CALIBRATOR FOR 2D GRID PLATE USING VISION COORDINATE MEASURING MACHINE WITH LASER INTERFEROMETERS

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Abstract:
A calibrator for 2D grid plate based on a commercial vision coordinate measuring machine (vision-CMM) was developed. A laser interferometer for calibration of x coordinate and two laser interferometers for calibration of y coordinate were attached on the vision-CMM. By applying multi step measurement method for the calibration procedure, the dimensional error in the calibrator could be reduced. The calibration uncertainty for 2D grid plate using developed calibrator could be estimated as sub-micrometer level.

Keywords: Grid plate, Vision coordinate measuring machine, Laser interferometer

1. INTRODUCTION

The importance of precision coordinate measurements is increasing because of the globalization of manufacturing. The coordinate measuring machines with imaging probing system (vision-CMMs) are widely used for dimensional measurement and form check in low-tech to high-tech industries because the vision-CMMs could provide non-contact and optical measurements, and consequently it could measure smaller forms compared to contact-type CMMs. Especially in manufacturing of mask patterns, that are used for semiconductor exposure and quality control of major parts for flat panel display, high-precision dimensional measurement of pattern positions were demanded, and vision-CMMs with high accuracy has been applied.

For the calibrations of the vision-CMMs, precisely calibrated line standards[1, 2] have been used. In the calibration procedure using a line standard, the line standards are measured several times in several setting positions for the purpose of scaling of x-axis and y-axis measurements and checking the orthogonality of x-axis and y-axis of the machines. 2D grid plates are used as test objects for checking scaling and orthogonality of x-axis and y-axis easily. Although 2D grid plates are convenient to use for checking vision-CMMs, calibration of 2D grid plates are supplied by few metrology institutes [3-6].

NMIJ has line scale calibration system with laser interferometer, thus it is able to be used only for one-dimensional scales, cannot used for 2D grid plates[7]. Moreover, since the line scale calibrator has “horizontal” microscope system, only thick line scales, which can stand on the stance that the graduation marks are on the vertical plane, could be measured. Because of those limitation of line scale calibrator, 2D grid plates could not be calibrated in NMIJ.

We started to develop 2D grid plate calibrator using commercial vision-CMM. The laser interferometers for calibrating x-axis and y-axis coordinates are attached to a commercial vision-CMM. For the purpose of reducing dimensional error, multi step measurement method was applied.

In section2, outline of the calibrator and procedure of multi step method is explained. In section 3, calibration of precision 2D grid plate is demonstrated. The calibration uncertainties of each axis are estimated to be sub-micrometer level.

2. 2D GRID CALIBRATOR

2.1 Calibration system of 2D Grid

The calibration system is based on a commercial vision-CMM (Mitutoyo Co. ltd., Ultra QV 350) (Fig. 1). Ultra QV has a microscope system with CCD camera sensor. The optical source of the microscope is halogen lamp. Available magnitudes of objective lenses are 1×, 2.5×, 5×, 10×, and 25×, and magnification lens system of 1×, 2× and 6× are attached. The microscope system has autofocus function. The driving systems for x-axis and y-axis are ball screw drives with air bearing stages. The sample setting

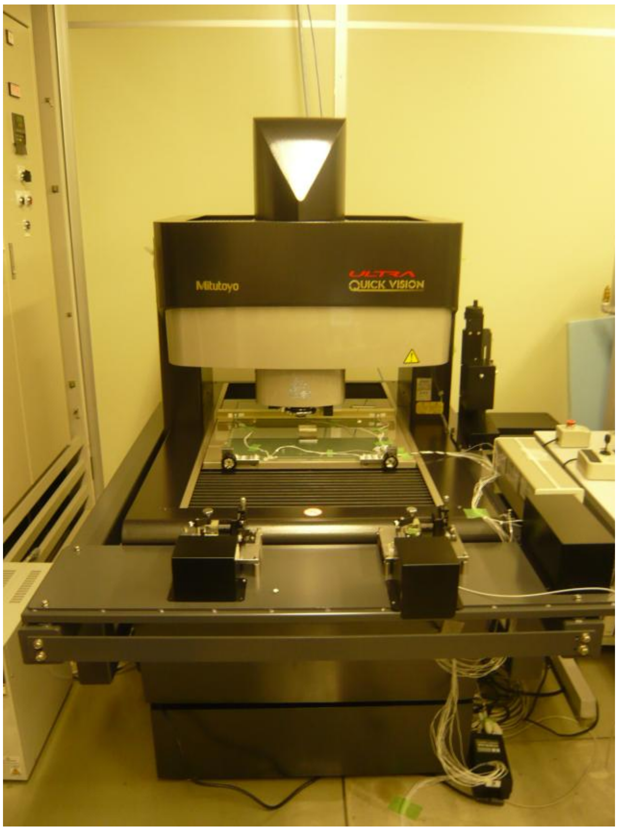


Fig. 1 Photograph of 2D Grid Calibrator

stage is on the y-axis stage, and the objective lens is carried by x-axis stage. The measuring range is 350 mm × 350 mm. Manufacturer's specification for measurement accuracy for x-axis and y-axis is $(0.3+L/1000)\,\mu\text{m}$.

We attached laser interferometers on x-axis and y-axis (Fig. 2). The laser source was Agilent 5517C with the wavelength of 632.991 nm. A corner cube reflector was put on the objective lens mount, and it was used for x-axis measurement reflector. Two corner cube reflectors were set on the sample stage as measurement reflectors for y-axis. Since the stage yawing of sample stage is directly effect on the measurement uncertainty of y-axis as cosine error, the calibrator has two interferometers for y-axis. Weighted average of two measurement axes were calculated and used as y-axis movement.

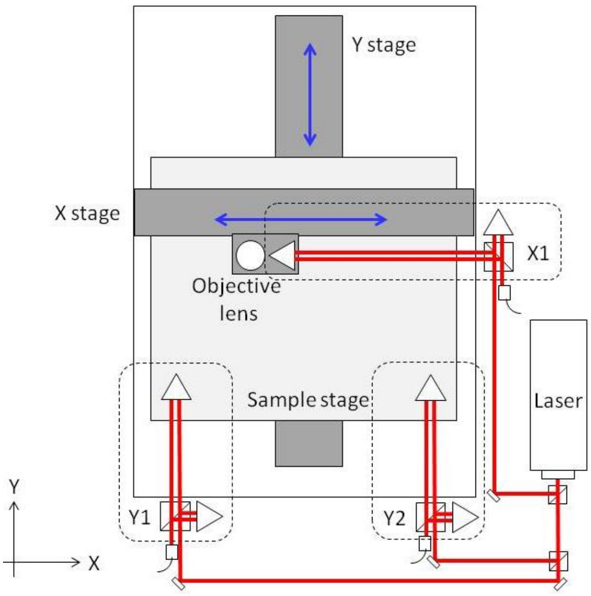


Fig. 2 schematic of the 2D grid calibrator

Measurement laser beam of x-axis was aligned parallel to moving axis of objective lens mount, and both of measurement laser beams for y-axis were aligned to moving axis of sample stage.

The position of the measurement reflectors were measured by data acquisition boards (Agilent 10897B) at common trigger timing for three interferometers. When the movable stages of the calibrator were stopped, the 100 timing triggers of 500 Hz were occurred, and the counts of the interferometers were received by the data acquisition boards. 50 data of corrected 100 data were averaged and used as the position data.

In prior to calibration of the grid plates, repeatability of the 2D grid calibrator were evaluated. For the evaluation, precision grid plate was used (Fig. 3). The size of the grid plate was 120 mm × 120 mm × 13 mm, and it was made of quartz. Two quartz plate with the thickness of 6.5 mm were glued. Between two plates, grid mask was sandwiched. The mark pattern shape was circle with the size of 2 mm diameter. 57 circle patterns were marked in the pitch of 10 mm in 100 mm × 100 mm square.

For the evaluation of repeatability of the calibration

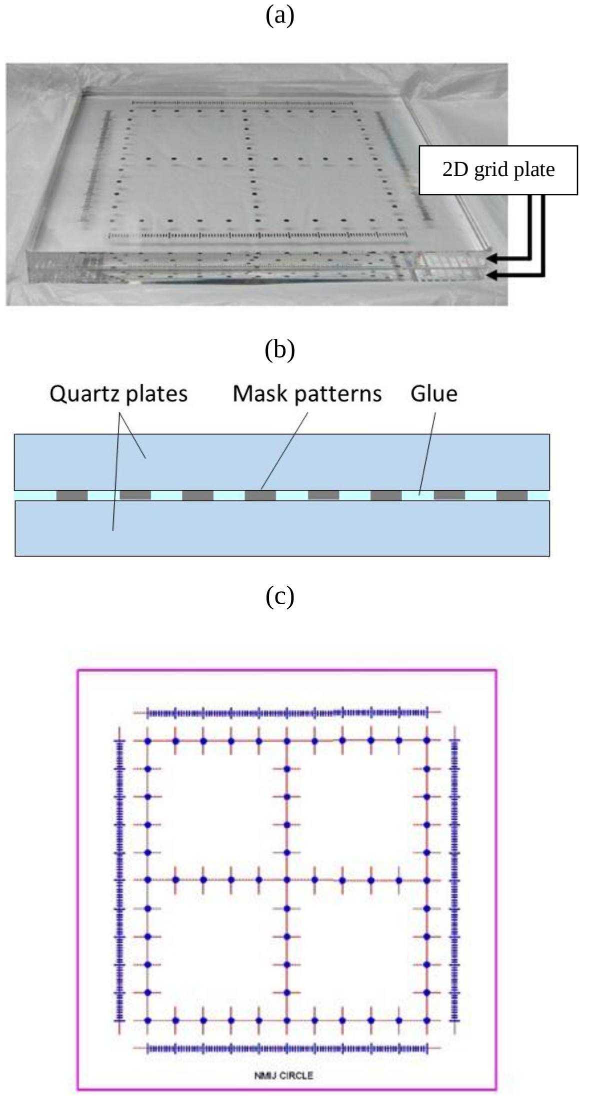


Fig. 3 Precision Grid Plate
(a) Photo of precision grid plate (b) cross-section view of precision grid plate. Mask pattern is clipped in two quartz plates. The glue has refractive index which was approximately the same with quartz. (c) layout of mask pattern.

system, the distances between two marks, mark1 and mark2, mark1 and mark11, mark1 and mark11 and mark1 and mark31 were measured ten times. The standard deviation of the measured distances were less than 0.15 μm.

2.2 Multi step method

Since vision-CMM has three orthogonal movable axes, there exist dimensional errors in addition to scaling errors in each movable axes. The scaling error could be reduced by using line standard or laser interferometer as the references. On the other hand, reducing dimensional error is not simple[8-11]. For the purpose of reducing the geometrical error of the 2D grid calibrator, multi step (4-step) method was applied for calibration of 2D grid plate[12]. The first step measurement was conducted in the orientation that the grid axis from mark1 to mark11 of the grid plate was aligned to the x-axis of the calibrator. Second step measurement was conducted in 90-degrees rotated orientation compared to the first orientation; the grid axis from mark1 to mark11 of the grid plate was aligned to the y-axis of the calibrator. As the same procedures, two more steps of measurements in third orientation, 180 degrees rotated orientation, and fourth orientation, 270 degrees rotated orientation, were conducted. The result of mark position calibration of the grid plate was calculated as the average of four measurements in four orientation. By applying four step measurement method, the dimensional error which exist in the 2D grid calibrator was cancelled and reduced.

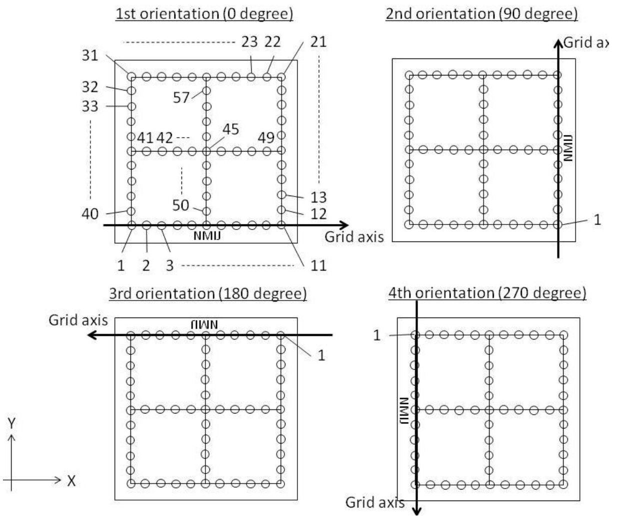


Fig. 4 Procedure of multi-step measurement

The measured precision grid plate was set in four orientations, 0 degree, 90 degree, 180 degree and 270 degree. Measurement for each orientation was started from mark1 and ended on mark57.

3. CALIBRATION RESULT

The positions of marks on the precision grid plate, which was mentioned in section 2.1, was calibrated by using 2D grid calibrator with laser interferometers. In each measurement orientation, position of the marks were measured in the order corresponding to the mark number. The distances from mark1 to the measured mark for x-axis and y-axis were measured by the laser interferometers. The temperature of the air around the laser beams and temperature of the grid plate were measured during the 2D grid plate calibration. The refractive index of air and the thermal expansion of the 2D grid plate were compensated. We used the objective lens with the magnitude of 1× and the magnification lens with the magnitude of 2×, the total magnitude of 2×. Whole one mark circle could be observed in one shot of the camera view.

The measurement result of that grid plate in four orientation and averaged result of four measurement results are shown in Fig. 5. The origin of the mark position of each orientation were aligned to the position of mark45, which is the center of the precision grid plate. The deviation of the results in each orientation were magnified 10000 times. The orientation of each measured result were aligned to 0-degree orientation. It shows that the variation of measurement results between four orientations was approximately 0.5 μm.

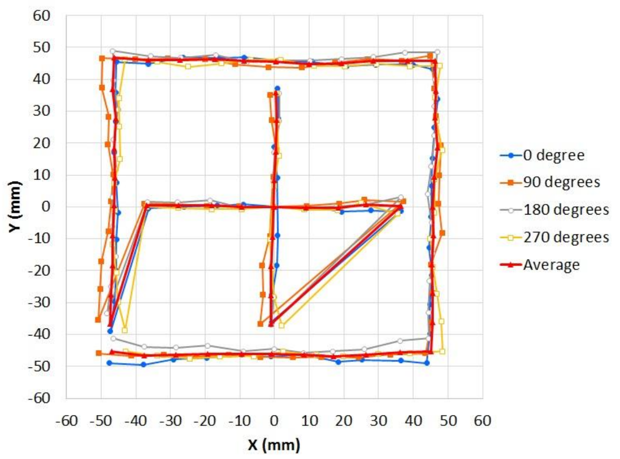


Fig. 5 Measurement result of 4-step measurement

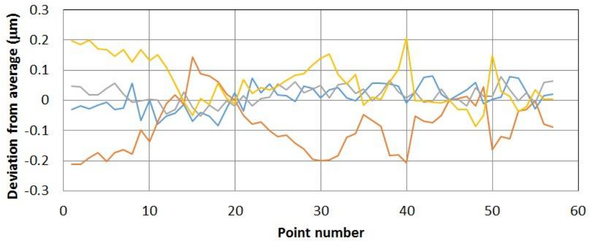
Blue circle: result of 0-degree orientation, orange circle: result of 90 degree orientation, gray circle: result of 180 degree orientation, yellow circle: result of 270 degree orientation, red circle: average of results of four orientation. The deviation from the nominal position were magnified by 10000 times.

The deviation of the measurement result of each orientation from average of result of four orientation is shown in Fig. 6. It shows symmetric property between 0-degree orientation and 180-degree orientation and between 90-degree orientation and 270-degree orientation.

To show dimensional error clearly, deviations from averaged result sorted in the order that shows the errors of x-axis and y-axis. Fig. 7 shows the sorted deviations and the average of them in x-axis (Fig. 7 (a)) and in y-axis (Fig. 7 (b)). The average of sorted deviations is the dimensional error. Although it shows that there were additional error for each measurement to dimensional error of the calibrator, the dimensional error could be reduced by averaging the results of four orientations. The maximum deviation from the averaged dimensional error was 0.1 μm. The residual error was thought to be caused by the repeatability error, the drift of laser interferometer, resetting error of the grid plate, and fluctuations in the calibrator.

By attaching laser interferometers to commercial vision-CMM and applying multi-step method to the calibration procedure, calibration error could be reduced in this calibration of precision grid plate. The calibration

(a)



(b)

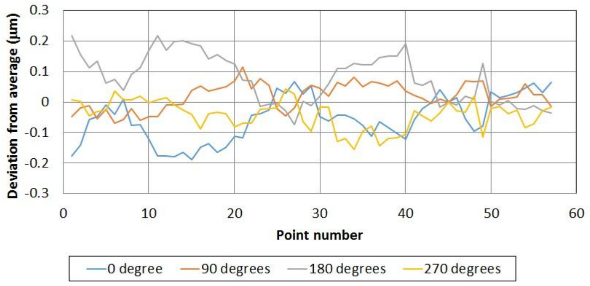
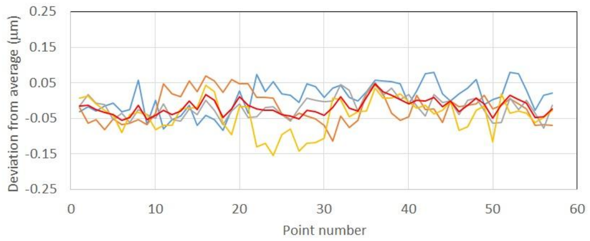


Fig. 6 Deviation from average of measurement result (a) x axis (b) y axis.

(a)



(b)

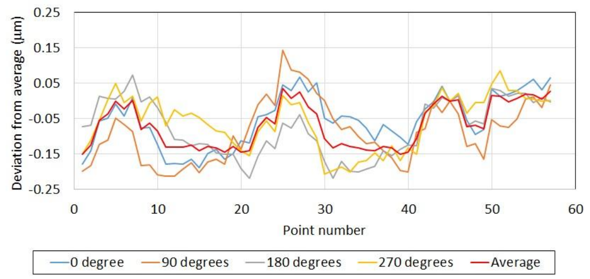


Fig. 7 Sorted deviation from average of measurement result

(a) x axis (b) y axis. The average of measurement result (red line) shows the dimensional error of this calibrator.

uncertainty of x-axis and y-axis could be estimated to be sub-micrometer level.

4. CONCLUSION

The 2D grid calibrator based on a vision-CMM with laser interferometers was developed. It has a laser interferometer on x-axis and two laser interferometers for y-axis. Multi step method (four step method) was applied for this calibration of precision grid plate for the purpose of reducing the dimensional error of the vision-CMM. The multi step method was well effective for reducing the dimensional error of the vision-CMM. By demonstrating calibration of precision grid plate, the uncertainty of this 2D grid calibrator is estimated to be sub-micrometer level.

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