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Design and performance evaluation of a serial multi-electrode electrorheological damper

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Abstract

This study presents the design and performance evaluation of a serial multi-electrode electrorheological (SMER) damper. The characteristics of electrorheological (ER) fluid and SMER damper are experimentally obtained. The design method for ER dampers is based on the requirements of the system damper such as controllable damping force, controllable ratio and the ratio of rebound damping force and compression damping force. Then the SMER damper is applied to the single-degree-of-freedom model of a vibration system to evaluate the performance of an SMER damper. The vibration control system uses a velocity control algorithm. The simulation and experimental response of the displacement as well as the acceleration indicate the effectiveness of the design of the SMER damper.

1. Introduction

Electrorheological (ER) fluids are polarized particles mixed with non-conducting liquids. When subject to an electric field, the viscosity and yield shear stress of the liquid increases with the electric field strength to such an extent that the liquid may become plastic within response time of approximately a few milliseconds. The plastic quickly turns into liquid again once the electric field is removed. This phenomenon of ER fluids is so-called ''ER effect'' [1,2]. ER fluids offer the potential for achieving easily controlled, fast acting, continuously variable dampers, using the continuously variable damping forces that can be obtained from suitable ER device [3]. Unlike an electromechanical valve, an ER valve can achieve flow control without moving parts in fluid control systems. Many researchers have studied the characteristics and applications of ER fluids. Because of their fast response to the electric field and wide control bandwidth, ER fluids can be used for controllable dampers and control systems [4].

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In order to improve the controllable damping force of ER dampers using low effective ER fluids, some researchers have used high viscosity ER grease dampers, long electrode stroke dampers or multi-electrode dampers to conduct experiments. For example, Marksmeier et al. [5,6] used high viscosity ER grease in their studies, developing a concentric electrode ER damper with a tested stroke of 0.02 m and a controllable force range from 0.6 to 0.7 kN at 0.3 m/s. Although the damping force can be promoted, the damping force of zero-field will be too high to make the controllable range of applied electric field relatively low. Sims et al. [7] developed a long-stroke ER damper with a single bypass valve and tested it with commercial ER material. This damper had a tested stroke of 0.016 m with a controllable force range from 1.2 to 3.8 kN at 0.2 m/s. Gavin [8] developed a multi-duct ER damper with a long electrode length of 0.235 m and electrode outside diameter 0.08 m. He tested a stroke of 0.08 m with a controllable force range from 2 to 6 kN at 0.25 m/s using a serial duct ER damper. However, the long stroke ER damper is restricted with its space in actual use.

Mui et al. [9] developed a parallel multi-electrode ER damper. This damper has a tested stroke of 0.01 m with a damping force 0.02 kN at 0.063 m/s when tested with a zeolite-based ER material. Makris et al. [10] developed an ER damper with a bypass ER valve. This damper has a tested stroke of 0.02 m with a controllable force range from 0.2 to 0.3 kN at 0.013 m/s with a zeolite-based ER fluid tested. The damping force of the damper and its controllable force range are very small, so the multi-electrode parallel to damping force and its controllable force range are also not very large. This can be demonstrated by the parallel multi-electrode ER damper studied by Kuo et al. [11], who used ER fluid mixed with silicone oil and corn starch. Gavin [8,12] studied numerical examples to focus on a large-scale damper, and showed that a simulated damper can regulate very large forces. He designed, tested and modeled three multi-duct ER dampers, which have controllable force levels from 2 to 6 kN at 0.4 m/s when tested with commercial ER fluids. Gavin also studied a large-scale and long-stroke damper applied to civil engineering, which has two piston rods in the cylinder. The SMER damper in this study has a tested stroke of 0.1 m and a hydraulic serial ER dampers, the controllable damping force is from 0.7 to 1.4 kN with 3-layer ER damper. If we use a 5-layer ER damper with electrode gap $h = 0.6$ mm, the damping force is from 1.32 to 3.6 kN at the rebound stroke.

The ER damper is a device with controllable damping force or damping coefficient, which can be applied to control vibration systems or semi-active suspension systems. For instance, in their studies, Wong et al. [13] and Wu et al. [14] used a parallel multi-electrode ER damper as well as various composite control strategies to improve both ride comfort and road holding. Brennan et al. [15] described the design and testing of a rotary vibration damper using ER fluid in the shear mode for a semi-active control system. Weyenberg et al. [4] applied ER dampers to the semi-active suspension systems of vehicles controlled by a modified sky-hook algorithm, and directly installed accelerometers and position sensors in vehicles to measure the feedback signals of the vehicles. The results showed that the level of vehicle body acceleration and the tire load variation were improved. Nakano [16] constructed a quarter car suspension system model and proposed several semi-active control algorithms for ER damper, which showed that the proportional feedback control using the information of absolute unsprung mass velocity is the most effective control strategy. Gordaninejad et al. [17] evaluated the performance of multi-electrode shear mode ER dampers under forced vibration through experiment, demonstrating the effects of the number of electrodes and electrode surface area of ER dampers. Choi et al. [18] proposed a cylindrical ER damper for a passenger car which showed that a continuously variable ER damper can be satisfactorily used for the feedback control of desired damping forces. Its controllability of damping force was improved by implementing a skyhook controller. Suh et al. [19] used a sky-hook control algorithm to improve the ride quality through computer simulation, and then the ER damper was installed in a passenger car for testing. The results of the experiment showed that the rms acceleration of control mode was generally better than that of passive mode. Onoda et al. [20] fabricated an ER damper and investigated the effectiveness of semi-active vibration suppression. Choi et al. [21] adopted the hardware-in-the-loop simulation method and used a sliding mode controller. The simulation results showed that the full-car ER suspension system was very effective for vibration isolation. Choi et al. [22] evaluated the performance characteristics of a semi-active ER suspension system associated with a skyhook controller and four ER shock absorbers to a full car. Their results showed that the semi-active system could be effectively employed in a passenger vehicle, improving both riding comfort and steering stability. Oh et al. [23] designed and fabricated an MR damper for semi-active vibration suppression, and their results showed that the performance of the MR damper was better than that of the ER damper.