

CMM CALIBRATION TOOL USING REFERENCE LASER INTERFEROMETER

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Abstract:

Recently, higher accurate and large size Coordinate Measuring Machine (CMM) is required in industry (especially aerospace and energy field). In case of large size CMM, very long gauge blocks or step gauge need for its acceptance test and calibration. However, the high accurate manufacturing of long size gauge blocks is very hard. Then tester used normal size of gauge blocks using stitching method in order to cover its long range of CMM. International rule of CMM acceptance test "ISO 10360-2:2009" accepts to use laser interferometer calibrated with an iodine-stabilized He-Ne laser and its combination with gauge blocks.

We developed a calibration tool using laser interferometer and gauge block. In order to improve the measurement uncertainty, this new tool uses a short length gauge block and positioning unit with motorized driving system. And this tool links measuring software to achieve full automatic measurement and calibration.

Keywords: Measurement, CMM, Interferometer, Reference laser, Calibration

1. INTRODUCTION

Previously, International Standard (ISO 10360-2:2001) [1] accepted to use only step gauge and gauge blocks for acceptance test. Therefore CMM manufacturer and user had to use them. The size of CMM has been expanding wider and larger for industrial application e.g., aerospace and wind energy industry. These applications require wider and larger measuring range with very accurate measurement on CMM. For these CMM, it needs very long and accurate calibrated artifacts in order to perform acceptance test. However it is very difficult to prepare long step gauge or gauge blocks with tolerable uncertainty for the acceptance test. As a result, CMM manufacturer and user are forced to use limited length of artifact with limited range or stitching method.

In 2009, the revised International Standard (ISO 10360-2:2009) [2] was published. This standard accepts to use laser interferometer as an artifact in following three ways. The first is to measure distance with bidirectional probing between a fixed short gauge block with single point probing on the front face and a positioned short gauge block by a laser interferometer with single point probing on the opposite face of the gauge block. The second is a combination of two procedures. The primary procedure is to measure the target distance between the front face of the gauge block at the starting position and it at on several positions which is calibrated by a laser interferometer with unidirectional contact probing. The secondary procedure is to measure the size of a short gauge block with bidirectional contact probing. This secondary error should add on the

primary error. The third is to take the probe position with CMM scale system, at the same time, to calibrate the probe position with laser interferometer by unidirectional measurement without contact probing. These methods can achieve the required acceptance test on wider and larger CMM. In the other hand, this standard requires seven direction length measurements in special for acceptance test. For this requirement, alignment system is needed to use laser interferometer and gauge in each special directions.

According to this background, we have developed a special calibration tool with a laser interferometer and a positioning stage for the combination of a corner cube prism and a gauge block. In order to minimize the measurement uncertainty, we have chosen the second way of measurement configuration based on ISO 10360-2:2009 that shows unidirectional contact probing. For very accurate positioning of gauge block, we implemented the motorized driving unit with precise guide way unit. This driving unit can be extended up to 4 m. In every positioning, this calibration tool reads position of the gauge block and compares the probing data on the CMM. In this case, gauge block positioning, CMM probing and data collection should be synchronized. Therefore we also prepared a new control software which send a command of tool position controller and original CMM software.

By using this calibration tool, it can make full automatic acceptance test and calibration on large CMM without complicated operation.

2. SYSTEM OF CALIBRATION TOOL

2.1 Laser Interferometer

We had developed the laser interferometer in 1989. This module uses a flexible single mode optical fiber connection from He-Ne laser to the cube corner. Then it is easy to align setting of calibration tool. The specification is shown on Table-1. [3]

This laser interferometer has a He-Ne tube with heater in order to keep internal temperature for stabilized wavelength. Compensation of wavelength in the air is most important factor for accuracy of measurement. This system has compensation sensor to correct wavelength against temperature, pressure and humidity. This accuracy can achieve 0.5 ppm with this compensation module.

Based on these feature, this laser interferometer is traceable to international standard. The laser of this tool is calibrated at the calibration laboratory of Tokyo Seimitsu accredited at ILAC-MRA. Iodine Stabilized He-Ne laser for the above calibration is calibrated by National Metrology Institute of Japan (NMIJ) with optical frequency comb generator.

Table-1 : Specification of Laser Interferometer

ITEM	SPECIFICATION
Maximum measurement range	10m (using corner cube)
Length of optical fiber	3m: Standard / 5m, 10m: Option
Accuracy (MPE_E)	$\pm (L \times 10^{-7} + 0.01 \times 10^{-6})$ m
Sampling rate	1 MHz
Light source	Wavelength stabilized single mode He-Ne laser
Optical output	approx. 0.3 mW
Wavelength stability	$\pm 1 \times 10^{-7}$
Power consumption	90 VA
Operating environment	Temperature: 10 to 40°C (Temperature change in operation: within $\pm 10^\circ\text{C}$)
	Humidity: 10 to 90%(Non-condensing)

2.2 Measuring Unit

In our design process, we focused to eliminate and to minimize measurement uncertainty. For this purpose, we kept the location of the laser beam, the gauge block and probing point on the same line.

If we choose the first way to use laser interferometer with bidirectional contact probing, we have to take additional alignment process in order to adjust the alignment of the gauge, because the opposite side of the gauge block is far from reflection point that is the top of corner cube prism.

This tool is consisted with following sub-units.

- a) Base
- b) Laser Head
- c) Gauge Block Stage
- d) Stage Controller
- e) Control PC/Software

The “base” is mainly configured as guide way to drive Gauge Block Stage. This base has a support which can make some position in horizontal, vertical and spatial direction and can be put with fixing plate on the table of CMM. On this sub-unit, we put origin sensor to recognize home position. All of sequence program should start from this position. This “Base” can be extended by use of extension base for required length.

The “Laser Head” has an alignment module to adjust the angle of this head for Base guide way.

The “Gauge Block Stage” is the main part of this system. On this stage, we put a cube corner prism and a short gauge block. These components should be aligned by mounting parts that tolerances are defined with the required alignment accuracy. This stage is driven by stepping motor, roller bearing and pinion on the rack which is located on the guide way of Base unit. When the stage is positioned, the roller bearing is released from guide way by air valve control and the stage is fixed completely. The positioning accuracy by stepping motor is not so accurate, but the real position is calibrated very accurately by laser unit. The relative distance between top of corner cube prism and front face of the gauge block is calibrated by CMM. The actual distance between the front face of the gauge block and the top of corner cube prism is critical parameter for calibration.

The “Stage Controller” is consisted with following module which is shown in Fig-2 (System Diagram).

- i. Motor Drive Controller
- ii. Air Valve Controller
- iii. Control Panel
- iv. Sequence Controller (incl. software)

These modules are synchronized to control the position of gauge block stage. In the beginning, operator can teach each position to measure by use of Control Panel manually.

The “Control PC/Software” is the main station to control this measuring unit. This sub-unit communicates with “Laser Interferometer”, “CMM PC/Software” and “Stage Controller”.

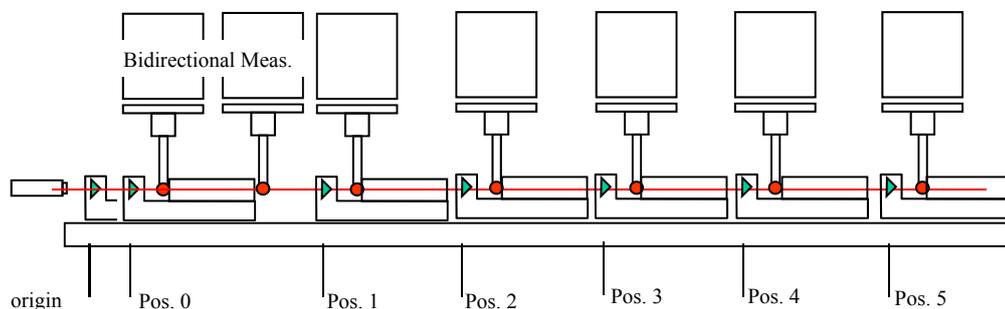


Fig-1: Concept of the tool

2.3 System Control

“System Control” is done by “CMM PC/Software” and “Control PC/Software”. The process is proceeded as follows.

- i. Boot each unit
- ii. Home positioning of “Gauge Block Stage” and CMM
- iii. Align “Gauge Block Stage” by CMM measurement
- iv. Start CNC program on CMM PC/Software

- v. Measure gauge block by CMM
- vi. CMM PC/Software commands to Control PC/Software to collect and verify the data of laser with CMM data
- vii. CMM PC/Software commands to Control PC/Software to move “Gauge Block Stage”
- viii. Control PC/Software calculates and issue the document of certificate

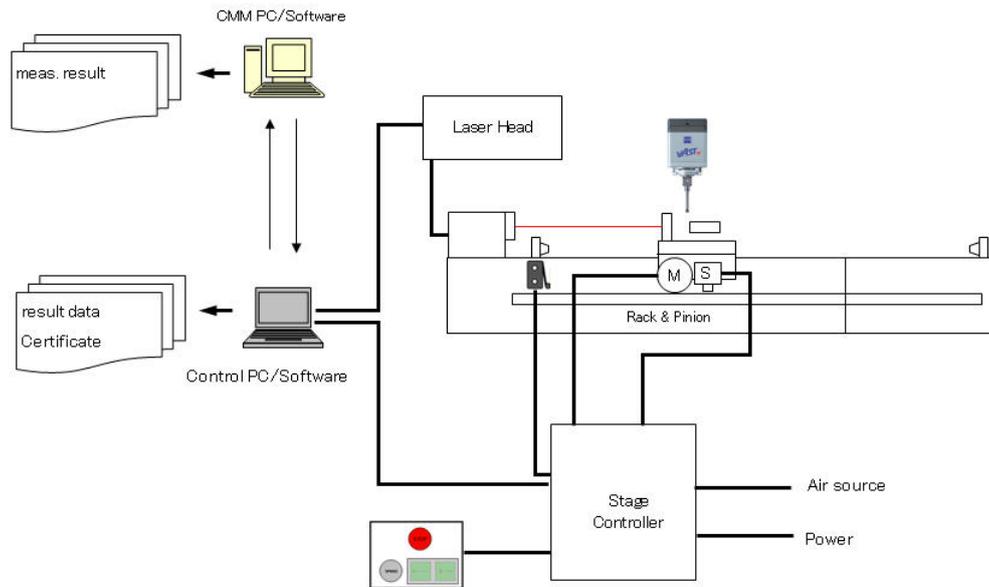


Fig-2: System Diagram

The above processes from (v) to (vii) are repeated with required times (three times and five lengths) automatically. Each measurement position should be programmed in CMM PC/Software and Stage Controller in advance.

After all seven direction measurement, operator should measure another 500 mm gauge block in one setting separately. Because ISO 10360-2:2009 requires normal CTE measurement in case of low CTE acceptance test.

After that, operator requests Control PC/Software to issue the certificates, and then it gives the document of certification.

3. ERROR ANALYSIS

We considered following error as an element of uncertainty.

- i. Inclination of gauge block
- ii. Deformation of guide way on “Base”
- iii. Step and inclination of guide way on “Base Extension”
- iv. Alignment error between top and housing of corner cube prism

- v. Fluctuation of air for laser
- vi. Deformation of fixture of gauge block by measuring force
- vii. Temperature distribution

3.1 Inclination of gauge block

Theoretically, the gauge block should be just aligned perpendicular to the beam direction of laser. But some small angle deviation which is come from the alignment error of fixture makes offset between the contact point of stylus and the cross point of laser beam in two directions. (vertical and horizontal)

We measured this inclination of the gauge block by the target CMM and it showed $1 \mu\text{m}/33 \text{ mm}$ in horizontal and $1 \mu\text{m}/7 \text{ mm}$ in vertical. Even if the positioning accuracy of CMM is 0.5 mm maximum, we can assume $0.015 \mu\text{m}$ in horizontal and $0.071 \mu\text{m}$ in vertical.

3.2 Deformation of guide way on Base

The guide way of “Base” is not theoretically rigid material and the weight of gauge block stage is approximately 3 kg. In this case, the guide way should be bended and its value is depended on the position of the

gauge block stage. Now we considered below model and made a simulation. (Fig-3,4,5)

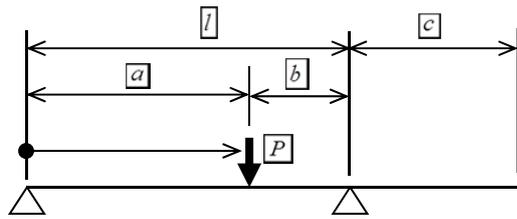


Fig-3: analysis model of guide way

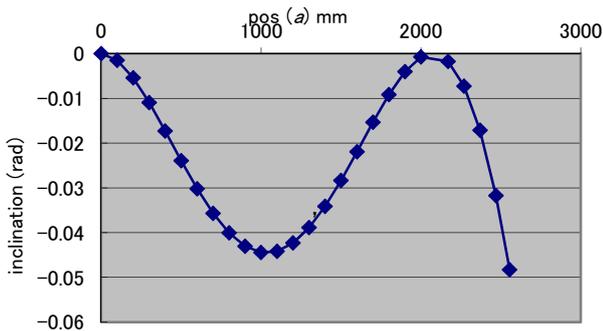


Fig-4: Characteristic of deformation

It shows that the gravity of stage makes inclination and offset, and the inclination of gauge block stage changes according to the position. Now we can calculate the error of measurement using following equation.

$$\delta = L - [L \cos\theta + (e + L \sin\theta - r \sin\theta) \tan\theta - r \cos\theta + r]$$

$$= [(L - r) (\cos\theta + \sin\theta \tan\theta) + e \tan\theta + r] - L \quad (1)$$

Based on this calculation, we reached the estimated error as 0.1 μ m in case of 3m guide way.

compared with original guide way. These errors come from the geometrical deviations of the parts. Then we had measured these values with the target CMM. Actually, the step was approximately 20 μ m and inclination was 20 μ m/1000 mm. We put this error into the calculation (1).

3.4 Alignment error of top and housing of corner cube prism

If possible, the top location of corner cube prism should be measured by CMM actually. However this prism is mounted in side of the housing. Then we estimated this relative location between gauge block using nominal tolerance of this mount housing and measured the actual location of the housing of prism on gauge block stage. It is approximately 20 μ m. We put this error into the calculation (1).

3.5 Fluctuation of air for laser

Normally, measuring room has air conditioner and it makes aerodynamic flow of air. This also makes fluctuation of air which influent the accuracy of laser measurement. The error with fluctuation of air is assumed to be 0.1~0.2 μ m/1000 mm in our experiment.

3.6 Deformation of fixture of gauge block with measuring force

When CMM makes trigger probing, the gauge block on the fixture is bent with measuring force. In the other hand, the laser beam takes certain effect with the fluctuation of air as shown above. In order to eliminate this influence, we take suitable period for averaging of laser data. This period should be longer than trigger measuring period with measuring force bending.

According to the above situation, it makes time shift between trigger probing and laser collection and actual position of surface of gauge block could be displaced based on the measuring force of probe head. It seems to be 8 nm/200 mN.

3.7 Temperature distribution

Even though air conditioner is equipped in the measuring room, there is some small distribution of temperature. It means that all of this distribution is hard to consider despite of environment sensor is used for laser interferometer. Therefore we assumed to use the averaged value of this distribution as 0.1 $^{\circ}$ C/m.

4. SUBMISSION

According to the above consideration, the part of error from this developed measuring unit is smaller than the error of laser interferometer itself. Then it should be useful tool to calibrate CMM and for its acceptance test. In order to show the reliability, we will continue this experiment and the data should be disclosed in near future.

3.3 Step and inclination of guide way by Extension

In case of longer measurement, the guide way of this "Base" can be extended by use of extension guide way. At the connection part, it shows small step and inclination

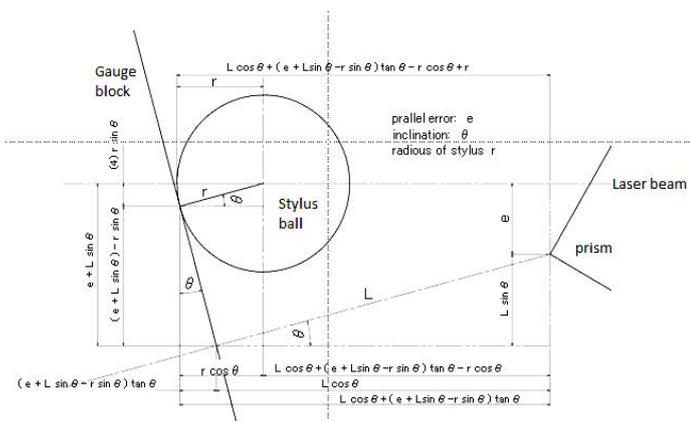


Fig-5: Analysis of Stage

ACKNOWLEDGEMENTS

The authors wish to thank for the corporation by Dr. Hirokazu Matsumoto, Mr. Masatoshi Arai and Mr. Nobuyuki Ohsawa.

Also the support of Mr. Tomotaka Yamagata and Mr. Katsuhiko Hatanaka should be appreciated.

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- [1] INTERNATIONAL STANDARD ISO 10360-2: 2001
- [2] INTERNATIONAL STANDARD ISO 10360-2: 2009
- [3] Data Sheet of Distax (Tosei-Engineering)