Characteristics of bearing stiffness of a spindle with high stiffness water hydrostatic thrust bearing for ultra-precision machine tool

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Abstract

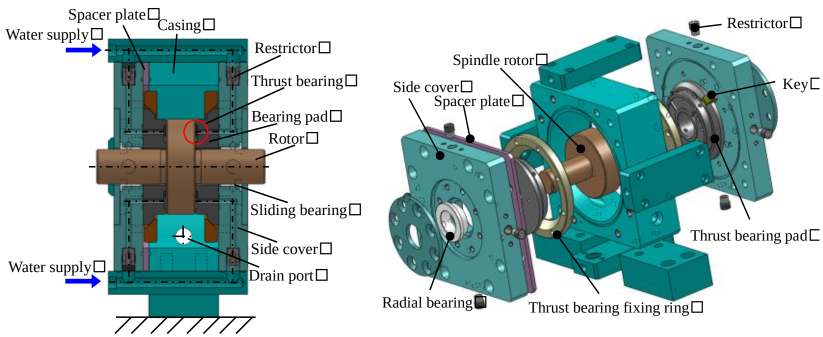
A spindle supported by water hydrostatic thrust bearings has been designed for ultra-precision machine tools. In this spindle design, we particularly aimed to design a water hydrostatic thrust bearing with higher bearing stiffness. The present paper describes the feature of the developed spindle and the water hydrostatic thrust bearing. The bearing stiffness of the spindle is then investigated theoretically and experimentally. The results indicate that the influence of the deformation of the spindle body due to the water pressure reduces the bearing stiffness. The experimental and simulation results show that the required bearing stiffness of 1 kN/μm can be obtained by designing smaller gap size by considering the influence of the deformation of the spindle.

1. Introduction

A spindle supported by water hydrostatic thrust bearings was designed[1]. An important application of the spindle is the spindle for the ultra-precision machine tool. The diamond turning and grinding of the high-hardness materials become increasingly important in the industries producing various moulds. In addition, the desired machining accuracy currently reaches several tens of nanometers or less. In order to achieve the precise machining accuracy for the high-hardness materials, the high bearing stiffness of the spindle is absolutely indispensable. A design objective of the spindle supported by the water hydrostatic thrust bearing was to achieve the high bearing stiffness of 1 kN/ μm. The characteristics of the designed bearing stiffness and required flow rate were considered theoretically. The present paper investigates the stiffness of the water hydrostatic thrust bearing of the spindle via calculations and experiments. In addition, the influence of the water pressure on the spindle deformation and the stiffness are considered via simulation.

2. Designed and developed spindle with water hydrostatic thrust bearings

The structure of the spindle is depicted in Fig. 1. The spindle is equipped with water hydrostatic thrust bearings. All the parts of the spindle except for the thrust bearing pads and sliding journal bearings are made of the stainless steel. As shown in Fig. 1, the rotor is placed between two thrust-bearing pads that are fixed with the side covers. The spindle was designed so that the bearing gap and restrictors that determine the bearing stiffness can be changed. Accordingly, the critical dimensions such as the bearing gap and the size of restrictors affecting on the bearing stiffness can be investigated experimentally. Bearing restrictors of the spindle were carefully designed[2] and fabricated. The developed spindle is depicted in Fig. 2.



(a) Cross section of spindle (b) Exploded view

Figure 1: Structure of designed spindle with water hydrostatic thrust bearings

Figure 2: Developed spindle

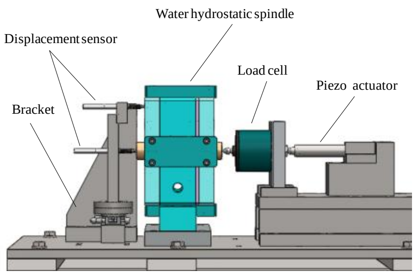


Figure 3: Experimental rig

3. Stiffness of water hydrostatic thrust bearing

The bearing stiffness of the water hydrostatic thrust bearing was measured. A schematic of the experimental rig is shown in Fig. 3. The external force was applied to the rotor of the spindle by a piezo actuator to measure the bearing stiffness. The force was measured by a load-cell set between the rotor and the piezo actuator. The deformation of the spindle body due to the applied force was measured by a displacement sensor. Then the influence of the deformation was compensated after the experiments in order to introduce actual displacement of the rotor. The bearing stiffness was then obtained by the applied forces divided by the rotor displacement. The measured bearing stiffness is represented in Fig. 4 and compared with the prediction by a theoretical model. As indicated in Fig. 4, the stiffness measured is relatively lower than that of the prediction. The desired bearing stiffness of 1 kN/μm can be obtained with the supply pressure of 2 MPa. However, the experiments were carried out with the supply pressure of 1 MPa due to the limitation of the pump performance.

In addition to the deformation of the spindle body due to the applied forces, the influence of water pressure on the spindle deformation is also investigated via simulation studies as shown in Fig. 5. The simulation study represents the deformation of the spindle body due to the water pressure is remarkable. The maximum deformation was observed for various supply water pressure as shown in Fig. 6. It is now verified that the spindle deformation becomes about 3 μm when the supply pressure is 2 MPa. The maximum deformation is observed at side covers near the center axis of the spindle. The deformation of the side covers increases bearing gap since the bearing pads are fixed on the side covers. The influence of the deformation due to the water pressure on the bearing stiffness was thus studied via simulation as shown in Fig. 4 and Fig. 5. The result indicates that the bearing stiffness decreases by 300 N/ μm if the supply pressure is 2 MPa. This implies that an effective

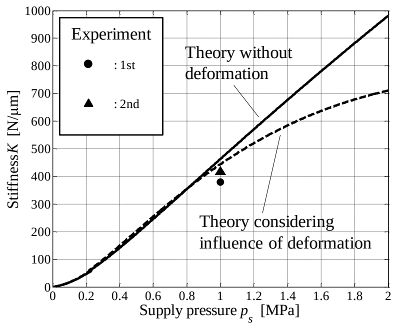


Figure 4: Bearing stiffness

modification of the spindle design must be needed in order to achieve the objective bearing stiffness of 1 kN/ μm. Specifically, an initial gap size has to be designed smaller than that of the initially designed gap so that the desired gap can be made as a result of the deformation due to the water pressure.

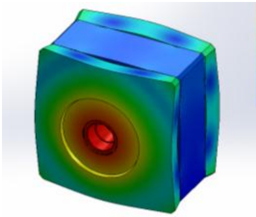


Figure 5: Deformed spindle body

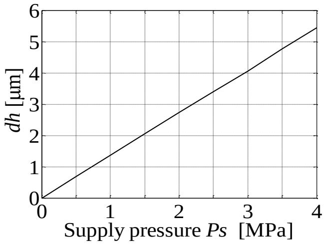


Figure 6: Maximum deformation

4. Summary

The stiffness of the water hydrostatic bearings of the developed spindle was measured. The stiffness measured was agreed with the prediction. However, the simulation results indicate that the water pressure deforms the spindle body, decreasing the bearing stiffness, if the supply pressure is increased. Accordingly, the resultant bearing stiffness becomes smaller than that of the design due to the deformation. It is considered that a possible countermeasure is to give smaller gap so that the desired gap can be made by the spindle deformation due to the water pressure. The validity of the countermeasure will be tested in the future works.

Acknowledgement

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