteria



4. Estimation of life is possible: Estimation of fatigue life of ball screw under given conditions is possible because the basics of life estimation are the same as those of rolling element bearings.

5. Ball screw lead: The specifications of ball screws are standardized in ISO, JIS, etc.

Preload Methods

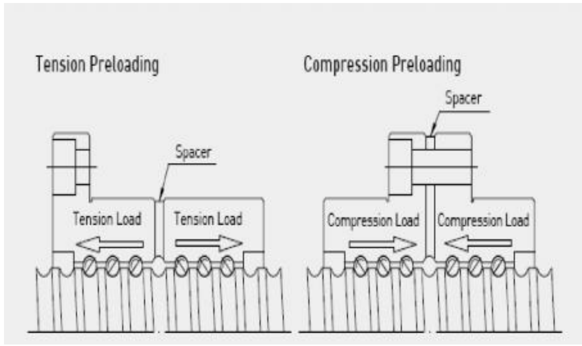
Preload: Preload is to create elastic deformations (deflections) in steel balls and ball grooves in the nut and the screw shaft in advance by providing an axial load.

Purpose of Preload: It eliminates axial play between a screw shaft and a ball nut. (Zero backlash)

It minimizes elastic deformation caused by external force. (Enhances rigidity)

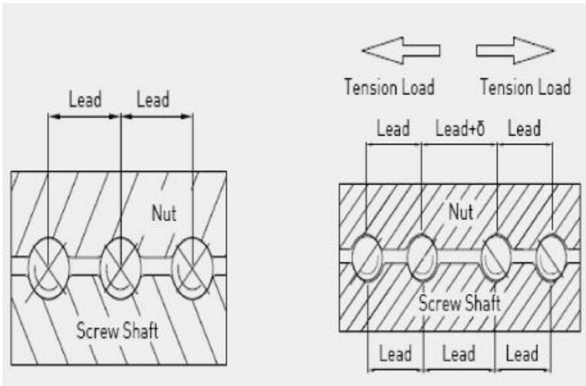
Double Nut Preloading: Preload is obtained by inserting a spacer between the two nuts. Tension preload is created by inserting an oversize spacer and effectively pushing the nuts apart. Compression preload is created by inserting an undersize spacer and correspondingly pulling nuts together.

Figure 2: Double Nut Preloading



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 to allow balls to contact at four points. The other way is called "the offset pitch preloading method". This method is replaced by double nut preloading method and has the benefit of compact single nut with high stiffness via small preload force.

Figure 3: Single Nut Preloading



Components Parts of Ball Screws

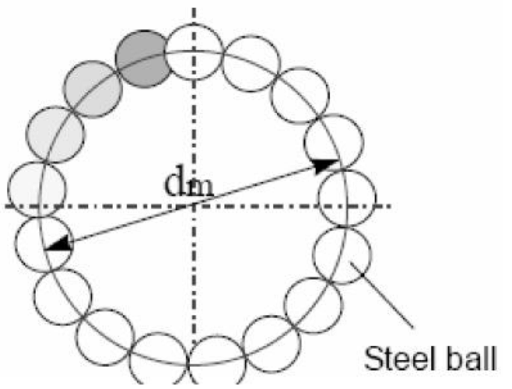
Screw Shaft

Profile of Ball Groove: The profile of ball groove looks like the shape of the roofs that are characteristic to Gothic-style buildings. It is called "Gothic arch" ball groove.

Figure 4: Profile of Ball Groove

Ball Pitch Circle Diameter: This is the diameter of a circle formed by the center of recirculating balls.

Figure 5: Ball Pitch Circle Diameter



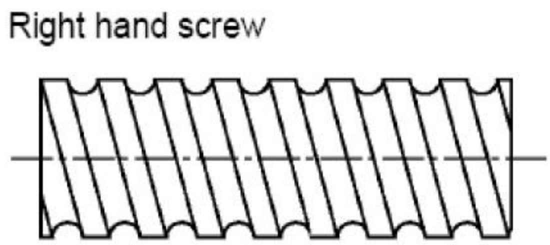
Root Diameter of Screw Shaft: This refers to the diameter formed by the bottom of ball grooves on the screw shaft. This is thinnest part of the ball screw, and it is needed to calculate the critical speed of a screw shaft.

Direction of Turns of Ball Screw Thread: There are two directions of turn, right and left hand screws. Mostly, right turn screws are used.

Right Hand Screw

If you trace the groove in clockwise looking at the screw shaft in its axial direction, the ball thread is away from you. Such screws are called right hand screws. As the illustration shows, the groove slants to the right.

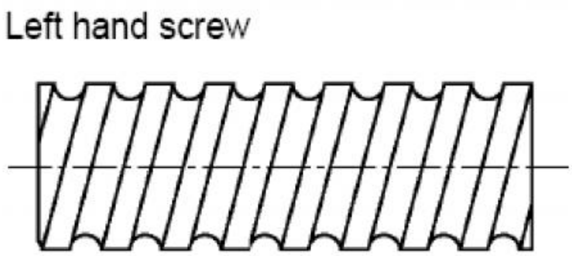
Figure 6: Right Hand Screw



Left Hand Screw

If you trace the groove in clockwise looking at the screw shaft in its axial direction, the ball thread approaches to you. Such screws are called left hand screws. As the illustration shows, the groove slants to the left.

Figure 7: Left Hand Screw

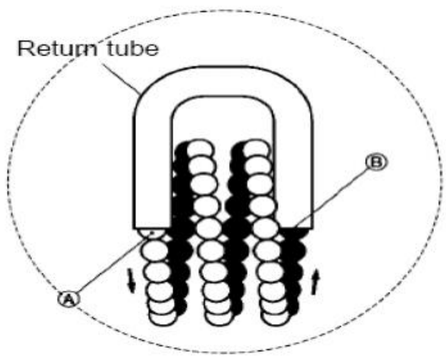


Ball Recirculation Systems and Their Parts

Profile of Ball Groove

Ball recirculation part: Return tube

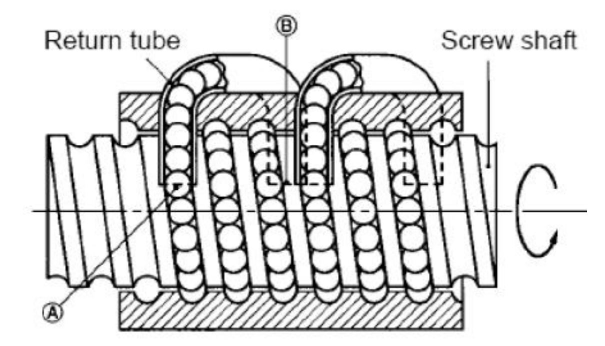
Figure 8: Profile of Ball Groove



Feature

- Applicable to wide range of combinations of shaft diameter and lead.
- Good const performance.
- Adaptability to mass production: Excellent
- Number of turns of balls/circuit: Generally 1.5 ~3.5 turns.

Figure 9: Profile of Ball Groove



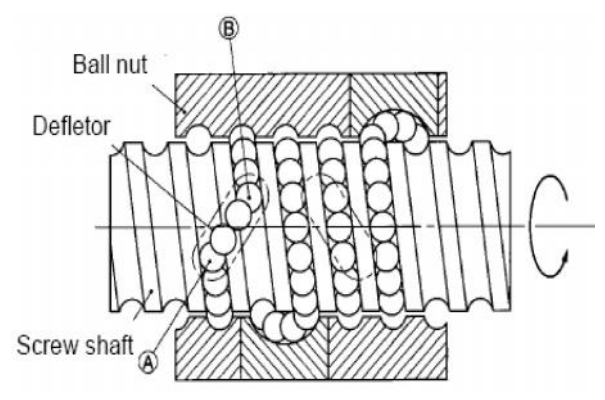
Ball Pitch Circle Diameter

Ball Recirculation Part: Deflector

Features

- Suites for fine pitch lead. Compact in ball nut diameter.
- Adaptability to mass production: Poor
- Number of turns of balls/circuit: One turn only.

Figure 10: Ball Pitch Circle Diameter



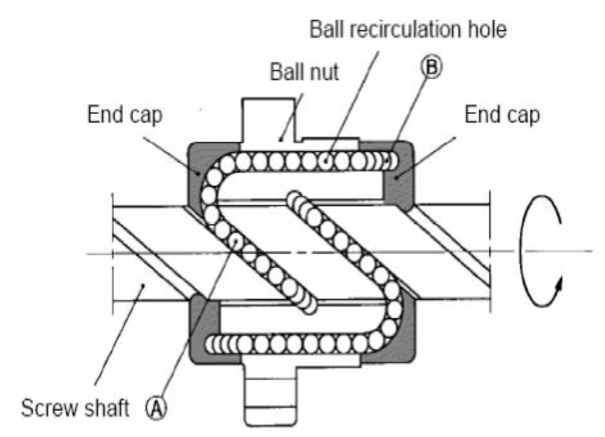
End Cap Type

Recirculation part: End cap (Ball recirculation hole is provided in the ball nut.)

Features

- For high helix leads for which the return tube and the deflector type are not applicable.
- Not versatile in production as a die mold is required for respective models.
- Adaptability to mass production: Moderate
- Number of turns of balls/circuit: 0.7 and 1.7 turns (Generally, it is applied to a multi start thread ball screw).

Figure 11: End Cap Type



CALCULATIONS

Design of Recirculating Ball screw:

Nomenclature

R = radius (effective) of the screw thread

R_0 = distance between centerline of ball with respect to screw axis

R_1 = ball radius (mm)

R_2 = groove radius (mm)

h = depth of thread

L = length of nut (mm)

α_k = contact angle (30°-60°)

$30° \le \alpha_k \le 60°$

Q = starting axial load (N)

P = load on each ball (N)

i = No. of threads through which ball recirculate (circuit)

λ = helix angle

Z = no. of balls in each circuit

E = Young's modulus (N/mm^2)

E_1 = Young's modulus for ball (N/mm^2)

E_2 = Young's modulus for screw (N/mm^2)

σ_c = contact stress (N/mm^2)

J = contact rigidity

D_o = pitch diameter of screw (mm)

p = pitch of ball screw (mm)

q_o = intensity of pressure (N/mm2)

l = stroke length (mm)

λ_1, λ_2 = factor according to mounting method

d_1 = minor diameter of ball screw (mm)

η_1, η_2 = Factor according to mounting method.

Permissible Axial Load

Buckling Load: With the ball screw, it is necessary to select screw shaft so that it will not buckle when maximum compressive load is applied in axial direction. So buckling load can be calculated by using following equation,

$P_1 = (\eta_1.\pi^2.E.I\ 0.5)/l_b^2$

But I is given by,

$I = \frac{®}{64} \times d_1^4$

To get the diameter,

$P_1 = \lambda_1 \times d^4 \times 10^4/l_b^2$

Available Data

1. p = pitch of ball screw
2. h = depth of screw thread
3. R = radius of ball screw
4. q_o = intensity of pressure
5. L = length of the nut

$q_o = Q/[2\pi.R.(L/p).h]$

Values selected from catalogue are Q, R_1, R_2, α_k, λ, R_o.

Now,

$b = \pi \times R_o/R_1$

$m_\sigma = 1.32\text{-}3.49\ (A/B)^2$

$A/B = (1\text{-}R_1/R_2)\ (1\text{-}(R_1/R_0)\cos\alpha_k)$

$Q = (0.7\ Z\ [||\sigma const||_{permissble}/m_\sigma]^3\ ) \times (R_1^2 \times R_2^2/[E^2(R_2 - R_1)^2])$

Hence,

$Z = i \times b$

Analysis of Rigidity

K = 2000 for steel material

$$J = K\sqrt[3]{Q \cdot i^2 \cdot Do^2 / R_o}$$

Efficiency of recirculating of ball screw

$\eta = \tan\alpha/(\tan\alpha + (F_B/\cos\beta)).(1 - (\tan\alpha.F_B/\cos\beta))$

Advantages

1. Ball screws are more efficient, requiring less torque.
2. Ball screws have lower friction and run at cooler temperatures.
3. Ball screws need to be replaced less frequently.

4. Ball screws require grease or oil lubrication to achieve design life.

Disadvantages

1. Ball screws require braking systems.
2. Ball screws can have problems with vertical applications.
3. Proper lubrication is needed.
4. Ball screws require braking mechanisms to eliminate back driving.
5. Ball screws are more expensive than lead screws.

APPLICATIONS OF BALL SCREWS

Ballscrews are used in the following fields:

1. CNC Machinary-CNC machine centre, CNC lathe, CNC milling machine, CNC EDM, CNC grinder, boring machine, etc.
2. Percision machine tools-Milling machine, Grinder, Gear manufacturing, Planer, etc.
3. Industrial Machinary-Printing machine, Paper processing machine , Textile machine, Special purpose machine, etc.
4. Electronic machinery-Robot measuring instrument, X-Y tables, medical equipments, Factory automation equipments, etc.
5. Aerospace industry-Aircraft flaps, thrust open-close reverser, fin actuator, etc.

CONCLUSION

The paper discusses about the Reciprocating Ballscrew, a high accuracy and precision motion is obtained. It has various advantages like High efficiency and reversibility, Backlash elimination and High Stiffness, Predictable Life Expectancy, Low starting torque and smooth running, Quietness, etc. The methods of Preloading of Reciprocating Ballscrew that consists of Double nut preloading, Single nut preloading. Ballscrews are used on various machine tools such as CNC Machining Centre, CNC Lathe, Industrial robots, Semiconductor machines, other machines like Measuring machine, Transporting machine, welding machine, etc., and Selection criteria of Ballscrew, Basic Calculations of Ballscrew like Analysis of rigidity, Efficiency of Reciprocating Ballscrew

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