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Geometry error precise measurement based rotation accuracy prediction method for hydrostatic rotary table

Jun Zha[1,2], Hangcheng Zhang[1], Yipeng Li[1], Yaolong Chen[1,3], Kejia Liu[1,2]

[1]*School of Mechanical Engineering, Xi'an Jiaotong University, Xianning West Road 28, Xi'an, Shaanxi, China*
[2]*Shenzhen Research School, Xi'an Jiaotong University, Hi-Tech Zone, Shenzhen, China*
[3]*State Key Laboratory of Manufacturing System Engineering, Xi'an Jiaotong University, Xianning West Road 28, Xi'an, Shaanxi, China*

Jun_zha@xjtu.edu.cn

Abstract
Hydrostatic rotary tables with high rotation accuracy characteristics have various applications in ultra-precision machining centers. However, effects of geometry error on rotation accuracy are not clearly explained due to the difficult of measurement and evaluation of them, and this leads to the running results unpredictability. In this study, rotation accuracy predition method for hydrostatic rotary table was proposed through the evaluation of roundness error of mandrel and parallelism error between the two thrust plates by Ultra-precision CMM. Firstly, the lower thrust plate and rotation mandrel were assemble together for the thrust bearing, and the mandrel axis locality 1 and perpendicularity error between them were evaluated. Secondly, assemble the upper thrust plate and disassemble the lower thrust plate and rotate the assemblies 180 degree for repeat the abovementioned measuring process to obtained the axis locality 2 and perpendicularity error. Followed by splicing the axis locality 1 and 2 in space for evaluate the geometry error of the thrust bearing. Thirdly, the geometry error of bearing bush, especially roundness error, were measured by ultra-precision coordinate measuring machine. Wherein, the roundness errors of mandrel and bearing bush at different cross-sections were evaluated by least square method. Finally, the averaging effect was analysed quantitatively by the validation of the measured geometry error and the previously reported rotation accuracy results. The results indicate the geometry error precise measurement based prediction method to be an effective approach to guide the design and assemble of hydrostatic rotary tables.

Keywords: hydrostatic rotary table, geometry error, error evaluation, rotation accuracy, averaging effect

1. Introduction

Rotation accuracy is the key point to describe the performance of hydrostatic rotary table which have various applications in ultra-precision machining centers. Its mechanical structure is made up primarily of thrust plates, mandrel and bearing bush except motor and encoder. Wherein, several manufacturing errors of mechanical structure have negative effect on the radial error motion [1]. Also, the axial rotation accuracy is largely pinned on prependicularity and parallelism error, and the assembly position is important as well [2]. Due to the error averaging effect existed[3], so that design guidelines following those traditional stardards for roller bearing supported rotary table have to be updated anyway. For example, the number of feedholes in bearing bush should be designed and optimized for improving the error motion by new model [4]. However, the definition of mechanical structure geometric tolerances is of paramount importance in the design stage involving rotation accuracy of hydrostatic rotary table.

Error averaging effect had conducted in previous research by studying the interrelation of motion error and mechanical parts geometry errors in hydrostatic rotary table and spindle. However, the basic data acquisition of geometry errors still has shortcomings, particularly the rotor system which thrust plates and manurel included. So hence one can see that the geometry error precise measurement and evaluation is especially important. For the hydrostatic rotary table with bi-directional thrust bearing, the interference will happened when the Ultra-precision CMM was adopted. Therefore, it is necessary to put forward a new measurement and evaluation method for geometry errors in hydrostatis rotary table.

The research presented in this paper aims at the development of measurement method to determine the roundness error of mandrel and parallelism error between the two thrust plates by Ultra-precision CMM for further rotation accuracy prediction in hydrostatic rotary table.

2. Geometry error measurement method

The measured geometry error of the mechanical structure in hydrostatic rotary table consist of the roundness of mandrel and bearing bush, flatness of thrust plates, parallelism between two thrust plates, prependicularity between thrust plate and mandrel. The rotor system consists of upper thrust plate, lower thrust plate and rotor. The schematic of the rotor system in hydrostatic rotary table was shown in Figure 1. In Figure 2, the physical photograph of two thrust plates and mandrel was given. The upper thrust plate in hydrostatic rotary table was used for supporting the machined parts, while the lower one is connected with the torque motor and encoder.

In this research the geometry errors were measured by a metering CMM (Leitz Infinity 12.10.7) with measurement error 0.3 + L/1000 μm (L is the measurement length) in entire work space. The measuring environmental conditions were as follows: room temperature was controlled within 20±0.2 °C, the humidity was 45 %. The measured components are made of 40Cr steel and the main structure parameters of the rotor system were shown in Table 1. Three times measurement for each measurement sites were conducted by continuous contact scanning or non-continuous point contacts method, the averaged values were employed to evaluate the geometry errors.

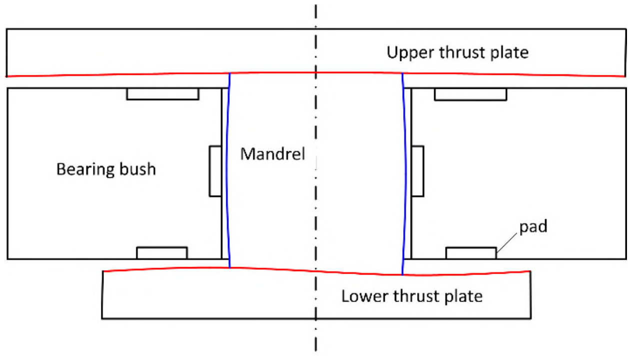

Figure 1. Schematic of the rotor-system in hydrostatic rotary table

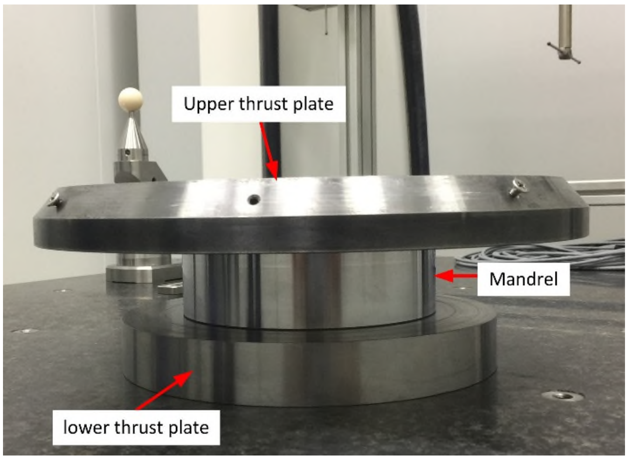

Figure 2. Thrust plates and mandrel in hydrostatic rotary table

Table 1 Main structure paremeters of rotor system in hydrostatic rotary table

Component	Value
Diameter of mandrel	150 mm
Inner diameter of bearing bush	150.04 mm
Diameter of upper thrust plate	310 mm
Diameter of lower thrust plate	220 mm

2.1. Bidirectional thrust bearing

The bidirectional thrust bearing was divided into two sub-rotor system for further measuring due to the structure interference. Where the lower and upper thrust plates are installed with the mandrel in two different measurement processes, respectively, as Figure 3 and 4 shown. The sub-rotor system 1 (lower thrust plate and mandrel) was fixed on the machine worktable by an anxiliary tool. Three sites (l1, l2 and l3) were selected for coordinate values acquisition further for flatness error evaluation by continuous contact scanning method. Also, for roundness error evaluation three sites (m1, m2 and m3) were selected on the mandrel. The flatness error of the lower thrust plate and roundness error of the mandrel were calculated by least square method based on the profile data. In addition, in order to ensure consistency of the mounting position of the two thrust paltes and mandrel, the corresponding position of all bolts were recorded to guarantee the validity of the calculated geometry errors.

In Figure 4, the sub-rotor system 2 (upper thrust plate and mandrel) was fixed on the machine worktable by hot melt adhesive to minish the disadvantage of installation deformation. Three sites (u1, u2 and u3) were selected on upper thrust palte and three sites (m4, m5 and m6) were selected on mandrel for flatness and roundness measurement, respectively.

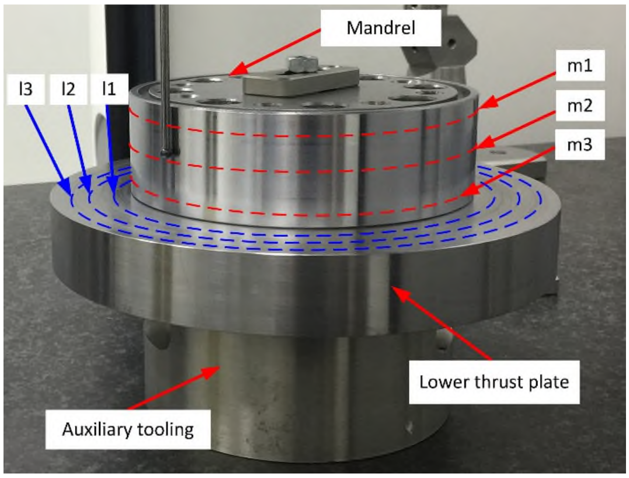

Figure 3. Geometry error measurement of lower thrust plate and mandrel

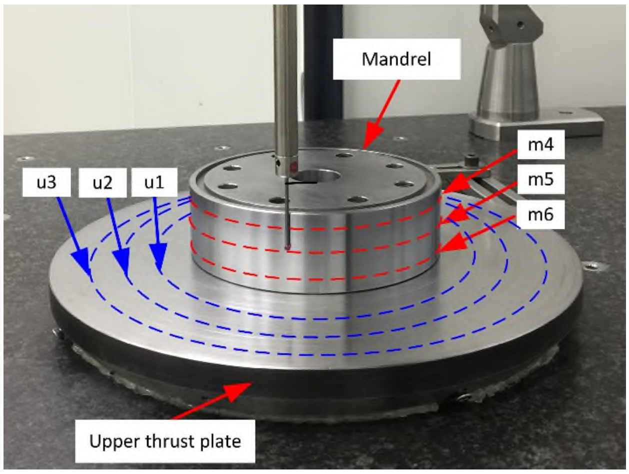

Figure 4. Geometry error measurement of upper thrust plate and mandrel

2.2. Journal bearing

Roundness error of the mandrel can be evaluated according to the measured coordinate data (combination of m1, m2 and m3, or m4, m5 and m6) of the aforementioned measurement processes. Taking into account the impact of oil-returning slots on bearing bush, a non-continuous point contacts method was employed for coordinate date acquisition of the upper and lower lands, as shown in Figure 5.

3. Geometry error measurement results and discussion

After the measurement conducted as the Figure 3 shown, the evaluated flateness of lower thrust plate was given in Figure 6. Subsequently, the mandrel axis locality of sub-rotor system 1 can be fitted. Repeat the whole process of the error calculation, the flatness of upper thrust plate (as shown in Figure 7) and mandrel axis locality of sub-rotor system 2 (according the measured data of m4, m5 and m6) can be draw.The calculated flatness error of lower and upper thrust plates were 8.6μm and 6.1μm, respectively. Set the mandrel axis locality as the datum, the prependicularity error in sub-rotor system 1 and 2 were

21.0μm and 14.0μm, respectively. Also, it can be calculated that the roundness of mandrel on three different cross-sections (m1, m2 and m3) were 2, 2.1 and 2.2 μm, respectively. The roundness error of bearing bush in cross-section b1 and b2 are 7.2um and 5.9um, respectively.

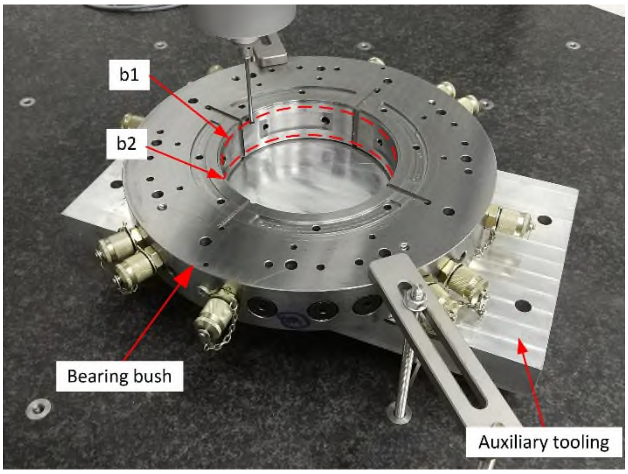

Figure 5. Roundness error measurement of bearing bush

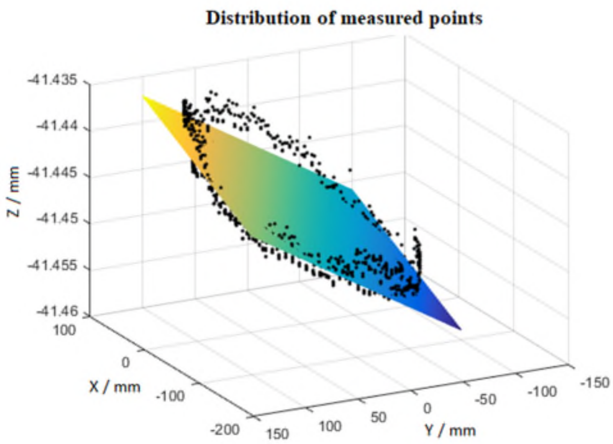

Figure 6. Flatness error of lower thrust plate

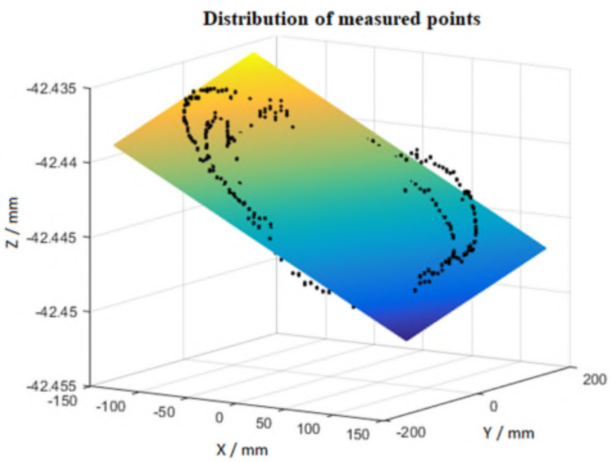

Figure 7. Flatness error of upper thrust plate

In order to obtain the parallelism error between the upper and lower thrust plates, it is essential to accurately set the two sub-rotor-system on the same datum according to the mandrel axis locality. Since the mandrel axis of the two sub-rotor systems do not coincide with each other, the angle between their direction vectors existed. To make the direction vectors parallel to each other, which means splicing the axis locality 1 and 2 together, so it is necessary to rotate the coordinates of the profile data of one sub-rotor system to specific angle. The result indicates that parallelism error between two thrust plates was 28 μm, as shown in Figure 8.

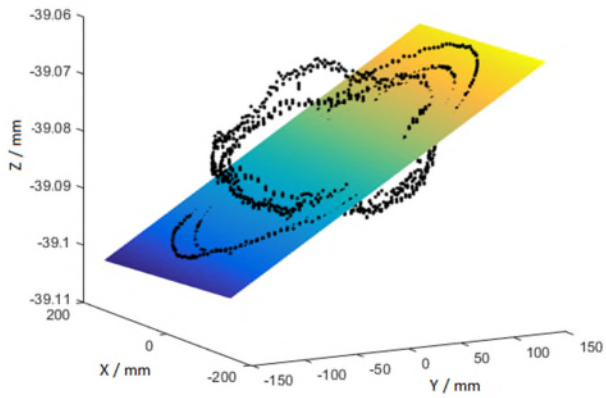

Figure 8. Parallelism error between the two thrust plates

Numerical experiment result shows that on the basis of the existing installation position, rotate the upper thrust plate 228° anticlockwise the optimal parallelism error obtained. The result indicates that the parallelism error between the two thrust plates can be optimized to 12 μm, as shown in Figure 9

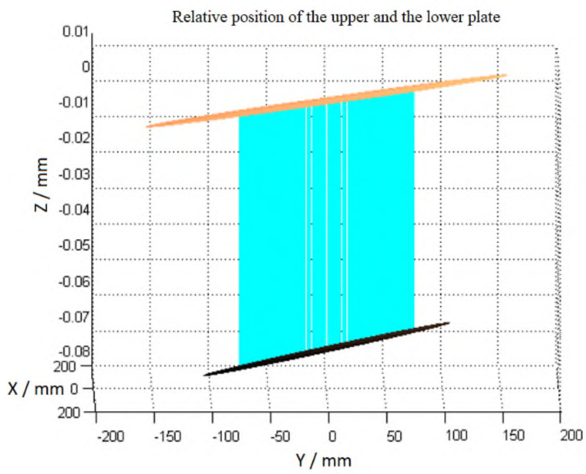

Figure 9. Results of geometric error

Error averaging coefficient was defined as the ratio of rotation accuracy to geometry error. Previous research reported that the axial rotation accuracy was 0.07 μm [2], which indicated the coefficient can be reached to more than 0.058 only considering the parallelism error in hydrostatic rotary table. In turn, the rotation accuracy can be predicted after the geometry error of assembled components were measured and evaluated. Measured radial rotation accuracy will be published later and the error averaging coefficient in journal bearing will be analyzed further.

4. Conclusions and future works

A ultra-precison CMM based measurement method to determine the geometry error of components for further rotation accuracy prediction in hydrostatic rotary table was proposed in this research. The measurement and evaluation of parallelism error between two thrust paltes was addressed by splicing the axis locality of two sub-rotor systems. Rotation accuracy can be predicted by comparing the measured geometry error and axial rotation accuracy, and hence guide the design and assemble of hydrostatic rotary tables. Future work will be focus on the effect of combination of flatness error, prependicularity error and parallelism error on axial rotation accuracy in closed hydrostatic rotary table.

Acknowledgements

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