An Active Aerodynamic Bearing for Ultraprecision Machining

H. Mizumoto[1], Y. Yabuta[1], S. Arii[1], Y.Tazoe[2], S. Yokouchi[2]
[1]*Tottori University, Koyama, Tottori, JAPAN*
[2]*Nachi-Fujikoshi, Nachi-Fujikoshi, Namerikawa, Toyama, JAPAN*

mizu@ike.tottori-u.ac.jp

Abstract

A high speed air-bearing tool spindle is proposed for attaining suitable cutting speed for small diameter of cutting and grinding tools. Increase in the spindle vibration at high rotational speed is suppressed by an active aerodynamic bearing incorporated into the tool spindle. For generating aerodynamic damping force, the wedge angle on the aerodynamic bearing surface is controlled by piezoelectric actuators. The effect of the active control of the aerodynamic bearing on the rotational accuracy of the tool spindle is analysed. Experimental result shows that the amplitude of the spindle vibration can be suppressed to be 0.1μm at the rotational speed of 50,000min^{-1}. The active aerodynamic bearing can also control the spindle position with the resolution of 1nm.

1 Introduction

Recently, small diameter of end-mills and grinding wheels are often used in the ultraprecision machining, and demand for a high speed tool spindle with low vibration is ever increasing. The air-bearing spindle is suitable for such tool spindle because of its high rotational accuracy. However, the spindle vibration inevitably increases as the rotational speed increases. For suppressing the spindle vibration, we proposed an active aerostatic bearing system employing active inherent restrictors, and the effect of the active control was shown at the rotational speed lower than 100min^{-1}[1]. For suppressing the spindle vibration at higher rotational speed, we proposed to employ an active aerodynamic bearing [2].

As shown in Figure 1, the proposed active aerodynamic bearing is incorporated into the top of an air-bearing spindle supported by ordinary aerostatic thrust and radial bearings. It is expected that the spindle vibration in the high speed range can be suppressed by the active aerodynamic bearing because the load carrying capacity of the aerodynamic bearing increases as the rotational speed increases. In the last euspen conference, we reported the effect of the active control at the rotational speed of 12,000min^{-1}[3]. In the present paper, the performance of this hybrid air-bearing spindle in the higher rotational speed is analyzed; maximum rotational speed to be tested is 50,000min^{-1}. It is also shown that the positioning of the spindle with nanometer resolution can be performed by the feedback controlling of the active aerodynamic bearing.

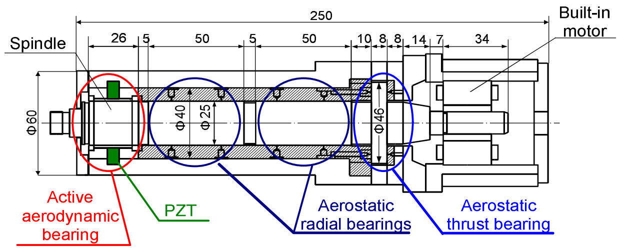

Figure1: Hybrid air-bearing spindle employing aerostatic radial /thrust bearings and active aerodynamic radial bearing

2 Control of active aerodynamic bearing

Front view of the active aerodynamic radial bearing and its feedback control system is shown in Figure 2. On the circular bearing surface, there are four elastic regions. According to the spindle vibration detected by a displacement sensor, a microcomputer (PC) controls the deformation of the bearing surface by using PZT embedded behind the elastic region of the bearing surface. Then a wedge region is formed on the bearing surface and the aerodynamic force is generated. Thus, the aerodynamic force on each elastic region can be controlled for suppressing the spindle vibration. When the spindle approaches to one of the elastic region, the wedge angle of this region is increased and the spindle is pushed back by the generated aerodynamic force.

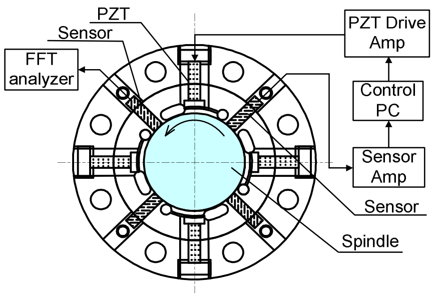

Figure2: Feedback control system for active aerodynamic bearing

3 Effect of active control on rotatonal accuracy of spindle

Figure 3 shows the effect of feedback control of the aerodynamic bearing on the spindle vibration, where the rotational speed is up to 32,200min^{-1}(520Hz). Without active control (on the left), the amplitude of the spindle vibration is larger than 0.2μm. Under control (on the right), the amplitude of the vibration can be decreased to as large as 0.1μm when the rotational speed is lower than 17,700min^{-1}(295Hz). However, the effect of the active control can not be observed at higher rotational speed.

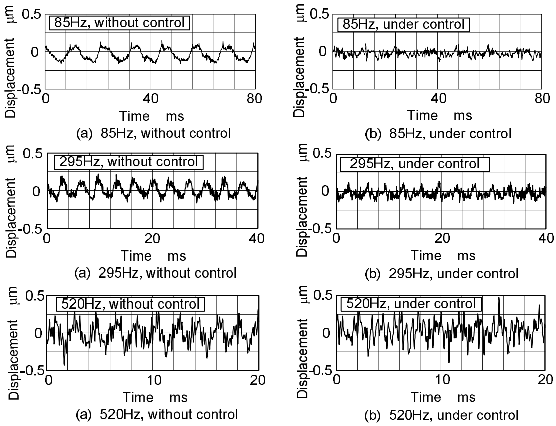

Figure 3: Effect of feedback control on spindle

Figure 4 shows the summarized effect of the feedback control on the spindle vibration; ordinate indicates the amplitude of the vibration at the dominant frequency synchronized with the rotational speed. It is shown that the active control can not be effective for the rotational speed higher than 400Hz. This is because the delay in the PZT control owing to the finite signal processing time in the control PC.

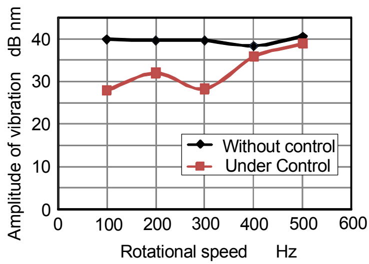

Figure 4: Summarized effect of feedback control

For improving the delay in the control, the feedforward control is effective. A sinusoidal signal synchronized with the rotational speed is supplied to the PZT. Then, as shown in Figure 5, the spindle vibration at the rotational speed of

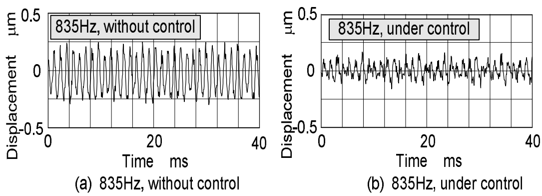

Figure 5: Effect of feedforward control on spindle vibration

50,000min^{-1}(835Hz) can effectively be suppressed.

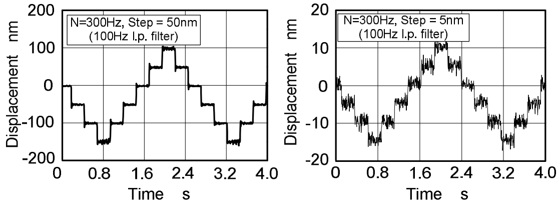

Figure 6: Positioning using active aerodynamic bearing

4 Step positioning

Figure 6 shows the step positioning of the spindle by the feedback control of the aerodynamic bearing at the rotational speed of 18,000min^{-1}(300Hz), where lowpass filter is used for eliminating the dominant vibration at the rotational speed. The stroke of the positioning is larger than 200nm and the positioning resolution is in the order of nanometer. Such positioning function can be utilized in the micro cutting as the FTS.

5 Conclusions

The results of the experiments show that the proposed hybrid air-bearing spindle is effective for suppressing the spindle vibration up to the rotational speed of 50,000min^{-1}(835Hz). Such performance is enough for small cutting tools of several milimeters in diameter. For the grinding tools of small diameter, higher rotational speed is needed. Final goal of our research is to suppress the spindle vibration less than 0.1μm at the rotational speed of 120,000min^{-1}(2kHz).

References:

[1] H.Mizumoto, et al. : "Rotational Accuracy and Positioning Resolution of an Air-Bearing Spindle with Active Inherent Restrictor," Proceedings of 10th International Conference on Production Engineering, Vol.1 (2001) pp.709-713.

[2] H. Mizumoto, et al., "A High-speed Air Spindle employing Active Aerodynamic Bearing System," Proc. of 10th Anniversary International Conference of the euspen, Vol.1 (2008) pp.394-397.

[3] H. Mizumoto, et al., "An Active Aerodynamic Bearing for Ultraprecisio Machining," Proc. of 9th International Conference of the euspen, Vol.1 (2009) pp.256-259