

# Development of micro probe for micro-CMM

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## 1. Introduction

This study describes the development of a probe for a micro coordinate measuring machine (micro CMM).

In order to guarantee the accuracy of products, a profile measurement evaluation process is indispensable. A CMM (Coordinate Measuring Machine) is generally used to measure product profiles. Although it can make various product measurements, such as the diameter of holes or complicated profiles, the measurement scale of a CMM is usually several tens of millimeters or more, and it is not suitable for measuring small parts of submillimeter order.

To measure micro-parts in nanometric order, the concepts of a nano-CMM<sup>1)</sup> and an ultra precision CMM<sup>2)</sup> have been proposed, and there have been many interesting studies on novel probe development<sup>3)-5)</sup>.

We conducted the basic research on a micro probe for a micro-CMM. As the first step, we developed a two-dimensional measurement probe. The actual probe for the CMM will be realized by extending our proposal to three dimensions. The probe is a contact type, and is also made to rotate on the detection side by an actuator. By comparing the signal at the time of contact with the phase of the circular motion, it is possible to detect the contact direction within a field.

In this research, we developed a prototype probe system, and conducted a preliminary experiment to verify the proposed principle. The results showed that accurate evaluation of profiles is possible.

## 2. Measurement principle

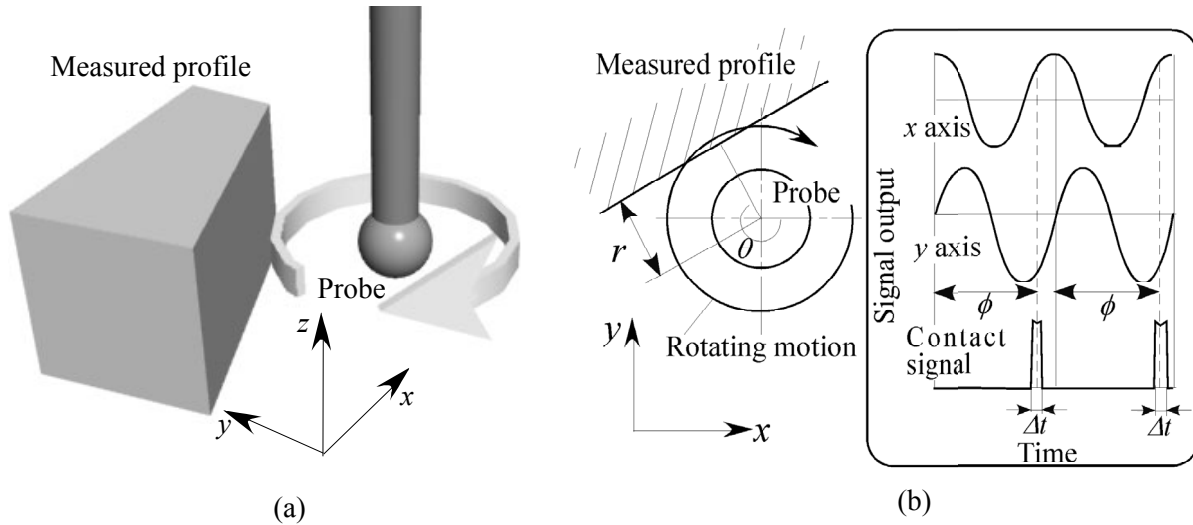
Fig. 1 (a) and (b) show the measurement principle of the proposed system. A contact type probe is rotated in a circular motion within several micrometers in the measuring plane. Fig. 1 (a) is a schematic of the rotating probe. In this system, most contact type probes could be selected such as the electrical touch type, optical type, or strain gage type. However the this probe must be able to detect contact from all directions in the measuring plane.

The circular rotation is applied by two right-angled actuators or a tube piezo actuator that can move in the  $x$  and  $y$  directions. As sine and cosine wave motion signals are applied to the  $x$  and  $y$  actuators, respectively, the probe is rotated in a circular motion.

A  $x$ - $y$  stage moves the profile to be measured until the probe contacts the profile. When the probe contacts profile, a series of data as shown in Fig. 1 (b) can be acquired. These signals are generated by the movement of the  $x$  and  $y$  actuators and a periodic contact signal.

From the  $x$ - $y$  stage coordinates, the two-dimensional position of the contact point can be detected. The length of the contact signal  $\Delta t$  depends on the displacement between the center of rotation and the contact point  $r$ . The phase of this contact signal  $\phi$  varies with the contact angle  $\theta$ , and can be calculated by Fourier analysis. Thus, the system can simultaneously detect the contact position and contact angle.

To obtain an equal response from all contact directions, the rotating motion should ideally be



**Fig. 1** Principle of measurement

perfectly circular and the probe should have a high-precision circular profile. However, if the probe motion or probe profile have some error, measurement accuracy can be confirmed by a calibration technique.

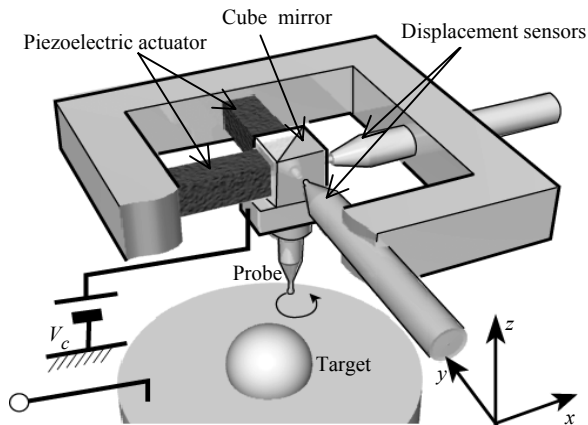
### 3. Development of prototype probe system

Using the MEMS technique, a small probe system for measuring micro machine devices or micro holes can be obtained. Our final goal is to develop such probes and a micro CMM. Before that however, we developed a prototype probe system to demonstrate our method and evaluate its accuracy.

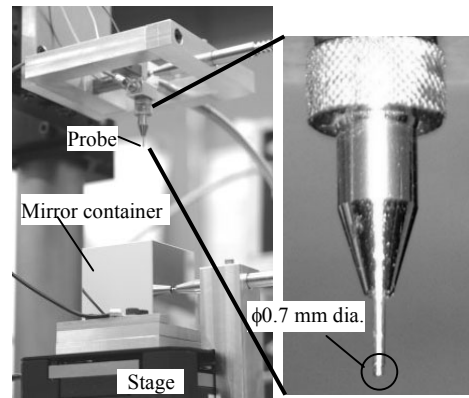
Fig. 2 shows a schematic of the prototype probe system, and Fig. 3 shows a photograph of the system. The probe used is an electrical touch type.

A 0.7 mm-diameter ball bearing is attached to the tip of this probe, and a 5 V contact voltage is applied to the probe. When the probe contacts the target, a computer detects the contact signal. The target in our experiment was a 2.5 mm-diameter ball bearing. This target was fixed to an aluminum base that was mounted on the precision stage. Conductive glue was used to fix the bearing to the probe and also to fix the target in place.

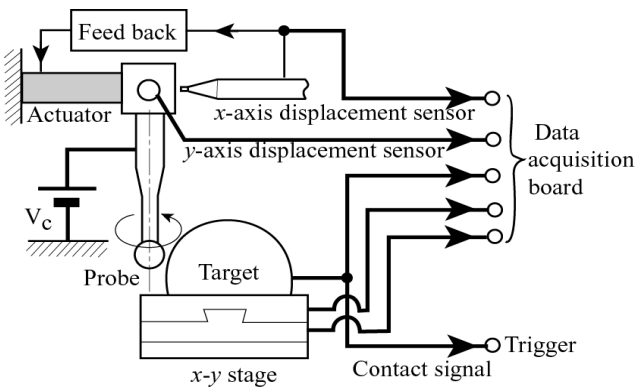
Feedback controllers move two piezoelectric actuators using two displacement sensors. The displacement sensors are of the optical fiber type. The measurement range of these sensors is 20  $\mu\text{m}$ ,



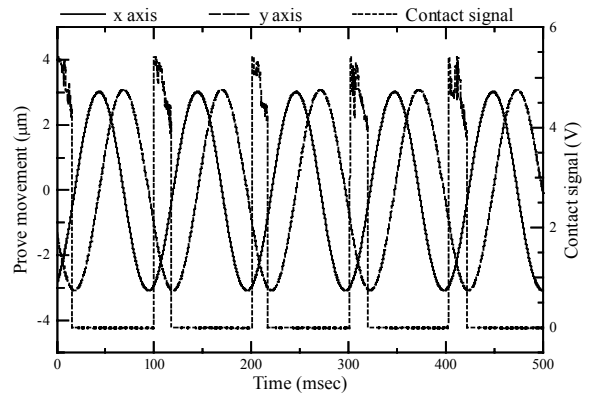
**Fig. 2** Prototype probe system



**Fig. 3** Photograph of prototype probe



**Fig. 4** Diagram of signal process



**Fig. 5** Contact signal and probe movement

and their resolution is of nanometric order. These sensors measure the movement of each actuator through the cube mirror. A two-output type function generator applies sine and cosine command signals to the feedback controllers, then the probe rotates. In this study, we set that the amplitude of each axis at  $3 \mu\text{m}$  and the frequency at  $10 \text{ Hz}$ .

The precision stage has a  $400 \mu\text{m}$  range in the  $x$ - $y$  plane. This stage is controlled by a feedback system using an optical fiber type probe and a mirror container. When contact between the probe and target is detected, the stage is stopped. The precision stage is attached to a manual stage for rough positioning. In future studies, a stepping motor type  $x$ - $y$  stage will take the place of this manual stage. An interferometer measures the movements of the precision and stepping motor stages.

Fig. 4 shows a diagram of the signal process. This figure omits the  $y$ -axis feedback system of the probe and the  $x$ - $y$  stage feedback system for simplicity of description. The computer moves the  $x$ - $y$  stage and detects the contact signal as a trigger. When contact is detected, the computer stops the  $x$ - $y$  stage and begins to acquire the movement signals of the  $x$  and  $y$  actuators, the contact signals, and the coordinates of  $x$ - $y$  stage. After acquiring these data, the computer moves the  $x$ - $y$  stage again to measure the next point. The data acquisition board can measure the synchronizing data of the  $x$  and  $y$  actuators and the contact signals. The internal clock of this board is used for the sampling time.

#### 4. Experimental results

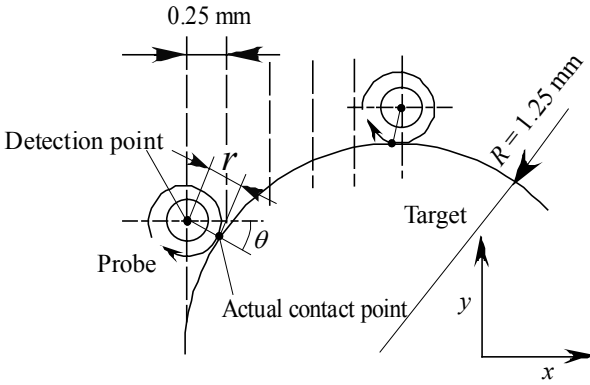
A preliminary experiment was performed to verify our probe system.

Fig. 5 shows typical output of the contact probe. A total of 512 points were sampled in 1 cycle. In this figure, the  $x$  and  $y$  actuators move in a sinusoidal curve without any deformation, and their phase difference is  $\pi/2$ . This output shows that the probe is moving circularly.

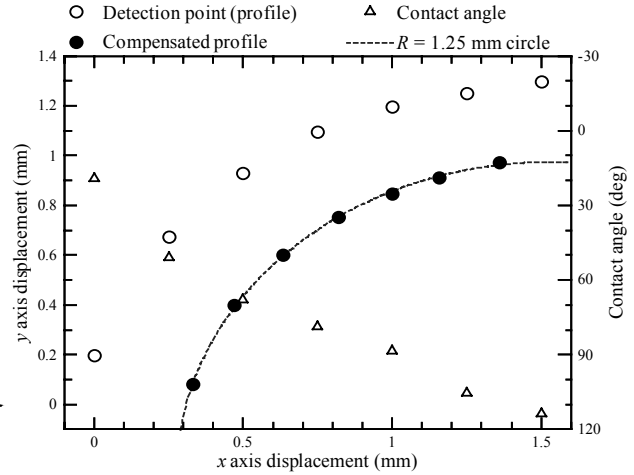
The periodic contact signal indicates the probe is repeatedly contacting the target and releasing from it. The time of each contact is almost the same, indicating that contact with the target does not affect the actual displacement between the center of the rotating probe and the surface of the target.

In the contact signal, the center point between the rising up point and setting down point is the contact direction. From 3 periodic data, the phase angle was calculated to be  $233.1^\circ$ . This result was confirmed from the actual experimental condition.

A profile measurement experiment was performed on the target. Fig. 6 shows a schematic of this experiment. The  $x$ - $y$  stage moves in the  $y$  direction and detects the contact point. After making contact, the stage shifts  $0.25 \text{ mm}$  in the  $x$  direction, and moves the  $y$  axis of the stage to make contact again. Because of the diameter and rotating motion of the probe, the actual contact points are different from



**Fig. 6** Profile measurement experiment



**Fig. 7** Result of profile measurement

the detection points. The actual contact point  $(x_t, y_t)$  can be calculated from the detection point  $(x_d, y_d)$  and contact angle  $\theta$  as follows:

$$x_t = x_d + r \cos \theta$$

$$y_t = y_d - r \sin \theta$$

Here,  $r$  is the displacement between the center point of the probe and the envelope of the rotating probe. More precisely,  $r$  changes with the contact time  $\Delta t$  shown in Fig. 1 (b), but in the present experiment we did not take this into account. Thus,  $r$  is the radius of the probe (0.35 mm) + the probe movement amplitude (3  $\mu\text{m}$ ).

Fig. 7 shows the result of the profile measurement experiment in terms of the detection point, the contact angle of each point, and the compensated contact point. The contact angle was calculated from each contact signal phase. The compensated profile means the actual contact point. This graph also shows the  $R = 1.25$  mm circle. This circle represents the ideal profile of the target. The center point of this circle was selected from the least square error to fit the compensated profile. From this figure, we can see good agreement with the compensated profile and the  $R = 1.25$  mm circle. This result indicates that the system could measure the actual contact angle and actual contact point, and confirms the validity of our measurement method.

## 5 Conclusion

We have proposed a new probe for a micro CMM that can simultaneously detect the contact point and contact direction. A prototype probe system was developed and a preliminary experiment was performed. The results of the experiment confirmed the validity of our method.

## References

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