BEARING SYSTEMS

FOR HIGH-PERFORMANCE MACHINE TOOLS

By Thomas J. Wenck

Many of the latest advances in the design and development of machine tools have been driven, in part, by a universal need to reduce costs and improve productivity. Today's machine tools offer enhanced capabilities promoting greater accuracy, higher speed, and greater stability, which promise to deliver production benefits. As a few examples, CNC lathes now feature four linear axes enabling two tools to work simultaneously; modularly designed and computer-controlled grinding machines adapt easily to perform different and multiple tasks; spindles are frequently designed as separate units to allow for quick interchangeability to reduce potential downtime.

As these and similar machine tools have become more complex, the demands on related system components have likewise increased. Superior performance is expected system-wide, and bearings specified for high-performance machine tool applications are no exception.

Bearings used to support spindles (the "hearts" of machine tools) must exhibit a range of characteristics typically unattainable by standard bearings for general-purpose applications. (For spindle applications, a bearing system will usually consist of various bearing arrangements, such as a set at the tool side and another set at the drive side.) The rigorous application demands have resulted in the development of high-precision bearings and bearing arrangements specially engineered to satisfy a wide range of exacting requirements in the machine tool environment.

In general, high-precision bearings for machine tools will be characterized by the following: narrow tolerances of dimension and form; a large number of rolling elements with small diameters; low sectional height; light and strong cages; and preloadable design. These features enable bearings to operate with minimal runouts, greater stiffness, high reliability, and to remain cool at high speeds, which are some of the more desired performance requirements. (Most bearing arrangements for precision machine tools will be customized to meet parameters.)

TYPES OF HIGH-PRECISION BEARINGS

An overview of "basic" types of high-precision bearings can serve as a useful first step in the selection process for machine tool applications:

ANGULAR CONTACT BALL BEARINGS.

These non-separable (essentially single-row) bearings (in a variety of series and designs) feature raceways in the inner and outer rings. The load is transmitted from one raceway to another at an angle to the bearing axis. These bearings, therefore, can carry axial loads acting in one direction, as well as radial loads. (Axial forces produced in the bearing when subjected to a radial load must be counteracted by an opposing force applied externally, so these bearings are adjusted against a second bearing.)

Angular contact ball bearings are supplied singly or in bearing sets, and as full steel or hybrids (bearings having steel rings and ceramic rolling elements.) Bearing sets are most often specified when the load-carrying capacity of a single bearing is inadequate, or if axial loads acting in both directions must be accommodated.

CYLINDRICAL ROLLER BEARINGS.

Available in many designs, dimension series, and sizes, these high-precision double-row and single-row bearings feature low cross-sectional height and high load-carrying and speed capabilities. They can enable spindle bearing arrangements to be designed for heavy radial loads, high stiffness, relatively high speed, and axial compliance. (Double-row cylindrical roller bearings can carry very high loads; single-row bearings are used where increased speed capability and more compact spindle design are needed.) Hybrid cylindrical roller bearings incorporate specially designed ceramic rollers for superior rigidity, speed, and service life.

ANGULAR CONTACT THRUST BALL BEARINGS.

These types are well-suited for applications demanding accuracy and rigidity of machine tool work spindles.

Single direction thrust ball bearings consist of a shaft washer, a housing washer, and a ball and cage thrust assembly. As the name suggests, these ball bearings can accommodate axial loads in one direction and locate a shaft axially in one direction.

Double direction thrust ball bearings consist of one shaft washer, two housing washers, and two ball and cage thrust assemblies. These types can axially locate a shaft in both directions.

HYBRID BEARINGS.

This type features rings and cages manufactured from bearing steel and balls (the rolling elements) made from silicon nitride weighing only 40 percent of their steel equivalents. This translates to low centrifugal force and low load on the raceway at high speeds. Hybrid bearings exhibit high-speed capability, long service life, and high wear resistance, and can also serve to provide electrical insulation.

Since the dimensions of hybrid bearings are the same as those of steel bearings, a switch to hybrid bearings requires no design changes. *(From our application files:* A leading machine manufacturer was able to design a high-speed angle grinder, using hybrid bearings, with the pneumatic turbine rotating at 60,000 r/min. Before the age of ceramics, this level of performance would have been impossible.)

BEARING CHARACTERISTICS

Perhaps the most common operating requirements for a spindle in today's machine tools are high running accuracy, high speed capability, wide speed range, great stiffness, low and even running temperature, and high reliability. Bearings for spindle applications are typically combined and customized to meet the specific operating conditions.

For example, grinding spindles operate in a very narrow speed range, and the bearing design will be optimized for the particular speed. Machining and lathe spindles, in contrast, often operate in a very wide speed range, and load and stiffness requirements will be different at the various speeds. A customized bearing system for these applications will likely represent a "compromise."

Whenever selecting bearings for a machine tool application, designers typically evaluate a range of properties in the context of an application's operating and performance parameters. The assessment can then guide designers to match bearing arrangement with application need. Among the bearing characteristics typically calculated and evaluated: load carrying capacity and life; rigidity; speed; preload; and tolerances.

LOAD CARRYING CAPACITY AND LIFE.

In general machinery applications, the bearing size required for a given bearing arrangement is usually determined by the load carrying capacity. However, selection is made not only in relation to the actual load, but also to the desired life and operational reliability.

For machine tool spindles, bearing size is almost always determined by criteria such as stiffness of the system, fixed dimensions for the tool holder, or the spindle bore. The bearings selected according to such criteria yield arrangements that often exhibit extremely long life.

For precision bearings, determining the load to which a bearing will be subjected is particularly complex, since it involves many influencing factors. (In these cases, special computer programs have been developed and should be engaged to calculate load carrying capacity and life.)

RIGIDITY.

The rigidity of a bearing arrangement will be influenced by bearing stiffness, which is the relationship between bearing load and deformation. The stiffness of a bearing depends on its type and size with these factors being the most important criteria: types of rolling element (rollers or balls); number and size of rolling elements; contact angle; applied load; and applied preload.

Because of a much larger contact area between rolling elements and raceways in a roller bearing than in a ball bearing, roller bearing stiffness will be much higher than ball bearing stiffness. In addition, as the contact area between rolling elements and raceways is smaller under light loads, the resulting stiffness will be lower than under heavy loads.

As a result, it is best to follow the rule of thumb: where high radial stiffness is required, bearings with the smallest possible contact angle should be used. Conversely, where high axial stiffness is desired, the contact angle should be as large as possible.

The number (not size) of rolling elements will have the greatest influence on bearing stiffness. A given percentage increase in the number of balls or rollers will increase bearing stiffness by a greater amount than the same percentage increase in rolling element size. In addition, the use of two or more bearings at one position will further increase the stiffness of a bearing arrangement. (Angular contact ball bearings supplied in matched sets are best suited in these cases.) Bearing stiffness can also be enhanced by preload.

SPEED.

The speed at which rolling bearings can operate is largely governed by permissible operating temperature. Bearing types with low friction (and, therefore, low heat generation) in the bearings themselves are most appropriate for high speed operation; and, in general, ball bearings will be chosen for high speed.

However, the overriding parameter that sets the actual limit for the operating speed in bearing systems is the maximum permissible temperature for safeguarding the lubricant life and the complete system's thermal stability. The operating temperature depends on many factors (bearings are only one consideration), ranging from the temperature of the environment and heat generated by motors to electrical losses and friction in the bearings.

As for heat generated by the bearings themselves, several potential causes can exist relating to the bearing's internal design, the material of the rings and rolling elements, type of lubrication, and/or the loads acting on the bearings (including preloading). (Designers will compensate by modifying bearing arrangements.)

PRELOAD.

Machine tool spindles are almost always fitted with preloaded bearings or preloaded bearing sets for two key reasons: preloading makes it possible to increase both bearing stiffness and the arrangement's running accuracy.

Single row angular contact ball bearings are generally adjusted against each other by axial displacement of the inner or outer rings until a certain preload (or a certain clearance) is obtained in the bearing arrangement. (Single row angular contact ball bearings that are mounted in sets can be matched in production so that when they are mounted immediately adjacent to each other, predetermined values of preload are obtained.)

Cylindrical ball bearings with tapered bore are preloaded by driving the inner ring up onto its tapered seating. For double direction angular contact thrust ball bearings, the spacer sleeve arranged between the shaft washers is dimensioned so that a suitable preload will be achieved once the bearing has been mounted. In very high speed bearing arrangements incorporating angular contact ball bearings, it is customary to axially preload by means of springs, which enables a constant preload to be maintained throughout a whole range of operating conditions.

In practice, the amount of preload that can be applied to a rolling bearing will be limited, because frictional losses and operating temperature increase with increasing preload, reducing bearing life. An optimum preload yields the greatest possible bearing stiffness for the smallest increase in friction.

TOLERANCES.

Tolerance classes for precision bearings are standardized internationally. (Hybrid bearings are made to the same tolerances as corresponding all-steel bearings.) For those application demands where extreme precision is required, even greater accuracy can be supplied by most major manufacturers.

Even in machine tools that utilize high-precision bearings, the performance objectives of maximum running accuracy, high speeds, and low operating temperatures can only be met if the mating parts and other associated components are made with equal precision. In part, this is because bearing rings are relatively thin-walled and will tend to adapt themselves to the form of the shaft or housing bore in machine tool applications.

Any deformation or variances from specs of the shaft and housing bore seating, therefore, will be transmitted to the raceways of the bearing rings. Resulting angular misalignment of one bearing ring in relation to the other may then cause high operating temperatures, especially where high-speed operation is intended. This can be avoided by machining all parts precisely, including the axial support surfaces for the faces of the bearing rings.

Potential problems can be solved at the outset by taking advantage of the design and engineering expertise offered by experienced bearing manufacturers. Such professional support can prove invaluable in selecting bearing types and arrangements and in designing customized solutions fitting application requirements. Whether striving for accuracy, stiffness, speed, load capacity, service life, or a combination, expertise sought at the beginning of the design stage can make all the difference in ultimately satisfying machine tool needs and expectations.

Thomas J. Wenck is Business Manager for SKF Precision Technologies and is based in Bethlehem, Pa. He has served more than 20 years with SKF. In his current position, Wenck assists in providing products and solutions for customers throughout the machine tool industry in the U.S.