August 2006

AEROSPACE ENGINEERING

Technology update

Calibration of CNC machine tools

Once considered strictly a quality issue, calibration and compensation have been directly linked to cycle-time reduction. A machine tool within tolerance can run higher feed rates and still maintain tolerances. Calibration allows online part inspection, saving time shuffling parts back and forth between the machine tool and CMM. Additionally, regular calibration can be used to predict when a machine tool will go out of tolerance.

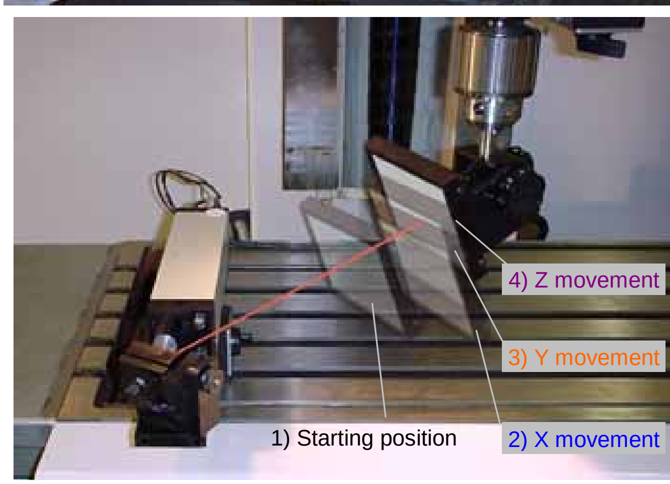
To operate laser calibration equipment a metrologist was once required. Machine tool covers had to be removed to align optical components on the table, spindle, and free-standing tripod. The process of 3-D (volumetric) calibration required several days, depending on the size of the machine. Therefore, calibration was not considered necessary when parts measured on a CMM were found within tolerance.

Today, technology and processes have significantly reduced the cost of laser calibration equipment such as that provided by **Optodyne,** the need for a metrologist or outside service, and machine tool downtime. A machinist with one day of laser calibration training can perform 3-D calibration of a 1-m^3 machine tool in as little as a half-day. The software automatically writes the compensation tables and uploads the CNC control.

For years, the Body Diagonal Displacement Method (BDDM) defined in the **ASME** 85.54 or **ISO** 230-6 standards has provided a quick check of volumetric error for such aerospace companies as **Boeing,** and many others. BDDM measures the four diagonals of the machine tool's work envelope cube, generating four sets of data, which includes all errors. However, it does not provide enough data to identify exactly where the error is located.

A newer process-the Sequential Step Diagonal Measurement Method (SSDMM) - collects 12 sets of data with the same four diagonal setups.

Two separate laser heads for master and slave axes measurement validate gantry-type machine tools, even with very long travels.



Stop-action photograph of Sequential Step Diagonal Measurement Method shows each of the steps for measuring 3-D (volumetric) errors in as little as two hours without removing machine tool covers.

Based on this measurement data, all three displacement errors, six straightness errors, and three squareness errors are determined without lengthy machine tool down time. Additionally, the measured positioning errors are used to generate a 3-D compensation table.

The SSDMM differs from BDDM in that each axis moves separately in sequence and the diagonal positioning error is collected after each separate movement of the x-, y-, and z-axis, providing three times the amount of data and allowing the positioning error for each separate axis movement to be measured.

The trajectory of the target is not a straight line and the lateral movement is quite large. A conventional interferometer cannot make these measurements because it does not tolerate such a large lateral movement. However, single-aperture laser interferometers, such as a Laser Doppler Displacement Meter, are unaffected by large lateral movements. With a flat mirror as the target, the movement parallel to the mirror does not displace the laser beam and does not change the distance from the source.

Predictive Maintenance (PDM) and other programs such as Machine Tool Variability Management System, Reliability and Maintainability, Failure Mode and Effective Analysis, and Total Productive Maintenance predict machine tool failure (out of tolerance). By comparing current and historic data collected with such instruments as laser calibration, vibration analysis, and IR thermography equipment, a prediction can be charted of when such machine tool components as the CNC, ballscrew, way systems, or servomotors will require compensation, service, or other necessary repairs.

A machine tool rated at 0.0002 in is checked every six months. Assume that at each of the last three calibrations, the tolerance has degraded by 0.000050 in. Based on the historic information, it is reasonable to predict calibration will be required within six months. Similarly, vibration analysis can reveal information about the spindle and other critical components for predicting maintenance and repair operations.

Optodyne's MCV 5004 aerospace loser kit for measuring 3-D errors of CNC machines.

Establishing a PDM program is a long process, beginning with the selection of machine tools for the program and technologies to calibrate and collect data. Next calibration equipment must be evaluated and purchased, then PDM procedures can be established, using the following basic steps:

- Monitoring machine tool conditions
- Diagnostics to identify problems
- Data analysis and corrective actions, and
- Early warning and prediction by integration of precision measurement system directly into the manufacturing operation.

After the basic steps have been detailed with specific repeatable procedures, acceptable levels of performance and accuracy must be defined. Additionally, measurements to establish a machine tool baseline must be taken. Machine tool measurements must be made at regularly specified time intervals and from the analysis, maintenance, and repair predictions integrated into production schedules.

Using a 3-D-capable machine tool for (in-process) part inspection can significantly reduce cycle time and improve accuracy. In the aerospace industry, inprocess inspection has failed to gain momentum because resolving positioning errors on the same machine tool that cut the part was expected to result in repeating the errors during the inspection process. However, newer laser calibration technology and processes meeting such requirements as ISO 9000 and ISO 17025 satisfy both manufacturing and quality programs and allow the use of on-machine inspection as a viable and credible process.

For example, gage accuracy requires a ratio of 4:1; therefore, CNC machine tool accuracy must be four times more accurate than the specified accuracy of the part. For on-machine inspection to meet this requirement, the accuracy of the machine must be verified. Using the measured 3-D positioning errors, a lookup correction table can be generated automatically by software, enabling in-process inspection software to compensate the machine's 3-D positioning errors. When using a machine tool for in-process part inspection, the cutting tool is replaced with a suitable probe, which measures part dimensions. The 3-D positioning errors can be tabulated as lookup tables or compensation tables, allowing the software to correct measured probe positions. With 3-D error correction, inherent errors in machine tool geometry and positioning can be eliminated to provide accurate dimensional measurement. Therefore, by satisfying the 4:1 gage accuracy ratio with volumetric error compensation, a CNC machine tool can provide the same high-accuracy as a CMM.

This article was written for *Aerospace Engineering by* **Charles Wang,** President, Optodyne.