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Design and Control of a 3-DOF Reaction Force Compensation Mechanism for Precision Stages

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Abstract
Precision stages are widely used in many industrial fields. In recent years, these precision stages are required to have higher speeds, larger sizes, and higher precision for higher productivity and product quality. In particular, these high-performance positioning techniques are classified as one of the most difficult technologies among inspection and production equipment. Vibration control is an important part of high precision positioning technology. Various vibrations disturb the precision system, which can degrade system performance. Therefore, minimizing the vibrations generated by the system helps improve system positioning accuracy. This paper presents a novel active reaction force compensation mechanism for the precision stage. The proposed active reaction force compensation mechanism minimizes vibrations caused by driving linear motors in the precision stage. In this paper, prototype design and experimental results are shown to confirm the possibility. The proposed reaction force compensation mechanism is compact in size, and has the advantage of being able to compensate for reaction force along multiple axes. Because the H-type gantry stage is widely used in the field of ultra-precision positioning systems, the developed mechanism was installed in the H-type gantry stage. The developed mechanism effectively reduces the initial displacement of the system base during acceleration and deceleration.

Keywords : precision stage, vibration control, reaction compensation, high speed positioning, voice coil motor

1. Introduction

Precision stages are used in a wide range of applications, such as semiconductors, LCDs and OLEDs. In recent years, in the field of precision manufacturing industry, the precision stage has been continuously required to have higher speed and higher accuracy for higher productivity and product quality [1,2]. A vibration in precision equipment degrades system performance. Therefore, vibration control is an important part of high precision positioning technology. The vibration caused by motion with high acceleration affects the positioning accuracy and working efficiency. In recent years, as the stage system becomes more precise and faster, vibrations caused by the reaction force generated by the linear motor has become a problem [3, 4]. When the linear motor is driven, the reaction force is transmitted to the system base. This force causes vibration into the total stage system. The vibration caused by the reaction force is a main factor that degrades the life and productivity of precision manufacturing and inspection equipment. The proposed reaction force compensation mechanism is compact in size, and has the advantage of being able to compensate for the reaction force along multiple axes. This paper presents the design and control of a H-type gantry stage in which a novel active reaction force compensation mechanism is mounted inside a base granite. In terms of structure and control methods, there are many differences from the stages developed in the past.

2. System Description

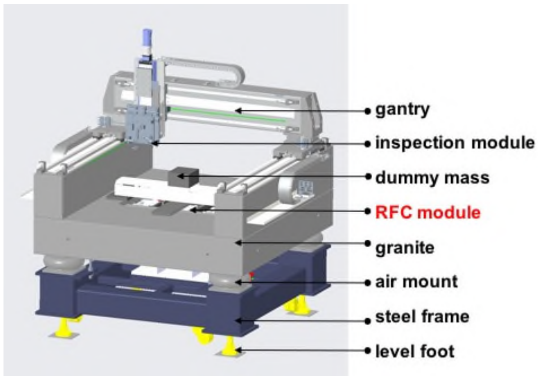

Figure 1. Concept design of a proposed gantry stage with a reaction force compensation mechanism

Fig. 1 shows the proposed precision gantry stage with a reaction force compensation mechanism. The proposed system was designed to have 3-DOF motion. Linear motors and linear guides were used in the X- and Y-axis directions and a servo motor and ball screw were used in the Z-axis direction. The base of the system was made of granite. The granite was mounted on four air mounts to reduce the bottom vibration. However, these four air mounts cause vibration in the base granite from the reaction force generated when the linear motor is driven. In order to compensate for the reaction force, a reaction force compensation mechanism was designed in the base granite.

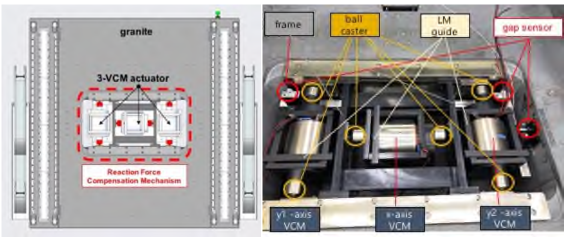

Figure 2. Proposed 3-DOF reaction force compensation mechanism

Fig. 2 shows the proposed 3-DOF reaction force compensation mechanism (RFCM) for the precision 3-DOF gantry stage. There are three VCM actuators and 3-axis capacitor sensors in the proposed RFCM. The actuator was selected by the calculated reaction force. The capacitor sensor was also selected considering the maximum displacement of the granite.

3. Control Algorithm

Since the gantry stage path and the acceleration/deceleration section are known in advance, the magnitude and the time at which the reaction force occurs can also be known. Therefore, the stage input command and the RFCM input command are simultaneously given to minimize the displacement of granite. After performing the input command, the capacitor sensor measures the displacement of granite and performs PID position control. Fig. 3 shows the developed control block diagram.

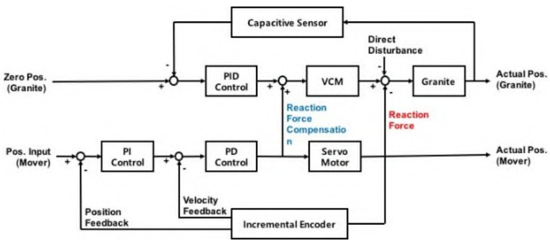

Figure 3. Control block diagram of RFCM

4. Experiment Results

In this study, a single axis stage and a dummy mass were installed on the granite to test the RFCM control algorithm. Fig. 4 and Table 1 show the experiment results. These results were obtained when a 50-kg dummy mass is moved 0.3 m with 1g of acceleration along the 1-axis linear stage above the granite. When the reaction force compensation module is not operated, the reaction force of the linear motor is transmitted to the granite, and the displacement is generated in the granite. However, when the reaction force compensation module was activated, the displacement of granite was reduced by 59%. In addition, the deviation from the initial position of granite was reduced by 52%. In order to improve the performance when applying the granite PID position control algorithm, the displacement of granite was reduced by 70%. The deviation of the granite was reduced by 93%. From these experimental data, it can be seen that the reaction force compensating module significantly reduced the reaction force generated by the linear motor. By reducing the reaction force, the stage can be operated at a higher speed and the productivity can be improved.

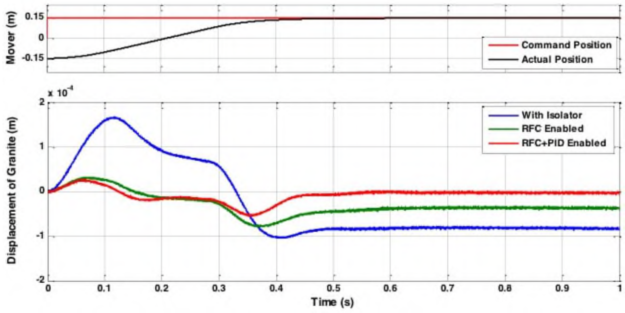

Figure 4. Experiment results of RFCM

Table 1 Displacement of granite

Experiment condition		1g, 0.3 m
Without reaction force control	peak to peak displacement	272 um
	difference of initial position	85 um
Only reaction force control	peak to peak displacement	111.2 um
	difference of initial position	41 um
Reaction force control with PID	peak to peak displacement	81.1 um
	difference of initial position	6.1 um

5. Conclusion

In this study, a novel type of reaction force compensation mechanism was designed, a prototype was made, and a simple experiment was performed to confirm the possibility. Experimental results show that the reaction force is compensated and the position error of the granite can be also compensated.

6. Future Works

The proposed system can compensate for a 3-DOF reaction force. In the future, it will be experimentally verified by applying a 3-DOF control algorithm. In addition, we will apply the developed reaction force compensation mechanism to the actual industrial inspection equipment to perform on-site verification.

Acknowledgments

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