Spindles Evolving, Revolving Faster

Higher cutting speeds with lower cutting forces help define today’s high-speed spindle systems.

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“I can’t be giving ya Warp 9 speed much longer, Mr. Spock. These engines are beginning to show signs of stress!”
The chief engineer for the Starship Enterprise—Star Trek’s Scotty—might have been as wary about today’s ever-increasing spindle speeds. These critical elements of the high-speed machining system are under duress from industries like aerospace, where shorter manufacturing lead times are preferred on large aluminum parts that formerly took a long time to machine. Imagine a machining center topping off at 6,000 rpm yesterday…and 100,000 rpm today! And with no loss in quality and reliability.

Wherever in-between lies the truth, the fact is that precision cutting tools are digging into metal at faster speeds than ever before, five to 10 times more than conventional machining, according to some experts. This puts the onus on spindles, along with their motors and bearings, to provide the necessary torque, rigidity, and accuracy.

John Easley, V.P. of Business Operations, The Precise Corporation, says more power can be provided in the same spindle-housing diameter than just a few years ago. “To satisfy the needs of machine builders to provide more torque and power without making major design modifications, Precise has been proactive in manufacturing permanent magnet motors” for its spindles, says Easley, adding that in some cases, these can provide 200% more power than in a conventional AC induction motor with the same diameter.

Years ago, some spindle speeds topped off at 60,000 rpm. Today, designers have the number 300,000 rpm in their sights! Easier said than done? Maybe, says Easley: “If the spindle is unable to hold accuracy and provide a reliable cut with the tool, it really doesn’t matter what other improvements are made on the machine to improve its efficiency, accuracy, and productivity.”

And while high-speed machining is no stranger to manufacturing centers, “the laws of physics take on greater significance in the machining process,” notes Mikron Corporation’s Vice President Mal Sudhakar. “Centrifugal forces, unbalance, vibration, thermal expansion, and other factors can affect process reliability and hinder reliable unmanned operation.”

SETCO’s V.P. of Engineering, Product Development, and Quality Bob Hodge says 20,000 rpm is considered the rate used to remove the maximum amount of material. Beyond that, well, look out. “Few out there really run their machine tools at, say, 40,000 rpm,” says Hodge. “The tooling just won’t take it.”

Hodge added, "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 permissable 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. Developments in seal design now eliminate the threat of contamination and coolant ingress; the most common reason for all spindle failures, according to Hodge.

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 industry.
Play By Numbers

If you’re thinking about replacing your machine’s relatively slow spindle with a high-speed version for more versatility, remember that it might lose the ability it used to have in performing those slow, deep-cut jobs. Oh, and one more thing, John Easley of the Precise Corporation notes that today’s spindle design is driven mainly by cost. “The overall value of the spindle must justify the potential productivity gains that can be achieved in a given application.” Accordingly, his company gives close scrutiny to the customer’s cutting parameters. We considering potential productivity and capability, however, one should not be thinking only in terms of rpm’s.

“You have to look at DN values,” says SETCO’s Bob Hodge. He is speaking of a number arrived at by multiplying spindle speed by the spindle’s bearing diameter. DM is a way to define speed of the bearings, where stiffness varies with speed. Larger bearings are stiffer and generally run slower, but smaller ones can run faster and more effectively—which is why speed alone is not a reliable indicator of a bearing’s capability. One can obtain the value of DN by simply multiplying spindle speed by the bearing inner diameter in millimeters. “A higher speed spindle can mean three-quarters-million DN and over,” say Hodge. “Our benchmark is one million DN.” On a machine running 70mm diameter bearings that translates into 15,000 rpm. Most of the machine tool industry in the United States uses DN values, while European builders and users refer to DMN,” which considers an average of both bearing inner and outer diameters.

Leveraging this new technology can make possible speed increases approaching double what was possible 10 years ago, say Hodge. 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.

Outside Forces

The forces of vibration and contamination threaten the peace of mind of every machine tool builder and user out there. Guarding against the former, Mikron is installing a sensor inside the spindle near the front bearings. The sensor measures vibration in terms of displacement, velocity, or acceleration. A monitor shows a range of values, color-coded for good-to-bad vibrating conditions. They can indicate when acceptable limits are being exceeded—or perhaps better yet, the machine can be programmed to stop automatically.

SETCO has incorporated sensors into some designs to monitor real-time conditions; like thermocouples and accelerometers. These can be embedded into the spindle to output temperature and other critical signals. "You can do a lot of worthwhile things with sensor technology," says Hodge. "The question is, what will you do with the data?" Sensor-embedded technology tends to be expensive, but Hodge claims it's a worthwhile step. If, for example, the force transducer reveals the bearings are working much harder than they should, the machine could go into automatic shutdown mode.

Throughout its spindles’ manufacture, Precise checks for spindle vibration at multiple points during assembly. “We set a standard vibration limit for the bearings at 2mm/sec, although the vast majority of our spindles fall well below this top limit,” says Easley, who lists another concern: natural frequency, which will cause high vibration to the rotating components and lead to premature spindle failure. “At a particular speed, every motion system has an inherent natural frequency. The most common example is the humming vibration one might hear coming from a roof rack on a car moving at a certain speed. Above or below this speed the noise goes away.

“This same principle applies to high speed spindles.” Precise designs its spindles so that within a given range of tool sizes, the spindle will never experience such a natural frequency.

Contamination

To prevent coolant, chips, and swarf from penetrating the spindle mechanism, Precise uses a front seal cover on the spindle’s nose, plus an air labyrinth seal that creates a positive air pressure barrier to the contaminants.

SETCO introduced the AirShield™ spindle seal system in 1999. "With over 4,000 AirShield spindle seals in service," Hodge adds, "we have not seen a single failure attributable to the AirShield performance. 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.

Get Your Bearings!

When spindle bearings lose their stability, the result can be excessive vibration, tool chatter, wear, and costly scrap. At the High Speed Machining Laboratory of Purdue University, studies are being conducted on bearing stiffness, and a program has been developed that illustrates how such stiffness, along with the bearing’s contact angle and deflection, all change in terms of rotational speed and radial load. The Intelligent Spindle Bearing Analysis Program (ISBAP) is modular, according to the department’s website (http://widget.ecn.purdue.edu/~simlink/a_hspin.html). It goes on to say that ISBAP is capable of predicting dynamic and thermal characteristics of spindle bearing systems.

In high-speed spindle systems, ball bearings are usually the first to fail. Advances in bearing systems have given rise to hybrid types that rule over those once made from steel; the race is steel, but the balls themselves have gone ceramic. These systems are more stable at high speeds. Ceramic ball bearings are also lighter, stiffer, and less affected by centrifugal force. The result is improved efficiency and less vibration. For anybody following the numbers, hybrid ball bearings can achieve a DN of 2 million.

Spindle Rejuvenation

Experts peg the global machine tool spindle market at $1 billion, and more than half of that amount goes for spindle maintenance and refurbishment: “renewal,” as Precise likes to coin it.

“We’re renewing the spindle to perform at essentially the same level as when it was originally sold,” says Easley. "For proper performance, certain balance grades and fit tolerances have to be met,” he adds. “Customers think about the complete cost of downtime and part quality. They quickly realize the true cost of a renewal is only a fraction, when compared to the risks and short term life on an outside-source repair.”

SETCO “remanufactures” its spindles, and there’s a lot more to rebuilding than changing bearings and races, according to Hodge. While inspecting components, one also looks for ways to make the spindle more robust, more reliable. “We upgrade the grease and bearing system and look at the sealing arrangement.”

If refurbishment is the last step in the spindle process, getting it right is the first—the principle which dictates a close working relationship between two sets of people: those who make the spindles, and those who manufacture the machine tool. Easley thinks it’s more important than ever before for one to work closely with the other. The goal is for an integrated machining solution. “Here’s the reality,” he explains. “The spindle is only one component of a complete machining system. A commodity spindle product will be unable to provide optimized performance, and a spindle by itself will never be the ultimate machining solution.

“To optimize machine performance and gain a competitive edge, both parties need to work closely together as partners to create a reliable, system integrated solution," says Easley.