DECEMBER 2001 / VOLUME 53 / NUMBER 12

BY MIKE GLOSSINGER

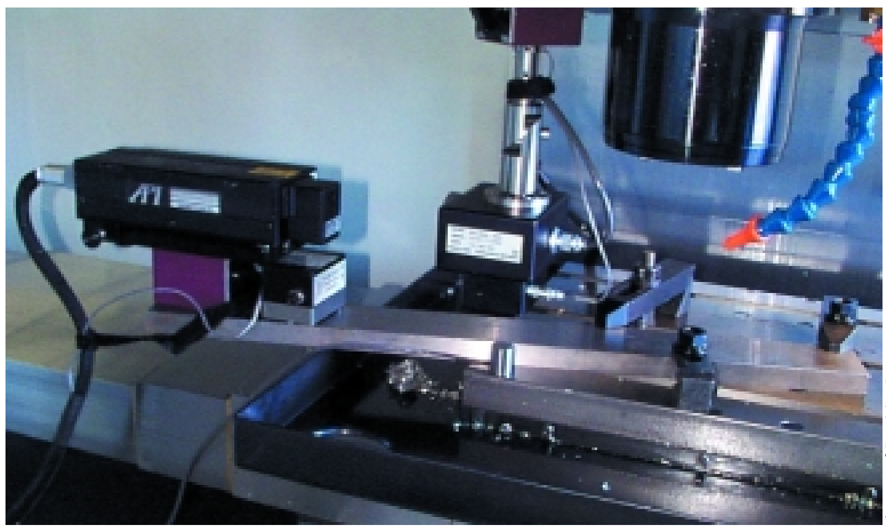
Shedding Light On Accuracy

How a laser-calibration system evaluates and corrects CNC machine tools.

When production parts are out of specification, or running at maximum tolerances but still within specifications, it's time to examine the machining process to discover the source(s) of the problem.

After eliminating the possibility of variations from worn cutting tools, part programming, fixture changes and raw materials, the production shop is left with determining if the CNC machine is the cause of the problem. It must first establish if the cutting tool is traveling to the right position, as commanded by the part program. A cutting tool on a 3-axis machining center, for example, is programmed to go to a series of X-, Y- and Z-coordinate positions. And because the machine has three linear axes, each must be measured.

Yet when evaluating the possible errors for a single axis, the complexity of the task comes into focus. Each axis can have six possible errors: linear travel, straightness in two orthogonal axes and angular errors for pitch, yaw and roll. In addition, the squareness of the three axes with respect to each other must be determined, which requires three additional setups and measurements. A 3-axis machine, therefore, has 21 possible sources of error.



This mounting arrangement of the laser measurement system allows full travel of the X-axis during measurement.

Machine Measurements

Machine tool measurements have been performed for many years using step gages, straight edges, squares and dial indicators. Taking these measurements requires a skilled and experienced operator, and the chance for computational errors is high.

And since every error measurement requires a separate setup, the time needed to perform 21 measurements is a major drawback. Production and time constraints often limit the number of measurements taken. Shops often try to identify and correct the major cause of an error without completely measuring the machine.

For example, the telescopic ball bar is a popular diagnostic tool. It's effective for establishing dynamic errors and providing relative axis-travel information. It also measures backlash, stick-slip, scale-mismatch and servo-timing errors. But it does not provide a reliable measurement of machine geometry beyond axis squareness.

Qualifying a machine with a laser interferometer eliminates the problems associated with other methods of measuring machine axes. The laser interferometer is recognized as the standard for precision length measurement and for establishing linear accuracy. Also, with special optics, it is possible to measure orthogonal straightness and two of the three angular errors: pitch and yaw.

The need to measure machine travel accurately led to the development of laser measurement systems. While many systems are available, most rely on one of three measurement strategies to achieve the same results. One strategy measures the diagonals of the work envelope; accuracy depends on the repeatability of the machine being qualified. In addition, this method does not provide the individual axes errors that help to identify the proper mechanical corrections that may be required, such as a squareness correction.

The other two strategies focus on direct measurement of the machine axes, with some systems measuring one axis at a time and others measuring multiple axes simultaneously.

An example of the latter is Automated Precision Inc.'s (API) 6D laser measurement system. It simultaneously measures five or six errors of a linear axis. This reduces measurement time up to 80 percent. Additionally, measuring the errors simultaneously provides better agreement on the relationship of these errors to one another.

After taking measurements with the API system, analysis may show that one axis is significantly less accurate than the other two. Having this information usually is sufficient to identify the axis requiring correction.

However, if each individual axis has errors, which may be less than the tolerances for the part being produced, it still must be determined if the machine can produce acceptable parts, since errors increase geometrically—summing angles in three dimensions. Doing this requires an understanding of how the errors of one axis generate errors in the other two axes.

Typically, this condition occurs on a CNC machine when the Y-axis is mounted on the X-axis. If the X-axis has a straightness error in the Y-axis direction, this error is added—or subtracted—to the Y-axis linear error that results. These errors cannot be seen in a measurement process in which the axes are moved one at a time. Furthermore, evaluating every possible additive effect of the 21 error parameters is quite complex.

Error-modeling software makes this analysis much easier. The software provides a volumetric error map that indicates the combined effects of the 21 individual errors measured on any area within the volume covered by the machine's axes. The software readily establishes whether or not a machine is able to produce parts within a specified tolerance.

Corrective Steps

Once it's been established that the CNC machine is the cause of the part-tolerance variation, the problem must

Laser Alignment: Outsourcing vs. In-House

By Alan Richter, Managing Editor

Whether a shop performs laser calibration and alignment of its machine tools in-house or outsources the work depends on numerous factors, said Mike Eckardt, president of CNC Machine Services Inc., Lake Orion, Mich. These include the number of machines it operates, the types of parts it produces, and the machine tool expertise available at the shop or that can be established via training.

"Quite a bit of expertise is needed," said Eckardt, whose company calibrates machine tools. "You need to understand the total system—everything that makes up the machine."

He noted that CNC Machine Services' technicians gained this experience by working for machine tool builders before joining his company. "Once someone is familiar with a CNC machine, laser calibration is the easy part," Eckardt said.

A technician typically brings $70,000 to $80,000 of equipment to a shop to check and correct every aspect of a machine tool's operation, such as pitch, yaw, roll, spindle contact, runout and vector alignments.

In addition to a laser, the equipment includes machine-maintenance tools, such as granite squares, flatness testers, a computer loaded with the appropriate software, mirrors and ball bars to check the consistency of the axes movements prior to performing laser alignment. Eckardt said it takes about 10 hours to service a machine. The cost of the service ranges from $1,000 to $2,500, depending on the type of machine, its tolerance requirements and the technician's traveling time.

A machine should be serviced once a year and always after a crash, he said. To minimize downtime, the service can be performed on weekends.

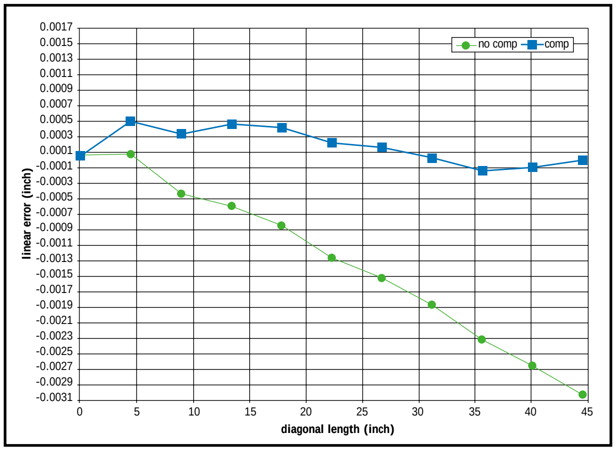
Eckardt said a shop should expect to spend $20,000 to $200,000 on a laser system, depending on its needs. For example, a shop producing aerospace parts would require a complex, multifaceted system. He said he doesn't know of many shops with in-house laser calibration equipment. "The Big Three automakers have laser units, but no one there knows how to run them," he said.

CNC Machine Services calibrates machines with an Optidyne 4000 laser system, which uses the Laser Doppler measuring system. The patented system's accuracy is within 0.1µin., and the Laser Doppler allows multiple measurements to be made in a single pass, which reduces setup times, Eckardt said.

Although laser calibration and alignment is required to ensure a machine makes accurate parts, Eckardt said it is the final procedure when servicing a machine tool. He added that a number of his competitors offer laser calibration without the full machine service, which initially saves a shop time and money but isn't the proper approach in the long run.

"Laser alignment and calibration is not the whole answer," he said. "There are many factors involved in servicing a machine, and unless you look at all of those factors, you're not fixing the problem."

For more information about CNC Machine Services Inc., call (248) 391-2341, visit www.cncmachineservices.com.



The slope of the lower graph illustrates how errors increase with distance before measurement and correction. The upper graph depicts error reduction after geometric compensation.

be corrected. To determine the most effective method of correction, the machine's repeatability must be evaluated.

Repeatability is a measure of the consistency with which a cutting tool goes to a command position. If, for example, the cutting tool receives a command to go to X=5, Y=5 and Z=0, and it goes to X=4.950, Y=4.950 and Z=0 four times out of four, it is a highly repeatable machine—but not an accurate one. When a machine repeats an error, even with a small variance, then it is simply a matter of adjusting the command position to correct for the error.

In this example, one might command the cutting tool to go to X=5.050 so that the tool arrives much closer to the desired X-axis position. Since this program change adjusts the command position only for the specific machine, however, it's not the best corrective method.

For this reason, most of today's controls allow adjustment of the encoder-position software to correct these errors. (This is often called "pitch compensation," because a common means of establishing axis travel is with a motor-driven screw and a nut. The position is established by having a rotary encoder count pulses on an optical disk, with a large number of pulses counted per revolution. Each revolution moves the machine one screw pitch.)

If an error is repeatable, it's possible to correct it through the controller. If an error does not repeat or varies more than the desired tolerance, then one must make either a mechanical or electrical repair to the machine.

Most machine controls provide users with the ability to adjust the linear position to correct for errors in linear travel—that is, pitch error. In addition, many newer controls provide for straightness correction in the orthogonal axis and squareness correction. And, some controls provide for correction of all 21 errors.

The error correction is frequently based on a 3-D grid, which has a set number of points in the machine volume. For each specific X, Y and Z point within the grid, a correction is quantified. Summing the 21 individual errors into a single correction for each point requires error modeling and computations that are often beyond the capabilities of many technicians who service machine tools. Three-dimensional error-modeling and correction software is available that develops these grids.

If a controller is unable to compensate for all machine errors and linear compensation alone fails to provide the desired results, corrections can still be made by altering the information supplied to the controller by the scale (encoder) system. This can be accomplished by a second controller that will alter the machine scale information provided to the machine controller based on the error-modeling software. Either way, the net result will be the same.

Evaluating CNC machines with laser systems allows for rapid and comprehensive analysis that would otherwise be time consuming and costly. And analyzing the data with error-modeling software reduces the complexity of the process and helps keep the production of quality parts on track.

About the Author

Mike Glossinger is a mechanical engineer and metrology product manager for Applied Precision Inc., Gaithersburg, Md. For more information about API, call (301) 330-8100 or visit www.apisensor.com.