Application Notes **AP1114**

Laser Non-contact Spindle error motion measurement

I. What is the problem?

In today's manufacturing world, high-speed machine tools with high feed rate and high-speed spindle are frequently required to deliver accuracy in the order of a few micrometers. To achieve the high accuracy, both the static volumetric positioning errors and the dynamic contouring errors should be measured and maintained to within a few micrometers (see AP-1113A). Furthermore, the spindle error motion should also be measured and maintained to within the allowed error budget.

Briefly, the major spindle error motion is caused by the alignment of the spindle rotational axis, the centerline of the tool holder and the centerline of the tool. All of these should be coaxial. Any deviation from coaxial will generate eccentric error motion. Other causes of the radial and axial error motions are the spindle bearings, structure error motion, etc.

Conventional measurement techniques using a precision spindle tester, capacitor transducers and an oscilloscope are complex and heavy. The precision spindle tester is very heavy and need periodic calibration. The capacitor transducers are limited by the sensitivity, range and non-linearity.

II. What is the laser spindle error motion measurement

The new laser non-contact spindle error motion measurement (Patent pending) is an add-on package to the MCV-500 laser calibration system. The combined system can be used to perform non-contact displacement measurement of a polished surface, such as a flat-mirror or a sphere. The accuracy and resolution are high, the range is large, and there is no need for a heavy precision spindle tester. It is cost effective and saves time. As compared with conventional techniques, the advantages of the laser measurement method are: 1, higher accuracy and resolution, 2, larger standoff distance, 3, easy setup and operation, 4, no need for a heavy precision tester and periodical calibration, and 5, save cost and time.

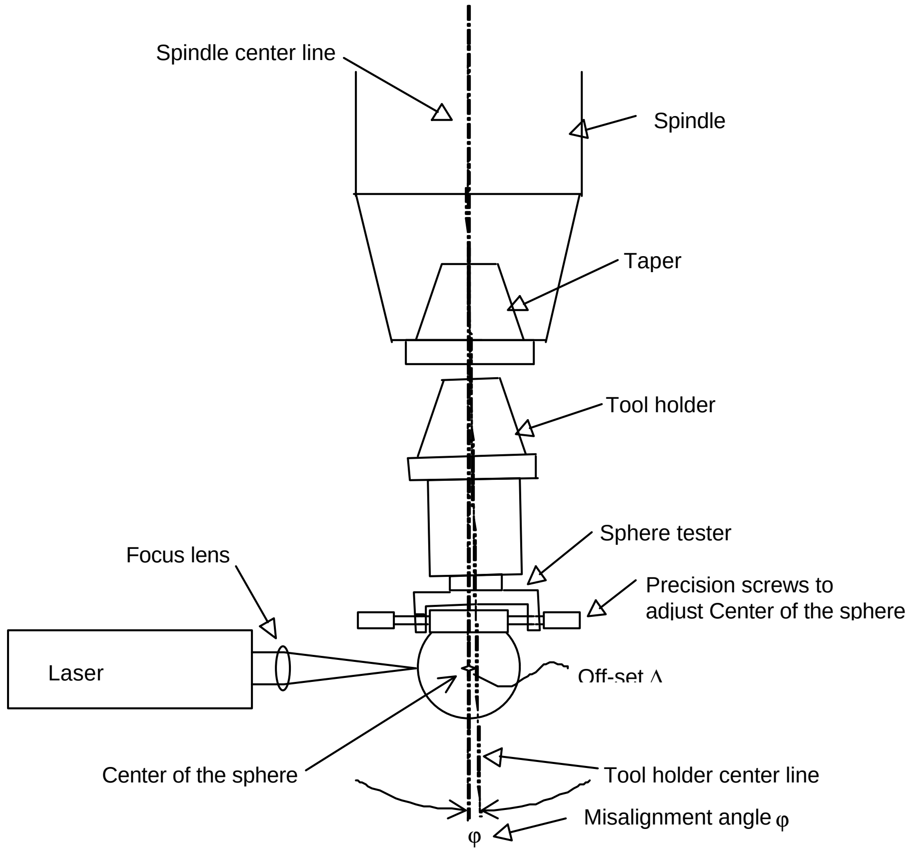

Fig. 1 A schematic of the spindle, the tool holder, the sphere tester, and the laser

III. How the laser non-contact measurement work.

A unique property of the MCV-500 laser calibration system is the single aperture optical arrangement. Since both the outgoing laser beam and the return laser beam are using the same aperture, it is possible to use a flat-mirror as the target.
Using a focus lens to focus the output laser beam to a polished metal surface, a metal sphere can be used as the target. As shown in Fig. 1, a precision metal sphere is mounted on a spindle and the laser system is mounted on the bed. A 4" focus lens is used to focus the laser beam on the surface of the sphere. Rotate the spindle, the distance variations between the laser system and the sphere surface or the spindle error motion, can be measured.

IV. Test results and analysis

Pointing one laser head in the x-direction, as shown in Fig. 1, first align the sphere to the center of rotation by adjusting the 4 fine thread screws. Then rotate the tool holder together with the sphere tester 180 degrees. Because of the symmetry, now the offset is twice the original offset between the spindle axis of rotation and the tool centerline. Manually rotate the spindle from X to -X and from Y to -Y. The maximum difference in X direction is ΔX_M and in Y direction is ΔY_M. The offset between the spindle axis of rotation and the tool center Δ can be determined by

$$\Delta = 0.25 * \mathrm{SQRT}[\Delta X_M * \Delta X_M + \Delta Y_M * \Delta Y_M], \qquad \text{Eq. 1}$$

$$\varphi = \mathrm{Arctan}\,[\Delta Y_M / \Delta X_M]. \qquad \text{Eq. 2}$$

The accuracy of this measurement is limited by the roundness of the sphere, typically 0.5 µm. To measure the total spindle error motion, rotate the spindle and record the laser system readings, $\Delta X(t)$ over several revolutions.

The total spindle error motion at a constant rotational speed can be expressed as a function of the angle θ and the number of cycles i.

$$r_i(\theta) = r_f + dr(\theta) + dr_i(\theta), \quad i = 1,2,3,\ldots N \qquad \text{Eq. 3}$$

where r_f is the fundamental error motion, $dr(\theta)$ is the residual error motion, $dr_i(\theta)$ is the asynchronous error motion, θ is the rotational angle, and N is the total number of cycles.

Here r_f is due to the offset between the spindle axis of rotation and the center of the tool, $dr(\theta)$ is due to the spindle bearing, the non-roundness of the sphere, and other synchronous error motion, and $dr_i(\theta)$ is due to the structure error motion or other asynchronous error motion. Once the total spindle error motion $r_i(\theta)$ is measured, the r_f, $dr(\theta)$, $dr_i(\theta)$ can be determined by the following relations.

$$r_f = \langle \langle r_i(\theta) \rangle_i \rangle_\theta \qquad \text{Eq. 4}$$

$$dr(\theta) = \langle r_i(\theta) \rangle_i - r_f \qquad \text{Eq. 5}$$

where $\langle\ \rangle_i = \Sigma_i\,[\ ]/N$ is the average over N cycles and $\langle\ \rangle_\theta = \Sigma_\theta\,\{\ \}/2\pi$ is the average over 2π angle.

The measured maximum deviation in x- and y-direction are 17 μm and 13 μm respectively. Hence the offset calculated by Eqs. 1 and 2 is 21.4 μm at an angle

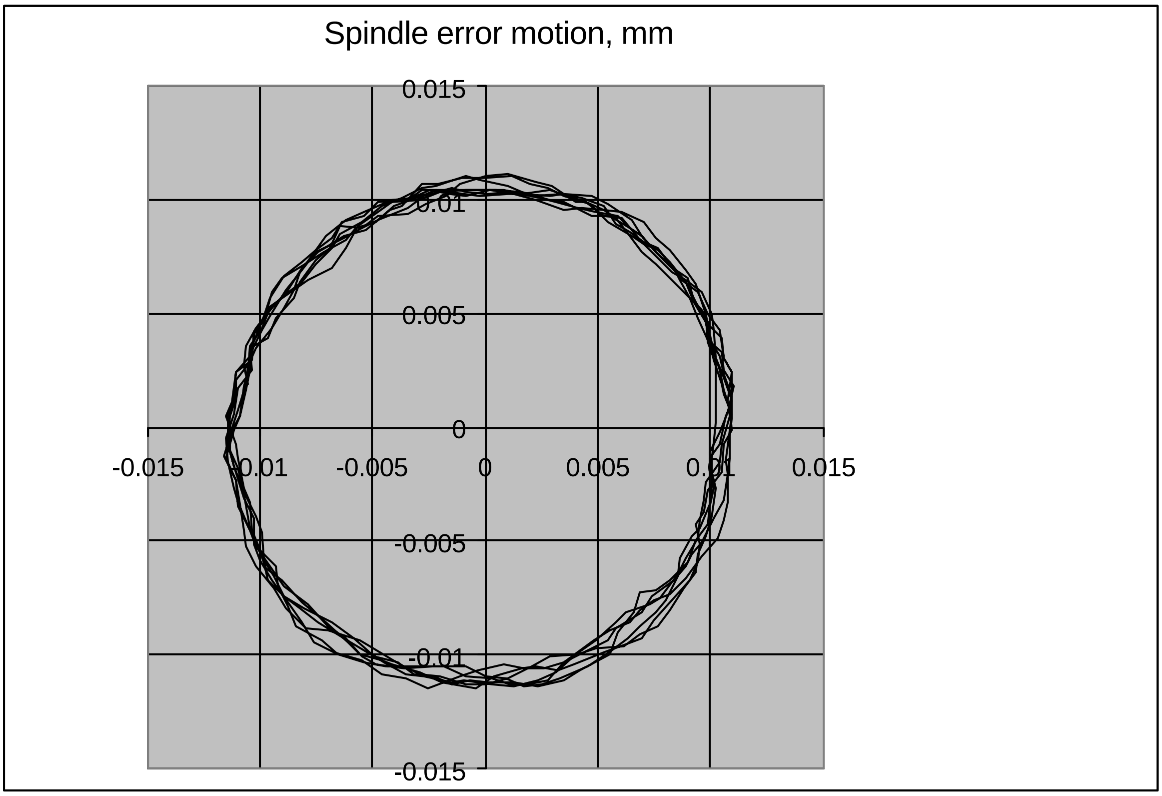

Fig. 2 A polar plot of the radial error motion after the tool holder was rotated 180 degree

φ = 37.4 degree. At the spindle rotation speed of 100 rpm and at a data rate of 125 data/sec, the measured data are plotted in Fig 2. Based on Eqs. 3, 4 and 5, the calculated fundamental error motion value is 0.005471 mm, the average error motion value is 0.001027 mm, and the asynchronous error motion value is 0.001633 mm.

V. References

1. Charles Wang, "A new laser non-contact method for the measurement of spindle error motion", unpublished.
2. J. Bryan, R. Clonser and E. Holland, "Spindle accuracy", American Machinist, Dec. 4,1967.
3. Axes of rotation, methods for specifying and testing, An American National Standard, ASME B89.3.4M-1985 by the American Society of Mechanical Engineers, 1985.

IV. Need more information.

Please call Optodyne, Inc. at 310-635-7481 or your local representative