euspen's 25th International Conference & Exhibition, Zaragoza, ES, June 2025
www.euspen.eu

Design and control of hybrid active vibration isolation systems using VCM control and pneumatic damper pressure control

Eunjong Choi[1], Sujin Jeong[1], Md Saiful Islam[1], Jaehong Shim[1], Kihyun Kim[1] and Hyo-Young Kim[1]

[1] *Department of Mechatronics Engineering, Tech University of Korea(TU Korea)*

kimhy@tukorea.ac.kr

Abstract
In ultra-precision stage control, the performance of active vibration damping systems is critically influenced by positioning accuracy. Active damping plays a key role in mitigating disturbance vibrations originating from the base of precision stages. These disturbances can arise from building floor vibrations or the reaction forces generated by the stage's movement. To address these issues, active vibration isolation systems using voice coil motors (VCMs) have been extensively researched in the field of precision engineering and successfully commercialized. Recently, as display manufacturing equipment has grown more advanced, efforts have been made to adapt VCM-based active vibration isolation systems—traditionally employed in semiconductor stages—to larger display production stages. While the precision requirements for display stages are less stringent than those for semiconductor stages, the larger size and weight of display stages present significant challenges, limiting the direct application of existing systems. This paper presents the development of an active vibration isolation system that integrates both pneumatic control and VCMs in an air mount to actively suppress vibration disturbances in large display production stages. he goal of this research is to use pneumatic control to actively mitigate vibrations generated by the heavy granite base of the display stage, while small residual vibrations are actively managed using VCMs. The results of the study are expected to help develop new curved display production equipment in the future.

Keywords : AVI, active vibration control, VCM, precision stage, display stage

1. Introduction

Vibration is a significant disturbance in precision manufacturing processes, exerting a profound influence on both productivity and product quality. In semiconductor manufacturing, where sub-nanometer linewidths are required, even micro vibrations, which were once deemed negligible, have now emerged as a major factor contributing to the degradation of final product quality and overall productivity. Consequently, the development of advanced vibration control technologies capable of effectively reducing external disturbances has become essential for achieving higher precision in the performance of motion stages [1],[2].

Active vibration control systems use actuators and sensors to reduce residual vibrations. These systems are particularly effective in managing two primary sources of vibration. The first source is disturbances transmitted from the floor. The second source is reaction forces generated during the acceleration and deceleration of the motion stage. Active vibration control systems are highly effective in suppressing low-frequency vibrations below 10 Hz caused by floor-transmitted disturbances, which are typically beyond the capabilities of conventional passive isolation systems. Furthermore, reaction forces generated during the high-speed operation of heavy or large-capacity stages induce vibrations that propagate throughout the system. By addressing both floor-transmitted vibrations and reaction-induced vibrations, active vibration control systems are essential for ensuring the stability and precision of the overall system. Conventional active vibration control systems for large motion stages typically use passive air mounts to reduce high-frequency vibrations and voice coil motors (VCMs) to control low-frequency vibrations.

2. Proposed Active Vibration Control System

The system proposed in this study is structurally similar to conventional active vibration control systems but incorporates a significant improvement. It introduces active control of air pressure in the passive air mounts, in addition to the standard VCM control. This dual-control strategy significantly reduces the current required by the VCMs, thereby minimizing heat generation during operation [3],[4].

In conventional systems, the VCM control gain is generally optimized for conditions where the center of mass remains centrally positioned. When the center of mass shifts, the performance of VCM control may degrade. While it is possible to dynamically adjust the control gain to account for shifts in the center of mass, this approach often involves complex control algorithms and results in only minimal performance improvements. In contrast, the proposed system adopts a feedforward pneumatic control strategy that actively considers the position of the stage during operation [5]. By integrating this approach, the system can effectively suppress vibrations without requiring additional adjustments to the VCM gain. Even when the center of mass shifts, the pneumatic control ensures stable performance by minimizing the need for complex tuning algorithms and maintaining effective vibration suppression under varying conditions.

This study proposes a novel active vibration control system specifically designed for large and heavy display production stages. By combining pneumatic control with VCM-based vibration control and suppression, the proposed system effectively addresses the challenges associated with large stages, ensuring enhanced performance and reliability.

3. Precision vibration control for uniform coating on curved display surfaces

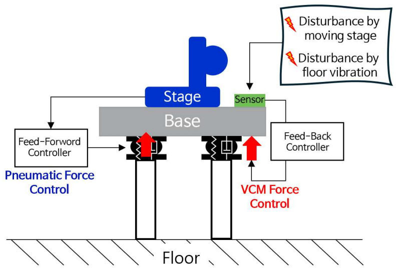

Figure 1. schematic of the proposed active vibration control system

Figure 1 illustrates the schematic configuration of the proposed active vibration control system. The system is designed to reduce reaction force disturbances caused by stage motion as well as vibration disturbances from the floor, using pneumatic control and Voice Coil Motor (VCM) control. The base is made of granite and is supported by air mounts, while the precision stage is fixed on top of the granite base. This combination of a granite base and air mounts is commonly used in precision systems, as it effectively reduces high-frequency floor vibrations. However, reaction forces generated by the stage itself can cause movement of the entire granite base. The stage in this study is designed for uniform coating on curved display surfaces. If the base of the stage is disturbed by reaction forces, the liquid coating material cannot be evenly applied to the display surface. This issue is particularly critical for curved displays, which have a high curvature and are likely to experience gravity-induced flow even under small vibrations. Therefore, controlling vibration disturbances is essential for achieving uniform coating.

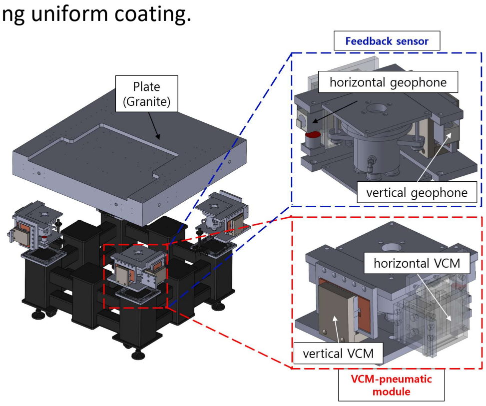

Figure 2. system configuration

Figure 2 shows the system configuration. A total of eight VCMs are used in the system, with four placed vertically and four horizontally to enable six-axis vibration control. Additionally, servo valves are employed to regulate the pneumatic pressure of the four air mounts. The feedback sensors consist of eight geophone sensors.

4. Simulation Analysis of the Proposed Active Vibration Control System

A simple simulation was performed to evaluate the feasibility of the proposed system. The simulation compared two cases: controlling the reaction force using only the VCM and using both pneumatic control and the VCM under the same stage operation conditions. Figure 3 shows the simulation results. When only the VCM was used for control, a maximum force of approximately 103 N was required. However, when pneumatic control was combined with the VCM, the required VCM force was reduced to about 73 N. This indicates that energy consumption can be reduced by approximately 30%. The maximum currents applied to the other three Z-axis VCMs also showed an average reduction of approximately 30%.

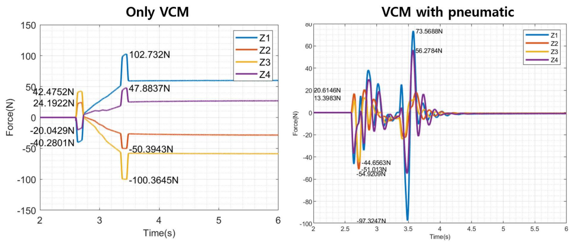

Figure 3. Performance Comparison with and without Pneumatic Control

It was observed from the simulation results that when pneumatic control was applied together with the VCM, the current applied to the VCM became more complex due to the nonlinear characteristics of the pneumatic system. However, this complexity only affects the input current to the VCM and does not lead to any significant displacement or instability in the granite base system itself. Additionally, in the steady state, when only VCM control is used, the force does not converge to zero but stabilizes at a specific value. This is because the returning force of the pneumatic mounts was not modeled in the simulation. In practice, even without pneumatic control, the air mounts would gradually return to their original equilibrium position, causing the VCM force to slowly converge to zero over time. On the other hand, when pneumatic control is applied, the force applied to the VCM immediately converges to zero. This suggests that pneumatic control can stabilize the granite base more quickly and effectively reduce heat generation in the VCM.

5. Conclusion

The proposed vibration control system is designed to minimize the reaction force of the stage and reduce floor vibrations to ensure uniform coating on curved displays. The reaction force from the stage motion is calculated, and the feedforward pneumatic control method helps stabilize the system more quickly while reducing the force needed by the VCM. Simulation results demonstrated that when both VCM and pneumatic control were used, the control force of the VCM decreased, effectively reducing heat generation in the VCM. In future work, the system will be fabricated, and various experiments will be conducted to validate the simulation results.

Acknowledgement

This study was supported by Korea Institute for Advancement of Technology(KIAT) grant funded by the Korea Government(MOTIE) [(P0021527) and [(RS-2024-00409639) HRD Program for Industrial Innovation] and This study was also supported by the GRRC program of Gyeonggi province [GRRC TU Korea2024-B02]

References

[1] Chen, Ping-Chang, and Ming-Chang Shih 2007 *Journal of Vibration and Control* **13** 1553-1571

[2] J. Lee, H. Kim, K. Kim, M. Kim, S. Lee 2017 *Journal of Mechanical Science and Technology* **31** 5711-5719

[3] Zhang W, Zhang H 2023 *Actuators.* **12**(2) 77

[4] H. Lee, K. Kim, H. Kim 2020 *Review of Scientific Instruments* **91** 2

[5] S Kim, D Kim, M Kwak 2023 *Applied Sciences* **13** 5