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FRICTION DRIVE SYSTEM FOR NANO-CMM

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Abstract: The Coordinate Measuring Machines (CMMs) are widely used for three-dimensional measurements of workpieces. For solving the limits and the drawbacks of the traditional CMM, we have started developing Nano-CMM that measures dimensions and orientations of three-dimensional parts in nanometer resolution. In this article, we introduce a friction drive system as a driving system for Nano-CMM. Using the friction drive system, straightness of the stages and thermal drifts of Nano-CMM are evaluated.

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

1. INTRODUCTION

Coordinate Measuring Machines (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 the novel system and the key technology as "Nano-CMM project". In this project, our intention is developing the CMM with nanometer resolution to measure three dimensional positions, orientations and parameters of three-dimensional features.

2. BASIC CONCEPT OF NANO-CMM

Figure 1 shows our target images of Nano-CMM. Almost all specifications of Nano-CMM are 1/100 of the specifications of traditional CMMs. For developing Nano-CMM, we established the specifications and the key points of each factor, such as scales, actuators, stages and a probing system [1]. 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 screw drive system or 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.

Figure 2 illustrates the construction of X stage, Y stage and a basement of Nano-CMM [2], [3]. In this construction, double Vee grooves with precision cylinders are used between X stage, Y stage and the basement of Nano-CMM (see Figure 3).

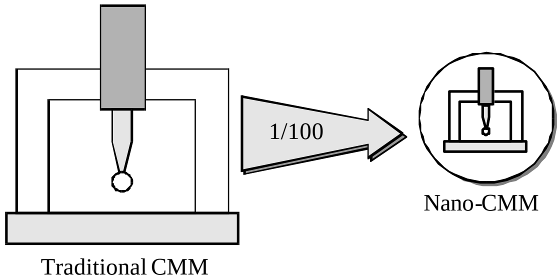


Figure 1. From traditional CMM to Nano-CMM

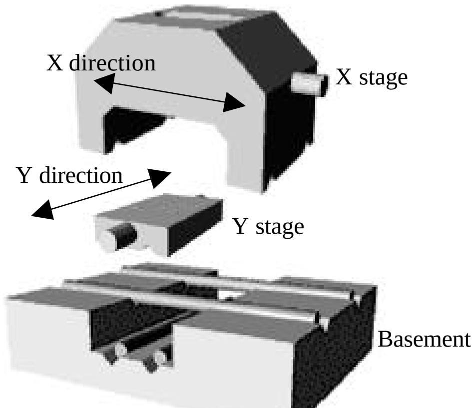


Figure 2. X stage, Y stage and basement of Nano-CMM

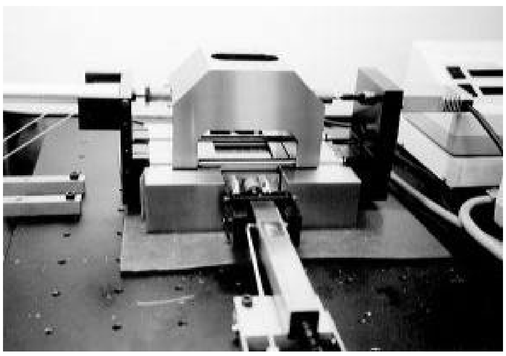


Figure 3. Basic construction of Nano-CMM

3. FRICTION DRIVE SYSTEM FOR NANO-CMM

As an actuator of the Nano-CMM, a conventional screw system was used for the first prototype. However, the rotational moment of the screw system influenced the straightness of the stages (see Figure 7 (a)). Therefore, a friction drive system has been adopted for the second prototype. Figure 4 displays the basic construction of the friction drive system of X stage of Nano-CMM. A capstan roller is rotated by a DC serve motor with a Harmonic Drive (1/100 reduction). And the 10 kgf pre-load is obtained to the capstan roller by two idle rollers with a pre-load spring. Figures 5 and 6 show the friction drive systems for X stage and Y stage, respectively.

The horizontal straightness of X and Y stages of the prototypes are evaluated by measurements on a surface of a gauge block in the measuring range of 10 mm. Figure 7 (a) illustrates the horizontal straightness of X stage of the first prototype of Nano-CMM with the conventional screw system and Figure 7 (b) illustrates the straightness of the second prototype with the friction drive system.

From these evaluations, the straightness of X-stage and Y-stage of the second prototype is approximately 50 nm and the repeatability of these stages is approximately 20 nm. The straightness of stages by the friction drive system is very improved in comparison with the straightness of stages by the screw drive system (see Table 1).

We conclude that the friction drive system is very effective for the actuator of Nano-CMM.

Table 1. Straightness and repeatability of X and Y stages of the first and the second prototypes

		1st prototype	2nd prototype
X	straightness	160 nm - 240 nm	40 nm - 60 nm
	repeatability	50 nm	20 nm
Y	straightness	70 nm - 80 nm	40 nm - 50 nm
	repeatability	40 nm	20 nm

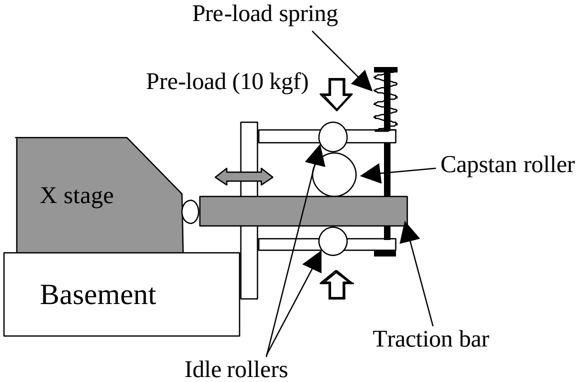


Figure 4. Basic construction of the friction drive system for X stage

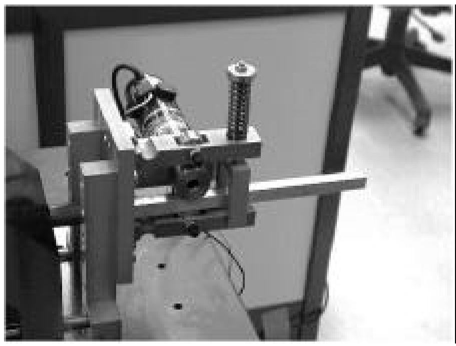


Figure 5. X stage friction drive system

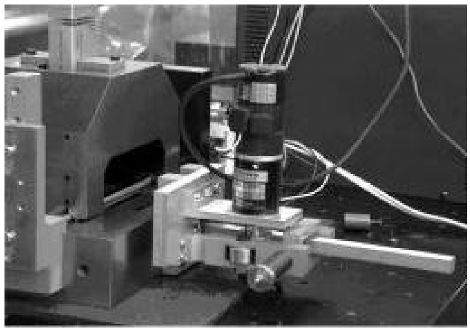
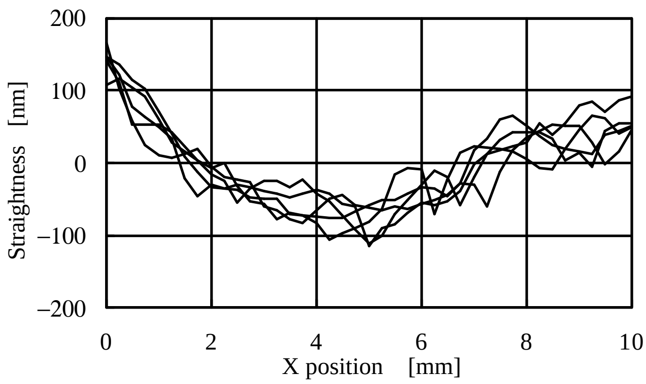
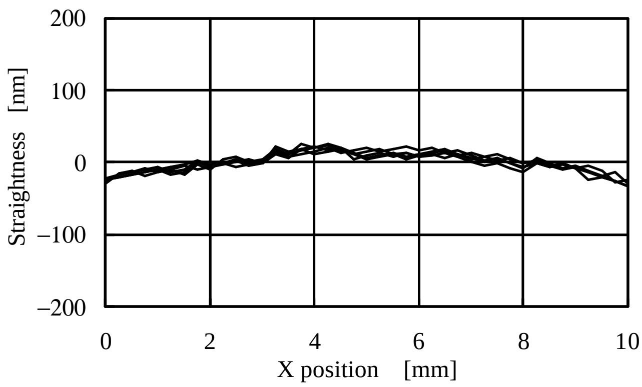


Figure 6. Y stage friction drive system.



(a) Screw drive system (the first prototype)



(b) Friction drive system (the second prototype)

Figure 7. Straightness of X stage: horizontal displacements of X stage in 10 times over 10 mm

4. THERMAL DRIFT OF STAGES

The results of straightness evaluations in the previous chapter are calculated without thermal drifts. Figure 8 shows the effects of thermal drifts in the straightness evaluations (20 times measurements in 60 minutes). The maximum displacement of drifts is approximately 180 nm at each X position. This displacement too big for the stages of Nano-CMM.

The tendency of the variations at three points (X = 0 mm, 5 mm and 10 mm) in 20 measurements are illustrated in Figure 9. It shows that the tendency of the change of the horizontal position is equal in three points.

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 (see Figure 10), 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. Figure 12 (a) 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 position correspond very well.

For reducing the thermal drifts, we make a small constant temperature box (see Figure 11). The box is made of polystyrene foam and the inside of the box is wrapped in aluminum foil. Figure 12 (b) shows the relationship between the measured temperatures and the variation of the horizontal position of X stage in the constant temperature box.

Table 2 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 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.

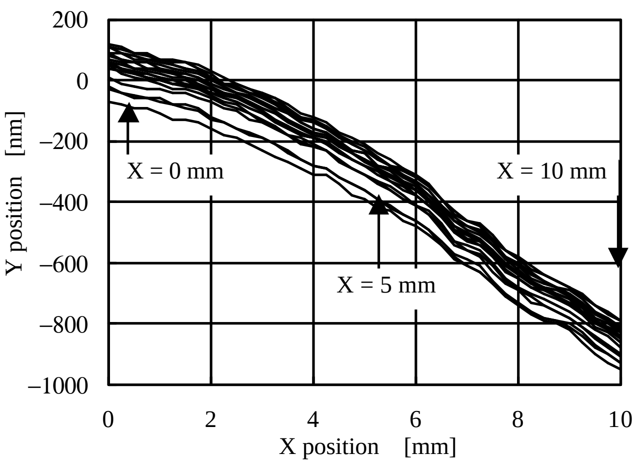


Figure 8. Y position variations of X stage by thermal drifts: 20 measurements in 60 minutes

Table 2. 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

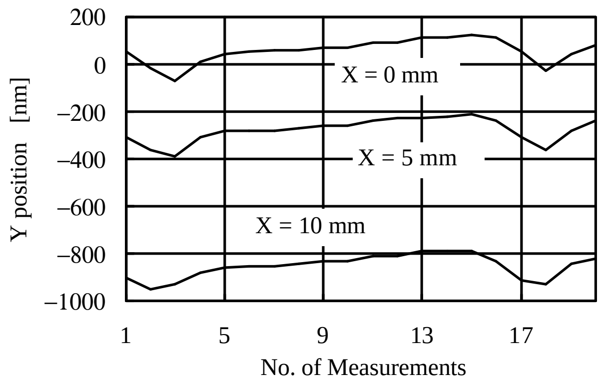


Figure 9. Y position variations of X stage at X = 0 mm, 5 mm and 10 mm

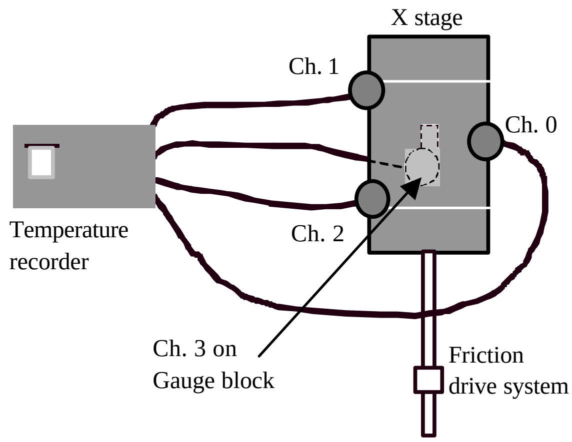


Figure 10. Positions of four thermometers (Ch. 0 - 3) on X stage and the gauge block

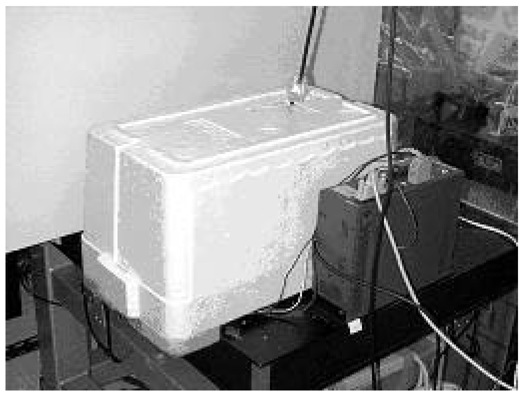


Figure 11. Constant temperature box

5. CONCLUSION

In this article, we introduced our developing projects "Nano-CMM project" carried out in the University of Tokyo. We reached the following conclusions from the developments and the series of experiments of Nano-CMM:

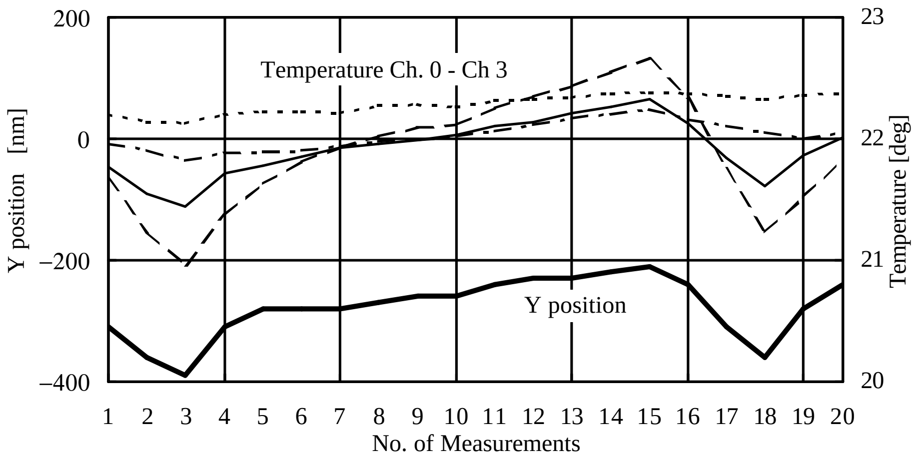
- We introduce the basic concept of Nano-CMM.
- The prototypes of Nano-CMM are made and tested.
- The friction drive system works well for the driving system of Nano-CMM.
- Straightness of the prototype of Nano-CMM is approximately 50 nm and the repeatability is approximately 20 nm.
- Thermal drifts of X stage is evaluated and the temperature constant box is made and tested.

6. REFERENCES

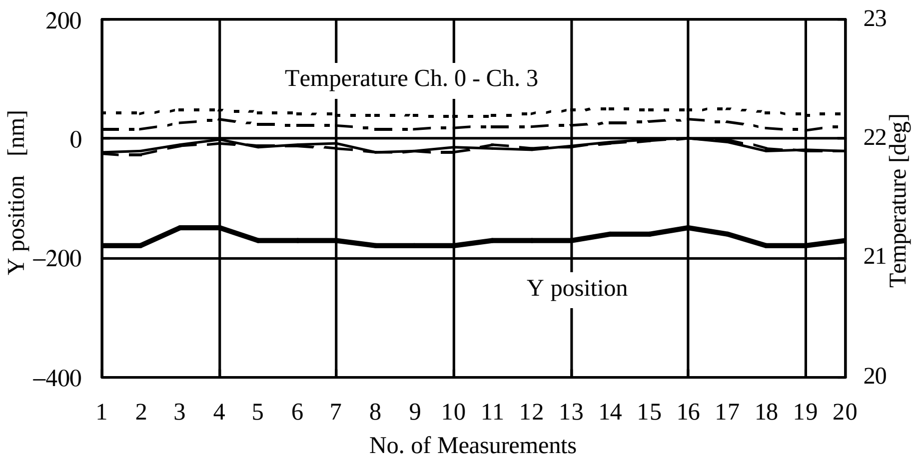
[1] K. Takamasu, A. Kobaru, R. Furutani, S. Ozono, Three dimensional position measurement using critical angle prism, *Proceedings of ISMQC*, Finland, 1992, p. 193-201.

[2] K. Takamasu, R. Furutani, S. Ozono, Development of Nano-CMM (Coordinate Measuring Machine with Nanometer Resolution), *Proceedings of XIV IMEKO World Congress*, Finland, 1997, p. 34-39.

[3] K. Takamasu, A. Kobaru, R. Furutani, S. Ozono: Three Dimensional Position Sensor Using Optical Collimator for Nanometer Resolution, *Proceedings of 7th Int. Precision Engineering Seminar*, 1993, 62.



(a) without the temperature constant box



(b) in the temperature constant box

Figure 12 Temperature changes and horizontal position changes without and in the temperature constant box