A Definition of Volumetric Error

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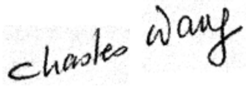

We believe that volumetric error more accurately reflects the accuracy to be expected from a machine tool than any other measurement that can be made. Therefore, it's our position that volumetric error should be determined and listed on the specification sheet of every machine tool offered to industry. On the other hand, we appreciate that measuring true volumetric error is challenging. We hereby propose a method of approximating true volumetric error that correlates well to true error, but is less difficult to measure than true volumetric error.

Traditionally, manufacturers have ensured part accuracy by linear calibration of each machine tool axis. The conventional definition of the 3-D volumetric positioning error is the root mean square of the three-axis displacement error. But linear calibration is inadequate to ensure the accuracy of 3-D parts, and using a laser interferometer to measure straightness and squareness errors can be relatively difficult.

The performance or accuracy of a machine tool is determined by 3-D volumetric positioning error, which includes linear displacement error, straightness error, angular error, and thermally induced error. The body diagonal displacement error defined in ASME 85.54 or ISO 230-6 is a good quick check of volumetric error. All the errors will contribute to the four-body diagonal displacement errors. The B5.54 tests have been used by Boeing Aircraft Co. and others for years.

Our new proposed measure of volumetric error, ESd,

includes squareness errors.

Currently, the ASME and ISO are working on a new definition of volumetric accuracy. One conventional definition of 3-D volumetric error is the root mean square of the displacement error of the three axes. This value, ELv, works as long as the dominant errors are the three displacement errors or leadscrew pitch errors. But linear encoders and error compensation have reduced most of these errors significantly. The largest machine tool errors are now squareness and straightness errors, so ELv is no longer an adequate definition of volumetric error.

True volumetric error includes three linear displacement errors, six straightness errors, and three squareness errors. True error (ELSv) can be defined as the root mean square sum of all the three errors in each axis direction.

When using body diagonal displacement error measurement, body diagonal error (Ed) does not include squareness errors. But Ed is currently defined in ISO 230-6 and AS M E 85.54 as a measure of volumetric error. Squareness errors can be included, and our new proposed measure volumetric error, ESd, includes squareness errors.

Some definitions: ppp/nnn indicates body diagonal direction with the increments in X, Y, and Z all positive/negative, and npp/pnn indicates the increments in X, Y, and Z are negative/positive, positive/negative, and positive/negative, etc. Body diagonal errors in each direction are Dr(r) ppp/nnn, Dr(r) npp/pnn, Dr(r) pnp/npn, Dr(r) ppn/nnp.

Based on the definition in ISO 230-6, E is defined as:

Eppp/nnn=Max[Dr(r)ppp/nnn]-min[Dr(r)ppp/nnn]
Enpp/pnn=Max[Dr(r)npp/pnn]-min[Dr(r)npp/pnn]
Epnp/npn=Max[Dr(r)pnp/npn]-min[Dr(r)pnp/npn]
Eppn/nnp=Max[Dr(r)ppn/nnp]-min[Dr(r)ppn/nnp].

And volumetric error is defined as:

Ed=Max[Eppp/nnn, Enpp/pnn, Epnp/npn, Eppn/nnp]. This definition doesn't include squareness errors. To include squareness errors, define the volumetric error thusly:

ESd=Max[Dr(r)ppp/nnn, Dr(r)npp/pnn, Dr(r)pnp/npn, Dr(r)ppn/nnp] – min[Dr(r)pp/nnn, Dr(r)npp/pnn, Dr(r)pnp/npn, Dr(r)ppn/nnp].

The definition ELv is still commonly used as the definition of 3-D volumetric error, and ELSv including straightness and squareness errors is true volumetric error. The Ed is defined in IS0230-6 and ASME 85.54 as a measure of volumetric error. We propose ESd, including squareness errors, as a measure of volumetric error.

Measurements conducted on 10 mid-size machining centers reveal that when compared to true 3-D volumetric error ELSv, ELv underestimates volumetric error.The Ed underestimates true volumetric error and varies with squareness errors. Finally, ESd underestimates 3-D volumetric position error but is relatively stable and not influenced by squareness errors. Thus ESd is a good measure of volumetric error.

Three partners collaborated with me in a project that has demonstrated the utility of ESd. They are Ondrej Svoboda and Pavel Bach of the Research Center of Manufacturing Technology, Czech Technical University, Prague, the Czech Republic, and Gianmarco Liotto of Optodyne. A more extended discussion of this subject, which includes our experimental data, is available at http://www.optodyne.com/opnew4/techart23.html. You can also request a copy by e-mailing me at sales@optodyne.com.