Review on Comparative Analysis of Ball Screw & Lead Screw

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Abstract - A ball screw uses recirculating balls to minimize friction and maximize efficiency. Design of ball screw is more complex, and requires hardened precision bearing surfaces and a ball recirculation mechanism.

A lead screw has low coefficients of friction between sliding surfaces. Lead screw is compact in size. It offers design flexibility, corrosion resistant and can be made to self-lock for vertical applications.

It is possible to design lead screw in optimum way if it is in eccentric loading. The main difference between a ball screw and a lead screw is in the way the load is carried between the moving surfaces. With the increase of screw speed, ball screw pair of noise levels are increasing, and the higher the speed, the faster sound pressure increase. Lead screw has relatively straight-forward geometry, performance and offers flexibility to be adapted to the needs of most applications. While there are many applications that require the high stiffness, thrust capacity and absolute accuracy of ball screws.

Key Words: **Lead screw, ball screw, threads, efficiency, accuracy, friction**

1. INTRODUCTION

1.1. Lead screw

Lead screws are threaded rods that are fitted with a nut. There are many types of threads used, but commonly used in industry is the Acme lead screw. Because the ACME thread is an industry standardized thread style, it is easily interchanged with parts from various manufacturers. The basic function of a screw is to convert rotary input motion to linear output motion. The nut is stationary and as the screw rotates, the nut moves forward and backward. Lead screw drive systems are available in a variety of sizes and tolerances. Contact is primarily sliding, resulting in relatively low efficiency and a wear rate proportional to usage.

1.2. Details of lead screw

i. Lead screws can operate at 100% duty cycle at light loads and moderate speeds, or they can run at lower duty with either high load and low rpm or low load and high rpm, but not both.
ii. Lead screw has more backlash as compared to ball screw.
iii. The previously referenced PV factor is the product of the pressure and velocity between the nut and screw. It helps to determine the load, speed and duty cycle that the nut can handle.
iv. Lead screw is to move the turret lathe by a précised increment for every rotation of the screw. As a result of this it allows the machine to generate threads on a work piece and helps in generating precise dimensions, and also to maintain a constant rate of metal removal.

Fig. 2. Lead Screw

1.3. The advantages of a lead screw are as follows

i. Large load carrying capability
ii. Simple to design.
iii. Easy to manufacture and no specialized machinery is required.
iv. Precise and accurate linear motion.

v. Smooth, quiet in operation.
vi. Low maintenance.
vii. They are self-locking.

1.4. The disadvantages of a lead screw are as follows

i. They have poor efficiency.
ii. Due to high friction between nut and screw, wear and tear is high.

2. Recirculating ball screw

The ball screw drive is an assembly that converts rotary motion to linear motion. It consists of a ball screw and a ball nut package as an assembly with recirculating balls. The interface between the ball screw and the nut is made by balls. With rolling elements, the ball screw drive has a very low friction coefficient, so the efficiency is greater than 90%. The forces transmitted are distributed over a large number of balls, giving a low relative load per ball comparatively [2]. Ball screw system is one of critical components in the advanced manufacturing with high accuracy requirement. Example- It is mostly used in CNC machine.

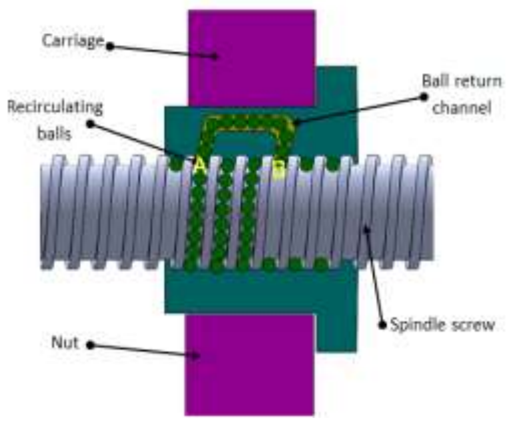


Fig.1. Ball Screw

2.1. Advantages of recirculating ball screw

i. They have very high efficiency (greater than 90%).
ii. No stick and slip phenomenon which results in durability.
iii. It has negligible wear and tear.
iv. It requires less starting torque.
v. They can be used for high speed operations.
vi. They can be easily preloaded to eliminate backlash.
vii. Noiseless operation.
viii. They have high reliability and durability.
ix. Their load carrying capacity is more than power screw of the same size.

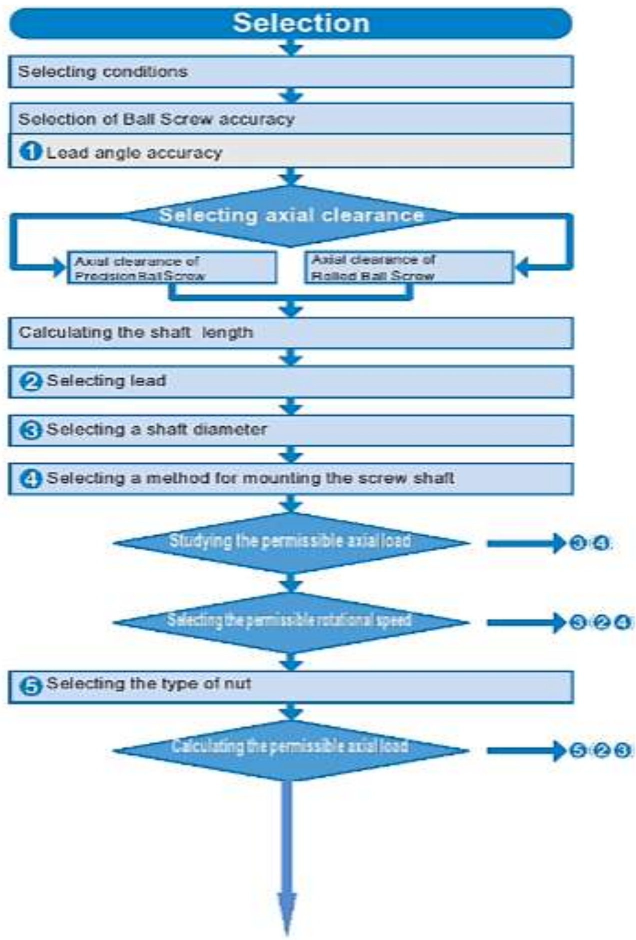
2.2. Disadvantages of recirculating ball screw

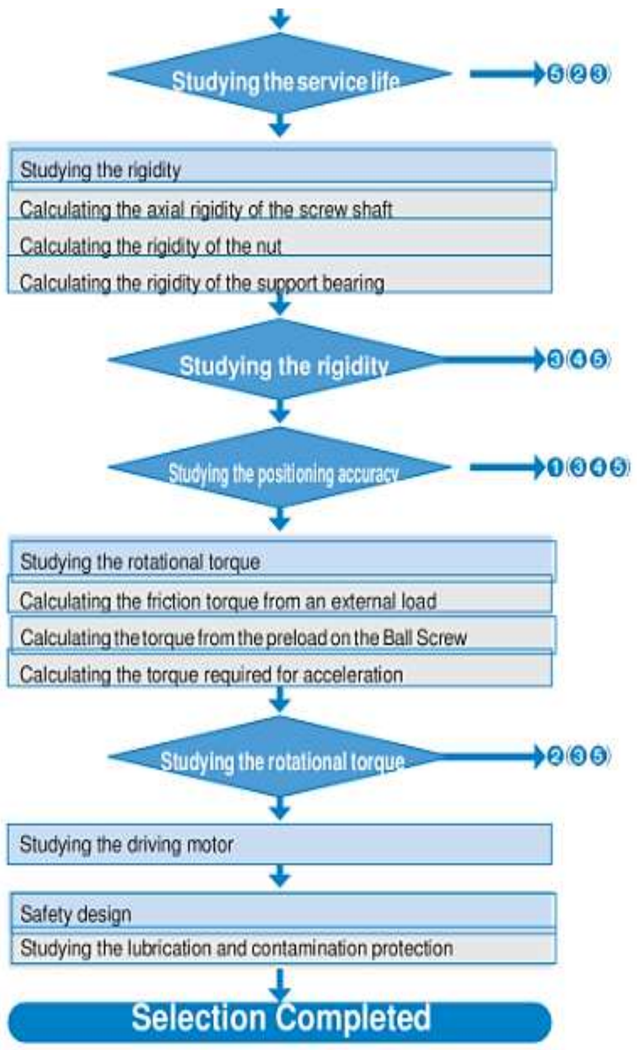
i. They are more costly than lead screw.
ii. Buckling of screw is serious problem at critical speed.
iii. They require thin film lubrication for satisfactory operation.
iv. They require periodic overhauling to maintain their efficiency.
v. They do not have self-locking properties [5].

3. Methodology

3.1 Ball screw selection

When selecting a Ball Screw, it is necessary to make a selection while considering various parameters. The following is a flowchart for selecting a Ball Screw [6].





3.2 Lead screw selection

1. Applied load

Axial load

$$F_b = f_b\left(\frac{d_r^4}{L_c^2}\right) \times 10^4$$

$F_b = maximum\ compressive\ (buckling)\ load$

$f_b = factor\ based\ on\ end\ support\ bearing$

$d_r = root\ diameter\ of\ screw\ (mm)$

$L_c = unsupported\ length\ of\ screw\ (mm)$

2. Critical speed

The critical speed will vary with the diameter, unsupported length, end fixity and rpm. Since critical speed can also be affected by shaft straightness and assembly alignment, it is recommended that the maximum speed be limited to 80% of the calculated critical speed.

$$n_c = f_c\left(\frac{d_r}{L_c^2}\right) \times 10^7\ (min^{-1})$$

Where, $n_c = critical\ speed\ (RPM)$

$f_c = factor\ based\ on\ end\ support\ bearing$

$d_r = root\ diameter\ of\ screw\ (mm)$

$L_c = unsupported\ length\ of\ screw\ (mm)$

3. PV equation

$$P = \frac{F_A}{A}$$

Where, P= pressure between screw and nut (Mpa)

$F_A = axial\ load\ on\ nut\ (N)$

A= area of contact

$$V = l_{hr}.rpm$$

Where, V=linear velocity between screw and nut (m/s)

l_{hr} = helix length per screw revolution (m)

rpm = required rotational speed of screw

4. Consider back driving

$$T_b = \frac{(F.P.\eta_2)}{2\pi}$$

Where, $T_b = back\ driving\ torque\ (Nm)$

F = Axial load (N)

P = Screw lead (m)

$\eta_2 = reverse\ efficiency$

4. Literature Review

Wenjing Jinet.al (2013) discuss about the methodology for ball screw component health assessment and failure analysis. In order to classify the multiple failure modes, one full size ball screw testing machine is set up to duplicate different health conditions including four failure modes lubrication starvation, preload loss, ball screw profile wear, and re-circulation system failure. In this research study, the failure modes lubrication condition and preload loss - are studied. By applying the SOMMQE and MD to calculate the distance from testing samples to the normal baseline, this research analyses the patterns of health value distribution of different failure modes and gives some pattern indications for each type of failure mode[1].

Supriya Kulkarni et.al (2015) discusses the demand for 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[2].

Xianghong Xu and Tao Yu (2015) have done the research on Ball Screw Pair for Noise Prediction that is based on the Virtual Lab and Experimental Verification. The analysis of ball screw pair in transient dynamics model based on the virtual acoustic prediction software is done. The acoustic finite element model is established in the Lab to extract the transient dynamics analysis. It concludes that the vibration response of the ball nut pair of time domain signals, and carries on the vibration signals of Fourier transform to obtain the frequency domain. As acoustic finite element boundary conditions are imposed to the acoustic model, which using acoustic finite element method. At last, the analysis of ball screw pair of outside sound field sound pressure value and experimental verification [3].

Robert Lipsett discusses why lead screws are the best fit for many linear motion applications and how to rightly apply them. It concludes that lead screws provide a versatile and economical linear motion solution. Lead screws have relatively straight-forward geometry and performance and offer the flexibility to be adapted to the needs of most applications. The demand for higher productivity requires machine tools to have faster and more accurate feed drive systems [4].

Zhe Du et.al (2016) has done the study of Dynamic characteristics of a ball screw with a load disturbance. The dynamic character of ball screw is the key factor that influences the machining accuracy of numerical control machine tool. To improve the dynamic characteristics of the NC machine tool, it is necessary to study the dynamic characteristics of a ball screw. In this paper, the kinematics of a ball screw mechanism is studied to find the dynamic process of the drive, and the load disturbance is considered to analyze the contact deformation based on the Hertzian contact theory. The velocity relationships among the ball, screw, and nut are analyzed, and the influence of the contact deformation on the dynamic characteristics is simulated and investigated experimentally. The results show that the relationships between the contact deformation, which is affected by the material characteristics, the contact angle, and the load of nut are nonlinear. The contact deformation is a factor that cannot be ignored when considering the dynamic machining error of high-speed and high-precision machine tools [5].

CONCLUSIONS

Reciprocating ball screw has high accuracy and precision motion as compared to lead screw. It has various advantages like high efficiency, reversibility, backlash elimination and high stiffness over a lead screw. Ball screw has negligible wear and tear whereas lead screw has comparatively high wear and tear. They both are used when it is necessary to change rotary motion to linear motion. Since the balls can rotate, there's less friction in ball screw as compared to lead screw.

However, the lower friction inherent in ball screw designs means they produce less heat, and therefore, can withstand higher duty cycles than lead screws can. In fact, duty cycle is only considered in ball screw selection when determining the amount of travel that the screw will achieve in its life. On the other hand, duty cycle and heat generation must always be taken into account when selecting a lead screw.

With recirculating steel balls to support the load, ball screws have a higher load capacity than comparably sized lead screws with plastic or polymer nuts. Lead screws with bronze nuts can drive heavier loads, but as the load increases, so does friction. And higher friction means lower duty cycle. Also related to load, ball screw sizing is based on the L10 bearing life equation, which provides a statistically proven estimation

of the screw's life, in meters or rotations traveled. The wear characteristics of a lead screw make life nearly impossible to predict. Lead screws with plastic nuts can be selected based on their PV value, but this gives a range of pressures and velocities that the screw can withstand; not an estimation of life.

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