An active bearing rotary unit with magnetic actuators for rotation error compensation

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Abstract

In this paper, we introduce an air bearing rotary unit with servo motor for precision control of rotation. For minimizing radial and axial rotational errors caused by manufacturing tolerances and process loads, a magnetic actuator for compensation of shaft position was designed. This magnetic actuator is designed with permanent magnets generating axial and redial bias fluxes with axially formulating flux paths. The bias forces can be adjusted by four electromagnets with radial poles and coils generating radial magnetic fluxes. By combinations of these PM (permanent magnetic) and EM (Electromagnetic) fluxes, the radial and axial forces are possible to control.

The spindle with air bearings was designed to have about 1 micrometer of repeatable rotational errors, so the actuator was designed and analyzed for compensating 1~2 microns of the radial and axial displacement. For the cost and simplicity of the system, no direct measurement method was implemented for rotational error compensation, but feedforward method for the repeatable compensation is applied. The repeatable rotational errors were measured with precision capacitive sensors and modeled as functions of the rotational angle of the shaft. The design, analysis results and experimental results for the prototype are described in this paper.

1 Introduction

Air bearings have been successively implemented ultra-precision machines as their frictionless characteristics and low motion errors by averaging effect. However, to improve motion errors or rotational errors, there could be some possible methods. First common method is passive re-machining of bearing guides or bearing surfaces. This gives permanent compensation but requires time and cost consuming precision machining process. Also active method can considered such as feedback control with actuators, or feedforward method. As the rotational errors are usually very small amount such as sub-micron level, precision measurement systems are required for feedback control scheme. So, the feedforward method without built-in sensors can be considered considering motion errors are repeatable for the air bearing system.[1] Hence, we proposed a rotary unit using air bearing with electromagnetic actuator for compensation of rotation error in feedfoward method.

2 Design of the active rotary unit

2.1 Design concept

Fig. 1 shows the proposed air bearing rotary table with a 3-DOF magnetic actuator. To control the radial and axial displacement of the rotary motion, the magnetic actuator is located in front of the air-bearing servo spindle. Total size of the unit is 140 mm of diameter and 260 mm of length. Porous pads made with carbon material were used for both radial and axial air bearings. A slotless DC servo motor (S-76, Aerotech) and an optical rotary encoder with 0.1 arcsec were applied for the to control angular position precisely.

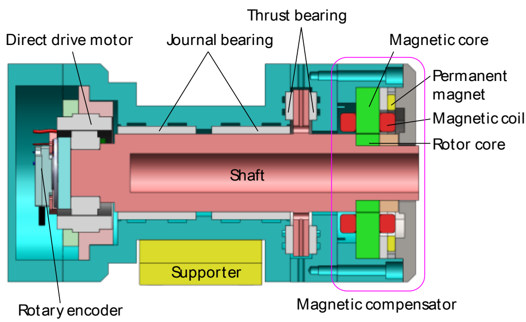


Figure 1: Proposed air bearing rotary unit with active magnetic actuator

2.2 3-DOF magnetic actuator for active compensation

The 3-DOF magnetic actuator was designed as Fig. 2 with combination of permanent magnets and electromagnets. The magnetic flux by permanent magnets flows in axial direction generating constant attraction forces for radial and axial direction. The four electromagnetic coils change forces for radial and also axial forces. The forces can be calculated from the magnetic circuit as Fig. 2 and designed as specifications of PM and electromagnets. The maximum forces were designed as 55 N for radial and 120

N for axial. The current gain for the compensation forces were designed as 57.9 N/A for radial and 36.7 N/A for axial direction.

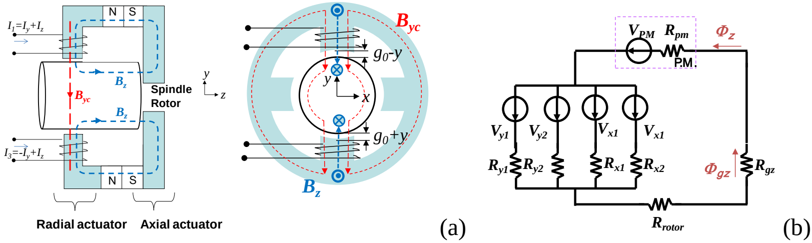


Figure 2: Magnetic actuator for 3-DOF forces(a) and magnetic circuit(b).

3 Compensation analysis

As the clearance for the magnetic actuator is 10 times larger than air bearing clearance, relationship between control current and displacement can be assumes as linear. Fig. 3 shows an example of motion error compensation by feedforward compensation. The calculated compensation current for four coils can be applied directly to the actuator.

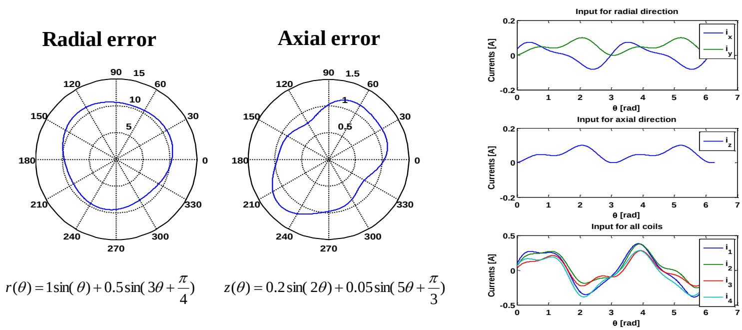
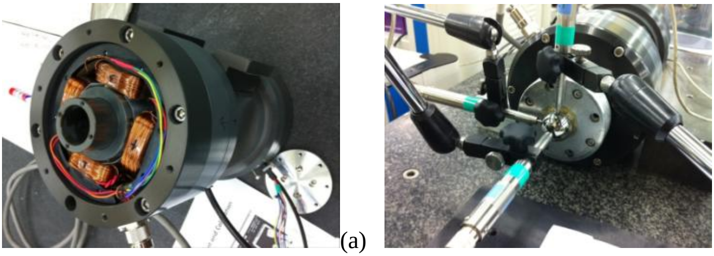


Figure 3: Example for rotational motion error compensation.

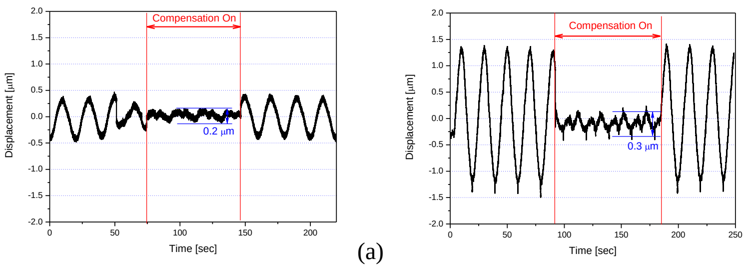
4 Experimental results

The designed prototype was manufactured as Fig. 4(a) and measured runout for radial and axial direction using capacitive sensors (ADE) as Fig. 4(b). The measured runouts including set-up error of the master ball were about 2.2 μm for radial and 1.0 μm for axial direction. The repeatable runout was modeled as a function of rotational angle as summation of sinusoidal functions up to 5 main frequency components, and compensation inputs were calculated and inserted to the magnetic actuator by the PLC program of the controller (UMAC, Delta-Tau). It can be noticed that the runouts were reduced to 0.2~0.3 μm peak-to-peak with feedforward compensation. Considering this results is applied for the runout with larger displacement, some components were remained because of non-linear effect of the acutator. However, this shows that proposed method can be used for reducing rotational errors of air bearing rotary units.



(a) (b)

Figure 4: Manufactured prototype (a) and set-up for runout measurement (b)



(a) (b)

Figure 5: Feedforward compensation results for radial(a) and axial(b) runout.

5 Conclusion and future works

In this paper, we proposed a air bearing rotary unit with magnetic actuator for reducing rotational errors. From experimental results of feedforward compensation of runout, this proposed system can be regarded as valid method. Further research for the non-linearity of the actuator and control method will be performed as future work.

Reference:

[1] Ro, S.-K., Kim, S., Kwak, Y. and Park, C.-H. A linear air bearing stage with active magnetic preloads for ultraprecise straight motion, Prec. Eng., 34, (2010), 186~194