Ball Screws —

extend the life of your machine tool axis, says Kevin Ewing

Ball Screw assemblies (BSA's) are important components in modern CNC machine tools that convert rotary motion into linear motion.

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They comprise a Ball Screw, with an external helical groove or raceway, a Ball Nut, with an internal helical groove or raceway, and a system for re-circulating balls, which are rolling elements fitted between the Ball Screw and the Ball Nut. BSA's are supplied in different lead accuracies, with or without pre-load depending upon the application. There are also different pre-loading methods - for machine tools, BSA's will usually have a two point angular contact pre-load.

In machine tools, BSA's most commonly drive each of the three axes ('X' 'Y' & 'Z') coupled with a servo-motor and encoder. Standard CNC machines are fitted with a control which is linked to the servo motor and encoder, but more expensive machines may also have linear feed-back via a scale attached to the axis. The servo-motor can make very small angular movements which, when coupled with the BSA, moves the axis as little as 1µm. Clearly, positional accuracy and repeatability of the BSA is an important part of overall machine tool accuracy.

BSA's fail for a number of reasons. The theoretical useful life of a BSA, or fatigue life (L10), is determined by the formula:

$$L_{10} = (Ca/Fm)^3 \times 10^6$$

Fatigue wear occurs when the surface of a material is weakened by repeated cyclic loading resulting in material fatigue. However, there are many extraneous variables which affect the life of a BSA in the field, such as contamination, incorrect lubrication, misalignment, or even application errors. However, a BSA's life can be considered in another way, known as its 'wear life' - the number of revolutions it can make before its positional accuracy deteriorates. For machine tool designers and maintenance engineers, wear life is an important factor to consider, as this will gradually deteriorate over time. This is especially evident in today's machine tools, which increasingly need improved positional accuracy and increased acceleration and linear speed.

Ball Screws have traditionally been designed using conventional materials. The Ball Screw and Ball Nut are most commonly manufactured in bearing steel and the rolling elements (balls) are manufactured in carbon chrome steel. However, during any sudden acceleration or change of direction, conventional rolling elements will not have a true rolling motion but will initially be prone to sliding and galling. This leads to adhesive wear and micro or cold welding because of the steel-ball-to-steel-raceway interaction, where surface projections, or asperities, are plastically deformed and eventually welded together by the high local pressure. As sliding continues, these bonds are broken, producing cavities on the surface, projections on the second surface, and frequently sub-micron abrasive particles - all of which contribute to future wear in surfaces causing surface roughness, excessive heat and eventual Ball Screw failure.

Of course, one way to improve this in traditional BSA's is to have them serviced at regular intervals, replacing the worn rolling elements, super finishing the raceways and re-preloading the assembly. This will increase the life significantly (if not left too late and material fatigue has not already occurred) and will also improve the positional accuracy.

To overcome the disadvantages of traditional ball screw manufacture, Jena Rotary Technology, part of Avingtrans plc, has developed the XLF range, which uses ceramic rolling elements, typically Silicon Nitride Balls, combined with a 0.5µm proprietary wear resistant coating in the raceways of the Ball Nut and Ball Screw. The load bearing property of the coated film is extremely high (300,000psi) and, with a dynamic coefficient of friction of 0.03, provides an exceptionally low friction surface. In field tests it has been shown that ceramic balls, combined with a coated BSA, achieve a noticeable reduction in adhesive and abrasive wear, resulting in lower operating temperatures, better thermal stability and lower vibration and noise levels than assemblies using steel balls.

Examples of rolling contact fatigue on ballnut raceway and steel ball element.

The lower operating temperatures are the result of the near perfect roundness of ceramic balls which, together with the much greater smoothness achieved in the manufacturing process, reduces friction by up to 70%.

The reduced mass of ceramic balls - about 40% of that of steel balls - greatly reduces impact damage in the transfer mechanism for re-circulating balls, another common failure mode observed in conventional BSA's. There is no metal to metal contact and ceramic balls do not react with steel raceways, again eliminating micro or cold welding and associated adhesive and abrasive wear. They are also much harder, wear resistant, and have been shown in tests to be 'self improving' - if swarf or debris is allowed to enter the Ball Nut, the harder ceramic balls will force the material into the softer bearing steel rendering it harmless.

Jena Tec XLF ballscrew using ceramic balls and proprietary coating.

The design of the XLF series results in superior performance when compared with conventional Ball Screw technology. Whilst the costs of coating and ball material results in a higher unit price compared on a like-for-like basis, the extended life of the XLF Ball Screw (typically up to twice that of a conventional assembly) means that the new series offers a valuable improvement in equipment reliability and cost savings in the longer term. It is particularly suited to high volume repetitive operations, eg in the automotive and process industries, where downtime and machine repair can have alarming cost implications in terms of lost productivity.