

QUALITY SCAN



Clive Warren

Business Manager, Calibration Products Div.
Renishaw Inc.

Hoffman Estates, IL

E-mail: clive.warren@renishaw.com

Use Laser Diagonal Measurements Correctly

Machine tools have traditionally been evaluated on linear accuracy—their ability to repeatably produce cuts to a determined level of precision in X, Y, and Z axes. As tolerances become tighter and parts more complex, however, interest is growing in determining the volumetric performance of machine tools. This is especially the case for contoured parts, where positioning errors can be compounded by simultaneous multi-axis motion, and large parts where toolpath deviation is amplified across longer machine travels due to the effects of Abbé and squareness errors.

What is required in the calibration of machine tools to optimize volumetric performance? For starters, a three-axis machine tool has 21 degrees of freedom that have an effect on positioning error, and interact to affect the volumetric performance of the machine. While some users worry that the measurement of all 21 error sources might be a complex task that takes several days to complete, the reality is that with the latest generation of laser interferometer systems, a competent technician can conduct a calibration in one day.

Laser diagonal tests are an effective way to detect changes in a machine tool's volumetric performance.

Quicker methods are available for monitoring machine tools for possible degradation. The ASME B5.54 and ISO 230-6 standards describe how to use telescoping ball bars and laser diagonal measurements to assess volumetric performance. Testing with a telescoping ball bar, which typically takes 10–15 min, will show if a machine is still performing to specification, and gives a reasonable diagnosis of specific individual error sources. Given the speed of testing and the information it provides, a ball bar test should be considered as an essential first check before using more-specific calibration checks.

The only volumetric check recognized in International standards (e.g. ASME B5.54 and ISO230-6), laser diagonal tests measure the positioning accuracy of the machine as it moves along each of four body diagonals. Picture the machining volume as a cube. The laser measures the diagonal distance from each lower corner to the opposite upper corner, and determines the positioning error versus the true dimension. In a perfect machine, all four diagonals would be

the same length and match the theoretical diagonal dimension for the defined machine volume.

Deviations between diagonal lengths indicate the presence of machine positioning errors, but do not conclusively identify the error source(s) or the degree of error. Because diagonal motion requires simultaneous movement in X, Y and Z axes, overtravel in one axis and undertravel in another can produce a “correct” diagonal length, and give a false impression of overall machine positioning accuracy (confirm this for yourself using the Pythagorean theorem). Standard B5.54 calculates a machine's volumetric performance from the diagonal with the largest range of positioning error. Depending on how axis errors stack, a machine with better volumetric performance can actually have an inferior rating to a machine with substantially larger volumetric errors, due to the error-canceling effect.

A variation on diagonal calibration, referred to as the step-diagonal or vector-measurement technique, has been promoted as also enabling calculation of linear accuracy, straightness, and squareness in a single test sequence. Rather than moving the X, Y and Z axes simultaneously to accomplish the diagonal move, each axis is moved sequentially to complete each step of the diagonal. The step method uses an angled mirror, mounted in the machine spindle, which returns the beam to the laser's return port as the machine zig-zags along the diagonal. However, unless the laser beam and plane mirror are perfectly perpendicular, and there are no roll, pitch, and yaw errors, step-diagonal measurement will introduce errors that cannot be separated from the linear-displacement errors.

This has been verified in an analysis by Kyoto University. The study found that conditions for correct laser and mirror setup in step-diagonal measurement are “simply not possible to satisfy.” The paper advised that “linear positioning errors must be independently measured.”

In summary, laser diagonal tests are an effective way to detect changes in a machine tool's volumetric performance, though diagonal tests alone do not provide a reliable measurement of absolute volumetric performance, nor should they be depended on for accurate data for compensation tables. They should not be used to compare one machine's accuracy against another's. ASME B5.54 suggests that in addition to the diagonal measurements, linear tests should also be taken. In fact, ASME B5.54 concludes its introductory paragraph by suggesting that a “more complete estimate can be obtained” by using traditional geometric accuracy tests. For machine accuracy and compensation determinations, there is still no proven or recognized substitute.