Application Notes **AP-1117**

Calibration of a Coordinate Measuring Machine (CMM) by a MCV-5002 Laser Calibration System

I. What is the problem

For volumetric calibration or compensation of a CMM machine, the linear position errors, the straightness errors, angular errors and squareness errors should all be measured for all three axes of motion. Traditional techniques for calibration of CMMs involve measuring angles using lasers, autocollimators and/or levels, followed by straightness measurements performed with either laser Wollenston Prism setups or straight artifacts, perpendicularity measurements done with the laser or artifact, and linear measurements performed with a laser or step gage. These measurements are time consuming.

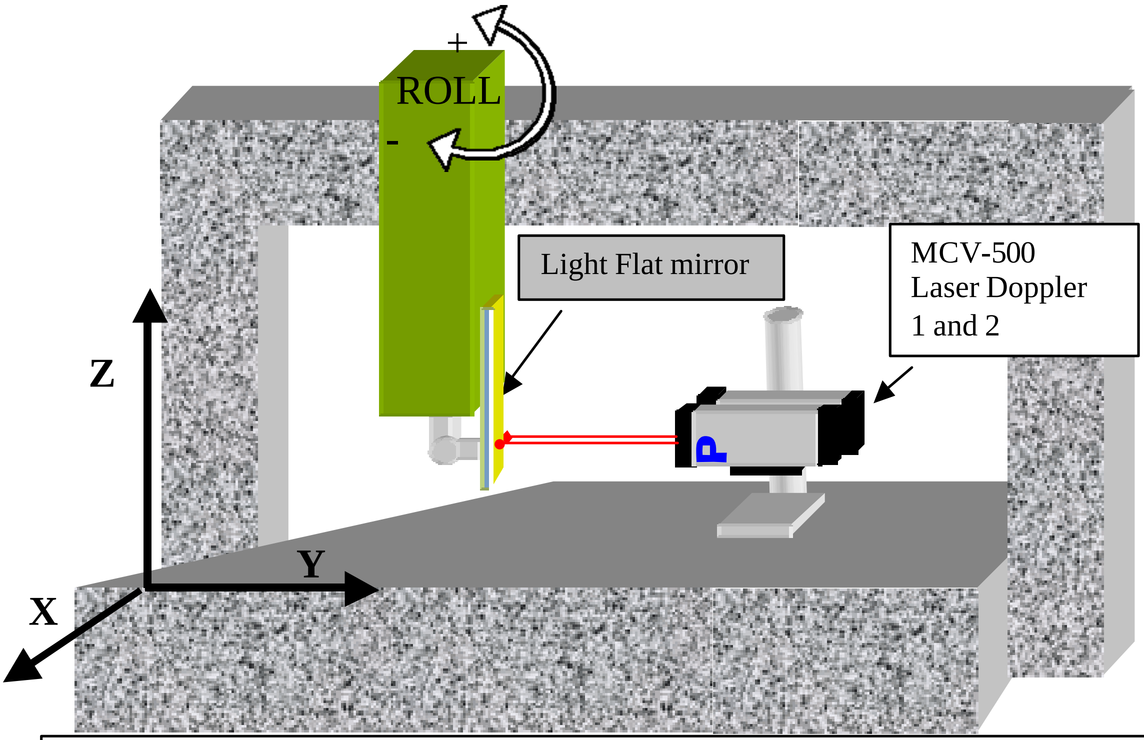

Fig-1 Measurement of ROLL angular movement along Z axis movement (Vertical)
Same set up for measurement Yaw along Y axis and Position error along Y axis

II. How MCV-5002 solves the problem

The MCV 5002 offers the capability to perform all of the above positioning error measurements. This will eliminate the complicated Wolleston prism setups and reduce the number of setups.

Angular measurements are performed using a dual beam laser setup and the roll measurements are performed using a dual beam laser setup with a long flat-mirror as target. After the completion of the angular error measurements these results will be fed to the computer and future readings compensated for these errors. Linear, perpendicularity, and straightness errors will be measured using the Vector or Sequential Diagonal technique[1, 2].

III. How it works

1. Pitch and yaw angular error measurement

Using two laser heads with parallel laser beams and a fixed separation, the pitch or yaw angular errors can be measured either statically or on-the-fly. This method is more accurate than using the quad-detector method. This is because the air turbulence deflecting the laser beam (similar to the twinkling stars in the evening) and introducing angular errors (See Ap- 1102).

2. Roll angular error measurement

Usually, roll angular error cannot be measured by a conventional laser interferometer. Instead, a precision level is used. However, a level can not be used to measure along a vertical or z-axis. Here, using two laser heads with parallel laser beams and a fixed separation, and a long flat-mirror as target, the roll angular errors of all three axes can be measured. This is because the MCV-5000 laser head is single-aperture, and a flat-mirror can be used as a target(See AP-1104 and AP-1108). It is noted that with a flat mirror as the target, any displacement parallel to the flat-mirror will not displace the return laser beam and will not effect the measurement. Hence only the displacement along the laser beam direction is measured. For long travel, it is more convenient to divide the total travel to several measurements and each measurement with the travel of the maximum length of the long flat-mirror. Another method to measure the roll is to perform two straightness error measurement separated by a fixed distance.

3. Displacement errors, straightness errors, and squareness errors measurement

The displacement errors, straightness errors and squareness errors can be measured by the vector or sequential diagonal measurement developed by Optodyne [1,2]. This method has been applied to the calibration and compensation of many CNC machine centers [3,4]. Briefly, for conventional laser body diagonal displacement measurement [5], the movement is a straight line along the body diagonal. It requires moving all three axes simultaneously along a body diagonal and collecting data at each preset increment.

The new vector or sequential diagonal measurement method, suggest moving the X, Y and Z-axis in sequence and collect data after each axis is moved. Hence the position errors due to the movement of each axis can be separated. The collected data can be processed as deviations measured in the body diagonal direction due to X-axis movement, Y-axis movement and Z-axis movement respectively. Hence three times more data is collected for each diagonal measurement. For the four diagonal measurements, there are 12 sets of data to determine the three linear position errors, the six straightness errors and three squareness errors.

It is noted that the trajectory of the target is not a straight line, and the lateral movement is rather large. Hence a conventional laser interferometer will be way out of alignment with such large lateral displacement. However, with a single aperture laser head and a flat-mirror as target, large lateral movement can be tolerated and the displacement along the laser beam direction measured.

IV. A comparison with conventional method

A comparison with the old method is shown in the table below.

Table of comparison, MCV-5002 and old methods

CMM Errors	Degree Of Freedom	Axis of Motion	Axis of Rotation	**Using MCV-500 Method of Measurement**	Number of setups	**Old Method of Measurement**	Number of setups
Angles	1	X	X	Flat-mirror	1	levels	1
	2	Z	X			Angular Laser	1
	3	Y	X	Flat-mirror	1	Angular laser	1
	4	Y	Y	Flat-mirror	1	levels	1
	5	Z	Y			Angular laser	1
	6	X	Y	Flat-mirror	1	Angular laser	1
	7	Z	Z	Flat-mirror	1	? ? ? ? ? ? ?	1
	8	Y	Z			Angular laser	1
	9	X	Z	Flat-mirror	1	Angular laser	1
Linear	10	X		MCV-500 VOLUMETRIC	4	Linear laser	1
	11	Y				Linear laser	1
	12	Z				Linear laser	1
Straight-ness			Direction				
	13	X	Y			Wollensten Prism	1
	14	X	Z			Wollensten Prism	1
	15	Y	X			Wollensten Prism	1
	16	Y	Z			Wollensten Prism	1
	17	Z	X			Wollensten Prism	1
	18	Z	Y			Wollensten Prism	1
Perpendi-cularity	19	XY				Wol.Prism opt.Square	1
	20	YZ				Wol.Prism opt.Square	1
	21	ZX				Wol.Prism opt.Square	1
				Total Setups	**10**		**21**

In summary, the MCV-5002 is very compact (all fit into 2 small carrying cases), efficient (measurement in hours instead of days), flexible (2 separate laser heads can be used together or separately), versatile (uses small retroreflector or flat-mirror target), and affordable.

V. Advantages to CMM Manufacturers

1. Elimination of Wolleston Prism (Straightness Optics) Setups
2. Reduction of number of setups
3. Elimination of artifacts and/or optical squares used to check squareness
4. Ability to perform full calibrations in the field
5. Simpler setups and easy operation.
6. Compact, portable and affordable.

VI. 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).

[2] John Janeczko, Bob Griffin, and Charles Wang, "Laser Vector Measurement Technique for the Determination and Compensation of Volumetric Position Errors, Part II: Experimental Verification," Rev. Sci. Instrum. Vol. 71, pp. 3938-3941 (October 2000).

[3] Charles Wang and Gianmarco Liotto, "A laser non-contact measurement of static positioning and dynamic contouring accuracy of a CNC machine tool," Proceedings of the Measurement Science Conference, Los Angeles, January 24-25, 2002.

[4] C. C. Chung, S. S. Yeh, J. F. Liang, L. Chou, J. T. Su, and C. Wang, "A laser vector technique for the measurement of static positioning errors and compensation," Proceedings of the International Dimensional Workshop, Knoxville, TN, May 6-9, 2002.

[5] "Methods for Performance Evaluation of Computer Numerically Controlled Machining Centers", An American National Standard, ASME B5.54-1992 by the American Society of Mechanical Engineers, P69, 1992.

VII. Need more information

Call Optodyne at 310-635-7481 or
your local representative.