3.6 BALL SCREWS

Ball screws are primarily employed in feed mechanism of CNC machine tools. When compared with conventional trapezoidal and Acme screws, the ball screws provide many advantages, which are listed below:

(a) In a ball screw, the load between the threads of the screw and the nut is not transmitted by direct contact, but through intermediate rolling members (spherical balls). The balls rotate between the helical grooves of the screw and nut in a manner akin to their function in ball bearings. An essential feature of almost all ball screws is the provision of recirculation of balls.

(b) Low coefficient of friction: It is of the order of 0.004 as compared to 0.1 to 0.5 which is typical of sliding friction power screws. Wear is therefore less and there is very little need for frequent adjustment.

(c) Higher transmission efficiency (2-9 times) which is particularly marked at low values of helix angle of screw ($2^o - 5^o$), that are typical of power screws. This high efficiency allows larger thrust loads to be carried with less torque.

(d) Friction force is virtually independent of the travel velocity and the friction at rest is very small; consequently, the stick-slip phenomenon is absent, ensuring uniformity of motion.

(e) By preloading the assembly, clearances and consequent backlash can be eliminated and the axial stiffness of the ball screw can be increased. It should, however, be noted that the axial stiffness of an unpreloaded ball recirculating screw is less than that of an ordinary power screw. The accuracy of the ball screw is also high.

i) ***General Arrangement Of Ball Screws :*** The basic idea of ball screw is to interpose a series of bearing balls between the screw and the nut. These balls roll in the grooves as the nut or screw moves and the rolling friction thus replaces the sliding friction of the conventional acme or trapezoidal screws.

As shown in Fig 3.16 the balls rolling in the grooves exit from the trailing end of the nut, and are picked up by the return tube inserted from outside and are recirculated into the leading end of the nut.

There are also systems in which the rolling balls circulate within the nut.

The ball screws can have circular or gothic arch grooves as shown in Fig 3.17.

Gothic arch grooves have a small axial clearance when they are used with a single nut, while circular arch grooves allow little axial deformation and a greater load capacity.

The greater the number of balls in a circulating system, the greater is the friction resistance. Therefore, use of an excessive number of balls is not recommended from design point of view.

ii) ***Nut Configurations :*** Ball screw nuts are available in different types:

(a) Round flanged nut with embedded tube for return of the balls.

(b) Round cylindrical nut with embedded tube.

(c) Small outside diameter flanged nut with outside tube.

(d) Rectangular nuts.

Nuts can be a double nut or single nut or simple type nut (single pre-load type).

iii) ***Mounting Methods :*** There are 4 distinct methods of mounting ball screws.

Mounting conditions	Application
One end fixed other end free	Low speed rotation Small screw life
Both ends supported One end fixed other end supported	Medium speed of rotation Medium speed high accuracy
Both ends fixed	High speed rotation High accuracy

The mounting method is in general determined from the view point of machinery design. However, careful consideration has to be given to it because the supporting method has a direct relation to screw stiffness, critical speed requirements and the allowable column loading, thus affecting even the selection of screw diameter.

iv) ***Materials And Heat Treatment :*** Table 3.4 shows the recommended materials and heat treatment for ball screw and nut. The ends of ball screws are usually kept soft to enable machine tool manufacturers to carry out proper sizing of length.

v) ***Preloading :*** A certain amount of radial or axial clearance exists in ball screws of the single nut type. When thrust loads are applied, the balls and grooves are deformed slightly because the balls are

TABLE 3.4 Materials and heat treatment of ball screw and nut

	Material		Heat treatment	Hardness
	BS	DIN		
Screw Shaft	EN 19 EN 9	50CrMo4 C55	Induction Hardened	HRC 58-62
Nut	EN 362	20MnCr5	Case Hardened	HRC 58-62
Ball	EN 31	10Cr6		HRC 62-66

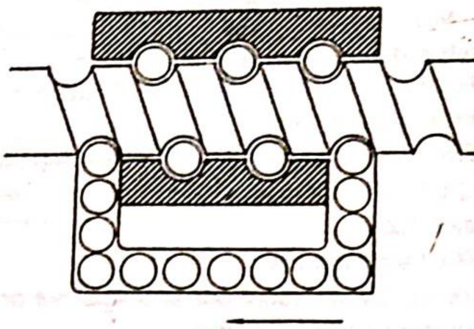

Fig. 3.16 Recirculation of balls in ball screws

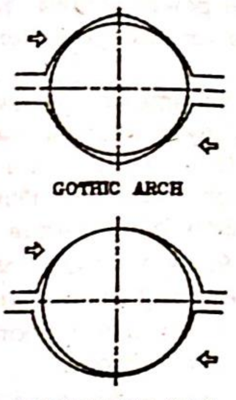

Fig. 3.17 Profiles of ball screws

pressed down to the grooves. "Backlash" is the sum of the axial clearance and the deformation caused by the axial loading.

The elimination of backlash, which is absolutely necessary for some types of CNC machines where precise positioning and high stiffness are required, is achieved by preloading. The amount of deformation is proportional to the load raised to the two-thirds power. As the load increases, the deformation becomes progressively smaller, though the deformation is big when the load is light. Moreover, the preloading reduces deformation when the axial load is not heavy, thus increasing the system stiffness.

The preload value has to be specified in accordance with the required stiffness (or with tolerable backlash), but is recommended as one-third of the operating load. If preloading is too heavy, this may result in lowering the life. Likewise, too little preload will lower stiffness of the assembly.

vi) ***Preloading Method :*** Preloading is to be applied in general to two nuts in tension or in compression. As shown in Fig 3.18(a) and 3.18(b), the shim plate necessary to achieve correct preloading is inserted between the two nuts, or between a nut and housing, and then they are tightened with a preloading bolt in the direction of compression, or pulled with two preloading pins in the direction of tension.

Some ball screws commercially available on the market are fitted with devices which allow the making of fine adjustment without the use of shim plates.

vii) ***Life And Basic Load Capacity Of Ball Screws :*** The life of a ball screw is determined by metal fatigue which causes the metal to start flaking rather than the ordinary wear characteristic of a conventional trapezoidal screw. As a ball screw rotates under thrust load, the constant thrust acts on the balls and grooves and thus the flaking phenomenon occurs on both of their surfaces.

It is difficult to measure such fatigue phenomenon accurately as this will depend on the operating conditions under which the ball screw is operated and the conditions can vary to an almost infinite degree.

The rated life is in general determined, therefore, by a value which more than 90% of the test samples can reach without flaking.

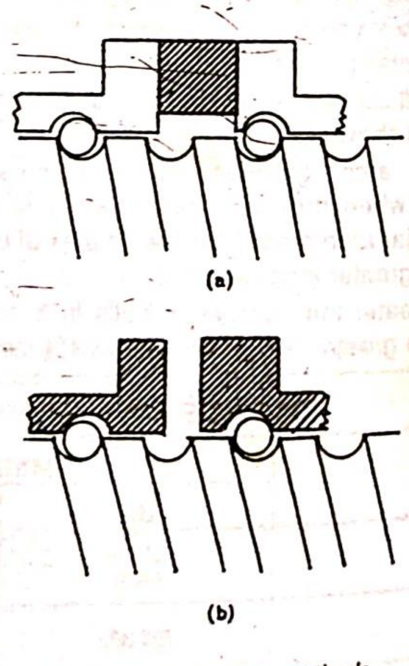

Fig. 3.18 Preloading methods

viii) ***Relation Of Life To Load :*** The applied operating load affects the life seriously. The relation of the operating life to the load is normally given as follows:

$$L = \left[\frac{C_a\ f_a}{f w\ f_a}\right]^3 \times 10^6$$

where,

L = operating life, in rev

C_a = Basic dynamic load raking, kgf

f_a = Axial load, kgf

$f w$ = Load factor (1 to 2)

ix) ***Basic Load Capacity :*** The basic load capacity indicates how much load a ball screw can withstand on the application intended. This can be divided into two groups: one is rated dynamic load when the nut travels, and the other is rated static load when the nut is at rest.

(a) *Rated Dynamic Load :* When the nut travels with load always in one direction, such a load as gives a life of 1 X 10^6 nut revolutions. This is specified as the basic rated dynamic load Ca.

(b) *Rated Static Load :* The rated static load Co is a load that causes a permanent deformation (perpendicular to the contacting surface of the balls and thread grooves) a ten thousandth of the ball diameter.

x) ***Selection Of Ball Screws :***

(a) *General Considerations :* Load, stroke, life, accuracy, driving torque, backlash, stiffness, lead, screw shaft diameter, etc., are the basic factors in the selection of ball screws. They are all interrelated and if one factor is changed the others also have to be changed. All these factors must be checked carefully in order to select the most suitable type of ball screws. A larger screw diameter ensures higher stiffness, but the force of inertia increases at the same time. A smaller screw diameter will, on the other hand, reduce both the inertia and stiffness.

(b) *Lead :* If the lead is fine, the positioning accuracy increases and the driving torque required will be small. On the other hand, however, the rotating speed has to be higher in order to obtain the maximum operational speed,and the system stiffness will decrease because of the necessity of having to use smaller diameter balls.

If the lead is coarse, it becomes possible to slow down the rotational speed and also to obtain a higher stiffness and longer life because of the large size balls which can be used, though the driving torque has to be higher and the positional accuracy will be slightly reduced.

(c) *Preloading :* A high preload makes it possible to obtain better positioning accuracy and higher system stiffness, but it will require a higher torque to drive the screw. If the preload is too high, the increase of the driving torque will exceed that of system stiffness, resulting in a decrease of life. Too high a preload may result in less positioning accuracy, depending upon the characteristic of the servo loop. Low preload gives low drag torque, but also low system stiffness and reduced positioning accuracy.