

DEVELOPMENT OF SPHERICAL FORM ERRORS MEASURING SYSTEM

--- DESIGN AND SOME EXPERIMENTAL RESULTS ---

Hiroyuki Kawa, Tohru Kanada and Takahiro Watanabe
Dept. Mech. Eng., Kanto Gakuin University,
1-50-1 Mitsuura-higashi, Kanazawa-ku, Yokohama-city, 236-8501 Japan

Introduction

Recent high-performance mechanical system requires high precision profile measuring techniques for mechanical parts. Especially, form errors of spherical parts, which are important in rotational mechanism, three-dimensional measurement and evaluation are needed. For example, sphericity of a steel ball, which is one of the elements for ball bearing applied in computer hard disk or aerospace device, is approaching to 1nm.

Some developments on spherical form profiles measuring techniques by means of original systems have been reported[1],[2]. Those systems have some merits and demerits such as (i) restriction on measurable range and sphere diameter and (ii) long measuring time due to manual operation. Furthermore, it is difficult to evaluate the three-dimensional spherical form by a few two-dimensional data. This report deals with the development of a three-dimensional measuring system for spherical profiles.

Target specifications

Measuring mechanism whose principle is radial method with rotating detector is designed and developed in the viewpoints as follows.

- (1) Measuring accuracy of up to several 10nm can be achieved for various diametrical spheres.
- (2) Measuring time, labor and errors due to human operation can be reduced by means of full automatic operation.
- (3) Improvement and prediction of performance for the device using spherical parts can be presented by the evaluation of obtained three-dimensional data.

Principle of measurement

After searching the position of the maximum diametrical cross section of a spherical specimen with contacting detector, as shown in Fig.1(a), the profile of the cross section is measured. Next, the specimen is rotated by a virtual center axis passing through the two poles as shown in Fig.1(b). Two rotating axes perform self-rotation of the sphere specimen.

Repeating the self-rotation and measurement of profile makes the measured points distributed correctly in longitudinal and latitudinal directions. Fig.2 shows the positions of measuring points and self-rotation axis. Therefore, the three-dimensional data can be expressed in polar coordinate ($r - \theta - \phi$) system. This will be helpful for further analytical evaluation[3].

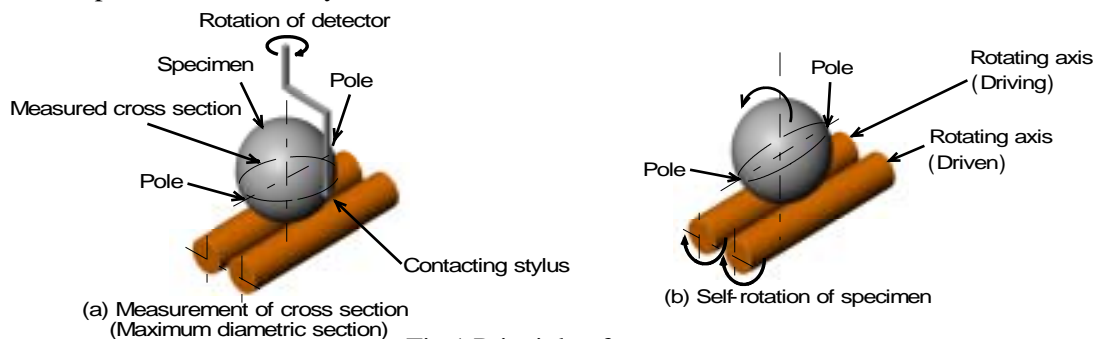


Fig.1 Principle of measurement

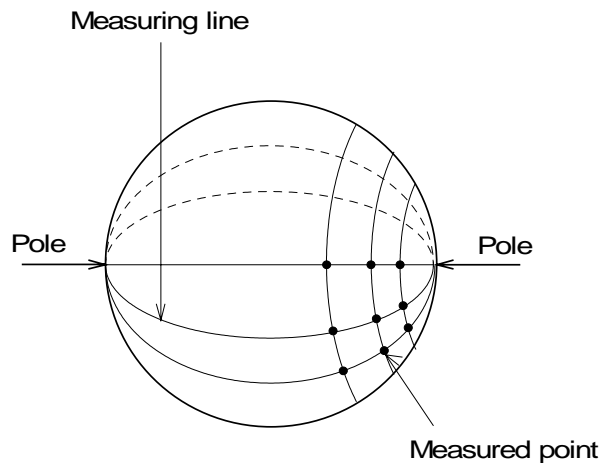


Fig.2 Measuring lines on the specimen

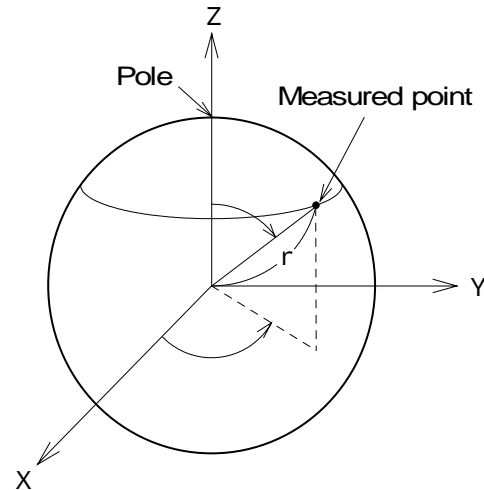
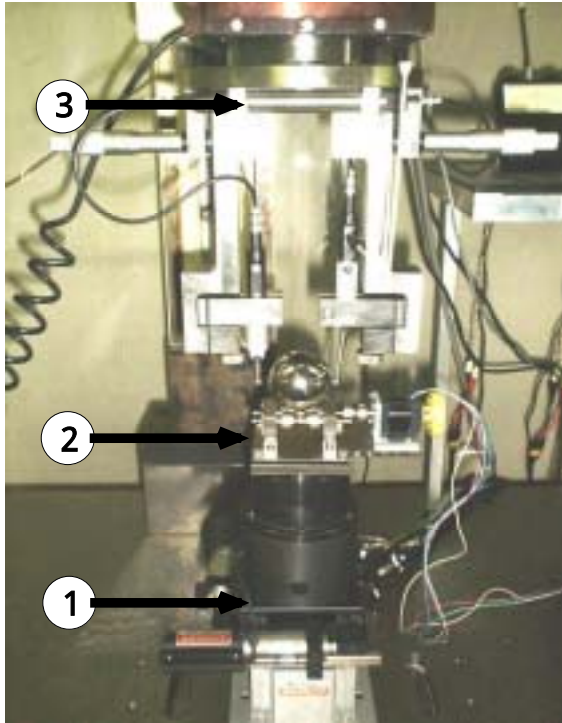


Fig.3 Polar coordinate system for spherical surface specimen

Outline of the system

The developed machine consists of the following four systems as shown in Fig.4 and Fig.5.

- (1) Specimen stage system: The specimen set on the stage can be positioned in X-, Y-, Z- and -directions. X- and Y-stages are for correcting the eccentricity of the specimen. Z-stage is for searching the position of the maximum diametrical cross section. -stage is for rotating the specimen around the vertical axis in the experiment of systematic rotational error by using reversal method. Stroke of X- and Y-directional movement is 10mm with the resolution of $0.0174 \mu\text{m}$. Z-directional stroke and positioning accuracy are respectively 10mm and $1 \mu\text{m}$. -directional movement can be positioned by 200000 separations for 360 degrees.
- (2) Specimen rotation system: The specimen is set between two axes. Then, -directional movement of the specimen is realized by means of friction drive mechanism. -axis is for changing the longitude of the specimen sphere surface. Fig.6 represents a measuring cross section changing device. The diameter of driving and driven axes with grooves is 15mm. Four contacting points between the specimen surface and the groove surface support the specimen. In order to restrict the run-out of the two axes, wave washers are used to apply preload to the axes. A pulse motor drives the driving axis and the driven axis is rotated by O-ring belt drive mechanism.
- (3) Z-axis and detector rotation system: Two detectors are fixed to an air spindle, which is rotated by a DC servomotor. Its revolution speed is from 0.5rpm to 6rpm. The systematic rotational error is nominally $0.04 \mu\text{m}$. The rotation angle of the detector is measured by an incremental rotary encoder pulse signal (81000 pulse/revolution). In proportion to the various diameter of the specimen, Z-directional movement of the detector is enabled. Two contacting detectors (wireless signal transmission) are prepared to the profile measurement. The maximum measuring ranges of the two detectors are $600 \mu\text{m}$ and $60 \mu\text{m}$. The maximum resolutions, $0.1 \mu\text{m}$ and $0.01 \mu\text{m}$.
- (4) Peripheral system: The above-mentioned three systems are controlled by a personal computer. Peripheral system includes the interface circuits between the personal computer and the other three systems.



Specimen stage system
 Specimen rotation system
 Z-axis/detector rotation system

Fig.4 Outview of the developed system

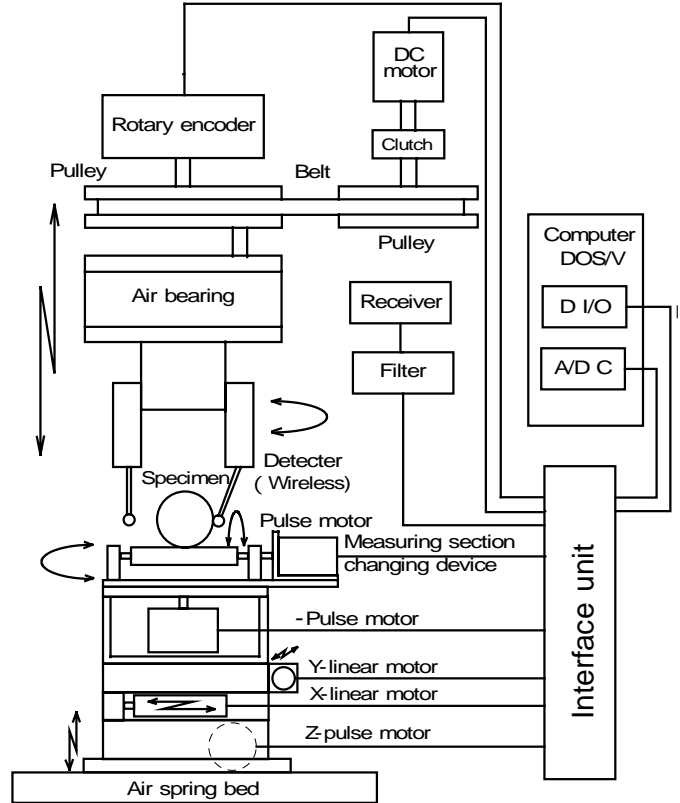


Fig.5 Schematic diagram of the system

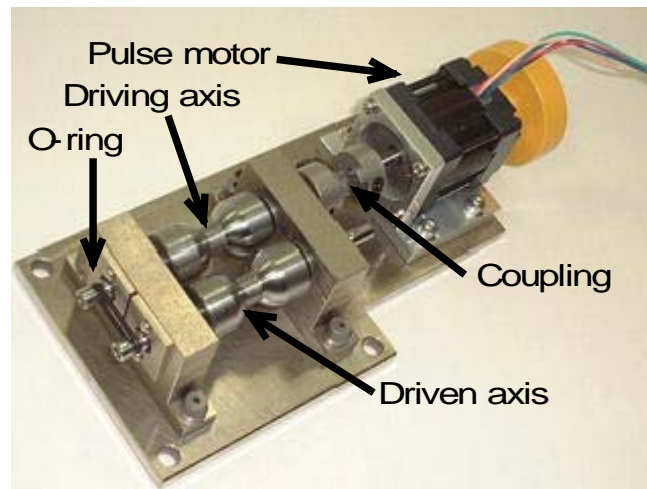


Fig.6 Outview of measuring cross section changing device

Experimental results

(1) Systematic rotational error separation using reversal method

Reversal method can clarify the systematic error and the specimen form error in a certain condition. Fig.7 shows an example of experimental results. Magnitude (peak-to-valley value) of the systematic rotational error is $1.5 \mu\text{m}$. This is considerably large and should be investigated.

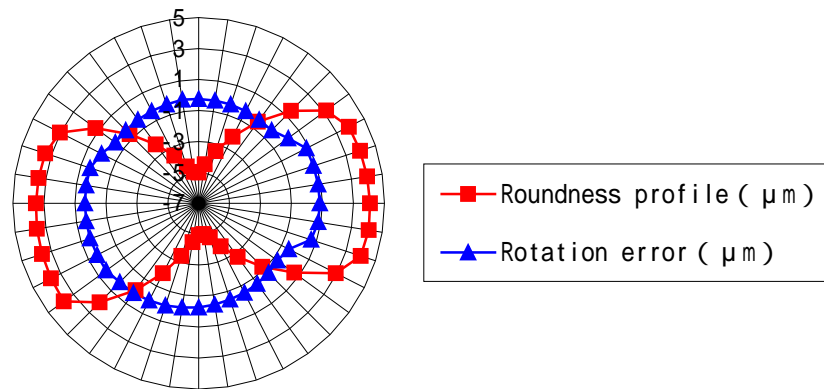


Fig.7 Result of systematic error separation

(2) Searching the position of the maximum diametrical cross section

In order to confirm the appropriateness of the computer control program for searching the position of the maximum diametrical cross section, Fig.8 was drawn. This result shows that searching procedure is completed before the real position of the maximum diametrical cross section is found. The difference between the real position and the recognized position by the computer program is from $70 \mu\text{m}$ to $100 \mu\text{m}$. This is also rather remarkable value and the algorithm should be inspected.

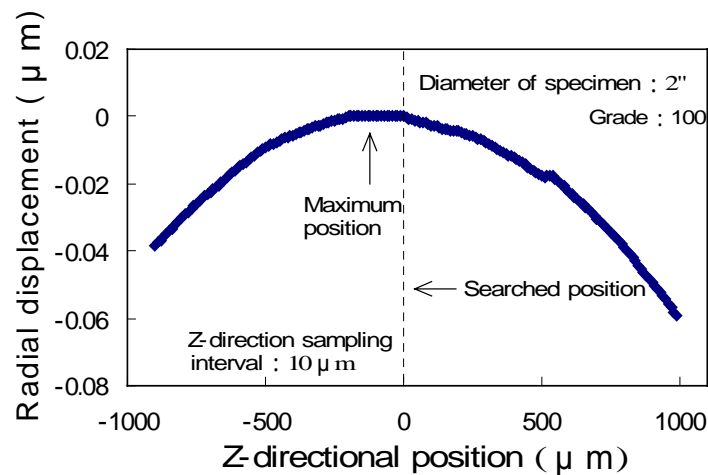


Fig.8 Result of maximum diametric section search

Conclusions

Three-dimensional spherical form measuring system is designed and developed. However, reduction and repeatability of the systematic rotational error should be investigated in near future. Furthermore, searching algorithm for the position of the maximum diametrical cross section should be improved in order to guarantee the three-dimensional positioning accuracy.

References

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- [3] T.Kanada: Estimation of Sphericity by means of Statistical Processing for Roundness of Spherical Parts Precision Engineering, 20-2, (1997), 117-122