INTRODUCTION

This study describes about the precision measurement method to evaluate the geometrical accuracy of micro measurement systems, which can measure the micro parts in high accuracy. To realize the micro measurement system, we have to evaluate accuracy of geometrical error of stages such as parallelism between each axis and orthogonal accuracy strictly. In this report, we show new measurement method of evaluating the parallelism between spindle axis (C-axis) and stage axis (z-axis). The principle of this measurement method was already shown in previous study[1], and just preliminary experiment was performed. In this report, the principle of this method is denoted again simply and has some experiment. The experimental results about this method can evaluate the parallelism of the measurement system. An orthogonal accuracy measurement method between each stage axis is also tested. Because the errors of the right angle in the cube mirror as a standard are cancelled by the summation of the 4-times measurement results, this method does not depend on the accuracy of right angle cube mirror. The basically experiment and analysis is performed and the results guarantee the validity of this method.

MEASUREMENT METHOD FOR THE PARALLELISM BETWEEN SPINDLE AXIS AND STAGE AXIS

FIGURE 1. is a new method to measure the parallelism of z-axis and rotational axis. This method uses a master ball and two displacement sensors. The master ball is attached to the spindle, and the sensor is set to the main axis. The parallelism is evaluated by two z-points measurement. In this method, there is a miss-alignment between the center of the spindle rotation and the one of the master ball. There is also an attaching position error between two z-points. Therefore, the rotational center Q is measured.

A jig unit holds two displacement sensors and it is able to rotate around the middle point of sensors. This rotation is less than one times. When the displacement sensor measures the master ball in point P, there is only one angle $\psi$, where P-P' line becomes the perpendicular bisector of O-Q line. At this angle, the outputs of two displacement sensors are same except for the phase. The rotation center exists in the extended line of that middle point. Of course, the rotation center point can be evaluated by one probe scanning on surface, but scanning for the minimum variation of sensor is time consuming. The proposed method is able to detect center point easily just comparing two sensors outputs.
BASIC EXPERIMENTAL RESULT FOR PARALLELISM MEASUREMENT

FIGURE 2 is an experimental setup for parallelism measurement. One capacitance type displacement sensor (ADE Microsense) is attached to the x-y stage. This stage puts on a θ stage to give a rotational motion in FIGURE 1. Because the x-stage shifts the sensor two times to measure P and P' points, this system is considered to have virtual two probes. The master ball as test work is a steel ball with 40 mm diameter, and the air spindle rotates within 60 rpm in these experiments.

The output in rotational center point is shown in FIGURE 3. P-V amount of this signal is about 0.037 μm. The most of this output is noise like and 1st order frequency component is almost negligible.

FIGURE 4. shows the variation of differential outputs of two sensors’ P-V amount with each rotational stage angle. The point, ΔPV=0, gives a suitable P-P' position which is perpendicular bisector of O-Q line. In this figure, the bisector point is 72 degree.

From this angle, the rotational stage rotates 90 degree and x-stage moves the sensor to detect center position. Typical output of this motion is FIGURE 5. The P-V value decreases with linear relation until 0 to 900 μm and after that, it increases reversely. The output at 900 μm position is like FIGURE 3.

After this measurement, the master ball is attached at Δz higher point. And the system measures the center point of rotational spindle in this height using same procedure as above mentioned. The difference between two measured center points means the parallelism of PV [um]
Orthogonality measurement of XY stage

Due to many reasons motion in one axis of the given stage cannot be perfectly perpendicular to motion in the other axis. This deviation from perfect orthogonality is called orthogonality error. Measuring amount of that deviation using some noble algorithm and device is main theme of this research.

Theoretical principle of this measurement of orthogonality of XY stage is in FIGURE 6. $\theta$ is orthogonality error, $e_i$ is mirror profile error from right angle and $\psi_i$ is setting error. The relationship between these values are as follows:

$$\theta = \frac{m_{1i}(x, y + d) - m_{1i}(x, y)}{d} + e_i + \psi_i = \frac{\Delta m_{1i}}{d} + e_i + \psi_i$$

Because of geometrical theory, summation of 4 corners angles becomes obviously $2\pi$. Then,

$$\sum_{i=1}^{4} \alpha_i = \sum_{i=1}^{4} \frac{\pi}{2} + e_i = 2\pi + \sum_{i=1}^{4} e_i$$

Therefore:

$$\therefore \sum_{i=1}^{4} e_i = 0$$

The profile errors are canceled. Finally, orthogonality error is calculated as below:

$$\theta = \frac{1}{4} \sum_{i=1}^{4} \left( \frac{\Delta m_{1i}}{d} + \psi_i \right)$$

Almost same method was already mentioned and evaluated theoretical uncertainty in previous study [2], [3]. But there are few experimental results. Then this time, we had a series of experiment to confirm this method in experimentally.

System setup and experimental results

Device set-up for stage control and measurement experiment is as FIGURE 7. XY stage (Suruga Seiki K101-30LHD-M) system is used for measured stage. The laser encoder (Renishaw RLD10-3P) measures the motion of x-y stage. The cube mirror and rotational stage is put on the top of the x-y stage to measure the orthogonality error.

The measurement experiment is conducted. For guarantee of repeatability of this measurement method, these below experiment conditions are followed:

<table>
<thead>
<tr>
<th>Table 1. Results of orthogonality measurement</th>
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<td>Angle</td>
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<td>Orthogonality error</td>
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used. 1) 4 time experiments are conducted. 2) For each time, stage including mirror and laser interferometer are reset at arbitrary position. 3) For each time, moving distance is 20 mm which is restricted by size of cube mirror and motion velocity is set to 20000 pps, or 400 um/s. 4) 1 more time experiment of different moving distance, 10 mm is additionally conducted. The result of experiment is shown in TABLE 1. The orthogonality error measured in both experiment has deviation of about 9.00e-7 rad or 4.75e-5 deg. corresponding to about 18 nm linear difference when stage moves 20 mm. Deviation of orthogonality error is very small and obtained result is reasonable. Through the results above, it is concluded that orthogonality error obtained by method suggested here has reliability in spite of some uncertainties.

Conclusion
This paper is summarized as follows. 1) New measurement method of evaluating the parallelism between spindle axis (C-axis) and stage axis (z-axis) is proposed. The experimental results about this method evaluate the parallelism of the measurement system. 2) An orthogonal accuracy measurement method between each stage axis is also tested. From basic experiment and consideration, the orthogonality errors can be obtained and these results are reasonable.

REFERENCES