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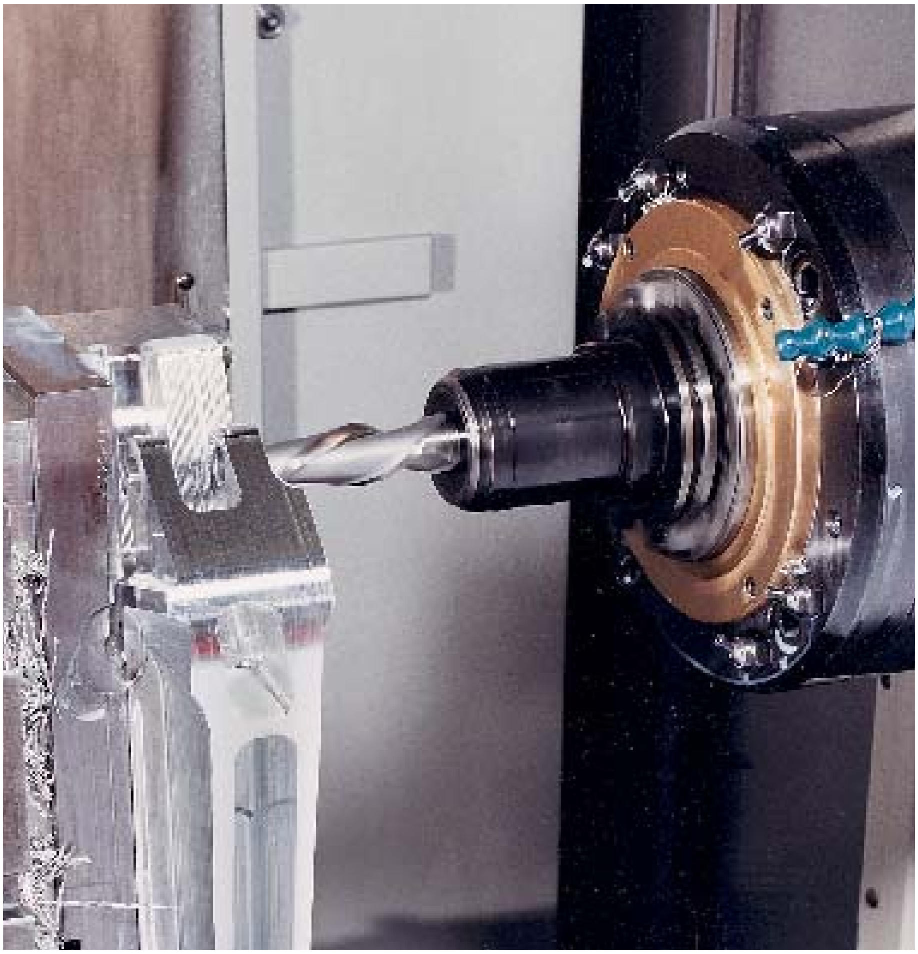
Can You Be More Precise?

You can fool your machine tool into holding tighter tolerances with error-compensation software.

First-time U.S. cellular phone purchasers are often surprised at the numerous functions possible with their new communications tool. Since so many buy the product purely for the phone-calling convenience, they don't think about the phone's ability to store phone numbers or list recently dialed/received calls or add-on features. Yet, even after learning about these features, many don't bother to figure out how to use them.

A similar scenario is at work in U.S. machine shops. Many have equipment that possesses error-compensation software that can improve a machine tool's accuracy, but few have taken the time to learn about it and put it to work.

Meanwhile, for those with machinery that lack this programming, software is available that can improve a machine's accuracy and, as a result, position a shop to garner new business by quoting jobs for tighter-tolerance parts.

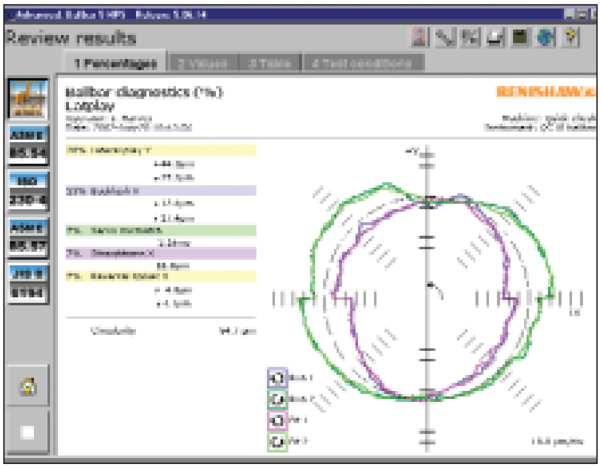


Makino

The accuracy of machine tools can slip as heat builds up in their spindles. Thermal-error compensation software can adjust for this. It can make entry-level machines precise enough to produce parts with tighter tolerances than otherwise possible, and it can keep highly precise machine tools, such as Makino's A77 horizontal machining center (shown), from ever being less precise, which is key in the machining of very-tight-tolerance components.

Can't Tolerate the Heat

Geometric and thermal errors can push many a machine operator to the brink. Despite careful



Renishaw

The ballbar plot simulator feature of Renishaw's Ballbar 5 HPS software allows the results of tests carried out using the company's QC10 ballbar system to be recreated on screen (shown) and then changes various machine geometry, play and dynamic parameters.

engineering, precision parts can fall out of tolerance as a machine tool's ballscrews wear—even minutely—or its spindle heats up during operation.

Take the case of the machine shop using a CNC turning center to manufacture parts with diameters that had to be held to a tolerance of ±0.0005". No problem—at first—but machine operators found that after 25 or so parts, the diameter began slipping increasingly out of tolerance—from ±0.0020" to 0.0028".

The shop struggled for 6 months to solve the problem, then sought assistance from engineers at the University of Michigan at Ann Arbor. The shop heard that the university had been perfecting software that predicts machine tool error based on geometric and thermal factors.

As Professor Jun Ni, the director of the university's S.M. Wu Mfg. Research Center, pointed out, if a machine tool component drifts in one direction, it can be corrected with an offset. But this machine's deviation was more complex, resulting from heat build-up in its spindle. "Whenever there was excessive time when the machine was not cutting, the machine would drift to a new unknown," Ni told CUTTING TOOL ENGINEERING.

The university engineers developed a compensation system that included temperature sensors and software that calculates the impact a rise in spindle heat has on the tool/workpiece interface. Not only was the problem eliminated, but accuracy improved to ±0.0002".

Previously, Ni and his associates were approached by The Boeing Co.'s Wichita, Kan., manufacturing facility to team with its engineers to apply the software techniques the university had developed to some of the airplane maker's machine tools.

In the mid-'90s, the company changed its philosophy for assembling airplane fuselages. In response to the growing cost of fixtures used to assemble large plane parts, Boeing sought to transfer some of the support provided by fixtures to the parts themselves, thus eliminating many tools and fixtures. The key to accomplishing this was accurate location of holes—ranging from 0.125" to 0.500" in diameter—and hole patterns milled into parts that in some instances span 30'. The facility had to reduce the variation—often ranging from 0.050" to 0.080"—in the manufacturing processes.

Boeing associate technical fellow Dr. Farhad Tadayon compared the new assembly strategy to assembling another form of transportation. "When you assemble a bicycle, you don't use fixtures or brackets to join parts. You basically align the parts' holes and fasten them together. That, fundamentally, was the approach we wanted to achieve," he said.

The answer was predicting the error resulting from increases in both ambient and machine temperature and "telling" the milling machine that drills the holes to operate as if there was no such heat rise. Tadayon called the process "virtual air conditioning. We couldn't air-condition the whole factory floor."

The adjustment helped Boeing-Wichita reduce the variance of its milling machines to 0.010".

While Boeing's experience may have been unique at the time, it isn't today. Faster spindle speeds are complicating many a machining operation, even if some shops aren't aware of it.

"The raised temperature generated from a milling machine spindle revolving at higher speeds has an impact on the accuracy of the spindle and on the structure of the machine," Tadayon said.

"The thermal growth of a spindle is very predictable, [being] based on the speed and amount of time it is running," said Tim Jones, product line manager, horizontal machining centers, for Makino, Mason, Ohio. "An algorithm can compensate the Z-axis for thermal growth to make the machine more accurate than it would be otherwise."

Thermal-error compensation can make less-precise machine tools more accurate, but owners of such machines should understand the equipment's modest capability complicates the process.

"A lower-end machine may not be designed with perfectly aligned ballscrews or its bed or guideways may not be built to a significant level of precision," said Jones.

Compensation software added to such a machine tool will slowly but surely become less effective.

"Over time, the machine will continue to get less and less accurate," Jones said, "but the software is going to stay the same, so the gap will continue to widen."

Boeing's Tadayon said shops running gantry-type milling machines similar to those his company uses to fabricate airplane fuselages must pay particular attention to thermal factors. "You see the significance of the impact of temperature fluctuation more on large machines, because you see a greater temperature change in those machine tools."

Predicting and compensating for thermal error is rather simple and quite cost-effective. Ni said the software and processor cost as little as $800. It is also inexpensive to add temperature sensors to the interior of a machine

Various types of workpiece inspection can be carried out using a spindle probe to evaluate a machine tool's accuracy and, then, set a Z-axis work coordinate system offset. This M12 spindle probe from Renishaw is battery-operated, so it can be held in a toolholder for quick loading and unloading into a carousel.

tool—often on the spindle housing or bearing.

"We've retrofitted close to 200 machines installed in the field," said Ni.

Improve Your Mechanics

Correcting geometric error is similarly affordable. In fact, it's likely no investment in software would be required to address imprecise guideways or axes that are not perpendicular to each other. Many relatively new machine tools have at least a minimal offset-management program that can take mechanical inaccuracies—such as those caused by pitch errors in a ballscrew—and calculate the compensation needed to right a machine's performance.

Offset-management software available with Cincinnati Machine's horizontal machining centers and other machine tools teams with optical scales on the equipment's axes to detect and eliminate "slop" within the drive train's gears, chains or belts. This, said Ken Wichman, a product manager with the Cincinnati-based machine tool builder, usually improves accuracy by 50 percent.

"Any gap or tiny variation between two threads of the ballscrew can be missed by a machine's motor encoder," Ni said. "But an optical scale attached to a slide can more precisely determine the backlash or pitch error in a ballscrew."

This approach can also correct the left or right wander of a machine tool's table.

"A machine shop's accuracy woes may just be a lack of using existing technology" already incorporated in its equipment, Wichman said.

Besides optical scales, the hardware required to evaluate geometric error could include a spindle probe or a ballbar.

A ballbar is a ball connected by a telescoping bar to a magnetic socket. You mount one end onto a machine tool's table and the other in the toolholder. A popular ballbar system from Renishaw Inc., Hoffman Estates, Ill., costs $7,490.

"You program the ballbar to run in a perfect circle," Ni said. "If the machine has no error, the reading is zero, indicating the radius never changed. Any variation from the nominal distance of the desired radius indicates inaccuracies."

If you machine castings, a spindle probe can be very useful. The device captures dimensions in the X, Y and Z axes.

"You may be able to machine a casting without probing it," said Wichman, "depending on what operations you perform. But, if you bore a hole, for example, you could find the cut is asymmetrical, so that on one side, you're loading the cutter up heavily and on the other side it's real light."

Renishaw spindle probe systems range from about $2,000 to $6,000.

By using probes and offset-management software, you can equalize loading and reduce cycle time, Wichman said.

"A spindle probe is a very commonly purchased option. Unfortunately, it is not commonly used," Wichman said. "Manufacturing supervisors don't spend the time to get their programmers up the learning curve on how to use it."

NURBS, Curves and Strong Words

If a new machine tool is in the offing for you, note that new interpolation programming is coming to the fore. While most machining centers allow linear, circular and helical interpolation, machine tool builders are beginning to imbed process-specific capability, including involute, exponential, polar coordinate and cylindrical interpolation.

The biggest change, Wichman said, is NURBS, or non-uniform rational B-spline. This provides the ability to cut a very smooth curve from just a few defined intermediate points along a set contour. This yields "soft" transitions as a cutter moves along the changing contour of the curved surfaces.

"When you don't have a simple circle or helix to follow, historically, linear interpolation was the only way you

The following companies contributed to this article:

The Boeing Co.
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Cincinnati Machine
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could cut the feature," said Wichman. "NURBS finds a way for the machine to actually follow the curve."

Neither NURBS, interpolation nor offset management should be used to counter dynamic error, such as chatter, vibration or lack of machine stiffness, Ni warned. "For chatter, for instance, you don't want to offset it. You want to suppress it."

Ni also warned a machine tool must be repeatable, even if it is not precise. "Usually, a machine's repeatability is much better than its precision—0.000039" or less vs. 0.00039" to 0.00079". So, if it's slowly drifting due to thermal distortion, software can easily compensate. However, if it has poor repeatability, software won't help much."

Ni and his associates call the precision possible through the use of error compensation "all-year accuracy." The practice of accounting for the effects of ambient temperature in the summer vs. the winter is no longer necessary. This is particularly a problem in large facilities in which it is difficult to maintain an optimum climate. Also a bygone problem: Warming up a machine tool for an hour before cutting metal.

"Through the use of software, we can maintain consistent accuracy regardless of whether it's morning or afternoon, summer or winter."

And consistent accuracy can also be maintained regardless of what's on the shop floor.

"I'm sure whatever machine tool a shop has, if it calls its vendor, the OEM will be glad to talk about how to add these features to existing equipment," Wichman said.