Manufacturing Engineering, 6/2002
Pre-cutting Prep. Pp60-66

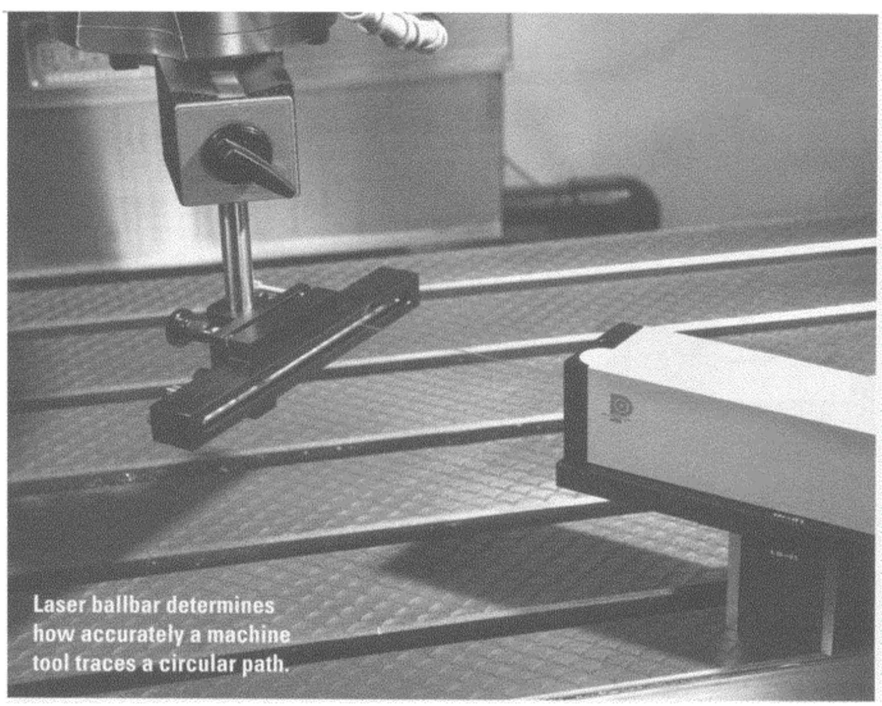
Checking the Volume

Charles Wang
President, Optodyne Inc. Compton, CA

Recently there has been a lot of discussion about the validity of a ball bar test, and the usefulness of the laser interferometer. Some say these instruments don't give enough information about the machine's performance. The laser interferometer checks each axis for position accuracy, but the results are independent of one other, Because the laser interferometer checks only the end-points. It does not check the machine under true dynamic conditions or the actual tool path.

Two forms of ball bar. They are the telescoping ball-bar and the laser. Both check the machine dynamically. The circular tests show how the X and Y axes work together to move the machine in a circular path. Path data, plotted in polar coordinates, show any deviation the machine makes from a perfect circle. The shapes are diagnosed and correlated to performance features such as servo mismatch, backlash, reversal spikes, squareness error, cyclic error, stick slip, and machine vibrations. The telescoping ball-bar is a one-dimensional measurement. Basically, only the radial changes along angular positions are measured. Angular positions are not measured but are calculated by assuming the machine feed rate is constant. Because the telescoping ball bar systems normally work with radii of 150-300 mm and feed rates of 6-10 m/min, they cannot follow circular tests with smaller radii, and the errors they detect usually trace back to problems with the machine's geometry rather than its controller.

These machine errors are larger than those produced by the control loops and consequently hide them. Because the telescoping ball-bar uses a transducer for the measurement, periodic calibration is necessary, and the unit is sensitive to temperature changes. The telescoping ball-bar has a cable between the transducer (inside the telescoping bar) and the electronic processor that makes a circular path with multiple revolutions difficult.

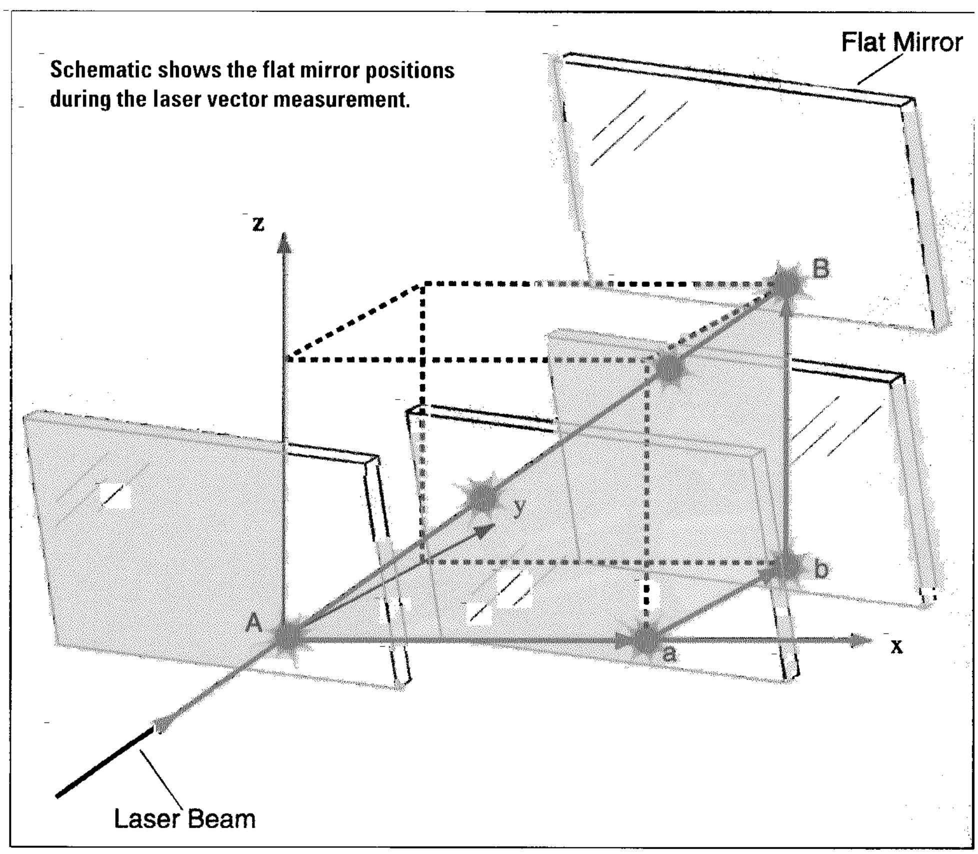


Laser ballbar determines how accurately a machine tool traces a circular path.

The laser/ball bar is a two-dimensional measurement device that uses a laser displacement meter and a flat-mirror target for the measurement. This system uses a modulated laser to reflect a beam off a moving target. The control detects the beam and processes it for displacement information to determine correct position. This noncontact system is highly accurate, typically 1 ppm, and traceable to NIST. Its measurements provide more information, such as feed rate or tangential velocity and acceleration. Also, the toolpaths are not limited to a circular path. For example, a toolpath with decreasing radius or a spiral path, is entirely possible. A circular path with many revolutions can easily be measured, and the radius of the circular path can be continuously varied.

Motion errors due to the mistuning of the CNC servocontrol system are often easier to observe on noncircular toolpaths. By comparing noncircular contouring-error profiles at different feed rates, motion errors due to mechanical structures, acceleration/deceleration, and those due to the CNC servocontrol system can be identified. The laser/ball bar system compares contouring-error profiles at different feed rates to identify motion errors due to mechanical structures and acc/dec, and those due to the CNC servo control system.

Volume analysis. One technique that is said to cover the failings of the interferometer and ball bar is volume analysis. Instead of checking a limited amount of axis motion, this process looks at the entire operating volume of the machine tool. Volumetric analysis uses a laser Doppler displacement meter in conjunction with a vector measurement technique. It measures linear position errors, vertical straightness errors and horizontal straightness errors for all three linear axes and three squareness errors. By measuring volumetric errors, the machine tool can be compensated over its whole volume, which improves the accuracy of the machine tool, not just linear displacement.



The technique uses four body-diagonal displacement measurements. These diagonal displacement errors are sensitive to all the volumetric error components, and therefore make an efficient test of volumetric accuracy. The vector method measures all three displacement errors, three vertical straightness errors, and three horizontal straightness errors with four set ups. A three-axis machine tool with a one-meter cube volume can be checked in about four hours.

For example, the working volume of a typical VMC has eight body diagonals, (a diagonal being defined by starting at one corner of the base plane and moving to the opposite corner at the top plane). These body-diagonals are defined by the positive or negative axis movement. The last four body-diagonals are the same corners as the first four diagonals, except the directions are reversed. There are, therefore, only four body diagonal directions with forward movement and reverse movement (bidirectional), and only four set ups.

For each setup, the operator measures machine spindle movement along each of the diagonals by executing X, Y, and Z portions of spindle travel sequentially, instead of simultaneously. Readouts are taken and recorded at each intermediate step. Usually, it is not necessary to move fixture, tooling, or enclosures. The system can be set up and operated by the machine's operator, with a learning curve of two to three hours.

With the data from the volumetric analysis, the system's software can generate a compensation table, which can be downloaded to the control. The table compensates for errors throughout the machine tool's volume. The accuracy gain reduces the bandwidth of errors by a factor of four, going from a typical volumetric error of 0.060 mm down to only 0.015 mm. These tables are uploaded into the machine's control, and all necessary changes are implemented at the control level based on the newly added input. The machinist need not interpret or massage the data produced. Improvements in volumetric accuracy are typically 300-400%, with some improvements as great as 900 % .