A Hybrid Actuator-driven Compact Tilting Motion Table System for Multi-axis Ultraprecision Machine Tool

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Abstract

This paper presents a newly proposed tilting table system for multi-axis controlled ultra-precision machine tools. The proposed system has a wide square tilting motion table. Tilting motion of the table is driven by a hybrid actuator which consists of a pneumatic actuator and an electromagnetic actuator. Performance evaluation results confirm that the developed system provides high motion accuracy under eccentric loaded condition.

1 Introduction

Multi-axis controlled ultra-precision machine tools have been recently developed for promoting precise parts with complicated geometries. In general, trunnion type tilting motion platforms[1] are widely used for conventional multiple-axis controlled machine tools due to high stability and high machining accuracy. However, the table size is relatively small compared with the dimensions of the overall system due to interference between tool and workpiece. In this study, therefore, a newly proposed top-table type tilting motion table system driven by a hybrid actuator was developed. The proposed table system structure provides wide machining area while the working table and the center of gravity are far from the rotational center. The tilting motion table system should be driven by a high performance actuator so as to achieve high torque and high accuracy simultaneously. The hybrid actuator developed[2] is integrated with two types of actuators: a pneumatic actuator and a voice coil motor (VCM.).

2 Tilting table system

2.1 Design concept

Figures 1 and 2 show a design concept and structural configuration of proposed hybrid actuator-driven tilting motion table system, respectively. Design concepts are as follows.

2.1.1 Non-contact structure

A driving shaft of the tilting motion is supported by aerostatic bearings and the pneumatic actuator has small gap between stator and rotor as seals so as to can eliminate non-linear phenomena such as friction and stick-slip.

2.1.2 Symmetric structure

Thrust bearings are allocated on the center of the system so as to achieve thermal symmetric structure, as shown in figure 2. In addition to a pneumatic actuator and VCM are symmetrically allocated against the driving shaft, which enables accurate torque transfer.

2.1.3 Top-table type structure

The table is installed in parallel with the driving shaft. This structure can provide wide working area which is almost equal to the installation area and high stiffness due to its closed structure.

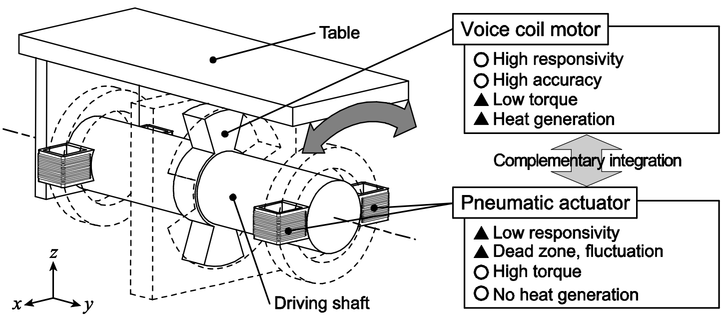


Figure 1: Concept of a hybrid actuator-driven tilting table system

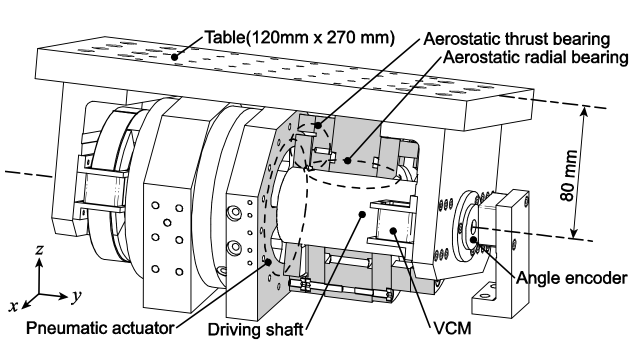


Figure 2: Structural configuration of tilting table system

2.2 Hybrid actuator

The proposed hybrid actuator consists of two types of actuators, i.e., an oscillating pneumatic rotary actuator and VCM. The pneumatic actuator generates a large driving torque without heat generation, while it is difficult to accurately control the driving torque due to the compressibility of the air and the existence of dead band. On the other hand, the VCM has quick response, linear characteristics and accurate control torque function, while the driving torque is not so high. In addition, heat generation from the VCM can causes thermal deformation in the overall structure. In consequence, both the actuators are coaxially arranged and simultaneously drive a common driving shaft so as to complement their characteristics each other.

2.3 Motion control system

Figure 3 shows the block diagram of the motion control system for the developed table system. A local pressure feedback control was implemented with pressure transducers, a PI compensator and a servo valve. The output torque is mainly generated by the pneumatic system. The torque error of the pneumatic actuator could be detected using local feedback loop and compensated by VCM. In consequence, the hybrid actuator could generate large torque with high accuracy and quick response. The developed table system could provide high motion accuracy using simple PID controller.

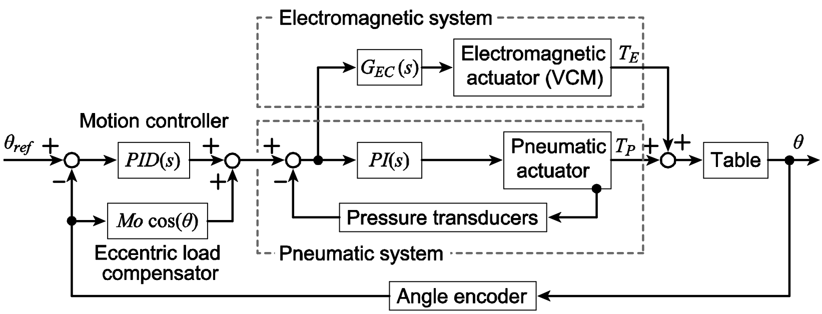
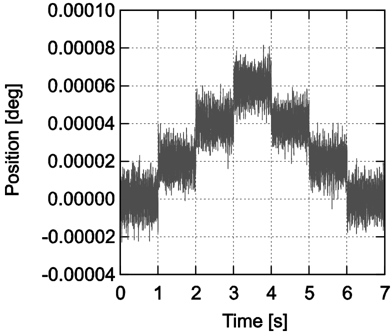


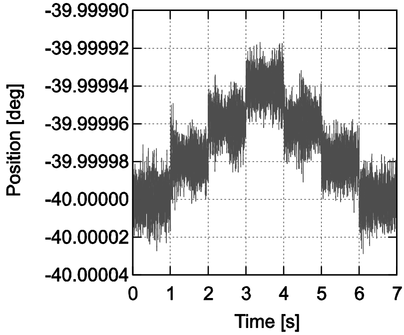
Figure 3: Motion control system for hybrid actuator-driven table system

3 Performance evaluation

Figures 4 (a) and (b) show stepwise responses of 0.00002 degree around 0 degree and -40 degree, respectively. At the table position of -40 degree, the eccentric moment becomes about 2.4 Nm which is lager than maximum torque of VCM. The experimental results confirmed that the proposed tilting motion table system achieves high positioning resolution of 0.00002 degree under the large eccentric loaded condition.



(a) 0 deg.



(b) -40 deg.

Figure 4 Stepwise responses of 0.00002 degree

4 Conclusions

A hybrid actuator-driven compact tilting motion table system was developed for multi-axis controlled ultraprecision machine tool. Performance evaluation results confirmed that the developed table system has fine positioning resolution under large eccentric loaded condition.

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[1] Moriwaki,T., Multi-functional Machine Tool, Annals of the CIRP, 57-2, 2008, pp.736-749

[2] Hayashi,M., et al., High Torque and High Precision Rotary Table System Driven by Hybrid Actuator, Proc. 9th euspen Int. Conf., Vol.1, 2009, pp.402-405