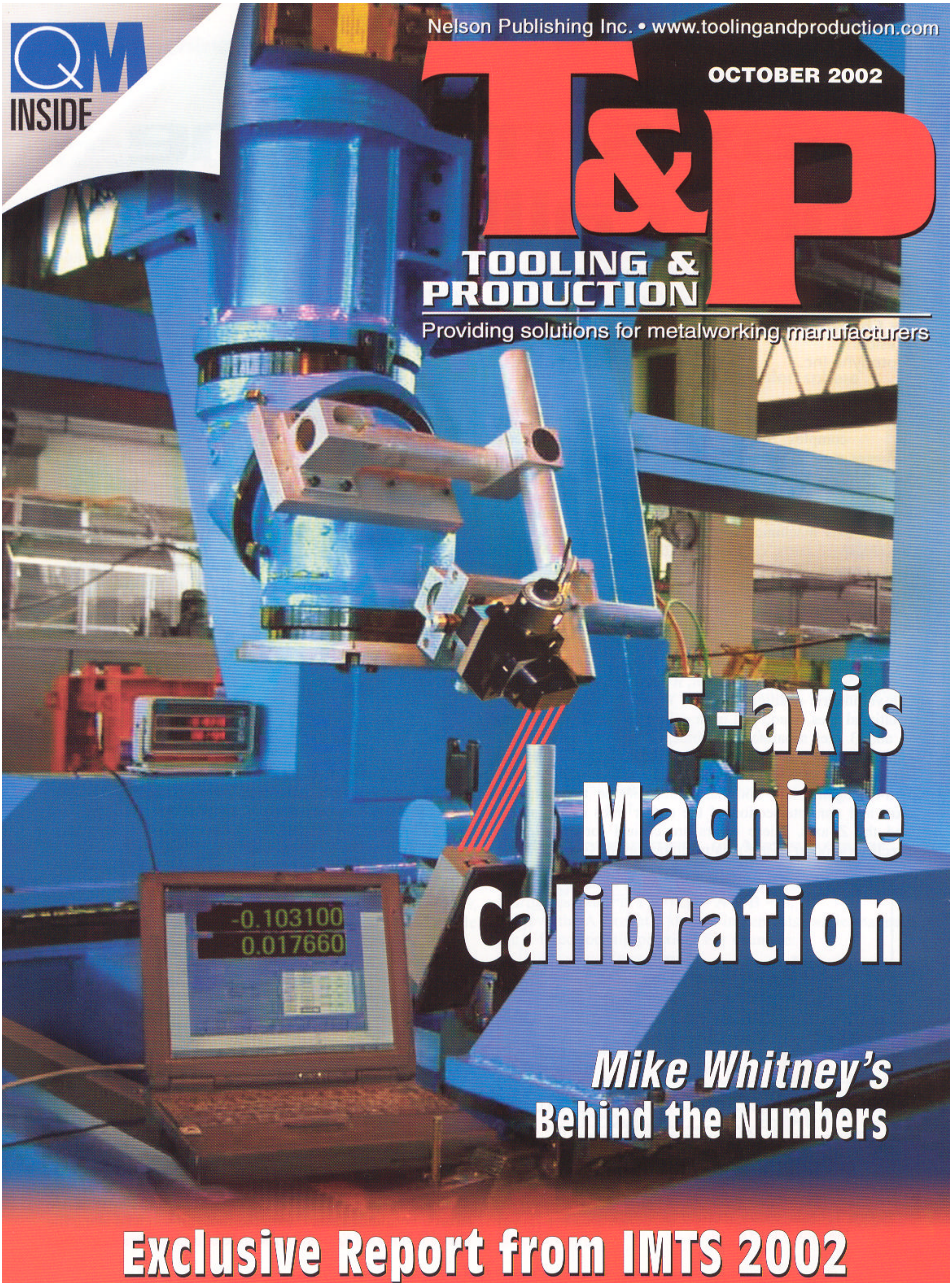

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5-axis Machine Calibration

Mike Whitney's **Behind the Numbers**

Exclusive Report from IMTS 2002

5-axis machine tool calibration

Vo/umetric and *tool* tip *position measurement* ensures *accuracy*

By Charles Wang, Ph.D. President
Optodyne Inc.

Calibrating a 5-axis machine tool can be a very complex, time-consuming, and expensive process, especially when machine downtime and the cost of an outside service are considered. Even finding a machine tool service provider with the equipment and experience to perform 5-axis calibration can be difficult. However, for shops using 5-axis machining center tools and CMMs, especially for aerospace parts, calibration is essential, if not mandated by customers. We have developed a new calibration method, using Laser Doppler technology that reduces the complexity, time, and expense of 5-axis calibration. The portable equipment can be easily used by a machinist, as well as machine tool service technician, allowing a shop to purchase its own equipment and schedule calibration when convenient.

For a 5-axis machining center, it is critical to calibrate both the volumetric positioning of X, Y and Z axes and the two rotational axes, A and B. Linear calibration of X, Y and Z and A and B axes separately and independently of each other is time intensive and ignores the straightness and squareness errors along each of the three linear axes, as well as skew, non-orthogonal and non-intersection of the two rotational axes and non-intersection of the center lines of the spindle and the Z axis. These errors are critical for ensuring the precision motion of a 5-axis machine tool or CMM.

Traditional rotary table calibration performed by Optodyne dual beam laser and automatic rotary calibration.

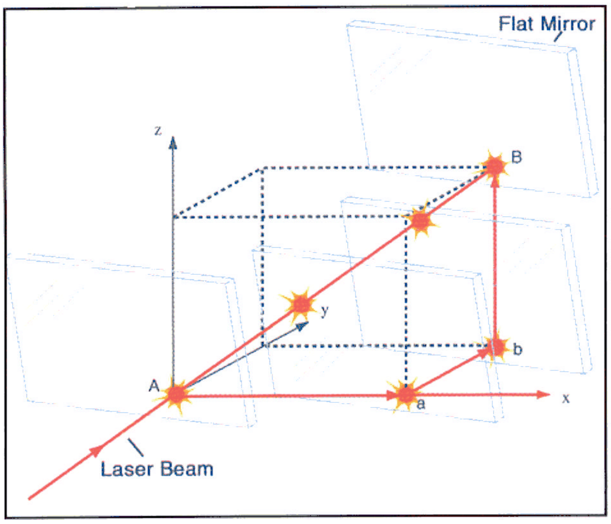


Figure 1. Laser Vector method far volumetric calibration (patent pending).

For this measurement, the tool tip is moved along the diagonal in the X-axis and stopped for measurement, then along the Y-axis and stopped for measurement, finally along Z -axis and stopped for measurement, until the whole volume is measured.

The solution offered by Optodyne is a three step process

Step l-Volumetric calibration: Laser Vector method calibrates volumetric errors, including three linear displacement errors, six straightness errors, and three squareness errors.

By measuring volumetric errors, the whole volume of the machine can be compensated, improving overall accuracy and not just linear displacement. Body diagonal displacement measurement is recommended by the ASME B5 and ISO 230-6 standard as an efficient check of volumetric accuracy. Body diagonal measurements are taken by moving the tool tip in X, Y, and Z axes along the diagonal simultaneously. This method will only indicate whether the machining center is accurate or not. It does not indicate the source of the errors so they cant be corrected.

The laser vector or sequential diagonal method indicates if the machining center is accurate and the cause of the errors. For this measurement, the tool tip is moved along the diagonal in the X-axis and stopped far measurement, then along the Y-axis and stopped for measurement, finally along Z-axis and stopped for measurement, until the whole volume is measured.

Because the laser head is mounted on the machine table and not on a tripod, the sheet metal enclosure, fixtures, and tooling do not have to be removed. This saves a significant amount of time. In fact, volumetric calibration of a one to two cubic meter 5-axis machining center can be run in about two or three hours. Software automatically generates compensation files for the leading controllers.

Step 2-Static measurement of A and B (rotational) axes determine tool tip displacement errors with a non-contact laser spindle tester. A precision metal sphere is mounted on a

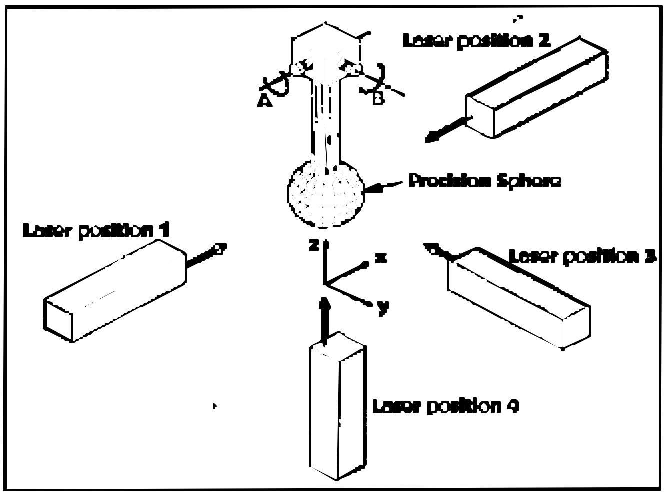


Figure 2. Schematics of a 5-axis spindle with a precision sphere and laser positions

spindle and the laser head with focus lens is mounted on the table. A 100mm focal-length lens is used to center the laser beam on the surface of the sphere. With a large standoff distance and only two components to align, i.e. the laser head assembly and precision metal sphere, the system is very quick and easy to set up. The laser head is pointed in the X- axis direction and the sphere is aligned with the laser beam by moving the spindle. By rotating the A or B rotational axes, the distance variations between the laser head and the sphere surface the angular errors are measured. (Figure 2)

Step 3-Dynamic measurement of A and B (rotational) axes uses various tool paths to determine tool tip positioning errors with a non-contact spindle tester. Tool **tip** positioning errors are measured dynamically along a fixed direction using various tool paths to determine angular, dynamic, and tool tip positioning errors. The spindle tester with precision sphere is utilized for these tests. First, the precision sphere is mounted in the spindle. Then the laser head is mounted in a position corresponding to the test. The laser beam is aligned with a focus lens, focusing at and perpendicular to the surface of the precision sphere. (Figure 3)

Formulas for Positioning on 5-Axis Machining Centers

The machine coordinates afe defined as (Xm, Ym, Zm, A, B). The center of rotation of A and B is defined as (XP. YP. Zp).

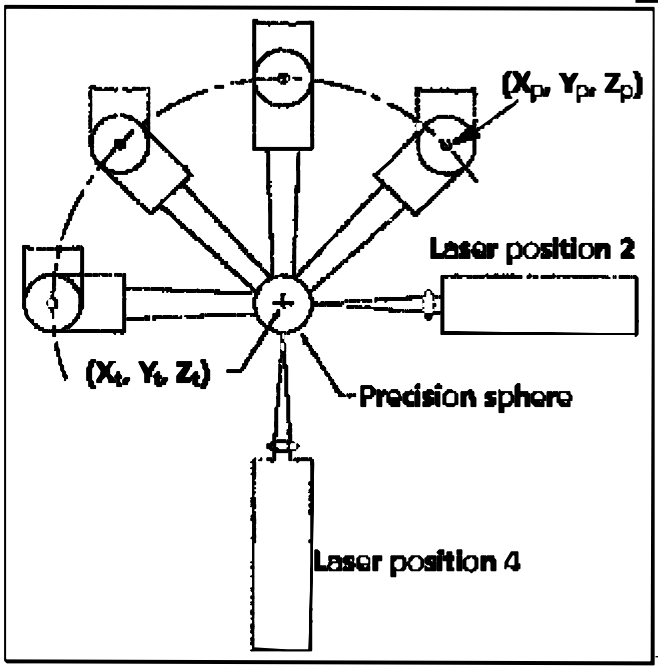


Figure 3. Schematics of a 5-axis motion with the center of the precision sphere, representing center of tool tip, at a fixed position.

The *tool* tip position is defined as (Xt, Yt, Zt). The relations

Xp = Xm + Cx, Yp =Ym + Cy,

Zp = Zm + Cz , where Cx, Cy, and Cz are constants.

Xt = Xp + RsinBcosA, Yt = Yp + RcosBsinA,

Zt = Zp + RcosAcosB, where R is the distance between center of rotation and the tool tip.

St.at.i£: Measurement. of A-axis Angular Accuracy [St.ep 2]

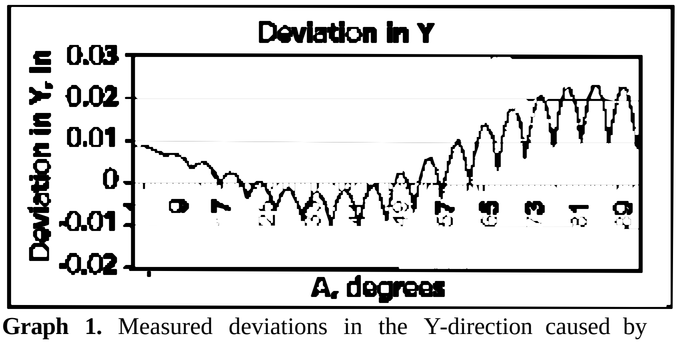
The laser head is mounted at position 3 (see figure 3). Starting position is Yp = Zp = A = B = O,

Move the A-axis at 5 degree increments, while maintaining a fixed tool tip position. For example:

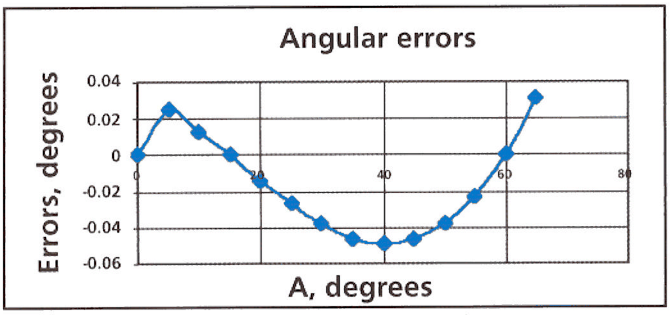
Yp = -RsinA

Zp = -R(I- cosA), where A =

0°, 5°, 10° …… 90°.



Graph 1. Measured deviations in the Y-direction caused by angular errors.



Graph 2. Angular errors of the rotational axis.

Therefore dA = -dYp/(RcosA), where dA is the angular error at A degrees and dY p is the measured deviation at A degrees.

Based on a sample parts program moving along a circle and keeping the tool tip at a fixed position by a rotating A-axis, the measured deviations in the X-direction are shown in Graph 1 and the calculated angular errors are shown in Graph 2.

Dynamic: measurement. of A-axis angular accuracy [Step 3]

Measuring the dynamic tool tip positioning errors is achieved by continuously moving the A-axis from o to ±90 degrees back and forth five times at B = O. Repeat the same movements at B = 30 degrees and 60 degrees. Continuously move B-axis from O to ±90 degrees back and forth 5 times at A = O. Repeat the same at A = 30 degrees and 60 degrees. For a complete measurement, repeat the above measurements with the laser head at positions 1, 2, 3 and 4, using the OPTODYNE 2D time base program to collect data continuously.

Tool Tip Positioning Measurement Errors

Laser system errors: *0,2.mm*
Precision sphere: 0,63*mm*
Machine positioning: 13 *mm*
Latera1 coupling: 1,8 *mm*
*(assume the maximum lateral movement is less than 0,25mm and 38mm diameter sphere).

The largest error is the machine positioning error 13 *mm*. Therefore, any improvement in the machine positioning accuracy will improve the too1. tip positioning measurement accuracy. Optodyne Inc.

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