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PROTOTYPE CONSTRUCTIONS OF MAGNETORHEOLOGICAL DAMPERS WITH ENERGY HARVESTING CAPABILITY

PROTOTYPOWE KONSTRUKCJE TŁUMIKÓW MAGNETOREOLOGICZNYCH Z ODZYSKIEM ENERGII

Abstract

The paper briefly summarises the design structure of a prototype linear and rotary magnetorheological (MR) damper with energy recovery capability, engineered by the authors, and provides selected characteristics of those devices based on laboratory testing.

Keywords: *damper, electromechanical transducer, signal conditioning and processing system, energy harvesting*

Streszczenie

W artykule opisano budowę zaprojektowanych i wykonanych przez autorów prototypowych konstrukcji liniowego i obrotowego tłumika magnetoreologicznego (MR) z odzyskiem energii. Przedstawiono również wybrane charakterystyki tych urządzeń wyznaczone na podstawie badań laboratoryjnych.

Słowa kluczowe: *tłumik MR, przetwornik elektromechaniczny, układ kondycjonująco--przetwarzający odzyskiwanie energii*

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1. Introduction

The recovery of energy involved in mechanical vibration has received a great deal of attention in the field of harvesting energy from the surroundings. There are three basic methods of mechanical to electric energy conversion: electromagnetic methods; electrostatic methods; the use of smart materials. Thus, the recovered energy can then be utilised to power other devices. The solutions with which recovered energy is used to power piezoelectric sensors in wireless monitoring systems are now well known. These solutions are applicable as long as the vibration frequency is in the order of several hundred Hertz, the amplitudes are in the order of micrometers and the energy sources have power ratings of several micro or milliwatts.

This paper introduces newly designed, prototype constructions of MR dampers, power-supplied with energy recovered from mechanical vibrations of frequency ranging from several to about 20 Hz and with amplitudes in the order of ten millimetres. Reports on these types of linear MR dampers can be found works [1–4, 17, 18], although information about rotary dampers is rather scarce. The available literature on the subject includes just the patent [16], which may be the associated with the lack of relevant applications and the need to fabricate the appropriate control system.

The MR devices presented in this paper were designed and fabricated by the authors as a part of their research program. The underlying assumptions are included in patent applications [9−12]. These devices incorporate an electromechanical vibration transducer (generator), so the electric energy required to activate the MR damper is recovered from a vibrating object [1−2, 6−8]. The transducer, operating in accordance with Faraday's law of magnetic induction, converts the mechanical energy into electrical energy (the velocity of the vibrating object is 'converted' into voltage induced on the converter coil). This voltage gives rise to a variation of current in the MR damper control coil (receiver), and of the force generated by the damper. Typically, MR dampers are not directly activated by output voltage from the converter, but the voltage signal is first conditioned in the signal conditioning and processing system.

A block diagram of the MR dampers considered in this study is shown Fig. 1.

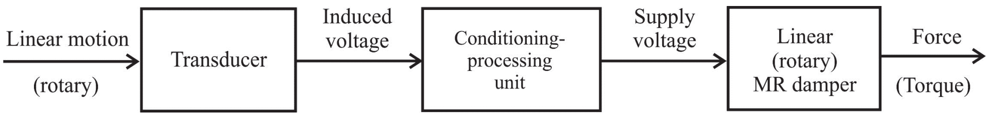

Fig. 1. Schematic diagram of energy harvesting in the MR damper

2. Structure design

The structure of the linear MR damper with energy harvesting capability is shown in Fig. 2. The device consists of a linear MR damper (1–7) connected to a linear electromechanical transducer (9–15) via a connecting lid (8). The MR damper incorporates a piston (4, 5) housing a control coil (6) and powered via a signal conditioning and processing unit (13). A magnetic field in the damper, induced by current flowing through the control coil, causes

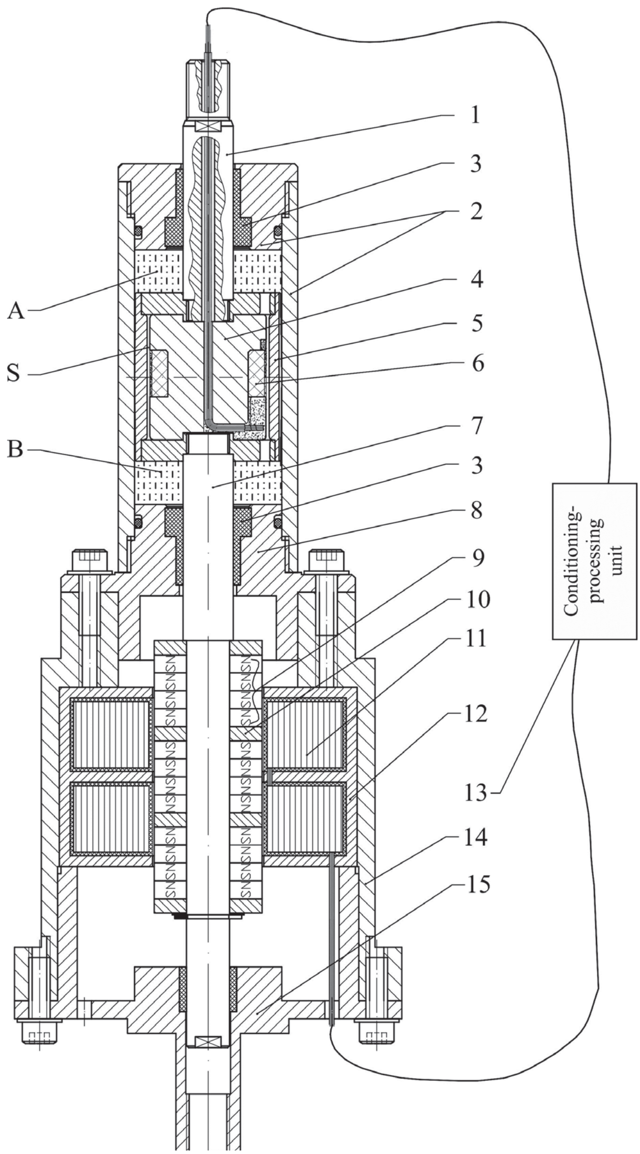

Fig. 2. Structure of a linear MR damper with energy harvesting capability: 1 – piston rod; 2 – damper housing; 3 – sleeve; 4 – piston core; 5 – piston ring; 6 – damper coil; 7 – transducer stem; 8 – connecting lid; 9 – permanent magnets; 10 – pole pieces; 11 – transducer coil; 12 – transducer coil housing; 13 – signal conditioning-processing system; 14 – transducer frame; 15 – transducer cover; S – slit, A, B – space filled with MR fluid

the MR fluid viscosity in the slit (S) to change, thus enabling the control of the MR fluid flow rate from the chamber (A) to (B) and in the opposite direction. There are piston rods on both ends of the piston and the rod (7) acts as the transducer stem supporting the permanent magnet systems (9), separated by pole pieces (10). The movement of the stem with the magnets inside the transducer coil (11) induces the electromotive force (emf) in the coil.

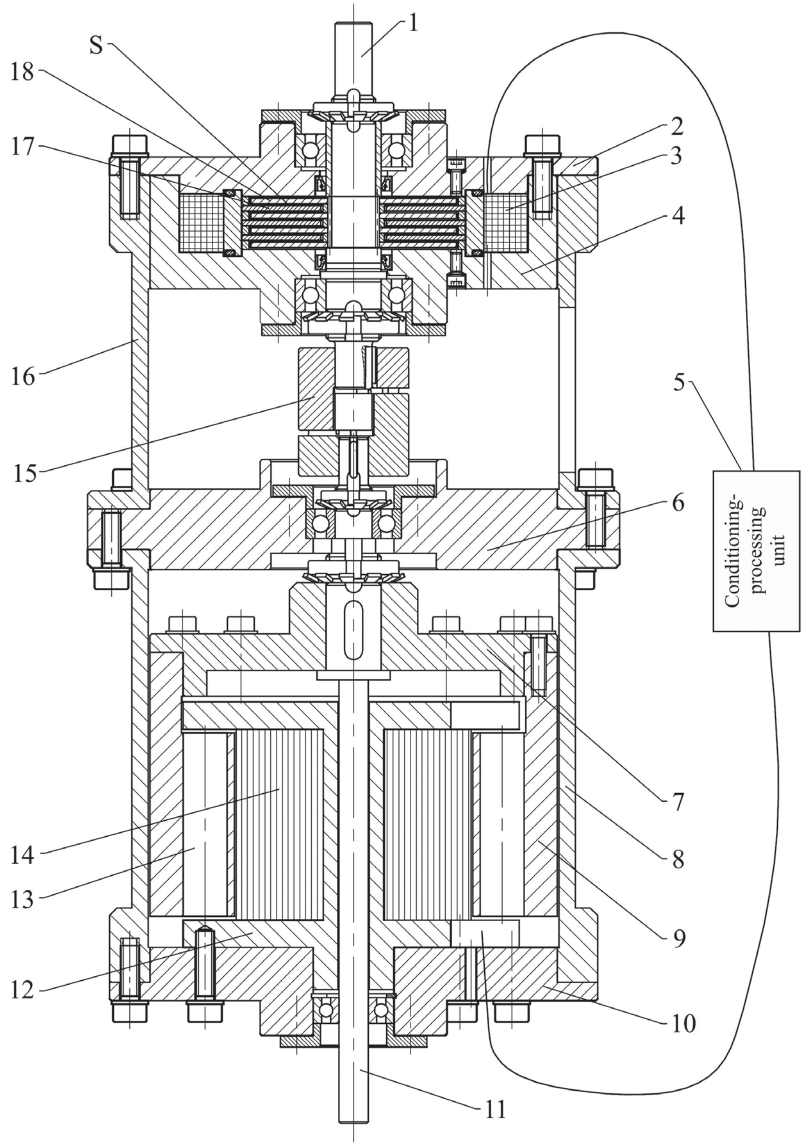

Fig. 3. Structure of a rotary MR damper with energy harvesting capability: 1 – shaft; 2 – damper lid; 3 – damper coil; 4 – frame; 5 – signal conditioning-processing system; 6 – plate; 7 – rotary frame; 8 – housing; 9 – sleeve; 10 – transducer cover; 11 – shaft in the transducer coil; 12 – pole pieces; 13 – permanent magnets; 14 – transducer frame; 15 – coupling; 16 – sleeve; 17 – immobile disc; 18 – rotating disc; S – slit

The design structure of the rotary MR damper with energy harvesting capability is shown in Fig. 3. The device consists of a rotary MR damper (1–4, 17, 18) connected to an electromechanical rotary transducer (6–14) via a sleeve (16). There is a set of rotating discs (18) supported on the shaft (1), a set of immobile discs (17) placed in the frame housing the control coil (3) and it is powered via a conditioning system (5). The magnetic field generated by current flowing through the coil causes the MR fluid viscosity in the slit S to change, thus enabling the control of the rotating discs' movement with respect to the immobile discs. The shaft in the damper is connected to the shaft in the transducer coil (11) via a coupling (15) and it supports the rotating frame (7) with the sleeve (9) on which the permanent magnets are arranged. There is a coil (14) in the notches on an immobile pole section (12) with radial incisions. When the magnets rotate, an electromotive (emf) force is induced in the transducer coil (14).

The engineered devices are shown in Fig. 4 and Fig. 5.

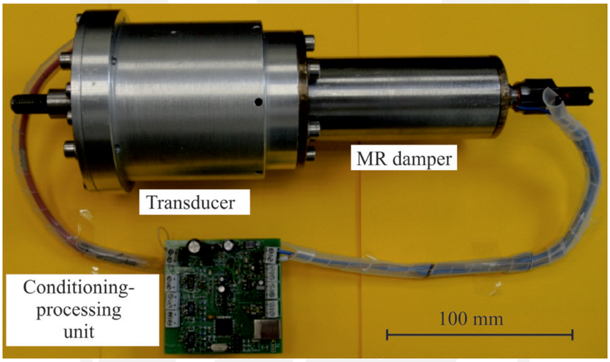

Fig. 4. Linear MR damper with energy harvesting capability – general view

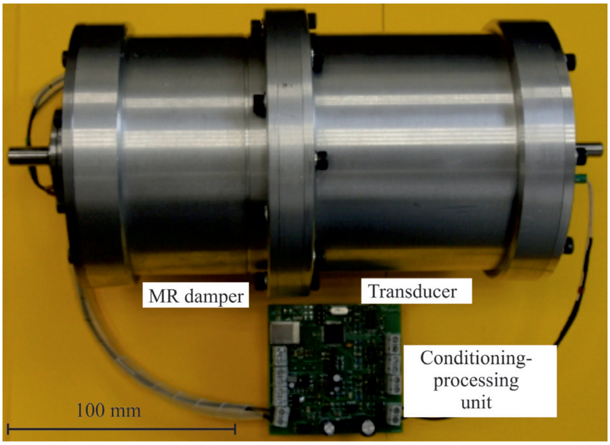

Fig. 5. Rotary MR damper with energy harvesting capability – general view

3. Characteristics

The engineered MR dampers were then subjected to tests in laboratory conditions to determine their basic operational characteristics.

The linear MR damper was tested on a testing machine under the applied sine excitations (displacement) of the piston. Tests were performed under an idle run when the coils in the transducer and the damper were not connected (1) or under load - in one case, the coils in the transducer and the damper were connected directly (2), in the other case, they were connected via the signal conditioning and processing system (3). The selected characteristics obtained under those operating conditions are shown in Fig. 6, giving the dependence between the force generated by the device on piston velocity and displacement under the applied excitations of amplitude 10 mm and frequency 3 Hz. These characteristics differ from that of a typical MR damper, the main reason being the cogging force appearing in the transducer [14]. The plots reveal that under loading condition 2, the maximal force generated by the device approaches 900 N, which can be related to 700 N (state 3) and about 500 N (state 1). The main reason for the force registered in state 3 being less than in state 2 is the voltage drop in the signal conditioning and processing unit [5].

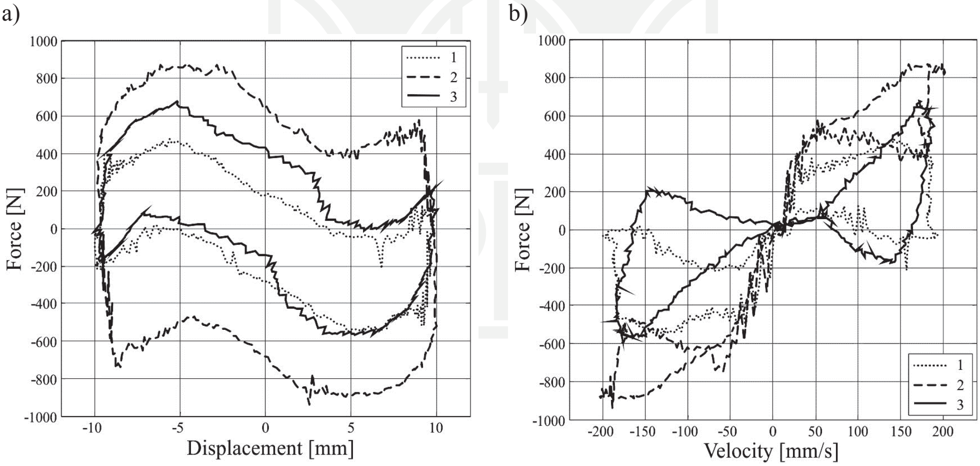

Fig. 6. Characteristic of a linear MR damper with energy harvesting capability: a) force vs displacement, b) force vs velocity

The rotary MR damper was subjected to laboratory tests on the test facility engineered specifically for the purpose of the research program [13]. The damper was tested in the direct powering mode only, at a rotational speed in the range 0–250 rpm. Selected characteristics of the MR device are shown in Fig. 7, giving the plots of voltage *U*, current *I* in the MR damper control coil and the torque *T* generated by the damper in the function of rotational speed. Of particular interest are changes in the torque generated by the damper, the contribution of the clogging moment being far from minor [15] and its decreasing with increasing rotational speed.

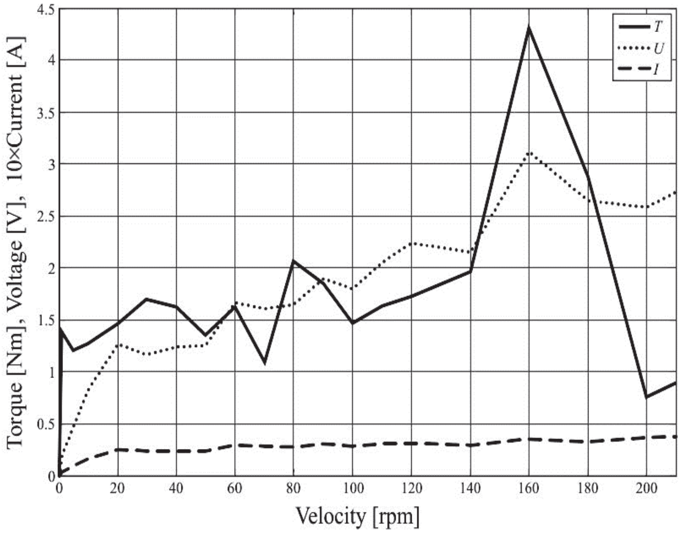

Fig. 7. Characteristic of a rotary MR damper with energy harvesting capability: voltage, current and torque vs velocity

4. Conclusions

The prototype designs of MR dampers with energy harvesting capability are described based on data provided in patent applications. Laboratory tests have revealed the need for further improvement of the devices and further research work has been now undertaken.

As regards the vibration transducers, their capacity will be enhanced, their size reduced and the cogging force/cogging moment will also be reduced. The signal conditioning system will be modified, which will involve an output voltage increase and reduction of the size of the device, as the transducer is planned to be integrated with the MR damper within a single housing.

The results of testing done on a rotary MR damper with energy recovery capability have revealed the need to change the structure design of the rotary generator such that the position of permanent magnets and that of the coil assembly should be reversed, the permanents magnets should be placed inside immobile coil assembly.

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