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Practical study on performance assessment for freeform measurement using CMMs

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Abstract

Industrial product's shapes have become increasingly complex with the development of multi-axis machining and additive manufacturing technology. A 3D form measurement is used to verify how different the manufactured form is from its designed form. To assess the manufacturing error of the product accurately, 3D measurement uncertainty evaluation is necessary. In one method, the measurement uncertainty is evaluated by measuring a calibrated gauge and evaluating the measurement bias and variation (ISO 15530-3). We developed a gauge used for bias evaluation of complex form measurements, and its calibration method. We report on the practical application of the proposed gauge, as well as the results of bias evaluation for complex forms measured with several tactile CMMs.

Three-dimensional measurement, Calibration, Measurement uncertainty, Freeform

1. Introduction

The planned shapes of industrial product parts are becoming increasingly complex in order to meet the demands for lightening, downsizing, high functionality and integral moulding. These freeform shapes are processed using a variety of techniques, including multi-axis machining, sinter moulding, and additive manufacturing. The difference between the actual and designed shapes must be verified for manufacturing process management and product quality assurance. For verification, it is necessary to measure the freeform shapes with small uncertainty.

To ensure the quality of geometric shaped parts such as circles, cylinders and spheres, the size, position and angle of the product feature must be measured with a caliper, dial gauge and protractor. The radius and centre positions of a geometric shape with a dimension from tens to hundreds of mm can be measured with sub µm–µm uncertainty.

Contrarily, to ensure the quality of complex-shaped parts, complicated form deviations, such as profiles, must be measured using three-dimensional (3D) measuring systems, e.g. coordinate measuring machines (CMMs). However, freeform measurement with sub µm–µm uncertainty is under development.

One of the primary reasons is the error in probe radius correction. Because the probe centre positions are recorded and not the contact positions between a probe and an object, it is necessary to estimate the contact positions using some method. By conventional methods, the measurement error caused by the error in the direction of probe radius correction vectors is estimated to be several µm.

In this research, we develop a freeform measurement method that does not cause the error of the probe radius correction vectors.

2. Development of accurate freeform measurement method

For a conventional 3D freeform shape measurement, two cross sections within a target cross section are measured, and the target cross section profile is estimated using CMM software. Surface meshes are generated using the probe centre positions on the two cross sections, and the direction of the normal vector to each mesh is determined to be the probe radius correction vector. The contact positions of the probe and the object are then estimated [1].

In case of an object with a curvature surface normal to a target cross section, the target cross section is calculated by linearly interpolating the probe centre positions on only two cross sections, resulting in a considerable measurement error.

We can now generate surface meshes from point cloud data of probe centre positions obtained by measuring the multiple cross section area covering the target cross section (Figure 1), determining the direction of the normal vector to each mesh to be the probe radius correction vector and estimating the target cross section profile.

However, when measuring a shape with a significant curvature and high sampling density, the error in the probe centre positions may cause an error in the direction of the probe radius correction vectors. As a result, the corrected positions may be calculated inside the probe or object surface (Figure 2).

In the paper [2], the method without determining normal vectors to be the probe radius correction vectors has been developed. However, the issue of contact positions being calculated inside the probe surface remains unsolved, and recalculation is carried out to eliminate incoherent positions. Furthermore, the method has been validated for measurements of a single target cross section, but not for measurements of more than two cross sections on 3D objects.

In this research, we developed a freeform measuring method with small uncertainty. The main steps are as follows.

- Multiple cross sections are measured.

- The trajectory that the probe surface passes is calculated instead of estimating the probe correction vectors (Figure 3).

Because the contour of the probe trajectory is the surface that the probe is most likely to contact, the region inside the probe trajectory is determined to be a contactless region; therefore, the conventional issue shown in Figure 2 does not occur.

Several methods are suggested for analysing the probe trajectory using point cloud data of probe centre positions. A dilation operation, offset by probe radius from the probe centre positions, can be applied to one of them. The method is theoretically proposed. However, experimental reports are inadequate [3]. Another method is to calculate the distance field from the probe centre position and an isodistance surface with a probe radius distance can be used. Furthermore, convolution of sphere features whose radii are the measured probe radii and whose centres are the measured probe centre positions can be applied.

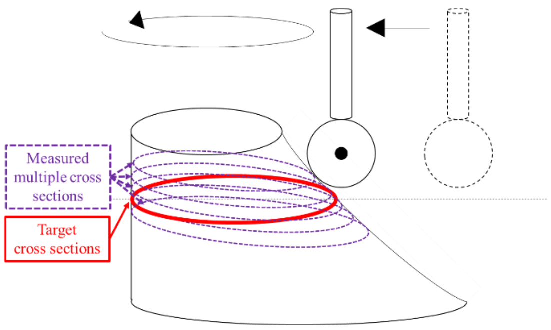

Figure 1. Measurement of multiple cross sections of a freeform shape

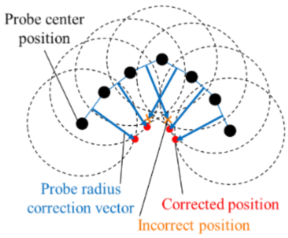

Figure 2. Probe radius correction by estimating probe radius correction vectors

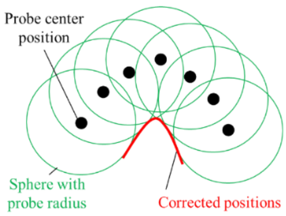

Figure 3. Probe radius correction by calculating the probe trajectory

3. Practical application of the proposed measuring method

We developed a gauge for evaluating the bias of freeform measurement [4,5]. The gauge is designed by dividing the freeform features of actual product shape into geometric features, such as arcs. Figure 4 shows a developed gauge designed for turbine blade inspection. The gauge has an inclined side surface and the cross section is devided into four sections of different curvatures.

We measured 21 cross sections within a target height ± 1.5 mm of the developed gauge with a 5-mm diameter probe. The sampling density was 25 points/mm. The curvature radius of measured surface was 3 mm corresponding to the area indicated by the blue hatch in Figure 4. As shown in Figure 5, the probe radius is corrected corresponding to Figure 3. As shown in Table 1, the measurement uncertainty of profile is estimated to be 1.1 µm. At this conference, we will report the results of bias evaluation for each probe radius correction method.

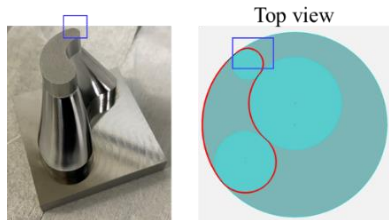

Figure 4. Devepoled gauge for evaluating the bias of freeform measurement

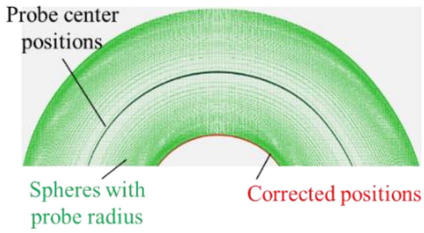

Figure 5. Measurement data of the gauge corresponding to the area indicated by the blue hatch in Figure 4

Table 1. Estimated measurement uncertainty of profile

Uncertainty factor of profile	Uncertainty [µm]
Error of probe center position	0.08
Probe size error	0.20
Probe form error	0.49
Thermal expansion compensation error	0.01
Extended uncertainty (*k* = 2)	**1.1**

4. Summary

The shapes of industrial product parts are becoming increasingly complex, and measuring such freeform shapes with CMMs with small uncertainty is in high demand. Therefore, Accurate probe radius correction is necessary. In this study, we developed a method for measuring 3D freeform shapes with small uncertainty by measuring multiple cross sections and analysing the probe trajectory instead of estimating the probe radius correction vectors. We will report the bias evaluation results for each of the probe radius correction methods.

References

[1] S. Liang, A. Lin, Probe-radius compensation for 3D data points in reverse engineering, Computers in Industry 48, 241-251, 2002

[2] A. Woźniak, J. R. R. Mayer, A robust method for probe tip radius correction in coordinate metrology, Measurement Science and Technology 23, 1-8, 2012

[3] S. Lou, X. Jiang, P. J. Scott, Applications of Morphological Operations in Surface Metrology and Dimensional Metrology 483, 1-12, 2014

[4] M. Watanabe, O. Sato, K. Matsuzaki, Fundamental research on 3D measurement of freeform features, 18th International Conference on Precision Engineering, 2020

[5] M. Watanabe, K. Matsuzaki, O. Sato, Y. Fukuhara, M. Terasawa, Feasibility study of performance assessment gauge for freeform measurement, International Journal of Automation Technology, 6, 15, 2021