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Roundness measurements of concave spherical surface using an AFM probe system

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Abstract
Major factors influencing the accuracy of a measuring instrument may vary for different systems. This paper presents roundness measurements of the concave spherical surface using an AFM probe system in an uncontrolled environment and the results are processed assuming that the temperature is varying linearly with time in short period. Processed results show a measurement repeatability of 128 nm. The errors induced by the temperature and environmental vibration are also identified.

Keywords: concave spherical surface, AFM probe, roundness, precision metrology

1. Introduction

Measurement accuracy of many commercial available coordinate measuring machines is in the range of 1 µm [1]. Measurements with sub-micron accuracy are needed when ultra-precision manufacturing is employed [2]. Some nanomeasuring machines can accomplish these measurements. These high precision measurements are usually done in a controlled environment [3]. In this work, the roundness of a cross section of a workpiece with spherical surface is measured on a simple AFM probe system to identify the error components that affect the accuracy in an uncontrolled environment.

2. Measurement System

Figure 1 depicts the setup for measuring the concave spherical surface. The setup is composed of 3 moving components. Manual stage and linear stag move in the Z and X direction separately. Air bearing rotary stage measures the angle with a scale. A tuning fork-based Akiyama probe [4] is mounted on the probe arm that is moving along with the linear stage. The vibration frequency of the probe will increase as the probe approaches and interacts with the measuring surface. The change is used as the feedback to control the linear stage. The linear stage uses a piezo drive and can move in steps of several nanometres. A linear variable differential transformer is used to measure the vertical displacement. All the setup is placed on an optical table with passive-air isolators. The room temperature is not controlled and no housing is used.

2.1. Horizontal cross section measurement

Touch-trigger mode is used to record positions of the linear stage to measure the horizontal cross section of the surface. The position measurement of the linear stage has a resolution of 2 nm.

The spherical surface of the workpiece has a nominal radius of 6 mm, as shown in Figure 2. The tuning fork-based Akiyama probe is hold vertically approaching the concave surface.

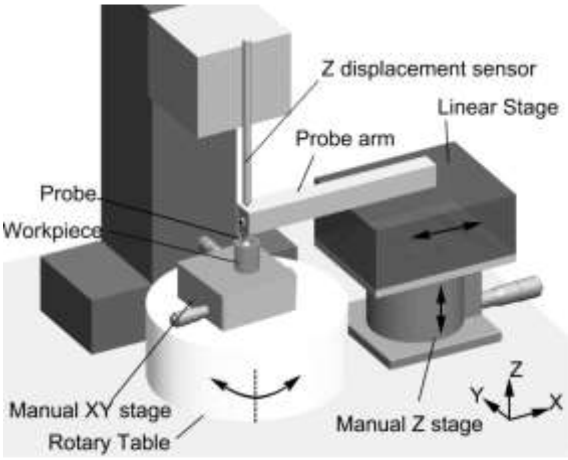

Figure 1. Schematic of the measurement system

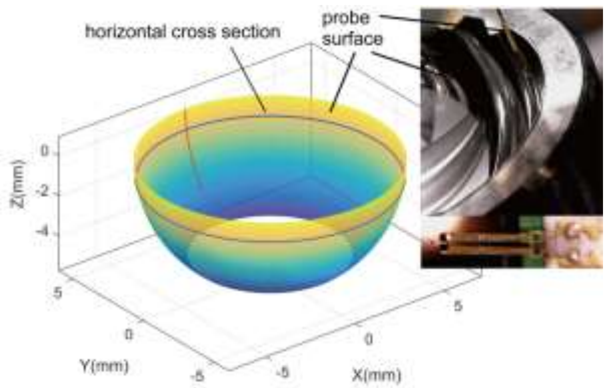

Figure 2. Measured concave spherical surface and probe

2.2. Vibration induced displacement measurement

The displacement due to environmental vibration is measured by keeping the probe in contact with the surface for the linear relationship between distance and voltage output.

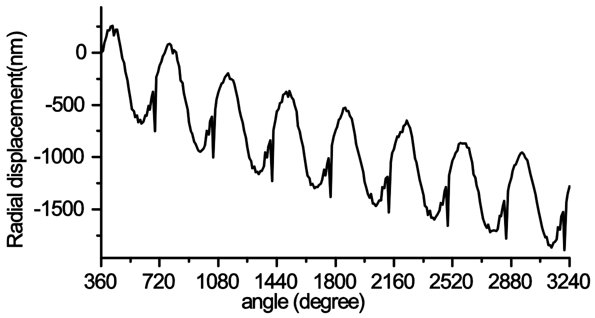

Figure 3. Measurement results of horizontal cross section

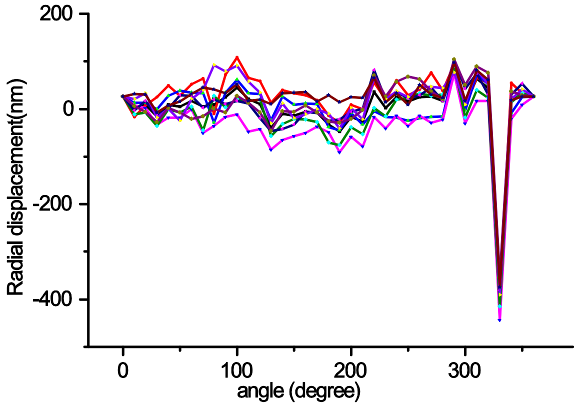

Figure 4. Roundness after removing the influence of temperature and eccentricity

3. Results and discussion

The measurement result is shown in Figure 3. 36 points are measured per round.8 rounds were measured in about half an hour. The displacement due to the temperature variation is 1280 nm which is clearly seen from Figure 3. Temperature variation is 2.2°C.The eccentricity is about 420 nm and produces a sine wave in the result. The roundness of the cross section is smaller than the eccentricity.

From the result in Figure 3, it is assumed that the displacement due to temperature is linear with time and angular positions. The influence of temperature is removed. A least square method is used to fit a cosine equation to remove the eccentricity error. Figure 4 shows the processed result. The repeatability is 128 nm. The average value that include the rotary table error is choosen as the result of roundness measurements. The maximum of radial displacement of the cross section is 105 nm except that there is a pit with depth of 400 nm on the surface. The metrology loop incorporates the scalar of the linear stage, optical table, the probe and rotary stage. This result includes the radial error of the rotary stage.

Figure 5 shows the relative displacement between the probe and work piece which is induced by environmental vibration is 35 nm. The result indicates that low frequency vibrations exist on the structure as the passive air isolators of the optical table doesn't work well for the relative low frequency which is around several Hertz.

The result of measuring a stationary surface using touch-trigger method is shown in Figure 6. The repeatability is 53 nm. The result includes the repeatability of the linear stage and probe.

Error sources of the measurements are listed in Table 1. The probe voltage drift is determined by the vibration frequency of the tuning fork which varies due to the ambient temperature and humidity variations.

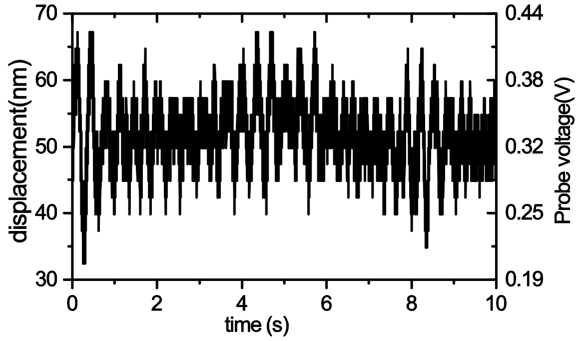

Figure 5. Probe output when it is in contact with the surface

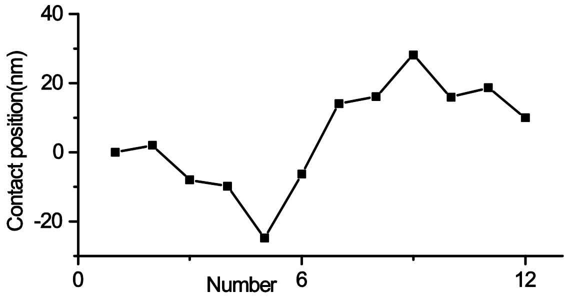

Figure 6. Touch-trigger repeatability of the linear stage

Table 1 The error sources for the measurement

sources		value/nm
Slow	Thermal errors for ΔT = 1 °C	581
	Probe voltage drift	21
	Linear stage and probe repeatability	53
Rapid	Environmental vibration	35

The linear stage moves only small displacement during the horizontal cross section measurement. Geometric errors are not included here.

5. Conclusion

The roundness of a cross section of a concave spherical surface is measured and the roundness measurement repeatability is 128nm. Some error sources that affect the measurement accuracy is identified. The largest error is 581nm/ C which is induced by temperature. Repeatability of linear stage with the probe is 53 nm. Error due to the environmental vibration is 35 nm. These sources are the important factors for improve the accuracy of the probe system. In future research work the metrology loop will be designed for an improved temperature stability.

References

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