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Volumetric Compensation over Part Volume

To improve the volumetric-positioning accuracy of machine tools, and to machine parts with consistent and tighter tolerances, 3-D volumetric calibration and compensation is essential. High-end machine tool manufacturers have called for volumetric calibration and compensation, and economy machine-tool manufacturers are also beginning to see its value. Until recently, measuring volumetric errors has been time-consuming and costly. However, the laser vector technique is much faster and less costly, making it practical to measure 3-D volumetric positioning errors.

Volumetric errors include three displacement errors, six straightness errors, and three squareness errors. Measuring and calibrating volumetric errors with a conventional laser interferometer requires a few days. The laser vector technique measures and compensates volumetric errors in a few hours. It uses the 3-D volumetric-positioning error measurements to generate positioning error maps, or to compensate for the 3-D volumetric-positioning errors.

The concept of volumetric calibration is often confused with calibration of three axes. It's important to understand that linear measurement along three axes is NOT 3-D volumetric calibration. Linear measurements do not consider straightness or squareness. The 3-D volumetric measurements include displacement, straightness, and squareness errors.

Within the part's working volume, the positioning error of an arbitrary point includes the positioning errors of each individual axis in all three axis directions, including the linear displacement error and the straightness errors—horizontal and vertical. At each point the error is the sum of errors in all three axial directions (*X, Y, Z*), plus the errors caused by the nonperpendicularity (squareness) of the three axes.

The total error is the vector sum of the errors in each axis direction, and the errors in each axis direction are:

$E_x(x,y,z) = D_x(x) + D_x(y) + D_x(z)$, error in x-direction at position x,y,z

$E_y(x,y,z) = D_y(x) + D_y(y) + D_y(z)$, error in y-direction at position x,y,z

$E_z(x,y,z) = D_z(x) + D_z(y) + D_z(z)$, error in z-direction at position x,y,z .

Note: The subscript indicates the error direction, values in parenthesis are the coordinates, and D is the error of each axis movement.

A conventional laser measures and compensates volumetric errors over the machine's entire working volume, which requires more measurement time, and provides fewer compensation points over the whole volume.

In a typical shop, part volume is much smaller than the machine's working volume. Because part volume is the volume that's crucial to be calibrated and compensated, time spent calibrating the whole machine could be eliminated. Additionally, calibrating only part volume allows the collection of more compensation points in a smaller volume, resulting in higher accuracy.

The laser vector technique allows just the part volume to be calibrated and compensated, and is based on the ASME B5.54 and ISO230-6 standards for body-diagonal-displacement measurement with sequential step movement.

Using conventional laser interferometers to measure the straightness and squareness errors is very difficult. It's time consuming and requires complex optics and expensive equipment. Using a laser Doppler calibration system and laser vector measurement simplifies setup and operation. It can measure the volumetric errors in two hours for a machine working volume of 1 m^3. By measuring part volume instead of the full working volume, even more time can be saved.

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For most high-end controllers having 3-D volumetric error compensation capability, uploading the compensation file to the controller will compensate for machine errors over the part volume. For most controllers, however, only the pitch errors of each axis can be compensated. If this is the case, based on the measured 3-D volumetric positioning errors, the part program can be compensated (to correct the x, y, and z positions) and achieve higher accuracy over the part.

Measuring linear distance along each axis no longer provides accurate information to ensure calibration and compensation for part-accuracy requirements. Straightness and squareness must also be measured. The most economical, fastest method is the laser-vector method. When used to calibrate and compensate over the crucial area, i.e. part volume, it's even faster, and accumulates more points. The result is a highly efficient and cost-effective process for ensuring part tolerances without taking your machine offline for an inordinate amount of time.