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Geometric error measurement with high accuracy by ultra-precision CMM for closed hydrostatic guideways

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Abstract

Hydrostatic guideways motion accuracy was far above the geometric error of guide rails due to the error averaging effect of pressured lubrication film, and hence has various applications in ultra-precision machine tools and measurement instruments. In the practical, the geometric errors of guide rails are difficult to measure particularly the form error, on account of the physical constraints after the assemble process completed. Furthermore, the different or uneven preload of bolts of keeper rail in hydrostatic guideways lead to the geometric errors changed in a local area which will affect the motion accuracy. And common measurement methods were unable to satisfy the requirements in this situation. Therefore, a geometric errors measurement method based on ultra-precision coordinate measuring machine for closed hydrostatic guideways was adopted to measure and evaluate the straightness error and parallelism error of guide rails under two different conditions. In the experiments all bolts preload were 15 Nm and 20 Nm respectively, and the respective geometric errors for four guide rails in vertical direction were measured by contacted scanning method. The parallelism errors for guide rails were calculated by the least square method. The analysed results can provide basic data for the uneven preload method research when considering the fluid-structure interaction and the effect of physical boundary conditions in hydrostatic guideways. Then the measurement uncertainty analyses were conducted for the measuring method. The research has the reference to verify the engineering applications and provides guidance for the quantitative analysis of error averaging and precision design of hydrostatic guideways.

Keywords: Geometric error, measurement, form error, closed hydrostatic guideways

1. Introduction

Hydrostatic guideways have various applications in ultraprecision machining machines due to its high precision capability compared with conventional rolling guideway [1]. Geometric error of guide rails in hydrostatic guideways are directly determining the motion accuracy, and it increased as the guide rails length increased [2]. So, getting high accuracy is not easy although the error averaging effect existed for gantry type machine tools with long stroke. It is well documented that the functional performance of hydrostatic guideways subject to guide rails is strongly affected by the resulting geometric errors. Because of this, the geometric error of guide rails should be measured and evaluated, for the quantitative analysis of error averaging and precision design of hydrostatic guideways.

2. Geometric error measurement by CMM

The geometric errors of the closed hydrostatic guideways, as shown in Figure 1, are inconvenient to measure due to the physical constraints of keeper and limited measurement space. In this study, the guide rails geometric errors were measured by a metering CMM (Leitz Infinity 12.10.7) with measurement error 0.3 + L/1000 µm (L is the measurement range) over the whole measuring span. The measuring environmental conditions were as follows: room temperature was controlled within 20±0.2 °C, the humidity was 45 %. The guide rails are made of granite with length 600 mm, and the measured length is 580 mm with interval 10 mm. The geometric errors of the two upper surfaces and two lower surfaces were measured three times in the vertical direction by contacted scanning method under two different keeper bolts preload, the averaged values were employed to evaluate the guide rails straightness errors and parallelism errors.

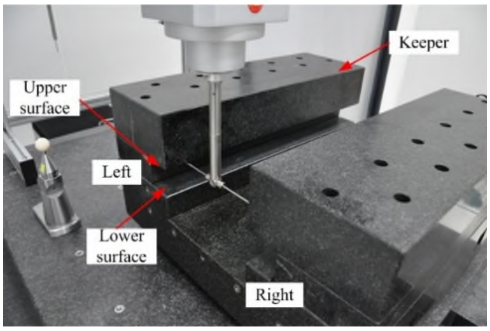

Figure 1. Guide rails geometric error measurement

3. Geometric error evaluation

3.1. Bolts preload 15 Nm

The straightness errors of left and right guide rails of lower surface are 1.4 µm and 2.0 µm, respectively, which calculated by the least square method. For the upper surface, the corresponding values are 3.6 µm and 5.8 µm. For the parallelism error evaluation, the lower surface act as a reference plane (two lines were measured), as shown in

Figure 2, and the value are 5.9 µm and 6.8 µm for the left and right two guide rails, respectively.

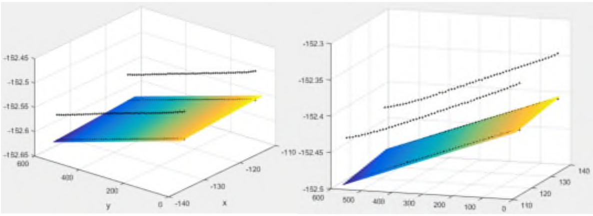

Figure 2(a). Parallelism error of left guide rails (15 Nm) **Figure** 2(b). Parallelism error of right guide rails (15 Nm)

The four lines on the left and right lower surfaces are used for fitting the reference plane by least square method, and the parallelism error between the whole lower surface and upper surface in the closed hydrostatic guideways is 8.6 µm, as shown in Figure 3.

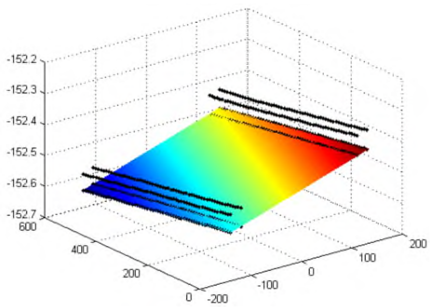

Figure 3. Parallelism error between upper and lower surfaces (15 Nm)

3.2. Bolts preload 20 Nm

The left and right lower surfaces geometric errors have not changed when the keeper bolts preload changed. The straightness errors of left and right guide rails of upper surface are 2.8 µm and 5.7 µm respectively when the keeper bolts preload is 20 Nm. The values have slight difference compared with the aforementioned experiment. In this situation, as shown in Figure 4, the parallelism error for the left two guide rails and right two guide rails are 5.6 µm and 7.4 µm, respectively. The right upper guide rail has relative large deformation which induced the parallelism error increased. And the resulting parallelism error between the whole upper and lower surface is 9.3 µm, as shown in Figure 5.

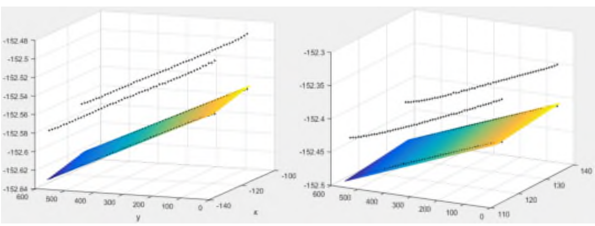

Figure 4(a). Parallelism error of left guide rails (20 Nm) **Figure** 4(b). Parallelism error of right guide rails (20 Nm)

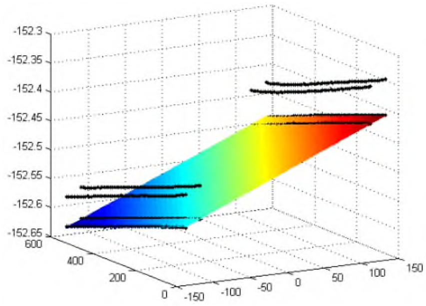

Figure 5. Parallelism error (20 Nm)

4. Measurement uncertainty analysis

The measurement uncertainty mainly results from CMM and measurement environment, and so on [3]. The significant uncertainty contributors include repeatability, indication error, dirt and hysteresis of CMM. The repeatability study has been conducted and the uncertainty component u_1 is 0.025 µm. The uncertainty component u_2 from the indication error is 0.173 µm, when a normal distribution is assumed. The uncertainty component u_3 from the dirt and hysteresis of CMM is estimated as 0.1 µm. Above components are considered as uncorrelated, the standard uncertainty of measured point is calculated by the formula

$$u_0 = \sqrt{u_1^2 + u_2^2 + u_3^2} = \sqrt{0.025^2 + 0.173^2 + 0.1^2} \approx 0.201\ \mu\text{m}$$

5. Conclusions

The geometric error measurement by ultra-precision CMM for closed hydrostatic guideways was conducted, and the measurement uncertainty was analysed in this research. The straightness errors of guide rails and parallelism errors between lower and upper are evaluated. In the future, the sampling strategy will be researched to optimize the geometric error evaluation. Also, the motion error will be studied for quantitative analysis of error averaging in hydrostatic guideways.

Acknowledgements

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