the SPiN on Precision SPiNDLE Technologies

By Bob Hodge
he spindle is the heart of the machine tool, and the most significant component when it comes to making parts. The major theme in manufacturing these days is higher productivity. For the spindle component, this equates to higher speed requirements, increased metal removal rates, longer design life, and improved reliability. Today, machine tools are required to perform a wider variety of tasks—under numerous speed and load conditions—and to undergo frequent tool changes. Under such conditions, spindles must accelerate and decelerate faster and more often, subjecting the spindle/bearing system to severe thermal load conditions. In addition, spindles are now exposed to the most extreme and hostile environments.

Fortunately, advances in spindle technologies have kept pace with these demands, allowing us the ability to achieve higher performance than ever before. By properly applying these new technologies, we can achieve sizable gains without sacrificing spindle reliability or longevity, as would have happened several years ago. New greases, specifically designed for higher speed spindles, allow for higher permissible operating speeds, lower operating temperatures, and longer spindle lives without the necessity to use inherently less reliable air/oil lubrication systems. Improvements in bearing materials and geometries allow for higher load capacities, speed, and precision, while providing lower operating temperatures. The development of a revolutionary seal design now eliminates the threat of contamination and coolant ingress; the most common reason for all spindle failures.

Today’s spindle designs offer the machine builder much greater performance and reliability than ever before. By properly applying these spindle technologies in specific applications, users can increase productivity in any and every industry. This article will review some of the recent developments that have produced substantial advantages that may be missing in your current spindles.
A Superior Spindle Seal System

SETCO introduced the AirShield™ spindle seal system into production in 1999 and now has over 4,000 of them in service. To date, we have not seen a single failure attributable to this system. Based on this, we conclude that the AirShield has virtually eliminated the number-one cause of spindle failure; bearing contamination caused by coolant, condensation, and solid particle ingress past the spindle seal system.

The AirShield design is simple, maintenance-free, and has no contacting moving parts to wear out. It requires only standard clean and dry shop air, and provides 100-percent dynamic and static protection against bearing contamination.

The AirShield uses a patented tangential air purge system that maintains a uniform internal pressure, eliminating problems of contamination ingress due to differential pressure common in other air purged seal configurations. The AirShield uses this uniform airflow to lift and exhaust past the lip of an elastomeric face seal creating a self-regulating seal that is tolerant to positive and negative pressure variations external of the spindle (see Fig. 1). As the spindle is subjected to high-pressure coolant spray, the associated forces narrow the escaping air path, causing increased back pressure and further increasing the effectiveness of the AirShield. Since in operation, the seal is non-contacting—nearly frictionless—and as such does not create any added heat or wear. Typically the AirShield is incorporated into the spindle bearing, retaining caps and seals between the bearing cap and the spindle shaft to protect the front and rear bearings. The purge air exhausts from the seal radially by lifting the seal lip from its contact surface and flowing through the small annular space created. Also, the purge air is introduced to the spindle at the point of the seal—external of the bearings. Unlike widely used positive internal pressure (PIP) purge air seal systems, the AirShield design does not exhaust air through the bearings, which is detrimental to spindle bearing grease lubrication.

![Figure 1 — The patented AirShield design equalizes and disperses air within the seal for 100-percent elimination of coolant ingress and spindle contamination.](image-url)
The field results are so conclusive that all new SETCO spindles equipped with the AirShield now carry a three-year limited warranty.

The AirShield is not limited to new spindle designs. SETCO has developed and now offers a line of Universal AirShield® spindle seals (see Fig. 2). The patented Universal AirShield is a compact, unitized version of the original AirShield design. It uses all the same operating features, and provides the same superior dynamic and static protection as the original AirShield. This seal has also proven itself both during extensive testing and in rigorous field applications.

The Universal AirShield provides a precision machined steel housing that encases the fluorelastomer lip seal and allows the AirShield to be produced with a smaller cross section. This makes the Universal AirShield available in incremental sizes from 25 mm-250 mm shaft diameter. We currently use the Universal AirShield extensively to upgrade the sealing system of existing spindles during rebuild. It is normally a very simple replacement for many of the less-effective spindle seals that are currently used. This creates a very cost-effective solution for improving spindle life and reliability.

**Lubrication Technology**

Increasing spindle performance is a balancing act. By increasing performance attributes in one area, you can change the reliability and operating characteristic requirements of other components. An example of this is evident in the area of spindle lubrication. For optimum performance and reliability of a precision spindle, the importance of proper lubrication cannot be overemphasized. Lubrication is an essential part of a spindle/bearing system and can have a dramatic impact on functional properties and service life. For precision spindles, selection of the type and method of lubrication depends essentially on the spindle speed, but is also influenced by other operating conditions such as loads and ambient temperatures.
During operation, properly selected lubrication:

- Reduces friction and wear by providing a viscous hydrodynamic film between the rolling element and raceway of sufficient strength to support the load and prevent metal-to-metal contact.
- Minimizes cage wear by reducing sliding friction.
- Can assist in preventing ingress of contaminants into the bearings.
- Dissipates heat generated by friction.
- Prevents oxidation/corrosion of metal bearing elements.

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Air/oil metered: feeding oil continuously by injecting oil into a compressed airstream by means of a mixing valve that intermittently discharges the proper quantity of oil using a metering pump.

Oil mist: the continuous spraying of atomized oil and air into the bearing through an atomizing pump and nozzle fed into a stream of compressed air, creating a mist.

For many years the state of lubrication system development demanded that high-speed spindle applications required oil lubrication. Recent developments, however, have shown this to no longer be true. The high cost, regularly scheduled maintenance requirements, pollution of the environment, the potential for the introduction of contamination, or using inadequate oil has driven recent developments in the field of grease lubrication for spindle bearings. Further, since the introduction of the AirShield sealing system eliminated external contamination as a major failure cause, grease service life became more of an issue as a reliability-limiting factor. These tribological developments have led to greases that far outperform those available previously in terms of both speedability and extended service life.

Over the last few years, SETCO has conducted extensive development and verification testing along with tribologists, grease manufacturers, and our largest bearing vendors. Principal in this testing has been the tribological properties of the grease, or the interaction with the grease in rolling element bearing contacts. We have evaluated the greases in terms of speed capability, operating temperature, frictional torque, and oil loss-service life. Through all of our testing, a couple of new base oil blends and thickener combinations have shown to perform substantially above previously commonly used high-performance spindle bearing greases.
SETCO now uses these newly developed high-performance greases in the majority of our spindles, including many of those for higher-speed applications that previously demanded air/oil lubrication. The new greases also provide substantially reduced operation temperatures, yielding greatly increased service life without reducing their load film thickness and load-bearing capacity. This enables the use of bearings that are lubricated for life. Combined with today’s rolling element bearing materials technology, we can achieve extremely high speeds, with speed factors of DN 2,000,000 and higher being attained.

The term “DN” is a factor used to judge the relative speed of rolling element bearings. It is the product of multiplying the bearing’s inner diameter times the speed of rotation. This term is widely used as a point of reference in the United States. However, there is a chance of confusion due to Europe’s using a similar factor DmN. This is similar to DN, with the exception of using the mean diameter of the bearing instead of the inner diameter. When comparing, it is important to know which factor is being used, in that the two values can differ greatly for a given bearing and speed (see Fig. 3).

Leveraging this new technology can make possible speed increases approaching double what was possible just 10 years ago. Also of note is that the lower operating temperatures can translate into improved thermal stability for critical operations like precision grinding and milling, where spindle growth must be held to a minimum (see Fig. 4).

The spindles that SETCO produces today are lubricated with these high-performance bearings and greases as standard. This upgrade is a substantial step toward our goal of having the most reliable spindles in the industry.

**Bearing Technology**

In the wake of continued and substantial improvements and diversification in the processing of bearing materials, rapid advancements have been made toward higher-speed capabilities in precision bearings for machine tools. These advancements have concentrated on bearing materials and tribology; the interaction of the contact surfaces between bearing rolling elements and the raceways, combined with the influence of a lubrication film separating them.

As a result, a new generation of spindle bearings is now available, and allows us to achieve performance levels not possible even a few years ago. Just as silicon nitride (ceramic) ball usage in bearings revolutionized spindle performance in the nineties, new raceway materials coupled with high performance greases are enabling spindle speeds and levels of reliability not previously possible.

The new raceway material is state of the art steel: highly alloyed with nitrogen, chromium, molybdenum, and vanadium. This, in combination with carbon, yields an extremely fine-grained martensitic steel that is through hardenable and very stable.

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Generically termed as “high nitrogen steel,” this new material is used to manufacture both the inner and outer races (rings) of this new class of rolling element bearings. Used in combination with silicon nitride (Si3 N4) rolling elements and newly available high performance greases, high-nitrogen steel rings offer significant improvements in spindle speedability and reliability.

For example, reliable speedability of these hybrid ceramic ball bearings with high nitrogen steel races has increased by as much as 70 percent over the traditional steel (52100) ball bearings. With varying bearing mountings and preload methods, an increase of 230 percent can be attained. The chart in Figure 5 shows that the speed limits, measured in DN, within the same basic spindle design drastically increase with the new technologies in bearing materials and geometries.

Testing conducted by bearing manufacturers have shown that hybrid ceramic bearings made of high nitrogen alloyed steel races outperformed standard hybrid ceramic bearings made of 52100 steel by a factor of 10 times higher service life. These developments are now offering enormous benefits in machine tools where high demands for speed and reliability are very important, such as those requiring frequent and numerous tool changes, and where down time is at a premium.

Today’s rolling element spindle bearings also feature optimized internal geometry and construction to enable minimizing the heat generation from internal friction. This also improves seizure resistance, enabling higher speeds—DN 2,000,000 and higher—with minimal thermal deformation. The resulting reduction in heat and distortion contributes greatly to the accuracy capability of the spindle.

Conclusion
The tremendous success brought by these advances in lubrication, bearing technology, and seal design provides many benefits—and not only to us, but also to the machine builders and end users. New high-performance greases, advanced materials used in bearings, and a revolutionary seal design provide the machine tool builder with spindles that perform better and last longer than ever before.

Our joint efforts—with lubrication suppliers, bearing manufacturers, and our own in-house research and development—has allowed us to respond to the industry’s need for spindles that are more precise, faster, and more reliable. Ongoing efforts will continue to allow us to provide the industry with precision spindles that offer the greatest performance and reliability for tomorrow’s needs.

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Bob Hodge is vice president of engineering, product development, and quality for SETCO—the largest independent manufacturer and rebuild of precision spindles in North America. He is a mechanical engineer with an extensive background in the design of precision rotating equipment, tribology, failure analysis, and bearing technologies. For more information visit the company’s Web site at [www.setcousa.com].