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TEST BED FOR ELECTROMAGNETIC GENERATORS POWERING MR ROTARY DAMPERS

SUMMARY

A laboratory test bed for testing electromagnetic generators to power rotary magnetorheological (MR) dampers is described in this paper. The construction of the rotary MR damper and the electromagnetic generator are presented. The goal of experiments on the test bed was to determine the characteristics of the generator acting as the source of energy for the damper and the results are discussed.

***Keywords**: electromagnetic generator, MR rotary damper*

STANOWISKO DO BADAŃ ELEKTROMAGNETYCZNYCH GENERATORÓW ZASILAJĄCYCH OBROTOWE TŁUMIKI MR

W artykule opisano stanowisko laboratoryjne do badań generatorów elektromagnetycznych dla obrotowych tłumików magnetoreologicznych (MR). Przedstawiono budowę zastosowanego obrotowego tłumika MR i generatora elektromagnetycznego. Omówiono wyniki eksperymentów przeprowadzonych na stanowisku, których celem było wyznaczenie charakterystyk generatora stanowiącego źródło energii elektrycznej dla tłumika.

***Słowa kluczowe**: generator elektromagnetyczny, obrotowy tłumik MR*

1. INTRODUCTION

Studies on obtaining energy from various sources, and its conversion to be used in powering equipment led to the birth of a new branch of science, called energy harvesting. One of the applications of energy recovery are modern sensors which do not require an external supply of energy.

This paper deals with the acquisition of mechanical energy from a rotating object and its conversion into electrical energy to feed an actuator in rotary motion. The rotating object is the source of mechanical energy, whereas the electrical energy generated is received by a rotary MR damper. Mechanical energy is converted into electrical energy by an electromagnetic generator. The generator's role is "to transform" the motion of the rotating object into electromagnetic induction force, which causes electric current to flow in the damper coil. The flow of current generates a magnetic field, which controls the damper's load torque. A schematic diagram of such a system is shown in Figure 1.

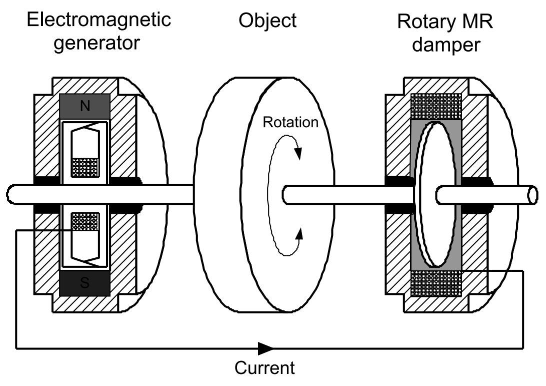

Fig. 1. Energy harvesting system: rotating object – electromagnetic generator – MR rotary damper

Descriptions of such systems, can be found in the literature: for instance, vibration reduction systems with an electromagnetic generator and a linear MR damper (Choi *et al.* 2007, Sapiński 2009, Sapiński *et al.* 2009).

In this field, patents were also granted on vehicle suspension control (Korea), an intelligent passive system for a land structure (Korea) and a magnetic generator for self-powered equipment (USA).

This paper describes a laboratory test bed designed and built for studies on newly designed electromagnetic generators for rotary MR dampers. The results of the experiments, whose aim was to determine characteristics of the generator supplying electrical energy to the damper, are discussed.

2. TEST BED DESCRIPTION

A schematic diagram and view of the test bed are shown in Figure 2. The electromechanical part consists of: a servomotor (with controller) (1), clutch (2), bearing (3), spring (4), rotary disk (5), belt transmission (6), MR rotary damper (7), encoder (8), beam load cell (9) and electromagnetic generator (10).

The driving motor shaft (1) is connected via an Oldham clutch (2) with a shaft set in a bearing (3). One end of the spring element (4) of specified stiffness is connected to the shaft, whereas the other end is attached to the bushing fixing the spring element. The bushing is connected to a rotary disk (5). Together the disk, the bushing and the spring element constitute a mechanical system with one degree of freedom and a specified inertia moment.

On the bearing-mounted shaft, to which the disc is attached, is the driving wheel of the belt gear (6), whose transmission ratio is 3.6. The driver wheel is attached to the electromagnetic generator (10). The generator is mounted in a support structure.

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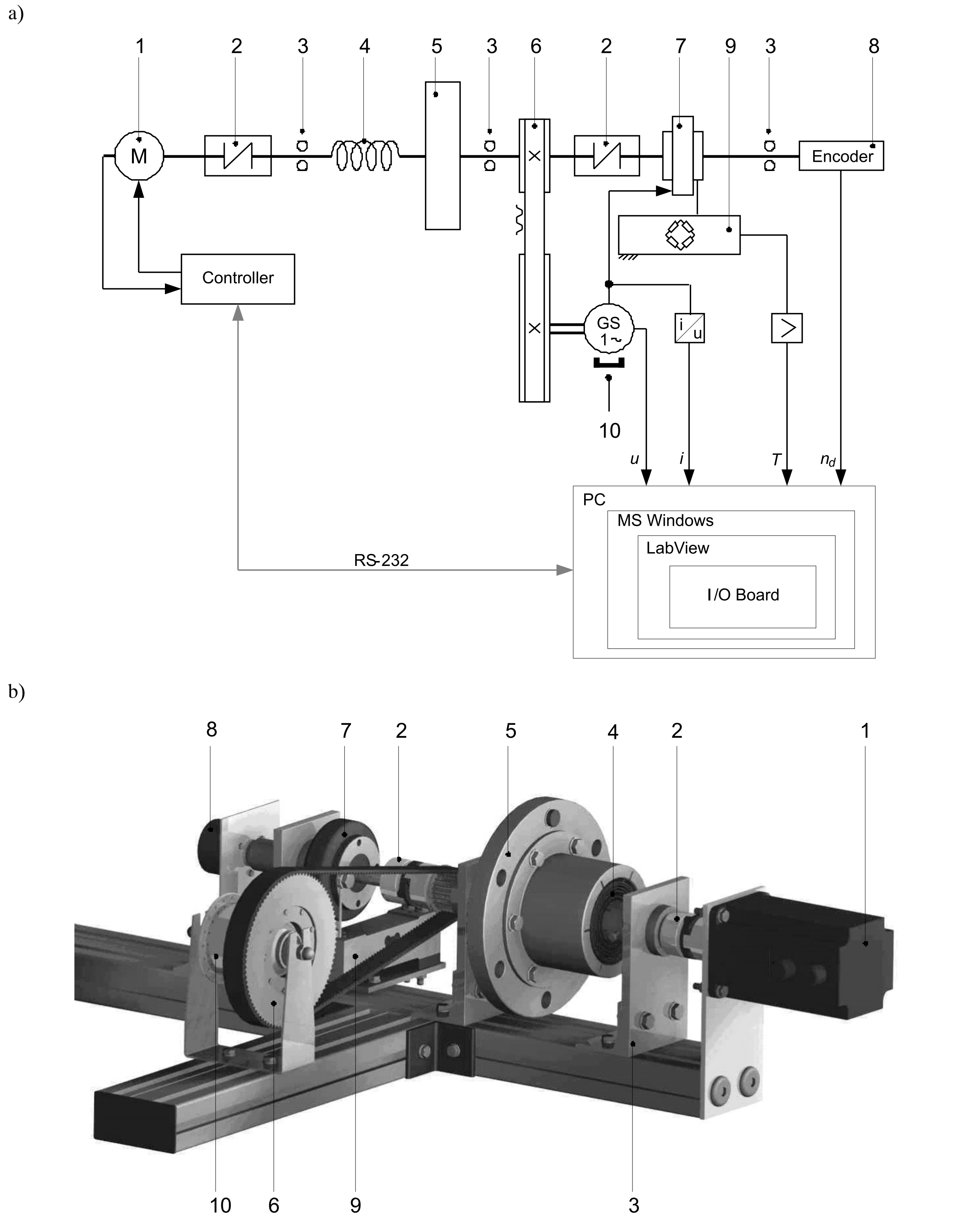

Fig. 2. Test bed: 1 – servomotor, 2 – clutch, 3 – bearing, 4 – spring, 5 – rotary disk, 6 – belt transmission, 7 – MR rotary damper, 8 – encoder, 9 – beam load cell, 10 – electromagnetic generator. Schematic diagram (a), general view (b)

The shaft on which the driving wheel is mounted is connected via the Oldham clutch to the shaft of the MR damper (7). The damper housing attached to the free end of the beam load cell (9). An incremental encoder (8) is connected to the damper shaft.

Structure of the MRB 2107-3 damper produced by Lord Co. (Lord Co. 2009) used on the test bed is shown in Figure 3. The damper consists of stationary housing (1) in which the shaft (6) together with the disc (3) attached to it and the coil (2) are situated. The disc fixed to the shaft rotates against the housing. The internal space of the housing is filled with the MR fluid (4). The damper works by changes in the viscosity of the fluid inside the housing caused by the changes of the magnetic field induced by the electric current in the coil. The damper's technical data are specified in Table 1. The dependence of the damper's load torque on the current in the coil is shown in Figure 4 in accordance with the manufacturer's data (Lord Co. 2009).

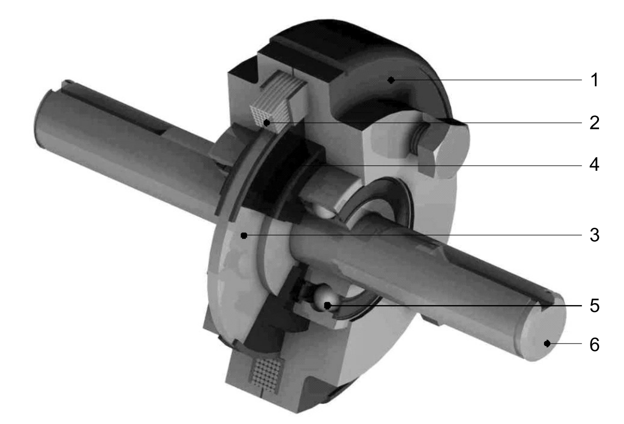

Fig. 3. Structure of the MR 2107-3 damper: 1 – housing, 2 – coil, 3 – disk, 4 – MR fluid, 5 – bearing, 6 – shaft

Table 1

Technical data of the MR 2107-3 damper

Diameter	92.2 mm
Length	36.6 mm
Weight	1.41 kg
Max. on-state torque	5.6 Nm
Min. off-state torque	< 0.3 Nm
Max. current	1 A
Resistance	8 Ω
Inductance	150 mH
Maximum revolutions	1000 rpm
Operating temperature range	(–30, 70) °C

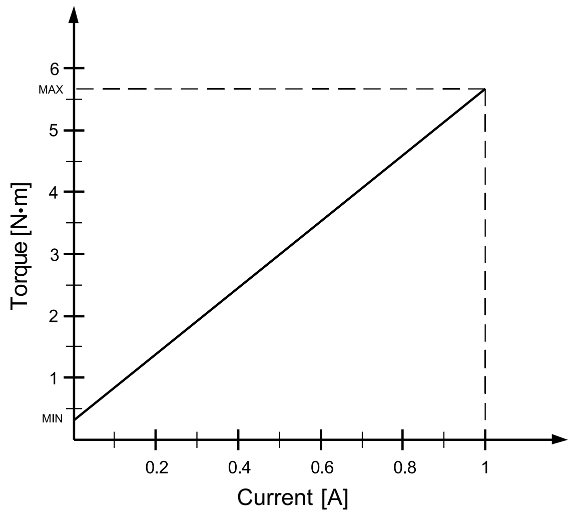

Fig. 4. Torque vs. current for the MR 2107-3 damper

The construction of the Shimano alternating voltage generator DH-3N30 (Shimano 2009) is shown in Figure 5. The generator's cylindrical rotor (1) consists of 28 permanent magnets (2) arranged on the circumference so that they form 14 pairs of magnetic poles. The rotor is mounted on the generator axle via ball bearings (5). The stator comprises 14 rectangular frames (3) made of ferromagnetic material. The frames are arranged radially and permanently fixed to the axle. A coil (4) is located inside the frames. The rotor's rotating motion relative to the stator generates a time-varying magnetic field, which induces voltage in the coil. The technical data of the DH-3N30 generator are specified in Table 2.

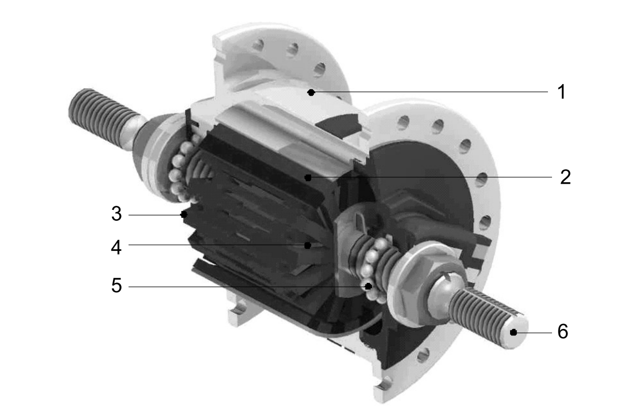

Fig. 5. Structure of the DH-3N30 generator: 1 – rotor, 2 – magnet, 3 – frame, 4 – coil, 5 – bearing, 6 – shaft

Table 2

Technical data of the DH-3N30 generator

Rated power	3 W
Rated voltage	6 V
Nominal rotational speed	100 rpm
Coil resistance	2 Ω
Coil inductance	30 mH

An HPB synchronous servomotor ESM 85 was mounted in the test bed as a driving motor, interfaced with the controller ESD 04 (HPB Industry 2009). Data are exchanged between the controller and the PC via an RS 232 communication port and a dedicated HPB software Motion View 2.13.

The following magnitudes can be measured on the test bed:

– voltage provided by the generator (u),
– electric current in the damper's control coil (i),
– damper's load torque (T),
– rotational speed of the shaft on which the damper is mounted (n_d).

Electric current was measured with a current-voltage transducer (i/u). The load torque of the damper T, was determined by the measurement of the force, using a BCM Sensor Technologies 1662 beam load cell (BCM Sensor Technologies 2009). The beam's measurement range is 500 N. The beam is interfaced with a tensometric amplifier based on an Analog Devices AD627 circuit (Analog Devices 2009).

The damper's rotational speed (n) was measured using an Omron E6C2-CWZ6C-360 incremental encoder (Omron 2009) with a resolution of 360 pulses per revolution and a maximum permissible speed of 6000 rpm.

The measurement data are acquired with a PC equipped with a National Instruments DAQCard-6036E AD/DA card (National Instruments 2009), operating in LabView environment (ver. 8.5) under MS Windows. The quantities measured with the AD/DA card are converted into a voltage signal within a range of –10 V to 10 V.

The test bed also allows studies concerning the efficiency of the mechanical-to-electrical energy conversion in the designed generators.

3. EXPERIMENTS

The goal of the experiments was to determine the characteristics of the DH-3N30 generator and the possibility of supplying power to the MR rotary 2107-3 damper. The characteristics were studied by increasing the motor's rotational speed by 100 rpm increments in the range from 100 to 1000 rpm. Taking into account the transmission ratio, generator rotational speeds ranges from 28 to 280 rpm.

In the first phase, the characteristics of the generator on idle were examined (with the output circuit open). Selected measurement results are given in Figures 6 and 7. Figure 6 shows the dependence of the generator's voltage at 55, 110 and 220 rpm as a function of normalized time t/T (relative to a period of voltage variation at a given speed). The periods were T = 0.08 s, T = 0.04 s, T = 0.02 s, respectively. Figure 7 shows the dependence of the generator's rms voltage on the rotational speed. The rms voltage changes in the range from 3 to 30 V and depends linearly on the speed.

In the second phase, the generator's characteristics were studied under load conditions. First, the generator was loaded with resistances R of 8, 25, 50, 100 and 200 Ω, and next with the MR rotary 2107-3 damper control circuit (the resistance and induction load with parameters specified in Tab. 1).

Selected measurement results for generator speeds of 55, 110 and 220 rpm are shown in Figures 8 and 9. Figure 8 shows the voltage-time variation for the generator loaded with a resistance, whereas Figure 9 shows the voltage-time and current-time variations for the generator loaded with the MR damper control circuit. The delay in the current relative to the voltage variation seen in Figure 9 is associated with the character of load on the generator.

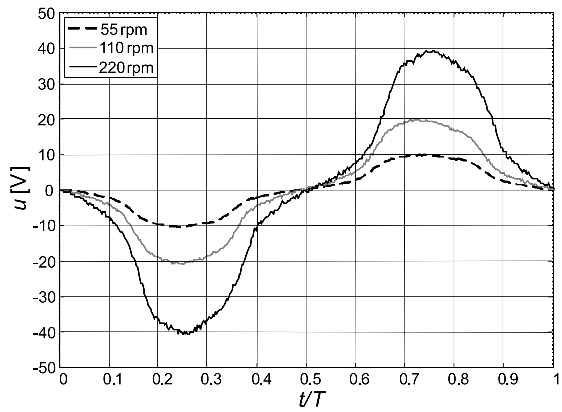

Fig. 6. Voltage vs. normalized time

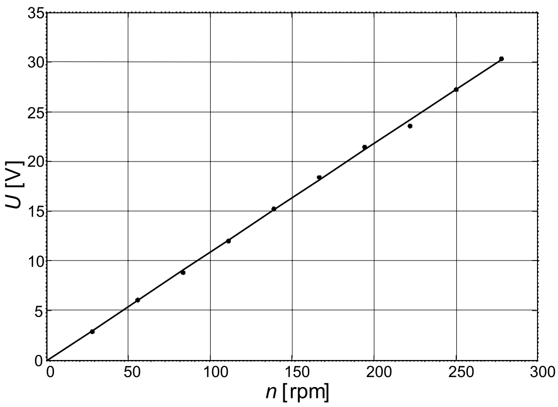

Fig. 7. RMS voltage vs. rotational speed

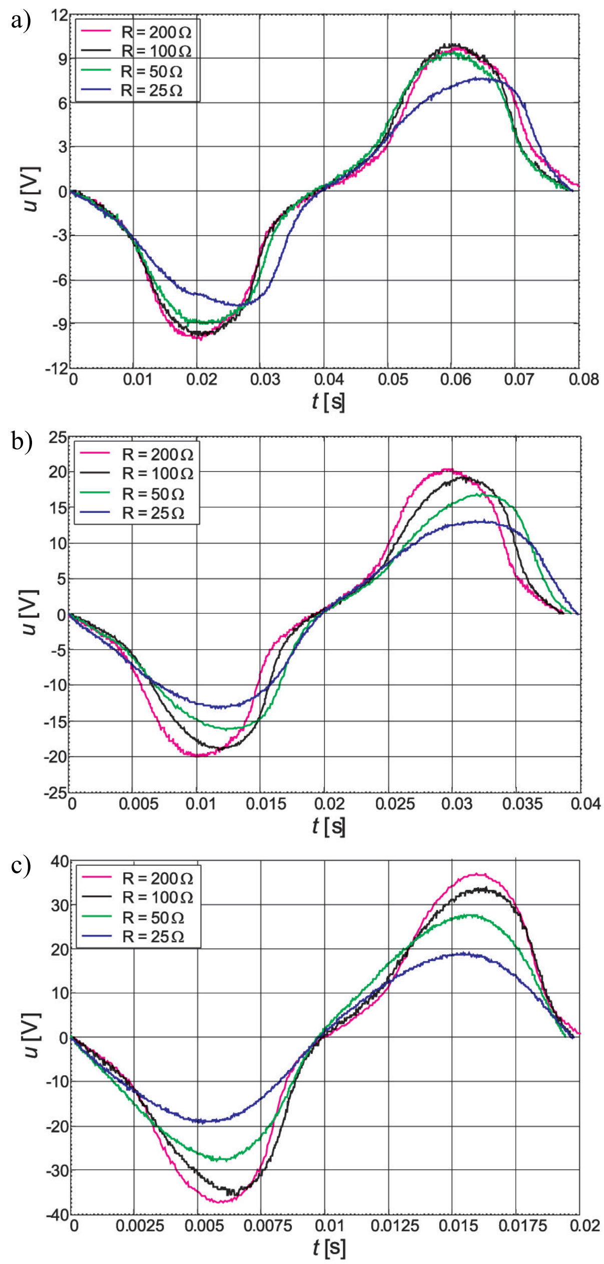

Fig. 8. Voltage vs. time: a) 55 rpm; b) 110 rpm; c) 220 rpm

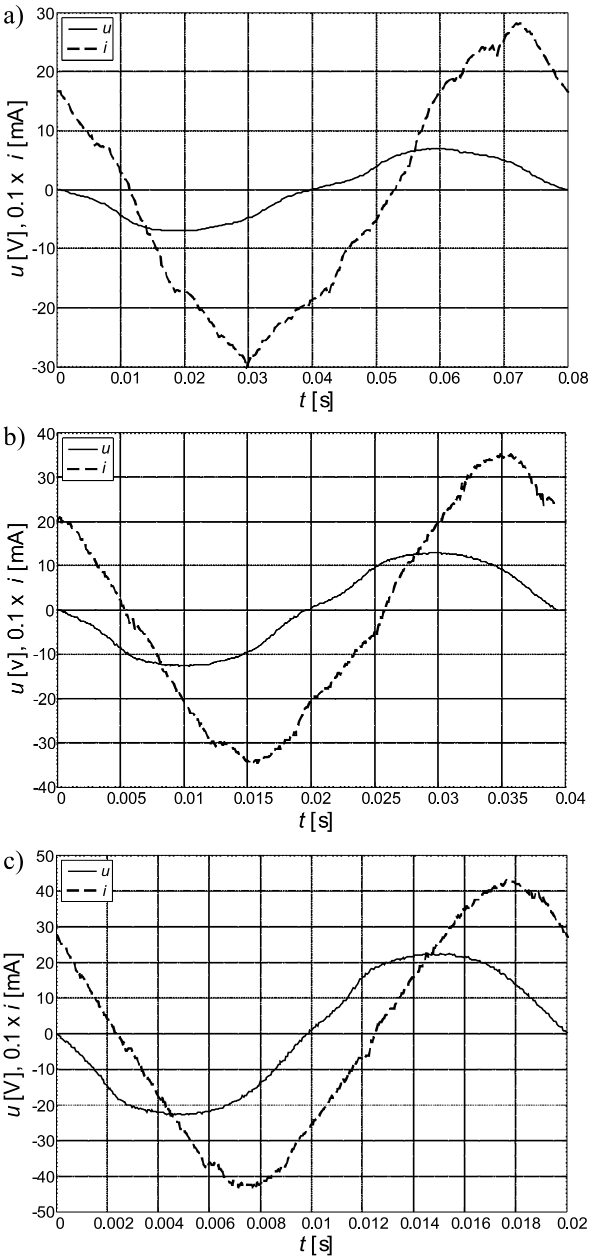

Fig. 9. Voltage and current vs. time: a) 55 rpm; b) 110 rpm; c) 220 rpm

Figure 10 shows the dependence of the rms voltage on the rotational speed. For the speeds studied, the rms voltage U varies from 2 to 4.9 V for resistance loads of $R = 8\ \Omega$; and from 2.9 to 28 V for $R = 200\ \Omega$, whereas for the generator loaded with a resistance-induction (control coil) the voltage ranged from 2.3 to 20 V.

Figure 11 shows the dependence of rms current I on the rotational speed for the generator loaded with the resistance or the damper's control circuit. The characteristic of the generator loaded with the control coil (Fig. 11) implies that the current flowing in the coil at a maximum studied speed of 280 rpm allows for the attainment of 0.3 of the maximal damper's load torque (Fig. 4).

Figure 12 shows the real power consumed by the load as a function of the rotational speed. The highest real power attained at the resistive load of $R = 50\ \Omega$ was 9 W, whereas for the generator loaded with a control coil, 4.5 W.

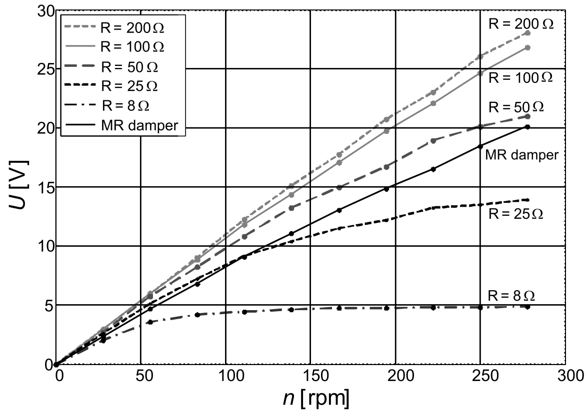

Fig. 10. RMS voltage vs. rotational speed

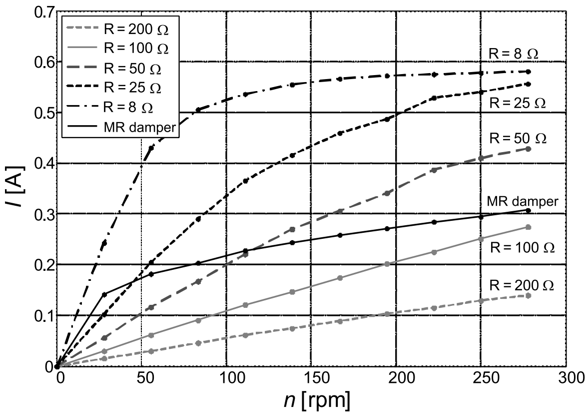

Fig. 11. RMS current vs. rotational speed

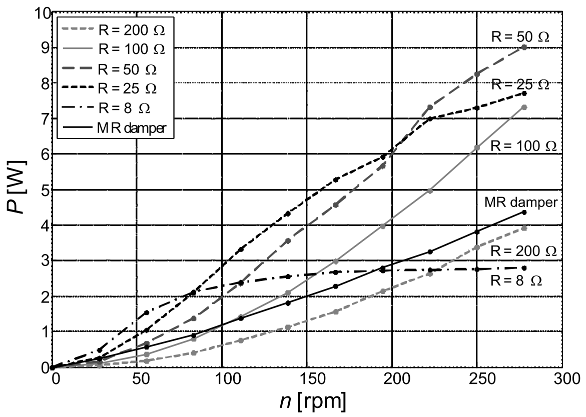

Fig. 12. Real power vs. rotational speed

4. SUMMARY

This paper presents a laboratory test bed for studies of electromagnetic generators powering MR rotary dampers. The construction of the generator and the damper studied is described. The paper discusses the results of the experiments conducted on the test bed where the generator's characteristics were determined.

The studies showed that for the generator's output loaded with the damper control circuit, the maximum RMS current is 0.3 A (Fig. 11). This value, according to the manufacturer's data (Fig. 4), makes it possible to attain a load torque equal to 30% of the maximal load torque of the MR rotary 2107-3 damper.

In the next phase, the study will focus on the energy harvesting system (Fig. 1), where the mechanical system studied will be a system with one degree of freedom (a disc with a spring element) (Fig. 2).

Acknowledgements

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