How to measure the 18 positioning errors and Circular contouring errors with a single laser system MCV-500C

I. What is the problem

Most machine tool operators know that for a 3-axis machine, just calibrating the 3 displacement errors or just compensating 3-axis pitch errors is not enough. There are 21 positioning errors, namely, 3 displacement errors, 6 straightness errors, 3 squareness errors, 3 pitch angular errors, 3 yaw angular errors and 3 roll angular errors. All of the 21 positioning errors may contribute to the volumetric positioning accuracy. Most laser interferometers can measure all of the above errors, except the 3 roll angular errors. Hence a total of 18 positioning errors can be measured. However, using a conventional laser interferometer, the measurement of straightness errors and squareness errors requires very complex and expensive optics. It is extremely difficult to setup and align and also very time consuming.

Conventional method for the circular contouring error measurement is using a telescoping ballbar or double ballbar. It is separate equipment. The measurement is contact with limited performance.

The ASME B5.54 and ISO 230 standards recommended 4 body diagonal displacement error measurement and circular contouring measurement to ensure the machine performance. However, if the machine is out of tolerance, the source of errors cannot be determined by the body diagonal displacement measurement and the circular contouring measurement.

II. What is MCV-500C?

The MCV-500C Complete Laser Calibration System is designed for the measurement of both the static positioning errors (18 errors of the 21 rigid body errors) and dynamic contouring errors. The MCV-500C can perform a quick check of the machine's performance based on the ASME B5.54 standard's one-day test. Using the laser vector technique, the volumetric positioning errors, including 3 displacement errors, 6 straightness errors and 3 squareness errors can all be measured. The measured errors can be used to generate a volumetric compensation file to achieve higher volumetric positioning accuracy. The volumetric error compensation sometimes called straightness error compensation (Fanuc), sag compensation (Siemens), non-linear compensation (Heidenhain), cross compensation (Fidia), or 3-D compensation (Fanuc 15I). We have demonstrated that using the volumetric error compensation, the volumetric positioning accuracy can be improved by a factor of 3 to 10.

For circular contouring measurements, the MCV-500C laser calibration system is non-contact, the radius can be varied continuously down to less than a fraction of an inch and there is no limit on the feed rate. The contouring accuracy can be used to diagnose the dynamic performance and for servo parameter setting of the machine. The true radius, the feed rate and the acceleration/deceleration can all be measured.

III. Why MCV-500C is different

Conventional laser interferometers are based on the Michaelson interferometer. There are two laser beams, the output beam and the return beam, which are parallel but displaced about 1", as shown in Fig. 1. Hence, large optics is required. Also, the alignment is critical, 3 elements have to be aligned on two parallel axes. The laser head is large and heavy, and a heavy tripod is needed to support the laser head.

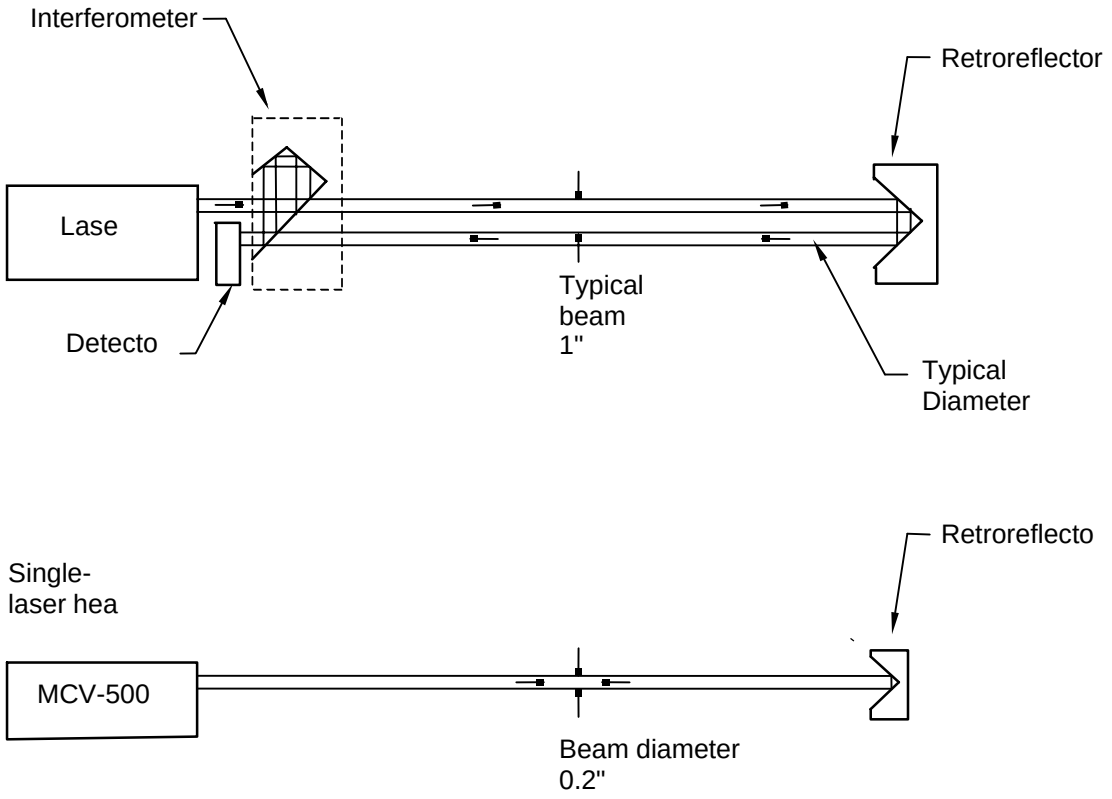

Fig.1 A comparison of a laser interferometer and a single-aperture Laser Doppler system with coaxial beam

The single-aperture MCV-500C laser system is based on laser Dopplermetry. The laser head is very compact (2" x 2" x 8.5" or 50mm x 50mm x 216mm) and is completed with stabilization circuits, electro-optics, and photo-detectors. As shown in Fig. 1, the output beam and the return beam are coaxial and share the same aperture. Hence large optics is not required and also a flat-mirror can be used as a target. Since there are only two elements to be aligned, the alignment is not as difficult. The compact size and lightweight of the laser head and optics allows the operator to mount the components to the machine directly with magnetic bases without the use of a tripod. Usually there is no need to dismantle the protective machine enclosure.

The technology is protected by 8 US Patents. There are many technical and journal articles describing the vector measurement[1, 2, and 3], angular measurement[4] and the laser/ballbar technology[5, 6, and 7]. The laser measurement is traceable to NIST and we are ISO 17025 accredited.

IV. How MCV-500C solves the problem and what are the benefits?

Using the vector measurement technique (US Patent 6,519,043, February 11, 2003), the MCV-500C can measure all 3 displacement errors, 6 straightness errors, and 3 squareness errors in 4 simple setups and within 2-4 hours. The measured error components can be used to fix the machine or generate volumetric error compensation files for the controller to compensate these errors. Using a single laser head, the angular errors can be determined by 3 displacement measurements along the same axis but at different Abbe offsets.

For circular contouring measurements, the MCV-500C laser calibration system is non-contact. The measured circular contouring errors can be used to diagnose the dynamic errors such as reversal spike, stick and slip, servo mismatch, vibrations, feed rate and acceleration, and many others.

The worldwide competition and quality standards such as ISO 9000 and QS 9000, demanded tighter tolerance and regular maintenance of all machine tools. The MCV-500C can be used to meet these requirements by providing regular calibrations and 3D volumetric error compensations.

Using the MCV-500C system will improve the machine performance and reduce expensive machine downtime. It is compact, easy to setup and operate, provides efficient and automatic measurement. It is also very flexible and versatile, the same laser can be used for both the volumetric positioning and the dynamic circular contouring measurement. Hence, less equipment is needed and offer savings on the capital and shipping cost.

V. References

[1] Charles Wang, "Laser Vector Measurement Technique for the Determination and Compensation of Volumetric Position Errors, Part I: Basic Theory," Rev. Sci. Instrum. Vol. 71, pp. 3933-3937 (October 2000).

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[3] C. Wang & G. Liotto, "A theoretical analysis of a body diagonal displacement measurement and sequential step diagonal measurement" in proceedings of the LAMDAMAP Conference, Huddersfield, England, July 4, 2003.

[4] "Pitch and yaw angular error measurement using a MCV-500 laser calibration system", Application Note, Ap-1119, Optodyne, 2003.

[5] Charles Wang and Bob Griffin, "A Noncontact Laser Technique for Circular Contouring Accuracy Measurement", Rev. Sci. Instrum. Vol. 72, No. 2, pp.1594-1596 (February 2001).

[6] Charles Wang, Bob Griffin, Mohammed Omari and Dotun Ajao, "Evaluation of Machine Tool Contouring Accuracy at High Feed Rates," Proceedings of the ASPE 15`h Annual Meeting, Scottsdale, AZ, Oct 22-27, 2000.

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