euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
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Lateral Vibration Control Using Real-time Motion State and Hybrid (MR-Pneumatic) Isolation Systems

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Abstract

A hybrid mount is an isolator joined parallel with a magneto-rheological (MR) damper. Hybrid mounts were initially designed to reduce vertical low-frequency vibrations. The pneumatic isolator maintains vertical positions and restricts floor vibration. The MR damper can reduce low-frequency oscillations of machine vibration and demonstrates a control effect on lateral vibration induced by high-speed plane motion. However, at least six sensors are required to control lateral and vertical vibration, which encompasses the controller and its logic complex. Simultaneous control of motion and vibration can be implemented using a multi-axis motion controller. The motion and vibration states can be monitored in real-time, where the motion states can be used for the vibration control. For this study, the vibration control logic was constructed using acceleration states, which indicates that three sensors for lateral vibration sensors can be replaced. The control logic was applied to a real-time motion controller for a high-speed XY stage in a simulated manufacturing machine. The machine used for this experiment was composed of four hybrid mounts, four vertical vibration sensors, a simultaneous controller, XY linear transfer units, a stone surface plate, and a moving mass. The results confirm that the proposed control method is effective on lateral vibration without a lateral vibration sensor and can be applied to current hybrid mounts.

Vibration Control, Semi-active Isolator, Magneto-Rheological Damper, Lateral Vibration, Plane Motion, High Speed Positioning

1. Introduction

Vibration is one of the most important environmental factors in sub-micro processes and guide lines are applied to install manufacturing machines [1]. Many isolation devices has been applied to manufacturing machines, however, resonance and low-frequency oscillation originating from mechanical movements exist [2]. These low-frequency problems can be reduced using a hybrid isolator with a parallel connection of a pneumatic spring and magneto-rheological (MR) damper. The hybrid mount has been developed for conventional vertical vibration, but, it is also effective for lateral vibration because of shear yield stress [3]. Three sensors are normally required to control lateral vibration. However, lateral vibrations are commonly generated from high-speed motion; hence motion control information can be applied for the lateral vibration control instead of the sensors. A simultaneous controller of motion and vibration in the previous research can monitor the status in real-time [4]. Therefore motion information can be used for lateral vibration control.

In this study, a method of lateral vibration control was proposed using the lateral damping effect of the hybrid mount and the simultaneous controller. The control method was derived using commanded acceleration, one of the motion status, and adjusted lateral damping. The control method was tested using a simulated manufacturing machine; the effect of controlling the lateral vibration was investigated.

2. System dynamics

The kinematic parts of a manufacturing machine are usually installed on a base plate, and the vibration control devices are generally placed under the base plate. The base plate is levitated using pneumatic force generated by the hybrid mounts. The levitating positions of the hybrid mounts were measured by sensors and were conveyed to the controller. The controller adjusted the flow control valve for pneumatic force to maintain the target level of levitation. The controller drives linear motors on the base plate with high-speed motion; in this way, vertical and lateral vibration is induced. The ratio of mass and stiffness of the hybrid mounts are usually low; hence low frequency oscillation is caused by the motion. The oscillation can be reduced by driving the electric current to the MR damper and increasing the damping constant. The vertical oscillation is measured by the laser sensors; however, the lateral oscillation is removed by monitoring the motion status. Figure 1 shows the concept of the simulated manufacturing machine and signal interfaces.

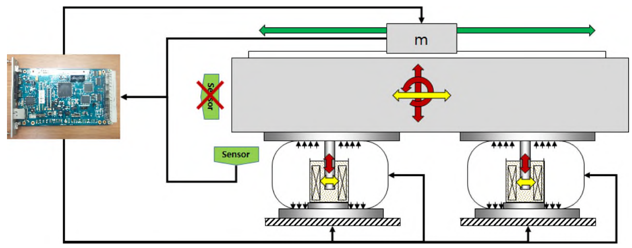

Figure 1. Diagram of a simulated manufacturing machine and signal interfaces

3. Control method and system

Lateral displacements of the base plate, X, can be estimated using the lateral displacements of the hybrid mounts, u, as follows:

$$X=\frac{1}{4}(u_1+u_2+u_3+u_4)$$

The vibration of the base plate is induced by the high acceleration, $\ddot{x}$, which can be monitored in the controller, as shown in the following equation:

$$(m+M)\ddot{X}+c_L\dot{X}+k_LX=m\ddot{x}$$

It is assumed that the damping constant in lateral direction was proportional to that in vertical direction. When an electrical current is driven to the MR damper, both the lateral damping and the vertical damping will increase. The second-order equation can be changed into state-space form as indicated.

$$\begin{pmatrix}\dot{X}_1\\ \dot{X}_2\end{pmatrix}=\begin{bmatrix}0 & 1\\ -\dfrac{k_L}{m+M} & -\dfrac{c_L}{m+M}\end{bmatrix}\begin{pmatrix}X_1\\ X_2\end{pmatrix}+\begin{pmatrix}0\\ \dfrac{m}{m+M}\ddot{x}\end{pmatrix}$$

Figure 2 shows the conventional motion profile of the linear motor and control logic using velocity and acceleration. The lateral damping increases in proportion to the acceleration. The control loop can be shown as in the block diagram. The commanded acceleration can be obtained from the motion status in the controller and is transferred to adjust the lateral damping.

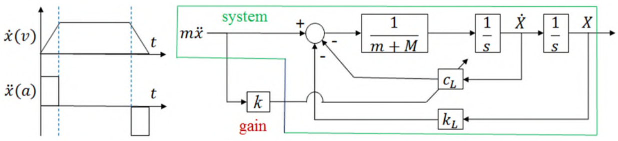

Figure 2. Motion profiles and a block diagram for controlling lateral vibration

Figure 3. Simulated manufacturing machine on the hybrid mounts and a laser vibrometer

Figure 3 shows the simulated manufacturing machine using an XY stage, which installed on a stone surface plate. Four hybrid mounts were placed between the surface plate and the base frame. The machine moves in the XY direction with high speed motion (400mm/s, 0.8G). A simultaneous controller (UMAC) drives the XY stage and the hybrid mounts. The vertical levitation was measured using four laser sensors (ILD-2300) and a protocol decoder board. The control method was applied to the controller using the PLC function of UMAC. The lateral vibration at the center of the surface plate was measured using a vibrometer (OFV505) during the high speed motion. The lateral vibration was measured on both the pneumatics and lateral MR control modes.

4. Results

When the pneumatics modes were implemented, mechanical resonance was caused by the high-speed motion. The pneumatics maintains the levitation positions and controls only vertical vibration; hence, this mode was not effective for controlling lateral vibration. The resonance frequency, before lateral MR control, was 1.37Hz. When the lateral control mode was implemented, the resonance was removed, as shown in figure 4. The horizontal axis indicates time (s) and vertical axis represents velocity level (mm/s). The peak-to-peak values of the cases were reduced 42% after the lateral MR control was applied. The settling time was 3.7 s after the lateral MR control. The peak amplitude in frequency response was reduced by 59% and peak frequency was varied to 2.36Hz, as shown in figure 5. Therefore, the hybrid mounts were effective for controlling lateral vibration using control method with motion status, which actuate the MR dampers.

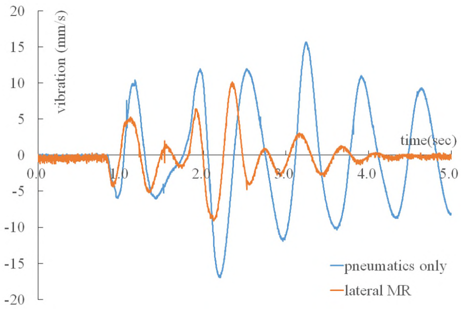

Figure 4. Lateral vibration before and after the lateral MR control

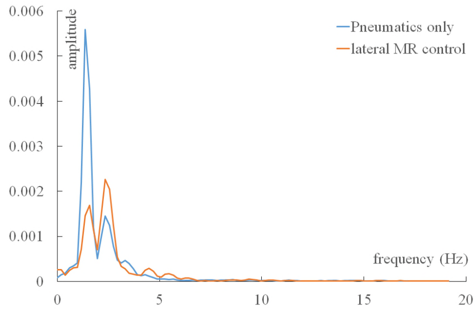

Figure 5. Frequency responses before and after the lateral MR control

5. Conclusion

This study proposed a method for controlling lateral vibration using hybrid mounts and a simultaneous controller for high speed motion of a manufacturing machine. The vibration control logic was constructed using acceleration states and embedded in a multi-axis controller. Once the lateral MR control was applied, the lateral vibration decreased for both the time and frequency domain responses. The hybrid mounts were originally designed for vertical vibration; however, they also demonstrated that they are effective for lateral vibration control.

Acknowledgement

We would like to acknowledge the financial support from the R&D Convergence Program of MSIP (Ministry of Science, ICT and Future Planning) and ISTK (Korea Research Council for Industrial Science and Technology) of Republic of Korea (Grant B551179-12-04-00). The hybrid mounts were provided by RMS Technology, Republic of Korea (http://www.rmstech.co.kr).

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