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The Keys to Calibration

Machine Tool 3D Volumetric Calibration Replaces 1D Linear Calibration

In the job shop or manufacturing environment, the increasing demand for manufacturing quality, accurate parts, while maintaining high productivity levels, is advancing the importance of measuring and compensating the 3D volumetric positioning errors of CNC machine tools.

Temperature variations in the environment, spindle and lead screw thermal loads, cutting loads, and coolants impact machine accuracy.

Once considered strictly a quality issue, calibration and compensation have been linked to production and cycle-time reduction. A machine tool within tolerance can run high feed rates and still maintain tolerances. Calibration allows online part inspection with machine tools, eliminating shuffling parts back and forth between the machine tool and coordinate measuring machine – CMM. Regularly-scheduled calibration is useful for predicting when a machine tool will go out of tolerance.

Easier Measurements

A metrologist was once required to operate laser calibration equipment. Machine tool covers had to be removed to align optical components on the table, spindle, and freestanding tripod. The process of 3D volumetric calibration required several days, depending on the size of the machine. Therefore, calibration was considered unnecessary when parts measured on a CMM were within tolerance.

Twenty years ago, the largest machine tool errors were linear displacement errors, such as lead or ball screw pitch errors and thermal expansion along an axis. Linear displacement errors have been minimized with the use of compensation and linear encoders and ballscrew cooling systems.

We live in a 3D world. Calibration of 1D linear displacement error is not enough. We have to calibrate 3D volumetric positioning errors. Since many types of errors, other than linear displacement, have a tremendous effect on 3D machining accuracy, the International Standards Organization has started creating a standardized world-class definition of 3D accuracy.

Cost Reduction

Today, technology and processes have significantly reduced the cost of laser calibration equipment, need for a metrologist or outside service, and machine tool downtime. Easy-to-use, economical measurement devices, and reductions in downtime and scrap parts make it one of the best times to replace 1D linear calibration and compensation with 3D volumetric calibration and compensation.

The Body Diagonal Displacement Method defined in the ASME B5.54 and ISO 230-6 standards was the standard quick-check of volumetric error.

A new process, the Sequential Step Diagonal Measurement Method, collects 12 sets of data with the same four diagonal setups. Based on this measurement data, three displacement errors, six straightness errors, and three squareness errors are determined without lengthy machine tool downtime.

The measured positioning errors are used to generate a 3D compensation table. 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 measures the positioning error for each separate axis movement.

Using a machine tool for in-process part inspection reduces cycle times and improves accuracy. However, in-process inspection has failed to gain momentum because resolving positioning errors on the machine tool that cuts the part are expected to result in repeating the errors during the inspection process. The measurement also should be four times more accurate than the part's accuracy to satisfy the gage accuracy requirement.

For on-machine inspection to meet this requirement, the machine's 3D volumetric accuracy must be measured. Using the measured 3D positioning errors, a lookup correction table can be generated automatically by software, enabling the inprocess inspection software to compensate for the machine's 3D positioning errors. By satisfying the 4:1 gage accuracy ratio with volumetric error compensation, a CNC machine tool provides the same high accuracy as a CMM and the inprocess part inspection becomes viable.

Charles Wang, Ph. D., is cofounder and president of Optodyne Inc., a leader in precision measurement and calibration systems for CNC machine tools and CMMs.

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