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A magnetorheological damper capable of force and displacement sensing

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ABSTRACT

A magnetorheological (MR) damper with embedded force and displacement sensors is devised to facilitate closed-loop structural vibration control. A piezoelectric force sensor and a linear variable differential transformer (LVDT) have been integrated with a conventional MR damping device. The piezoelectric sensor is used to sense the damping force produced by the damper, while the LVDT is employed to measure the displacement of the vibrating structure at the damper location and the movement of the damper piston. Calibration of the piezoelectric force sensor is conducted through force-controlled tests with sinusoidal force excitations of different amplitudes and frequencies. The sensing and damping performances of the devised MR damper are evaluated under displacement-controlled excitations, with different current inputs being commanded to the damper. The experimental results demonstrate reliable displacement/force sensing and controllable damping capabilities of the devised damper. The sensing-while-damping function of the damper hence offers its potential for real-time feedback structural vibration control.

1. Introduction

In the past decade, magnetorheological (MR) fluid and MR damping devices have been extensively investigated. Among the various applications of MR fluid, MR dampers have gained considerable attentions in vibration control of civil and mechanical structures. The MR fluid inside MR dampers is a suspension of micrometer-sized magnetic particles in a carrier fluid. Upon exposure to a magnetic field, the free-flowing linear viscous MR fluid can change to a semi-solid with controllable yield stress in milliseconds [1]. Therefore, by inputting different electrical currents to the electromagnet inside an MR damper, the magnetic field applied to the MR fluid can be varied so that the yield stress associated with the MR fluid and hence the damping force of the MR damper can be readily controlled in milliseconds. When applied for structural vibration control, MR dampers can serve as passive dampers in the case of small-amplitude vibration and be activated once large vibration occurs, thus greatly reducing the power requirement and making the devices fail-safe. Owing to these attractive properties, MR dampers have got applications in a variety of areas such as vibration control of stay cables in cable-stayed bridges [2–6], seismic protection of infrastructures [7–9], vibration damping of automotive seats and suspensions of vehicles and trains [10–12], and stability augmentation of helicopters [13].

In a certain current practices, MR dampers are used in an open-loop mode of operation or as purely passive control devices, which hinders full utilization of their capabilities. One solution is to practically implement suitable closed-loop feedback control strategies to command the MR dampers. However, as MR dampers are highly nonlinear, it is not straightforward to build an accurate inverse dynamic model for closed-loop operations of MR dampers. In order to overcome the deficiency of inverse dynamic modeling, a force feedback control loop is often deployed [14]. Recently, an MR damper with an embedded piezoelectric force sensor has been developed to possess force sensing and controllable damping functions with the intention of facilitating real-time closed-loop vibration control of civil and mechanical structures [15,16]. Previous studies have shown that real-time measurements of the damping forces produced by MR dampers and the responses (displacements, velocities or accelerations) are required for accurately modeling forward and inverse dynamics of MR dampers and for online employment of the models in feedback control activities [17–20]. Since it is simpler and more precise to obtain velocity/acceleration signal via numerical differentiation of the measured displacements than to obtain displacements through integration of the acquired velocities/accelerations, displacement will be a preferable quantity to be measured if required.

In this paper, a new phase of development of MR damper with embedded transducers is presented. By extending the previous

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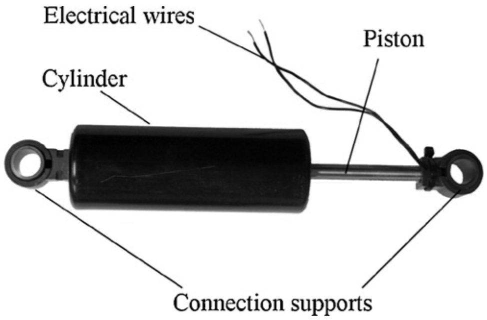

Fig. 1. Photograph of a conventional MR damper.

study [15,16], a piezoelectric force sensor and a displacement transducer are assembled with a conventional MR damper to form a new version of MR damper with dual-sensing capability. It is desirable that the devised MR damper is able to real-time monitor the forces produced by the damper as well as the responses of the vibrating structure and the damper. The real-time monitoring signals will be utilized to provide enough information for forward and inverse MR damper models incorporated in a feedback control loop to fulfill a real-time closed-loop control operation for structural vibration mitigation.

2. Configuration of MR damper with dual-sensing capability

Fig. 1 shows a photograph of a conventional actuation-only MR damper. It comprises a cylinder with MR fluid, an electromagnet, a diaphragm, an accumulator and a piston housed inside, a pair of electrical wires extended from the electromagnet, a piston as well as connection supports. By applying currents to the electromagnet through the electrical wires, rheological characteristics of the MR fluid can be reversibly changed so that the corresponding damping performance of the MR damper is expected for suppressing structural vibration.

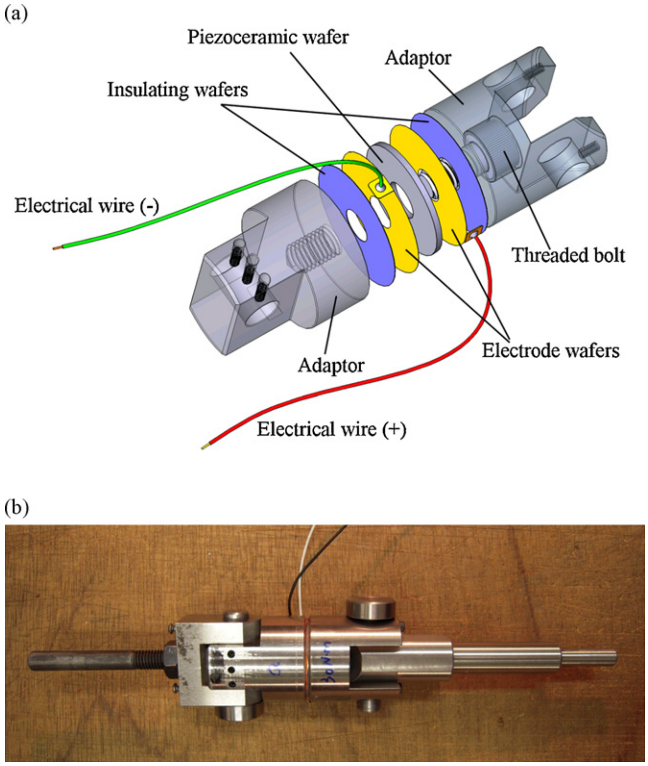

Fig. 2. (a) Schematic diagram and (b) photograph of piezoelectric force sensor.

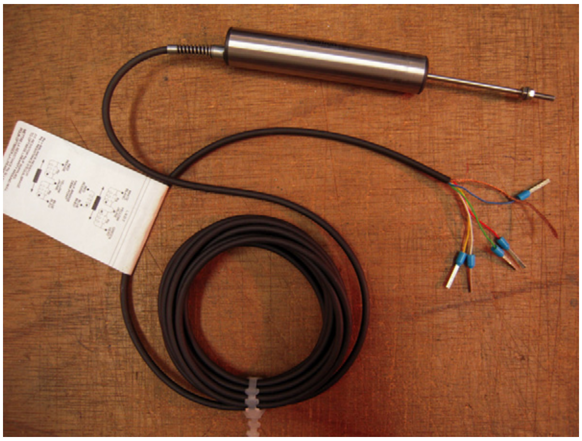

Fig. 3. Photograph of LVDT.

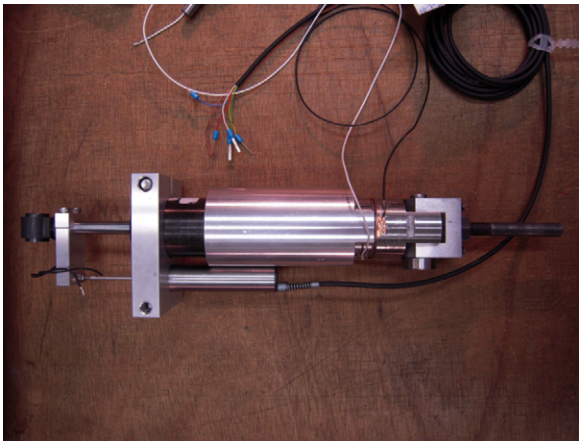

Fig. 4. Photograph of MR damper with dual-sensing capability.

To endue the conventional MR damper with a self-sensing function, a piezoelectric force sensor is fabricated and integrated with the damper. The most widely used force sensing materials are piezoelectric materials because of their wide usable frequency range, fast response and reliability [21]. Their extensive applications in force sensor fabrications have been reported [22–24]. A schematic diagram and a photograph of the piezoelectric force

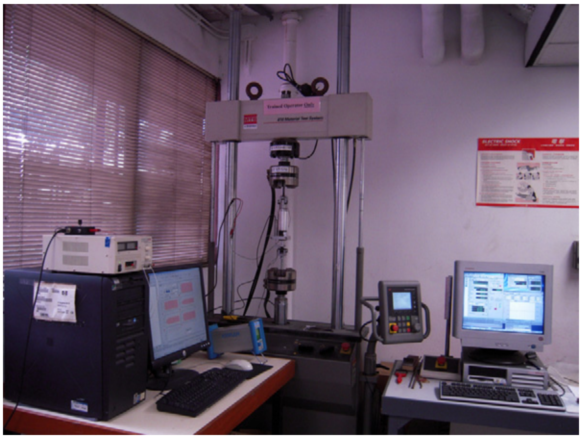

Fig. 5. Experimental setup of calibration and performance tests.