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EVALUATION OF PROPERTIES OF NANO-CMM BY THERMAL DRIFT AND TILT ANGLE

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Abstract – We have started developing novel systems and key technology as "Nano-CMM project". In this project, our intention is developing the CMM with nano meter resolution to measure three-dimensional positions, orientations and parameters of three-dimensional features. For developing Nano-CMM, we evaluate properties of stages for Nano-CMM by thermal drift and tilt angles. In this report, the thermal drift and tilt angles of stages of Nano-CMM were evaluated. Then we made the new prototype of Nano-CMM made of low thermal expansion iron steel to reduce the influence of thermal drift and we also propose new construction of Nano-CMM for reducing the effect by tilt angles.

Keywords: CMM (coordinate measuring machine), nano meter measurement, thermal drift

1. INTRODUCTION

Coordinate Measuring Machine (CMMs) have been developed and widely used to measure quickly and complex shapes with high accuracy as improving precision of industrial workpieces. The system and the key technology of traditional CMMs come to maturity in this 10 years.

However, the limits and the drawbacks of the traditional CMMs are clearly such as the limit of accuracy, measuring range, measuring speed and so on. Therefore, we have started developing novel systems and key technology as "nano-CMM project" [1-5]. For developing Nano-CMM, we established the specifications and the key elements of each factor, such as scales, actuators, tables and a probing system. Firstly, we decide that Nano-CMM has simple and symmetric constructions made of single material for stability of measurements. Therefore, a conventional scale system (optical glass scale) and a double Vee groove mechanism are selected.

For developing Nano-CMM, we evaluate properties of stages by thermal drift and tilt angles. In this report, the thermal drift and tilt angles of stages of Nano-CMM were evaluated. Then we made the new prototype of Nano-CMM made of low thermal expansion iron steel to reduce the influence of thermal drift and we also propose new construction of Nano-CMM for reducing the effect by tilt angles.

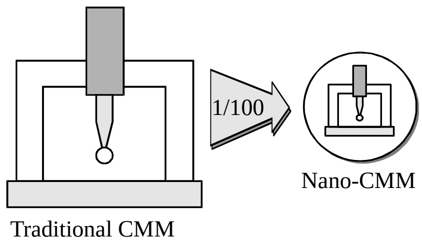

Fig. 1 Traditional CMM to Nano-CMM

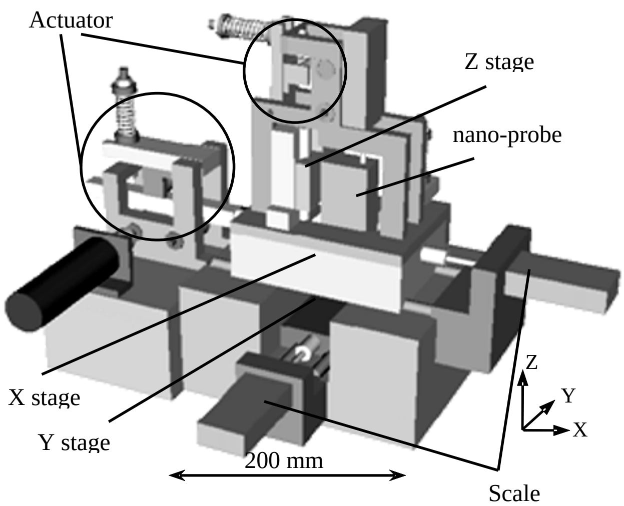

Fig. 2 Basic construction of Nano-CMM

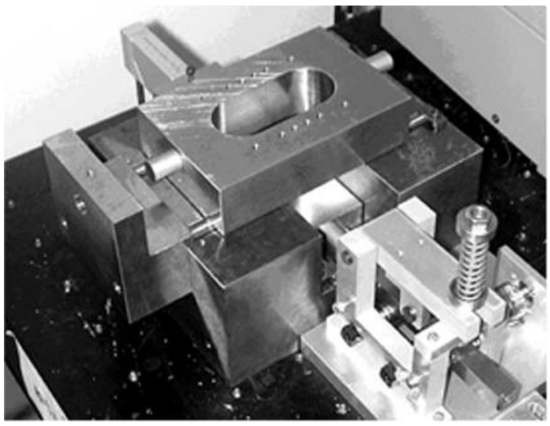

Fig. 3 Photograph of Nano-CMM

2. BASIC CONCEPT OF NANO-CMM

Fig.1 shows our target images of Nano-CMM. Almost all specifications of Nano-CMM are 1/100 of the specifications of traditional CMM. For developing Nano-CMM, we established the specifications and the key points of each factor, such as scales, actuators, stages and a probing system. Firstly, we decide that Nano-CMM has simple and symmetric constructions made of single material for stability of measurements. Therefore, a conventional scale system (optical glass scale) and a double Vee groove mechanism are selected.

The main items of each factor of Nano-CMM are listed as follows:

- Scale: an optical glass scale system with 10 mm measuring range and 10 nm resolution is selected for absolute accuracy, large measuring range and high stability.
- Actuator: a friction drive system is selected for large moving range, high resolution and feedback control by scale.
- Table: symmetric construction of sliders with a scale and a double Vee groove with PTFE (Teflon) thin films is selected for stability.
- Materials: silicon, Zerodure, aluminum or steal are considered for single material, high thermal conduction rate and low thermal expansion rate.

Figs. 2 and 3 illustrate the construction of Nano-CMM. In this construction, double Vee grooves with precision cylinders are used between X stage, Y stage and the basement of Nano-CMM.

3. THERMAL DRIFT OF NANO-CMM [1]

Fig. 4 shows the effects of drifts in the straightness evaluations (20 times measurements in 60 minutes). The maximum displacement of drifts is approximately 180 nm at each X position. These displacements are too big for the stages of Nano-CMM.

We install four thermometers in X stage and measure the variations of temperatures at four points (Ch. 0 - Ch. 3) on X stage and the gauge block, because these variations could be estimated to be the thermal drifts. The variations of the temperature at the four positions and the variation of the horizontal position at the center of X stage (X = 5 mm) are measured. Fig.5 shows the relationship between the measured temperatures and the variation of the horizontal position of X stage in the laboratory. The change of the temperatures and the change of the horizontal displacements correspond very well.

For reducing the thermal drifts, we make a small constant temperature box. The box is made of polystyrene foam and the inside of the box is wrapped in aluminum foil. Fig.6 shows the relationship between the measured temperatures and the variation of the horizontal displacements of X stage in the constant temperature box. Table.1 shows the relationship between the temperature changes and the horizontal position changes of X stage without the box and in the box. We conclude that the

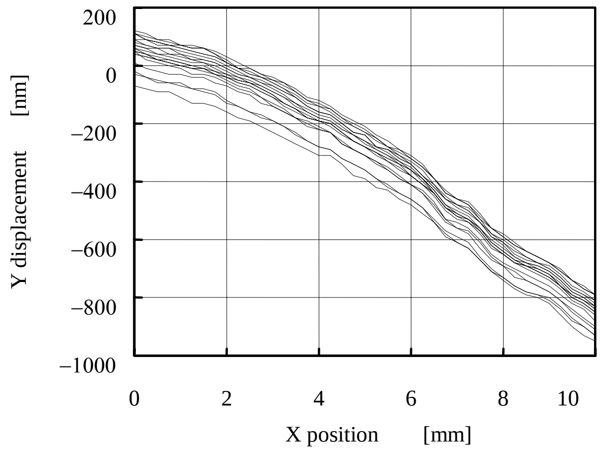

Fig. 4 Y displacement variations of X stage by thermal drifts: 20 measurements in 60 minutes

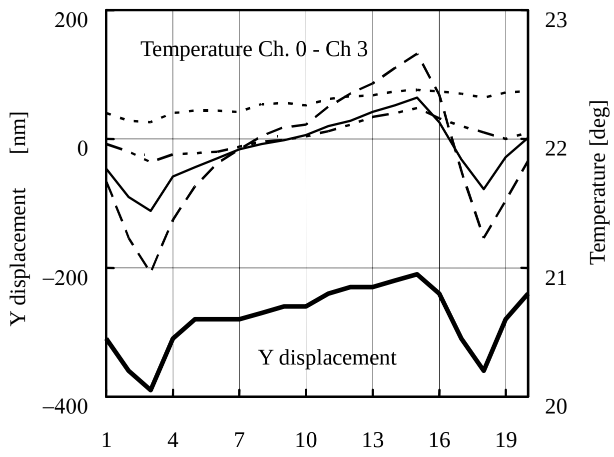

Fig. 5 Temperature changes and horizontal displacement changes of X stage

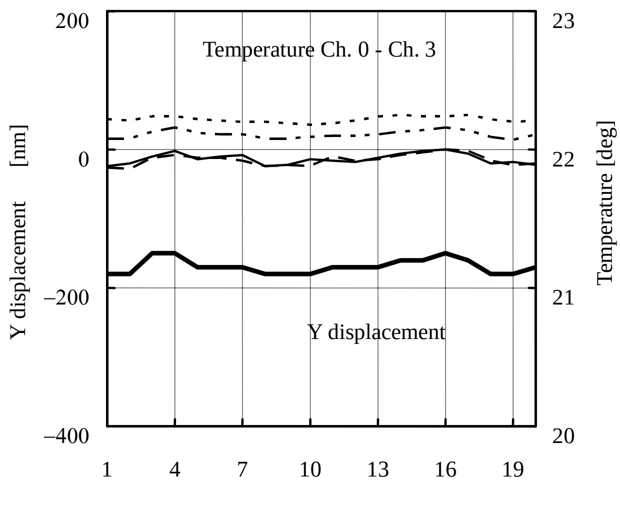

Fig. 6 Temperature changes and horizontal displacement changes of X stage in constant temperature box

position change is in proportion to the temperature change and the constant temperature box is effective to reduce the thermal drifts. As for the thermal drifts are still bigger than our target specifications, good temperature control or low thermal expansion material should be necessary.

Table.1 Temperature changes and horizontal position changes without or in the constant temperature box

	temperature changes	horizontal position changes
without the box	0.56 ºC	180 nm
in the box	0.11 ºC	30 nm

4. MEASURING TILT ANGLE OF STAGE [2]

Straightness of the stage is measured in order to evaluate accuracy of the stage until now. However, one dimensional behavior of the stage is only realized by measuring straightness. The stage movement includes three translation motions and three rotary motions. The position of the probing system is effected from these tilt angles of the rotary motions. Table 2 (a), (b) and (c) show displacement of X, Y and Z stages influenced by the tilt angles and Abbe’s offsets.

Therefore, we measure tilt angles of the stages in order to realize three dimensional behaviors of the stages. Three sensors with glass scales and an optical flat are used for this measurement. Figs. 7 and 8 illustrate the constitution of the experiment. In this experiment, three sensors can detect pitching, rolling and Z displacement of the stage. Furthermore, the sensors on the side surface of the stage can detect rolling, yawing and Y displacement of the stage.

The stage moves by speed of 70 μm/s and 5 back-and-forth motion by the forward movement on 30 sec and the backward movement on 30 sec. Fig. 9 shows the tilt angles (pitching, rolling and yawing) of X stage. And, Y displacement and Z displacement of X stage are displayed on Fig. 10 (a) and (b), respectively. The forward slope and backward slope f Y and Z displacements are not same. From this behavior, we conclude that the forward and the backward motions are not on the same line. It is because the sliding guide by the double Vee gloves and the precision rods is over constraints guide. Then the sliding contact points are changed from the direction of the motion.

The X and Y effective displacements of the position of the probe are 200 nm and 120 nm, respectively. Therefore, we have to compensate the effective displacements and/or reduce Abbe’s offset of the stages of Nano-CMM.

Table 2 (a) Displacement of X stage by tilt angles

	X position	Y position	Z position
Pitching α_x	$x_1 - x_1 \cos \alpha_x + z_1 \sin \alpha_x$	0	$x_1 \sin \alpha_x + z_1 - z_1 \sin \alpha_x$
Rolling β_x	0	$z_1 \sin \beta_x$	$z_1 - z_1 \cos \beta_x$
Yawing χ_x	$x_1 - x_1 \cos \chi_x$	$x_1 \sin \chi_x$	0

Abbe's offset is (x_1, 0, z_1)

Table 2 (b) Displacement of Y stage by tilt angles

	X position	Y position	Z position
Pitching α_y	0	$y_2 \cos \alpha_y - y_2 + z_2 \sin \alpha_y$	$z_2 \cos \alpha_y - z_2 - y_2 \sin \alpha_y$
Rolling β_y	$-z_2 \sin \beta_y$	0	$-z_2 + z_2 \cos \beta_x$
Yawing χ_y	$-y_2 \sin \chi_y$	$y_2 \cos \chi_y - y_2$	0

Abbe's offset is (0, y_2, z_2)

Table 2 (c) Displacement of Z stage by tilt angles

	X position	Y position	Z position
Pitching α_z	$x_3 - x_3 \cos \alpha_z + z_3 \sin \alpha_z$	0	$x_3 \sin \alpha_z + z_3 z_3 \sin \alpha_z$
Rolling β_z	$x_3 - x_3 \cos \beta_z$	$x_3 \sin \beta_z$	0
Yawing χ_z	0	$-z_3 \sin \chi_z$	$z_3 - z_3 \cos \chi_z$

Abbe's offset is (x_3, 0, z_3)

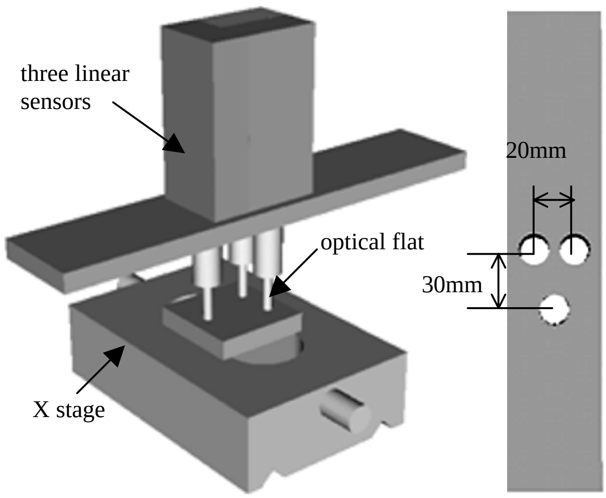

Fig. 7 Overview of experiment to measure tilt angles (pitching, rolling and yawing) of X stage by three linear sensors and an optical flat

Fig. 8 Photograph of measuring method of tilt angles of X stage

4. CONCLUSIONS

In this article, we introduced our developing projects “Nano-CMM project” carried out in the University of Tokyo. We reached the following conclusions:

1. Straightness of the prototype of Nano-CMM is approximately 40 nm and the repeatability is approximately 20 nm.
2. Thermal drifts of X stage are evaluated.
3. Tilt angles of X stage are evaluated.

For reducing the thermal drift and effects from the tilt angles, we made a new prototype of Nano-CMM using low thermal expansion cast steel. Then, we design the novel construction which reduces the effect of displacement of the probe by the tilt angles of the stages. Fig. 11 shows the construct of the new prototype of Nano-CMM. The characteristics of the novel Nano-CMM as follows:

1. Reducing the tilt angles by shorting the length between the probe and center of gravity of the stage.
2. Probe position is changed form Z stage to Y stage for decreasing the center of gravity.

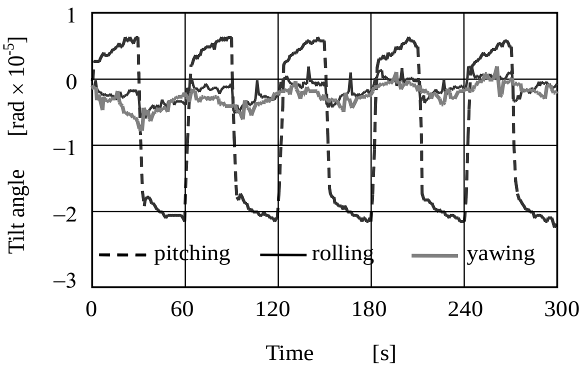

Fig. 9 Tilt angles (pitching, rolling and yawing) of X stage during 5 times of forward and backward movements

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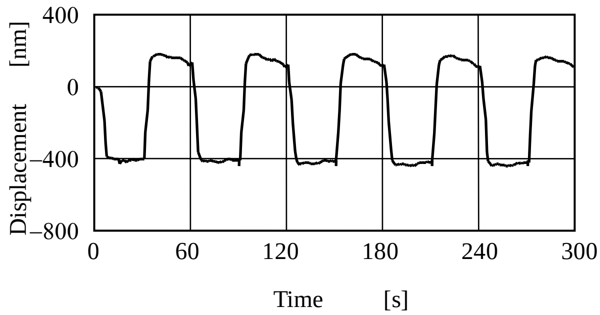
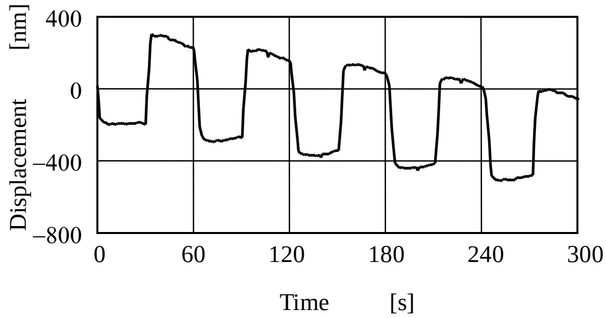


(a) Displacement of Y stage



(b) Displacement of Z stage

Fig. 10 Displacement of Y and Z stage

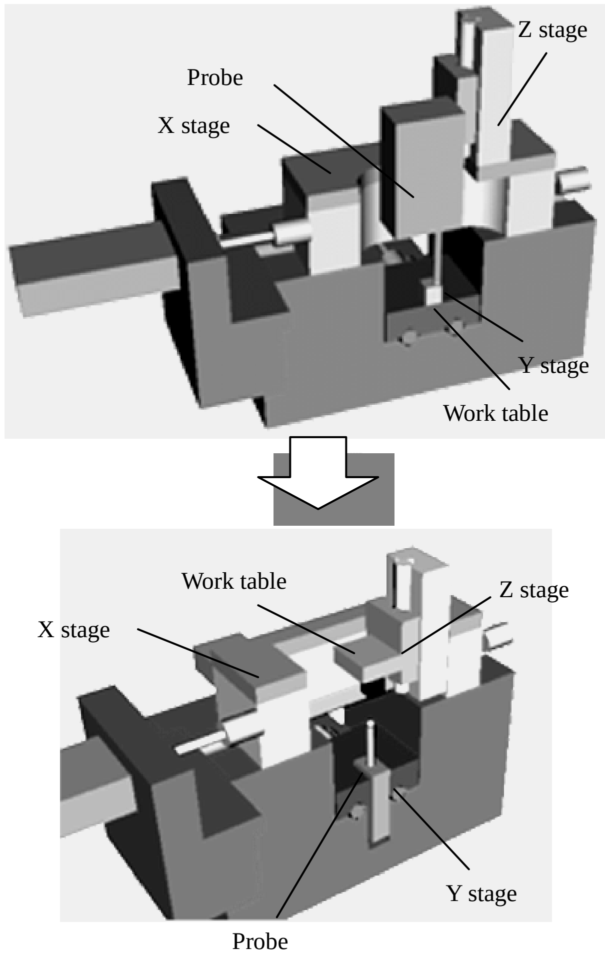


Fig. 11 Construction changes from old prototype to new prototype