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Damping Control Effect of Lateral Vibration Induced by Plane Motion Using Hybrid (MR-Pneumatic) Isolation Systems

HyungTae Kim, HyoYoung Kim, AnMok Jeong, JongWook An, and CheolHo Kim[1]

[1]*KITECH, ChoenAn, South Korea*

[1]*kimhy02@kitech.re.kr*

Abstract

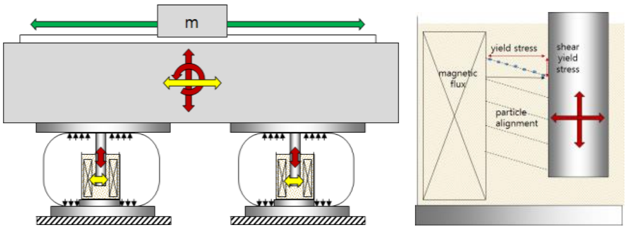
MR (magneto-rheological) fluid dampers decrease long oscillations of a pneumatic isolator used for manufacturing machines. In our previous study, a hybrid isolator was constructed by attaching an MR damper inside a conventional isolator. The hybrid isolator could adjust the damping friction force, and hence, long oscillations caused by high-speed motion could also be reduced well. In previous studies, the hybrid isolator was designed for vertical vibrations. However, lateral vibrations could also be reduced by controlling the MR damper. The damping friction force of the MR fluid was considered to increase in both vertical and lateral directions when the MR damper control was activated during the plane motions. In this study, the yield stress model of MR fluid was reviewed when electric current was applied to the MR damper. Then, the hybrid isolator could control lateral vibration, which was verified in the experiment. The lateral vibration measured by a laser vibrometer indicated that the transient response and the settling time of the lateral vibration were reduced when the MR damper was activated. Hence, the MR damper could be applied to control lateral vibrations induced in common manufacturing machines.

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

1. Introduction

Machines used for manufacturing semiconductors and flat panel displays are sensitive to vibrations because even small vibrations can affect product quality. Pneumatic isolators are usually installed under these machines to isolate ground floor vibrations according to the vibration criteria [1]. The response of pneumatic isolators involves long and low frequency oscillations when vibration is caused from an internal mechanism of the machines because of heavy mass, low stiffness and low damping. An MR damper could adjust damping and could be combined parallelly within the pneumatic isolator. This configuration of combining the pneumatic isolator with an MR damper is called a hybrid mount [2]. The hybrid mount reduces vibrations in the transient as well as in the steady state. Hence, it is useful for isolating vibrations caused by high-speed kinematic motions in current manufacturing machines [3].

Most studies involving multiple DOF models for isolation and absorption were considered for vertical vibration caused by an impact response [4]. However, high-speed motions in current manufacturing machines are mostly driven in xy-plane. This induces both vertical and lateral vibrations. The lateral effect is not considered in conventional models, and thus, the effect of lateral vibrations from high-speed plane motions can be critical in manufacturing machines. In the above-mentioned previous study, a 3-DOF control model of a hybrid mount could decrease the vibrations caused by high-speed planar motions. Resonance could occur due to the lateral motion in the case of pneumatic isolators. However, the resonance was suppressed after the application of a MR damper in a pneumatic isolator [5]. The control model depends on the vertical direction, and hence Z direction control was considered. Nevertheless, it was revealed that lateral vibrations decreased in the experiments when the MR control was activated. Thus, in this study, the vibration control effect of the MR fluid was investigated. Furthermore, an experiment was conducted to verify the vibration absorption. A laser vibrometer was utilized to measure the attenuation of vibrations.



(a) (b)

Figure 1. (a) The vertical and lateral vibration control model caused by planar motion using hybrid isolators (b) A stress model in an MR damper

2. Vibration model

Hybrid mounts were installed on the floor to support a machine body whose weight was between 1.0 and 3.0 tons. The machine body levitated as pneumatic pressure was supplied to the hybrid mounts. An MR damper was fixed in the centre of an air chamber that was formed with high-elasticity rubber. A rod attached to an upper plate was submerged into the MR fluid. The damping friction force of the MR fluid was adjusted using an electric coil that generated magnetic force. As shown in Figure 1(a), a stage on the machine body moved a mass in the planar direction. The conventional vibration model considered vertical vibrations as shown by the red arrows in the Figure 1(a). However, the planar motion indicated by the yellow arrows also generated lateral vibration. An MR controller was used to apply an electric current to the coil when vertical vibration was detected by laser sensors. As result, magnetic flux was generated in the MR fluid, and particles in the MR fluid aligned along the magnetic flux path. Then, yield and shear yield stresses were generated from the particle alignment [6]. The yield and shear yield stress caused the lateral and vertical damping friction force, respectively, as shown in the figure 1(b). Thus, the lateral vibration was decreased via the hybrid mount even though it was designed for isolating the vibrations in the vertical direction. The electric current was applied for vertical vibration control due to the lateral motion. Therefore, the lateral vibration was also decreased by the yield stress. The lateral vibration control was not expected during the design of the hybrid mounts and was a beneficial side effect.

3. Experiment and results

A test stage for a simulated manufacturing machine was constructed on granite. Four hybrid mounts supported the test stage and the 4 hybrid mounts were fixed above an iron base on the floor. The stage had 400mm x 400mm strokes in the planar direction and the maximum speed of the strokes was 400mm/s with an acceleration of 0.8G. The moving mass on the stage and the granite was 75kg and 1500kg, respectively. Air pressure levitated the granite and the electro-proportional flow valve controlled the height of levitation. The damping friction of the MR damper was adjusted electrically. The electrical inputs to the flow valve and the MR damper were amplified using current drivers. The vertical vibration was measured by four laser sensors (ILD-2300), and the data were transferred to a controller (UMAC) via Ethernet. The controller decoded the sensor data, and determined the outputs for the hybrid mounts considering stage movement in real time. The lateral vibration during the planar motion was measured in the centre of the granite by using a vibrometer (OFV505) with and without MR control. The experiment apparatus is shown in Figure 2.

Figure 3 shows the lateral vibration measured along the x axis during planar motion. A vibration cycle was composed of steps of acceleration, constant velocity and deceleration of the planar motion. The amplitude and oscillation without MR control were greater when compared to those with MR control. However, the results with respect to the settling time were opposite to that of the amplitude and oscillation results. Figure 5 shows the frequency response results. The frequency of the peak amplitude changed from 1.5 Hz to 0.5 Hz. The amplitude decreased by 76% after the application of the MR control. The results indicated that the proposed hybrid mount could control lateral vibration even though the mount was designed for vertical vibration control.

4. Conclusion

The mechanism of lateral vibration control was investigated through a hybrid mount designed for vertical vibration control. The hybrid mount was composed of an air spring and an MR damper. When a magnetic flux was applied in the MR fluid in the MR damper, yield and shear yield stresses were generated. This indicated that the damping friction was generated in both vertical and lateral directions. In the experiment, lateral vibration was induced from high-speed planar motion and was measured by a laser vibrometer. The results indicated that the hybrid mount reduced the oscillation and amplitude of the lateral vibration. This effect suggetsted that the lateral vibration could be controlled with the current hybrid mounts designed in previous studies.

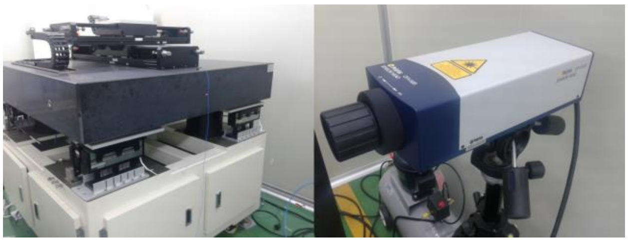


Figure 2. Experimental step-up of the simulated manufacturing machine supported by four hybrid mounts and the vibrometer for measuring the lateral vibration

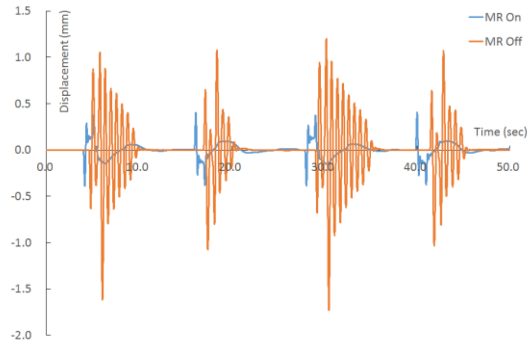


Figure 3. Time domain responses with and without MR control

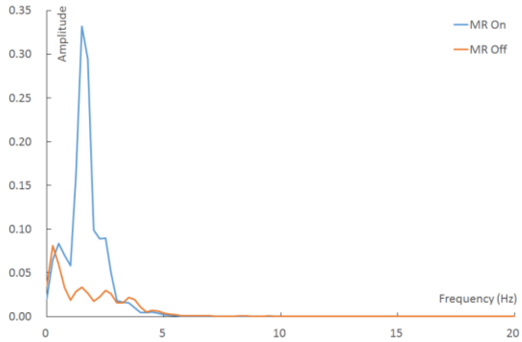


Figure 4. Frequency domain responses with and without MR control

Acknowledgement

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