Basic Concepts of Nano-CMM
(Coordinate Measuring Machine with Nanometer Resolution)

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ABSTRACT The movement towards the use of three dimensional parts for macro machines and micro mechanism has been gathering pace over the last five yeas. However, there is no CMM (coordinate measuring machine) that can measure sizes and positions of such a small parts in nanometer resolutions. Therefor, we has started to develop a novel CMM with nanometer resolutions as nano-CMM. The objects for nano-CMM are to measure three dimensional positions and sizes of micro machines and parts of micro machines. In this report, the basic concepts and constructions of nano-CMM are described.

Key Words: Three dimensional coordinate measuring machine, Nanotechnology, Nanometer resolution, Micro mechanism

1. BASIC CONCEPTS OF NANO-CMM

There are two types of instruments in profile metrology (Fig. 1); the size measuring instruments have developed from vernier calipers, micrometers and dial gages into the coordinate measuring machine (CMM), and the form measuring instruments which measure surface roughness, form deviations and profile, develop into three dimensional profile measurement instruments. Each type of instrument has the reference of axis and the data processing computer now. Therefor, both types will become a CMM.

Furthermore, in profile metrology AFM (Atomic Force Microscope) and STM (Scanning Tunneling Microscope) are used as profile measuring instruments in nanometer resolution. However, we have no nano-resolution measuring instruments for three dimensional machine parts. Therefore, we need to develop nano-CMM

We established the situations and the objects of nano-CMM as follows: (Fig. 2)

- Trend toward coordinate measuring instruments from the profile measuring instruments and the size measuring instruments to the coordinate instruments.
- Objects for precision metrology are products in manufacturer.
- Needs of development of nano-CMM against AFM.
- Workpieces of nano-CMM are micro machine parts, micro robots and optical components.

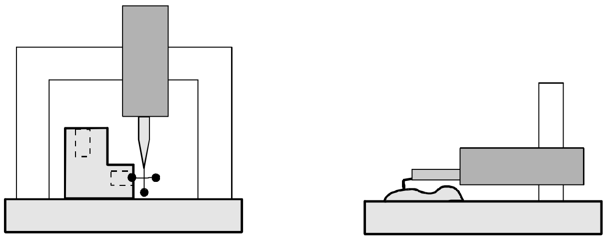

Fig. 1 Coordinate metrology and profile metrology

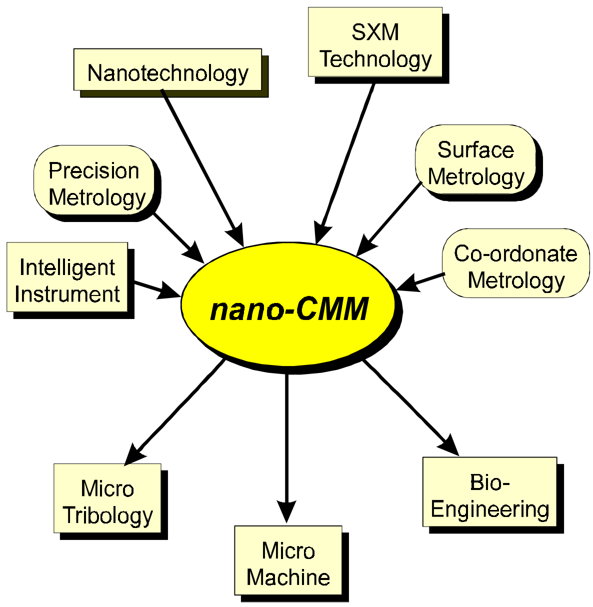

Fig. 2 Concepts of nano-CMM

2. DEVELOPMENTS OF EACH FACTOR OF NANO-CMM

Table 1 and Fig. 3 show our target specifications of nano-CMM. All specifications of nano-CMM are 1/100 or 1/1000 of specifications of conventional CMM.

For developing nano-CMM, we established the specifications and the key points of each factors, such as scales, actuators, tables and the nano-probe (probing system for nano-CMM). Firstly, we decide that nano-CMM has simple and symmetric constructions of single materials for stability of measurements. Therefore, conventional scale system (optical glass scale) and V sliders mechanism are selected.

Nano-probe system has two or three dimensional sensing system with nanometer resolution. Therefore, It is the most difficult item that developing the nano-probe system. And the calibration and traceability methods are also very important to develop the nano-CMM system.

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

2.1 Scale

- Absolute accuracy and large measuring range.
- High stability: analog sensor or scale.
- Absolute calibration and traceability.
- Optical glass scale: resolution is up to 10 nm.

2.2 Actuator

- Large moving range and high resolution.
- Feedback control by scale.
- No precision positioning.
- No high speed positioning.
- Conventional screw.

2.3 Table

- Symmetric construction.
- Slider with scale and actuator.
- Smooth sliding mechanisms (Fig. 4)
- Double V sliders with PTFE (Teflon) thin films.

2.4 Nano-Probe (Fig. 5)

- Ball probe.
- Sphericity of ball is nanometer order.
- Two or three dimensional sensing.
- Nanometer resolution.

2.5 Materials

- Single material.
- High thermal conduction rate.
- Low thermal expansion rate.

Table 1 Specifications of nano-CMM

	Conventional CMM	nano-CMM
Size of Machine	$(2000\ mm)^3$	$(200\ mm)^3$
Weight of Machine	1000 kg	10 kg
Measuring Range	$1\ m^3$	$(10\ mm)^3$
Resolution	1 μm	10 nm
Accuracy	5 μm	50 nm
Diameter of Probe	5 mm	50 μm
Measuring Force	10^{-1} N	10^{-3} N
Accuracy of Scale	1 μm	10 nm

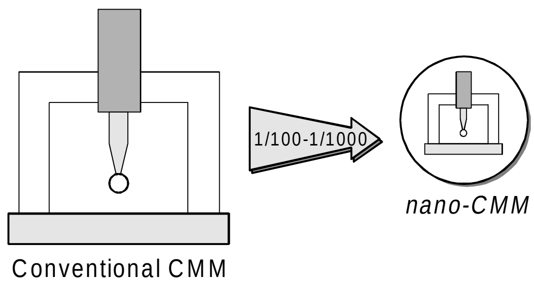

Fig. 3 From conventional CMM to nano-CMM

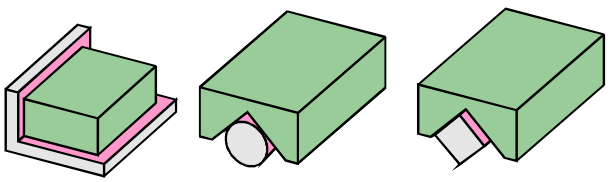

Fig. 4 Smooth sliding mechanisms

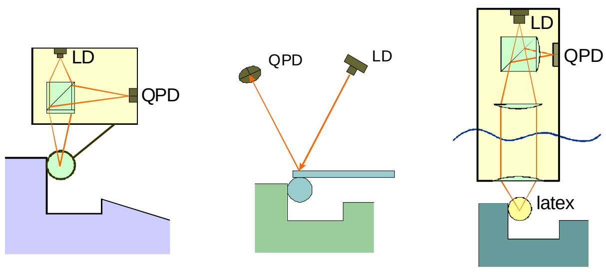

Fig. 5 Examples of nano-probe system

3. CONSTRUCTRIONS OF NANO-CMM

Fig. 6 shows the basic constructions of nano-CMM, it consists of a base, X-stage, Y-stage, actuators and scales. To determine the form of X-stage, we analyzed the 4 models of X-stage in influences from stress deformations, thermal conduction and thermal deformations.

Fig. 7 shows 4 models of X-stage, models 1 and 2 have rectangle forms as the inside of bridges and models 3 and 4 have arch type forms. The FEM software (FINAS) is used in all analysis as follows.

3.1 Stress analysis

Firstly, the influences of measuring force and moving and binding forces are calculated. Fig. 8 indicates the one of results of stress analysis under the following conditions:

FEM software:	FINAS	
Force:	X direction	50 N
	Y direction	50 N
Binding:	X direction	springs
	Y direction	V sliders
Material	Body	Aluminum
	V slider	PTFE (Teflon)

The maximum deformation of X-stage of 4 models (Models 1, 2, 3 and 4) by the stress of forces are 27 nm, 22 nm, 2 nm and 1 nm, respectively. The best forms in this analysis are models 3 and 4, because arch type form is strong for stress from each forces.

3.2 Thermal conduction analysis

Secondly, thermal conduction of each materials (5 materials: Aluminum, Cast iron, Stainless steel, Zerodur and Silicon) are analyzed using model 4. Fig. 9 shows the results of thermal conduction under the following conditions:

FEM software	FINAS	
Heat conditions:		
	Friction at V slides	21.3 °C
	Friction and heat by motors	21.2 °C
Material:		
	Aluminum, Cast iron, Stainless steel, Zerodur and Silicon	
Temperature:	20 °C.	

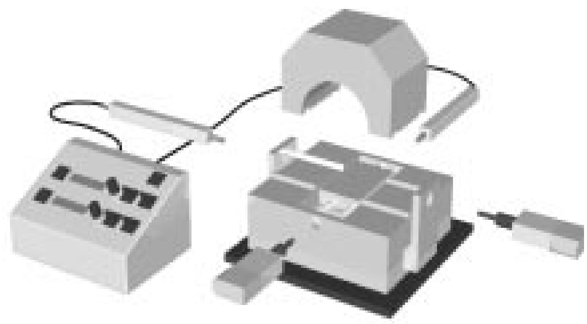

Fig. 6 Constructions of nano-CMM

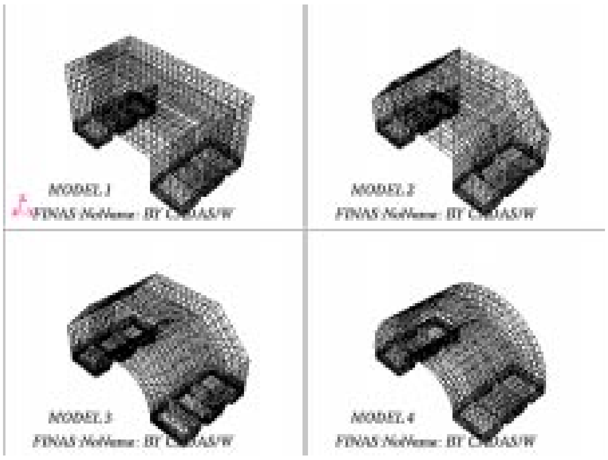

Fig. 7 4 models of X-stage

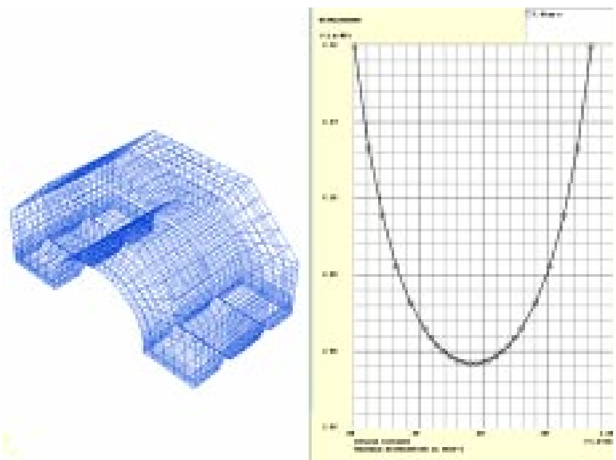

Fig. 8 Deformation of X-stage by stress of forces

The times for thermal balance of X-stage (materials: Aluminum, Cast iron, Stainless steel, Zerodur and Silicon) are 40 sec, 180 sec, 335 sec, over 500 sec and 70 sec, respectively. The best material which has high thermal conduction rate is Aluminum.

3.3 Thermal deformation analysis

Fig. 10 indicates one of the results of the thermal deformations by thermal stress. The maximum thermal deformations of each materials (Aluminum, Cast iron, Stainless steel, Zerodur and Silicon) are 1.3 µm, 0.6 µm, 1.1 µm, 0.0002 µm and 0.2 µm, respectively.

The thermal deformations are over 100 times larger than the stress deformations. Therefore, we conclude that the thermal conditions is more important than the force conditions in nano-CMM.

4. CONCLUSIONS

We reached the following conclusions from the series of simulation to determine the constructions of X-stage by FEM.

1. From stress analysis, the best form is the bridge with arch type form at inside.
2 In thermal analysis, Aluminum, Zerodur and Silicon are the good materials for nano-CMM
3. Thermal deformations are over 100 times larger than stress deformations.
4. The thermal conditions is more important than the force conditions in nano-CMM.

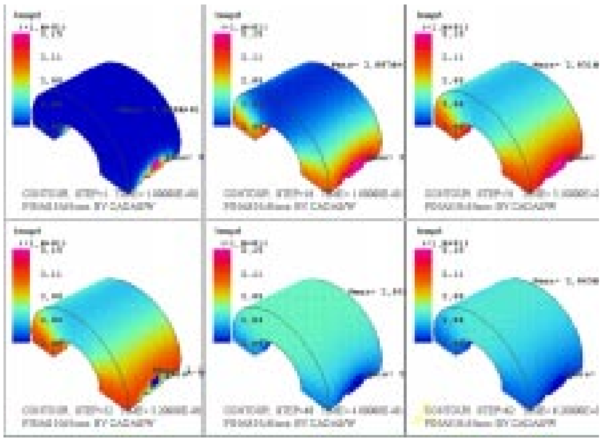

Fig. 9 Thermal conduction of X-stage

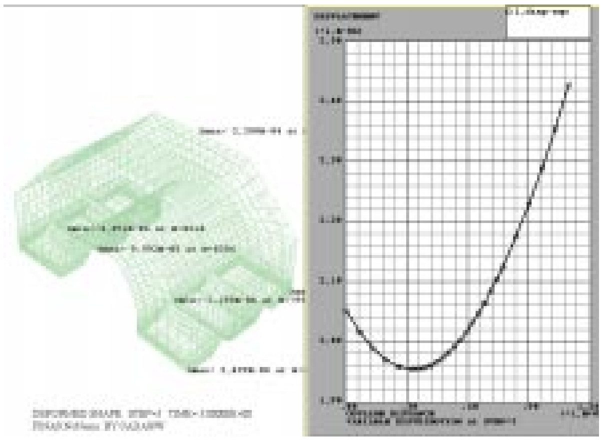

Fig. 10 Deformation of X-stage by thermal stress