MACHINING CENTERS

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## GRINDING STRATEGIES GO FROM GOOD TO GREAT

VMC Technology Stretches Applications, Productivity

Keeping Machines Honest with Advanced Calibration, Optimization

Geometry, Parameters and Strong Toolholders Vanquish Drilling Problems

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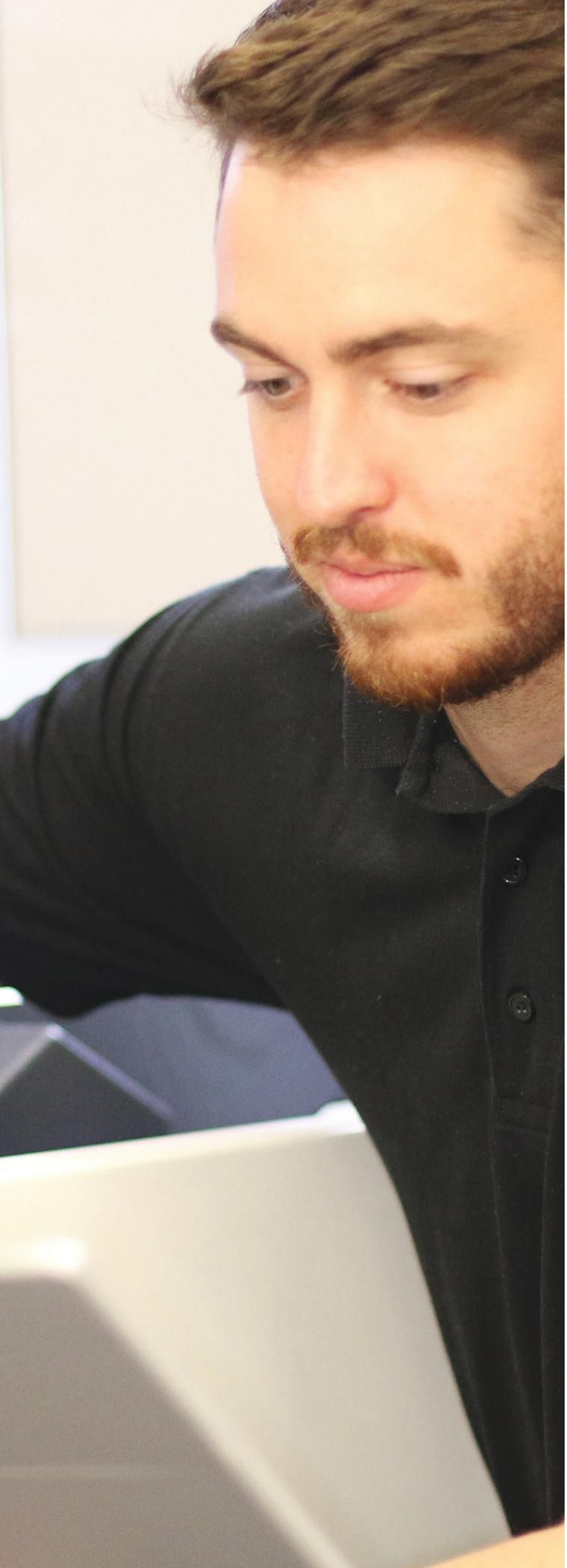
# Keeping Machines Honest with Advanced Calibration, Optimization


*Calibration devices, such as this Renishaw XM-60 multi-axis calibrator, have become more powerful, yet easier to use. (Provided by Renishaw)*



*The science of making and keeping metal cutting machines calibrated is improving, including advanced means of compensating for some errors in near-real time*

**ED SINKORA**
Contributing Editor

There's nothing mysterious about the need for calibration. As Michael Wilm, business manager for calibration products, Renishaw Inc., West Dundee, Illinois, put it: "When you get gas for your car, you count on the pump being calibrated. That's why we calibrate machine tools. If you don't calibrate a machine tool you have no idea it's going to give you reliable service for manufacturing your product."

Just as important, when you calibrate your machines, you learn more about their capabilities. Operators are better able to assign jobs with specific tolerances to machines capable of holding them, reducing the odds of producing scrap. Conversely, said Andreas Huebner, service coordinator for machine builder SW North America Inc. New Hudson, Mich., if your machine isn't properly calibrated and you produce parts out of tolerance, that means taking the machine out of production. It will need quality checks to bring it back up to operational standards. "This ends up being an expensive process because of the extra labor and unplanned resource use," he said.

Even if the need for calibration is not in question, there is much to know about when and how it should be done—and by who. Even more exciting are techniques for advanced error compensation that can make significant improvements to part quality.

## When to Calibrate

There is wide agreement that you should calibrate your machine when it is first installed, regardless of how well the factory calibrated it, and regularly thereafter. There may be problems caused by its jostling journey to you. It needs a baseline for comparison to future checks. The frequency of those future tests, and to some extent the checks involved, depend on the parts you make and the tolerances you're trying to hold.

Steffen Hailer, head of product management and application engineering at calibration software provider AfM Technology GmbH, Aalen, Germany, said that, depending on your tolerances and the stiffness of your machine, rotational errors (pitch, yaw and roll) should be recalibrated every one to two years. This depends on the hardness of the material being machined. "The encoders should be recalibrated before each critical part if the machine fails an acceptance check," Hailer said. "Even if there are no tolerance issues noted in the CMM reports, calibration is recommended every six months during routine maintenance."

***Okuma's Five-Axis Auto Tuning System uses a touch probe and a datum sphere to measure and auto-compensate for 11 types of geometric errors in about 10 minutes, or a fuller set of adjustments in 30 minutes. (Provided by Okuma)***

A regular schedule delivers another key benefit to calibration: predictive maintenance. Charlie Cagle, field service manager for Okuma America Corp., Charlotte, N.C., summarized this nicely when he said: "You never hear from the customers who do annual calibrations, because everything they do is on a predictive basis. If they see a problem pop up in an axis, they fix the problem when it's small. If you let a small problem become a giant burning fire, you'll find yourself under the gun with a part deadline and a down machine. All for something that you would have seen six months ago if you had done the calibration. Predictive maintenance is about planning your downtime."

You should also re-calibrate a machine after it experiences a collision, or after key components like a ball screw or rail are replaced. There are more subtle environmental factors that may spur the need for re-calibration. For example, frequent earthquakes in some regions of the country can be problematic. "On the West and East Coasts tidal changes cause the ground to fluctuate, which causes machines to bend and twist," said Renishaw's Wilm. "So it's very important to measure in the spring and the fall to see if there is any movement, especially on things like aerospace gantries, where you have 30 meters or more of axis travel."

Machines with three-point bases are less susceptible to such influences, but they're not common. Even with a constant temperature, if the location of the heat source changes seasonally, that can change machine geometry.

But "it's all about the process," said Wilm. "You should only calibrate a machine at intervals that will give you an indication of when it's going to change and that's different for each application and possibly even each part." In other words, you don't know how often you should calibrate until you know more about your process.

## Who Should Calibrate Machines?

Only trained personnel should calibrate machine tools, though some of the most sophisticated calibration tools are easy to use, if costly in some cases. Okuma recommends that calibration of its machines be done either by an Okuma distributor or by shop personnel trained by one. All Okuma distributors provide full service, including calibration techs. Huebner said SW feels the same and the company covers calibration as part of maintenance training in its SW Academy. AfM's Hailer said that a shop can be more flexible and react faster in urgent cases if their personnel can calibrate their own machines, which returns us to Wilm's point about "process."

"The people who own the machine should control their own process, making sure that from start to finish you're putting out a good product," he said. If you can trust an outside source to calibrate your machines, so be it.

Wilm further cautioned that many people don't understand that the calibration itself needs to focus on the planned work for the machine. "So if, for example, you're making aluminum parts, you want to move over the parts as if the machine were on aluminum. Although the drive mechanism or positioning devices in the machine may be made of steel, you need to adjust your calibration devices to match the coefficient of thermal expansion of aluminum." Even the OEM technician will "get it wrong" if you don't make sure he takes your process into consideration.

Cost is a consideration, said Jeff Seliga, marketing manager for Renishaw Inc. "A ball bar in the $10,000 range is perfectly affordable for most job shops, while a laser system costing many times that may not be, and in that case you would want to contract with an outside service provider. Conversely, an aerospace shop may have very stringent tolerances and as part of their overall business model needs high level calibration equipment on-site for immediate traceability."

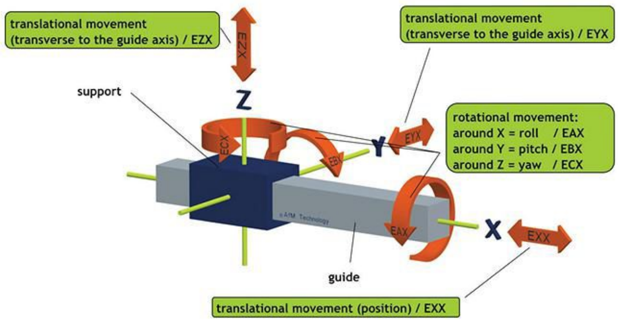
## Ball Bar Offers Lots of Info

Perhaps the single most popular and effective piece of calibration gear available today is the ball bar. Relatively inexpensive and easy to use, the ball bar yields a wealth of information. Simply attach one magnetic mount to the machine spindle and another to the table and place the ball bar between the two mounts. A ball bar is a telescoping bar with precision balls at each end. Software drives the machine through a circular path and a sensor in the bar measures any deviation from the ideal path. The software then interprets those deviations to identify a number of different error sources: squareness, straightness, linear positioning, backlash, lateral play, and reversal spikes.

A system like the Renishaw QC20-W will present this information graphically while quantifying errors by axis, indicating both geometric and dynamic errors. A geometric error affects the geometry of a part whether or not the machine is moving. A dynamic error occurs only when the machine is in motion, such as a reversal spike caused by a delay when the axis goes into reverse, explained Wilm. He added that such an error would create flat spots on a part when cutting pockets or radii.

"You can change the size of the ball bar in order to exaggerate what you're looking for," he said. "If an important function of the machine is making pockets, use a very small ball bar and a very fast test. If you're looking for geometry, you want to use a very large ball bar or a very slow test. That allows the ball bar to exaggerate the geometry."

On the other hand, a ball bar picks up combinations of errors and doesn't necessarily pinpoint exactly what's wrong. As Cagle of Okuma America explained: "If your test finds a circularity error and says 80 percent of the problem is backlash in the X axis, you still have to do additional detective work to determine what in the X axis is causing the backlash. The test doesn't specify 'your ball screw is bad.'" Cagle refers to the ball bar as a "30,000-foot view of




***Three translational and three rotational movements comprise the six degrees of freedom of a single linear axis (in this case X). A typical five-axis machine has 43 possible deviations, not counting the spindle. (Provided by SIOS Messtechnik)***

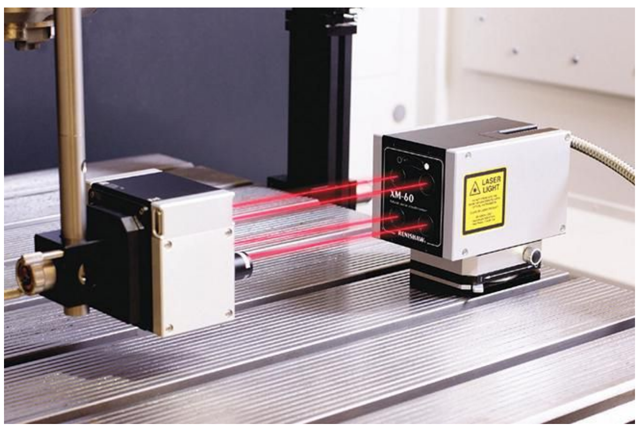
what's going on with your machine, like going to the doctor and getting your blood work. If you do it every year, you start to see patterns and you can make predictive maintenance decisions versus reactive maintenance decisions."

The ball bar also doesn't identify errors like roll about the axis of travel. And there's a lot that could be wrong when you consider that every axis has six degrees of freedom (6DOF). As Wolfram Meyer, senior principal for machine tool and CMM calibration at SIOS Messtechnik GmbH, Ilmenau, Germany, explained, the 6DOF for a linear axis are positioning deviation, movement up and down, lateral movement, pitch, yaw, and roll. There are also 6DOF for each rotary axis. The actual deviation at each nominal position is represented as a set of values called a "component deviation."

On top of that, Meyer explained that you also have to consider the "location deviations" for each axis, three for each linear and five for each rotary axis. A linear axis is almost always designed to be perfectly square with respect to two other linear axes (e.g., a 90° angle between X and Y and X and Z) and the angles describing the difference between the actual axis and ideal axis are summarized as three squareness errors. Rotary axes are more difficult to explain but each has five such deviations. Add it up for a five-axis machine with three linear axes and two rotary axes and you have 43 possible deviations. (3 x 6 + 3 for the linear axes and 2 x 6 + 2 x 5 for the rotary axes.) Meyer also explained that 80 percent of the error in a rotary axis usually comes from location deviations and 20 percent from component deviations, while it's the opposite for linear axes.

Identifying and measuring some of these deviations is best done with a laser interferometer. Some laser systems, like the SIOS SP15000 C5 and the Renishaw XM-60, even measure all 6DOF simultaneously while moving down the axis. (Strictly speaking, the SIOS C5 measures 5DOF with the laser and simultaneously measures roll with an electronic level.)

The accuracy of these systems is traceable to international standards and as good as you can get because, as Renishaw's Wilm explained, you're measuring with the wavelength of light, the unit on which all length measurements are based. These units even account for the effect of air temperature, air pressure, and humidity on the light. For example, Wilm said a change of 1°C could cause a one ppm uncompensated error in a measurement. All environmental factors taken together could add up to a 20-50 ppm error in a measurement if not compensated. But these are insignificant compared to ignoring or mistaking material temperature. "If I'm using a thermal expansion coefficient of 10 ppm, I'd have a one micron per meter uncertainty and just a 0.1°C uncertainty would cause a one ppm error."




***The Renishaw XM-60 laser interferometer measures all six degrees of freedom simultaneously while moving down the axis. (Provided by Renishaw)***

So if a temperature measurement is off by 1°C when machining aluminum (coefficient of expansion of 24 ppm), the error will be 24 μm/m, which becomes significant in some applications. Meyer said that in addition to providing critical information for compensating the nominal position, constantly measuring the temperature and visualizing the gradients "provides a lot of information about the machine structure, its thermal behavior, and the quality of the calibration process. But to do that easily you need wireless sensors like the LCS System from SIOS."

Other calibration technology includes 3D probes (now standard in high-precision machine tools), spindle analyzers (spindles are typically built to extremely high tolerances and then assumed to be good when installed), and rotary axis calibrators. There's some controversy on the last item as many people assume that if you have a scale on a rotary axis you don't need to calibrate. But Wilm said that's wrong since most have a single read head and "if there is any eccentric motion of the shaft holding that ring or read head, you're going to get positioning error based on that eccentric motion." A rotary axis calibrator uses a laser to determine the actual rotary position. Finally, the tools discussed so far should not be used in isolation. Combine them to create a total picture and a complete correction plan.

## In-Process Calibration

If you find some aspect of your machine is out of spec, you either have to fix it mechanically or live with producing bad parts and risk bigger failure to come. But small errors can be compensated for automatically, and there is new technology that addresses this.

Swivel compensation is a simple but critical example. As Cagle explained, on a multi-function lathe like the Okuma MULTUS, an operator needs to find the center of rotation of the articulating head to control the tool tip. Otherwise, accurate simultaneous five-axis machining is impossible. The same would hold for any swiveling or articulating head, or a trunnion table in a machining center. Okuma performs this check with a test bar and an indicator. Software then uses the results to automatically correct the position of the head in X and Y relative to the tool tip.

Okuma also offers a Five-Axis Auto Tuning System that uses a touch probe and a datum sphere to measure and auto-compensate for 11 types of geometric errors in about 10 minutes, or a fuller set of adjustments in 30 minutes. For example, Cagle explained, if the X and Y axes are straight but the probe detects a slight error in Z, the control could "interpolate a straight traverse in Z, perhaps by moving X two microns over the course of a meter." In another example, multi-sided machining with tools inclined at different angles for each surface, the system automatically improved the maximum machining surface error from 25 to 10 µm. Meyer added that Siemens, Heidenhain, and Fidia also offer software options that use a sphere to compensate for deviations in rotary axes.

Mitsui Seiki USA Inc., Franklin Lakes, N.J., has been working on more than just automatic error compensation. The company is closing the manufacturing loop to finish a part accurate to within a few microns and then prove it while it's still in the machine. Accounts Engineer Béat Ries explained that the company does this by combining an advanced laser interferometer from SIOS, software from AfM, and a NIST traceable artifact—a step gage with multiple dimensions measured by a lab whose certification is recognized by the National Institute of Standards & Technology.

After the laser interferometric measuring process is complete, the calibration technician uploads compensation values for pitch error, bi-directional error, and the 3D "volume of data" directly to the FANUC control without any additional input. AfM has also created interfaces for Siemens, Heidenhain, Fagor, and Bosch controls. The control is then able to automatically make improvements in an already precise machine. To take one example, measuring the Y axis on a Mitsui Seiki Vertex 750 machine found a maximum positioning error of 13.4 μm across the entire 800-mm span, which the SIOS interferometer and AfM software reduced in one cycle to 0.54 μm, an improvement of 96 percent. Calibrating all three linear axes took 77 minutes and enhanced the overall accuracy by 95.7 percent. Meyer pointed out that such results show how well the SIOS interferometers compensate for environmental influences like temperature and air pressure, as well as dead path error. “Reaching these levels also requires speeding up the calibration process and one advantage of the SIOS interferometer is its high data acquisition rate,” he said.

What’s more, AfM now offers software that provides the ability to confirm and certify the linear and volumetric accuracy of a machine according to international standards within 15 minutes, just by probing the NIST traceable artifact. Better yet, Ries pointed out, if a machine repeatably returns the correct measurements on the artifact, the accuracy of the machine’s measurements on the prismatic parts it has finished can be trusted. This closes the manufacturing/QC loop and, at least on a Mitsui Seiki machine, makes ultra-precision machining virtually automatic.

## FYI

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