Ball screw systems for efficient & dynamic linear motion

Basic facts on ball screws for machine designers

Ball screws are precise mechanical components that turn rotary motion into linear motion. Their function is efficient and they offer high dynamic performance. However their application can be complex because of the need to consider factors such as speeds, loads, accuracy, duty and lifetime. This article presents an overview of the basic information that a machine design engineer should know in order to make educated choices. With performance on offer up to 2 m/s, with 90% efficiency, high dynamics and zero backlash, it is worth getting to know ball screws. Applications for transport and positioning in industrial machinery with screw diameters from 14 to 100mm are covered.

A ball screw system has two basic components, the ball screw which is a threaded shaft and a ball nut which has an internal thread that echoes that of the screw. Within the nut are contained a quantity of balls whose rotation allows the nut to move linearly along the screw. In most cases rotation of the screw achieves linear movement of the nut, but rotation of the nut on a fixed screw can achieve the same. The ball screw and the thread or raceway within the nut are machined to high levels of precision defined by international standards. The efficient action of the balls in the raceway of the nut causes axial displacement and they are returned to their original position after one or several revolutions using diverting elements called liners.

Balls screws offer certain performance advantages compared to alternative linear motion technology that suit them to a range of transport and positioning applications. They can be used for fast (up to 2m/s) and slow requirements with running efficiencies about 90%. Dynamic load ratings are from 10 to 150kN although operating factors will usually reduce these figures. Screws can have lengths anywhere up to 5m or more. Dynamics and rigidity are high. Compared to alternatives of hydraulic and pneumatic systems, ball screws offer high efficiency (no power loss when not operating), no leakage of hydraulic contaminents to the atmosphere, and particularly they are easy to control with electric motor drives.

The international standards BS ISO 3408 and DIN 69051 are a big help in the selection and application of ball screw systems. They define performance ratings, accuracy grades and the dimensions of screws and nuts. As a general guide, the performance of one system manufactured to these standards will match that of another, although components will not be interchangeable. The standards define accuracy grades and the most common of these are grades 3, 5 and 7. These relate to thread errors of a 300mm length and even the lowest of these three levels has a tight limit of 52 microns travel error. Class 7 is the least accurate yet it suits about 80% of industrial applications. Class 5 reduces errors by half and suits precision positioning. Class 3 reduces by half again to give extremely high precision, for example in machine tools.

Ball screws are machined from alloy steel with a final hardness of 58-61Hrc. Two different production processes are used according to the accuracy grade required. Thread rolling is a plastic deformation process where the thread is formed by pressure from large dies. After rolling the screw is hardened and polished, and accuracy classes 7 and 5 are possible depending on the thread diameter. Hard whirling is a recently developed precision machining technique that produces accuracy levels similar to grinding but with higher production speeds and lower costs. Case hardened bar stock is machined by ceramic tools that are rotated at high speed. The cutting ‘chips’ take away the heat leaving the screw cool and minimising distortion. Whirling produces accuracy grades 5 and 3, similar to grinding which is still used in some factories. Exceptionally manufacturers such as Servomech may offer ball screws from stock allowing significantly shorter lead times.

Ball nuts are also machined in alloy steel with a hardness matching the screw. High accuracy can be obtained by machining all surfaces in one operation on a CNC machining centre followed by hardening and a precision skim of the critical dimensions. This is followed by hand assembly with a range of commercially available steel balls that are available at nominal size, also three levels up and down with variations of a few microns. Thus the assembly operation can use balls that give smooth running at minimal backlash.

There are two designs of ball recirculating systems. With a radial liner the balls travel for one revolution of the raceway and are then deflected back to the start point by an insert known as the liner. There are typically 3 or 4 raceways with liners located in the wall of the

nut. Liners are manufactured in hard plastic for normal temperatures, in steel for ambients above 80ºC. The alternative ball recirculating system is known as the frontal deflector where a single raceway takes the ball in several revolutions down the length of the nut. A deflector (liner) then diverts the balls into a return tube machined in the nut body. They pass axially back up the length of the nut and a second deflector returns then to the start position. Selecting the optimum recirculating system is rather complex and a task best left to the manufacturer.

Ball nuts can have standard dimensions to DIN 69051 or special to customer requirements. Single nuts suit rolled or whirled screws but have a small amount of backlash typically below 0.1mm. The backlash can be removed using preloaded single nuts where raceways inside the nut have a micron shift in the thread lead. This preloads the balls with a consequent small decrease in load capacity of the nut. Double preloaded nuts restore the load capacity by using extra length and balls. Generally backlash free preloaded nuts are used with whirled screws of accuracy grade 5 and 3 for positioning applications.

The first rule in ball screw selection is that radial loads should be zero or very low. Ball screws are designed for axial loads and radial loads will sharply decrease lifetime. Selection calculations are best left to the supplier who can optimise from available features such as multi-start threads, ball recirculating systems, and who then takes responsibility for the sizing. Many factors are involved, for example

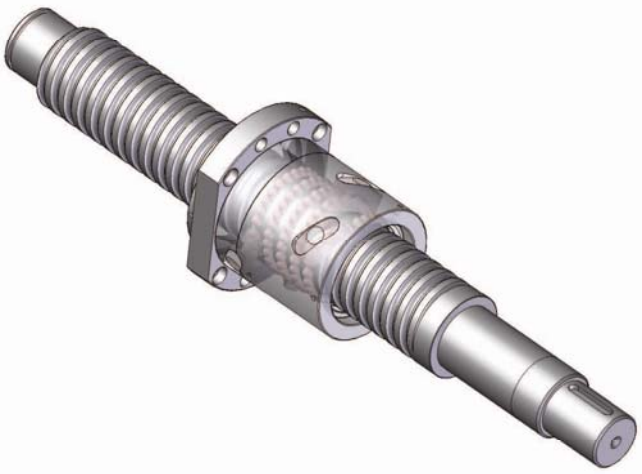
- Speed profiles and duties
- Maximum/minimum loads
- Mounting fixtures and orientation, critical speeds & buckling
- Environment conditions and type of lubrication
- Required lifetime

There are further practical aspects for consideration by the machine designer. The mounting of the ball screw, which rotates in the majority of applications, should be in good quality angular contact bearings to accept the thrust loads. Ball screws should therefore be ordered with ends customised to suit the mounting, for example with plain diameters,

keyways, grooves. The choice of lubrication is best left for the supplier's recommendation. Oil is best to maintain cooling and achieve long life, but many customers opt for grease. Loads and speeds may dictate the type of cooling. Handling of ball screws requires care, both to protect from mechanical damage and to avoid any contamination of the thread. Ball nuts should not be disassembled from the screws as reassembly requires specialist skills.

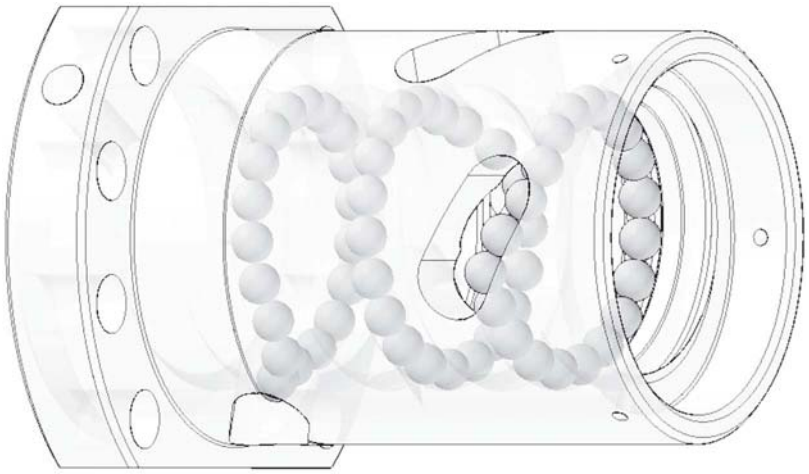
The precision and performance of ball screw systems is the result of decades of development. Designers are well advised to understand the basic concepts but to leave final selection to the product experts of the supplier. Within their performance scope, ball screws offer the highest combination of speeds, accuracy, efficiency and ease of control.

Servomech manufacture ball screw systems entirely in-house at their factory in Bologna. Screws are manufactured by rolling or whirling with diameters 14 to 100mm and are stocked in lengths to 5.7m. Accuracy classes from 7 to 3 are offered and screw pitches can be from 5 to 40mm. Single, double and preloaded nuts to DIN 69051 or special dimensions are available. Servomech ball screw systems are available in the UK through Techdrives (www.techdrives.co.uk) with strong engineering support to optimise selections.

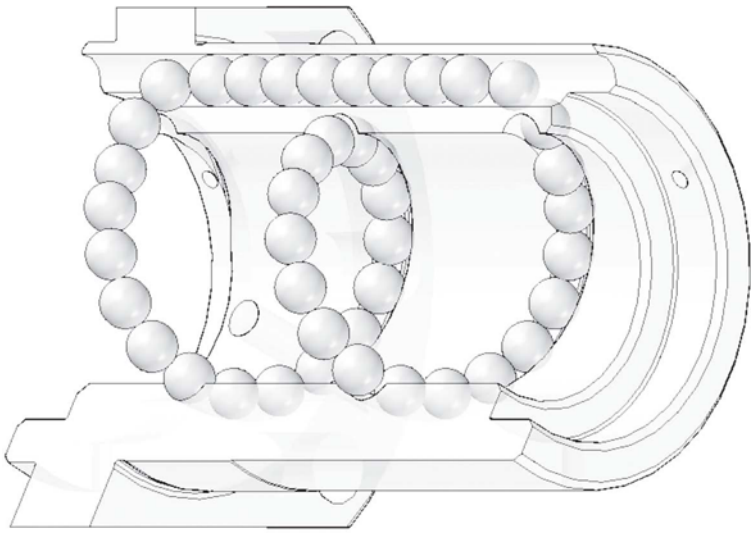


Ball screw assembly, nut with radial liners.

Components of a ball screw system – radial liner type.



Ball screw nut – radial liner type



Ball screw nut – frontal deflector type