JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
59, 1, pp. 173-178, Warsaw 2021
https://doi.org/10.15632/jtam-pl/130633

SHORT RESEARCH COMMUNICATION

PRELIMINARY STUDY ON A VACUUM PACKED PARTICLES TORSIONAL DAMPER

Robert Zalewski, Dominik Rodak

Warsaw University of Technology, Institute of Machine Design Fundamentals, Warsaw, Poland

e-mail: robert.zalewski@pw.edu.pl; dominik.rodak@pw.edu.pl

The paper presents a prototype of an innovatory controllable torsional damper. The device is composed of Vacuum Packed Particles. Such structures are made of granular materials placed in a hermetic soft encapsulation. Generating so called underpressure inside the system changes global dissipative properties of the granular structure. The partial vacuum value is a convenient way to control physical properties of the granular structure. The authors introduce an original prototype of a torsional vibration attenuator. In the experimental part, preliminary experimental results are presented and discussed. To capture the real response of the device, a Bouc-Wen rheological model is adopted.

Keywords: Vacuum Packed Particles, torsional damper, experimental research, Bouc-Wen model

1. Introduction

Contemporary vehicles are in the vast majority objects intensively exploited, which makes their individual systems highly exposed to damage and breakdowns. The extremely loaded component of every vehicle is obviously the power unit and its crank-piston assembly components, the gearbox and engine equipment. The source of main loads acting on the assembly are gas and inertia forces arising during combustion of the fuel-air mixture, resulting from masses set in reciprocating or rotary motion (Singh *et al.*, 2015). The nature of these forces is periodic, and their frequency depends directly on the rotational speed of the motor shaft. Three basic types of vibrations in the crankshaft structure can be distinguished (Ivanovic and Popovic, 2007): transverse vibrations, longitudinal and torsional vibrations – caused by torsional deflections of the cranks.

Experimental research (Bzura, 2012) indicates that only torsional vibrations cause a serious threat to the operation of engines and crankshafts. To minimize the impact of such a phenomenon, torsional vibration dampers are commonly applied.

In this paper, the authors introduce an original and innovative prototype of a semi-active torsional vibration damper. The proposed device is composed of Vacuum Packed Particles (VPP) (Bartkowski *et al.*, 2019). It is a structure made of a granular material placed in a soft and airtight encapsulation. By applying partial vacuum to the system, the loose grains exhibit semi-solid like behavior (Loeve *et al.*, 2010). The global features of VPP are similar to magnetorheological fluids and elastomers (Zalewski and Pyrz, 2013). The underpressure, which is defined as a difference between the atmospheric and internal pressure, influences “intergranular” forces. Increasing the value of partial vacuum causes reorganization of particles resulting in compaction of grains. Additionally, higher underpressure values correspond to higher values of friction forces acting in the contact points between particles. Such a mechanism enables convenient and real time changing the physical (mechanical) properties of VPP. In consequences, VPP may be placed among the so called “smart materials” group.

Typical experimental results carried out for a VPP torsional damper prototype are presented and discussed. The influence of the underpressure value on recorded damping characteristics is emphasized. To capture the real behavior of the investigated device, a Bouc-Wen rheological model is adopted. The verification of experiments and numerical simulations is presented. The paper is concluded with a summary and proposition of further perspective objectives.

2. Experiments

The introduced in the paper device is depicted in Fig. 1. The main parts of it are the outer (1.1) and inner (1.2) drivers. They define a workspace for a granular material. The workspace is closed with two silicone membranes (1.3) sealed between drivers (1.1, 1.2) and flanges (1.5, 1.6) allowing for generating partial vacuum inside the system. An input hollow shaft (1.4) is fastened to the inner driver (1.2) by a clamping sleeve. The air is removed from the system by a vacuum pump through the input shaft. The partial vacuum is generated thanks to special holes hollowed out in the inner driver (1.2). The input shaft and the inner driver are sealed with a simmering. The inner driver and the input shaft are centered with the rest of the damper by a flange (1.5). Then, the torque is transferred through the VPP material to the outer driver, which is fixed to the flange (1.6). The output shaft is mounted to the damper with a clamping sleeve (1.7).

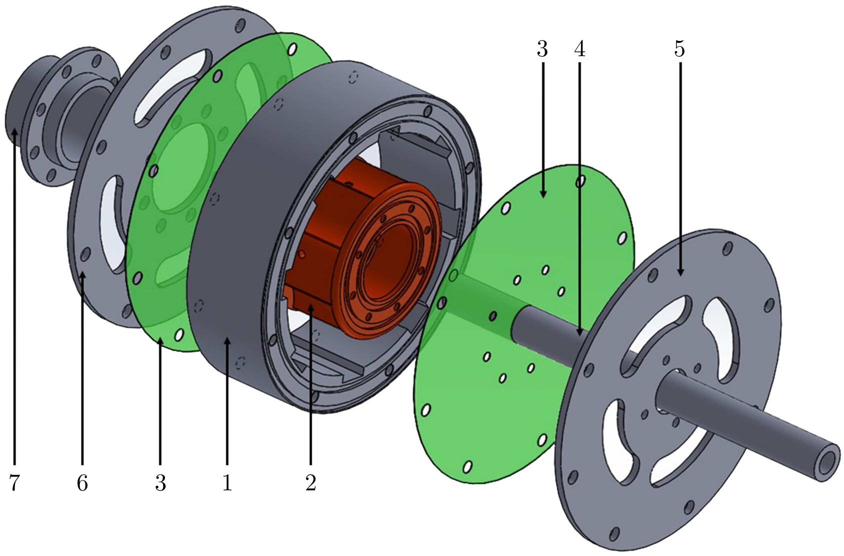

Fig. 1. Scheme of a VPP torsional damper

Preliminary quasi-static experiments were carried out on a test stand depicted in Fig. 2. In laboratory tests, the damper was tested in a constant range of torsion angles ($\pm 5^\circ$) limited by two pin limiters (2.5). The load was applied manually by the lever (2.6). The loading velocity was equal to 0.5 deg/s that gave the strain rate of $0.0014\,\mathrm{s}^{-1}$ to avoid inertial effects. The experiments were conducted for different values of underprerssure given by the vacuum pump (2.2). The input side of the damper was fixed in the lower plate of the mounting set. The output side was connected to the measuring assembly with a driving shaft. The torsion angle and torque values were measured by an incremental encoder (2.10) and torque sensor (2.8), respectively. The encoder and torque sensors were connected to each other with couplings (2.7, 2.9). The experimental data was recorded by a universal acquisition card (2.3) connected to a PC. The signal from the torque sensor had to be amplified by a signal amplifier (2.4).

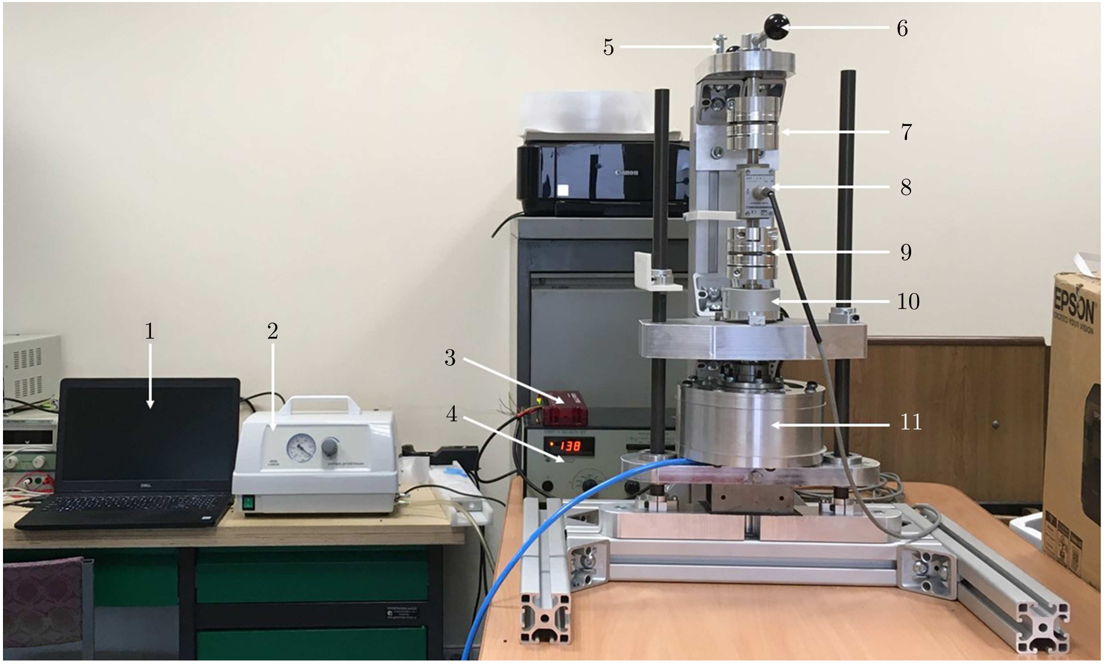

Fig. 2. Experimental setup

Damping characteristics (torque vs. rotation angle) were captured for four various underpressure values (0.0; 0.01; 0.02 and 0.05 MPa). The experimental results are depicted in Fig. 3.

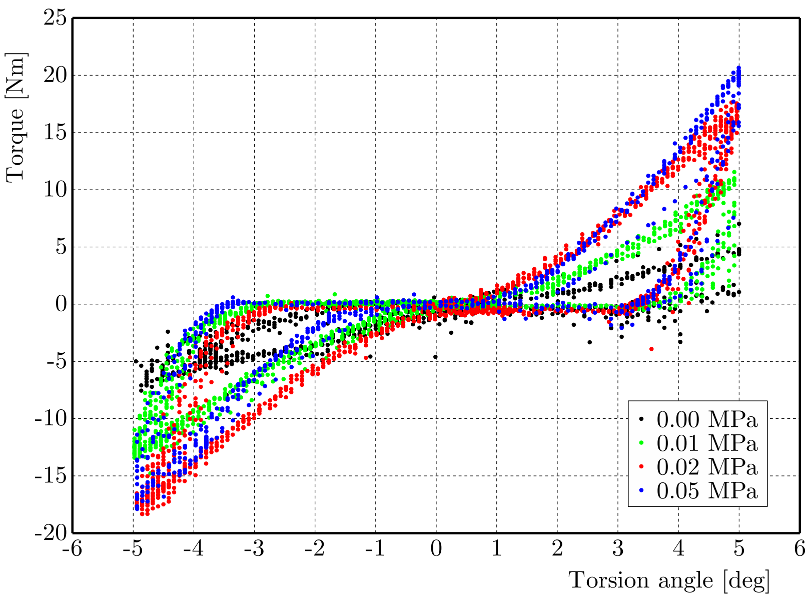

Fig. 3. Damping characteristics for various underpressure values

The influence of the partial vacuum value on damping properties of the investigated device is evident. Higher values of the underpressure increase dissipative properties of the device. For example, the torque corresponding to the maximal rotation angle for 0.05 MPa underpressure is about three times higher than that for the zero state (atmospheric pressure).

3. Bouc-Wen model

The Bouc-Wen model (Wen, 1976) describes the behavior of various devices such as magnetorheological fluids (MRF), magnetorheological elastomers (MRE) (Graczykowski and Pawłowski, 2017) or VPP linear dampers (Bartkowski *et al.*, 2019). It consists of a damping element, elastic element and the element responsible for generating hysteresis loops placed in parallel. The Bouc-Wen model is an effective theoretical formulation that enables one to reflect the recorded hysteresis loop of the investigated device. The equation describing the dissipative force that a damper can generate is as follows

$$M(t) = \ddot{\phi} + 2\xi\omega_n\dot{\phi} + \alpha\omega_n^2\phi + (1-\alpha)\omega_n z \tag{3.1}$$

and the variable z, which is responsible for the shape of the hysteresis loop, is expressed as follows

$$\ddot{z} = -\gamma z|\dot{\phi}||z|^{n-1} - \beta\dot{\phi}|z|^n + A\dot{\phi} \tag{3.2}$$

where: $M(t)$ is the force function, ξ – linear viscous damping ratio, α – rigidity ratio, ω_n – pseudo-natural frequency of the system, n – degree of the polynomial, γ, β, A are parameters of the hysteresis loop shape.

The model includes seven material parameters that must be identified based on the experimental results.

Based on the experimental results, a preliminary Bouc-Wen model identification process was carried out. Figure 4 reveals the verification of real and numerical results. The captured values of the model parameters are presented in Table 1.

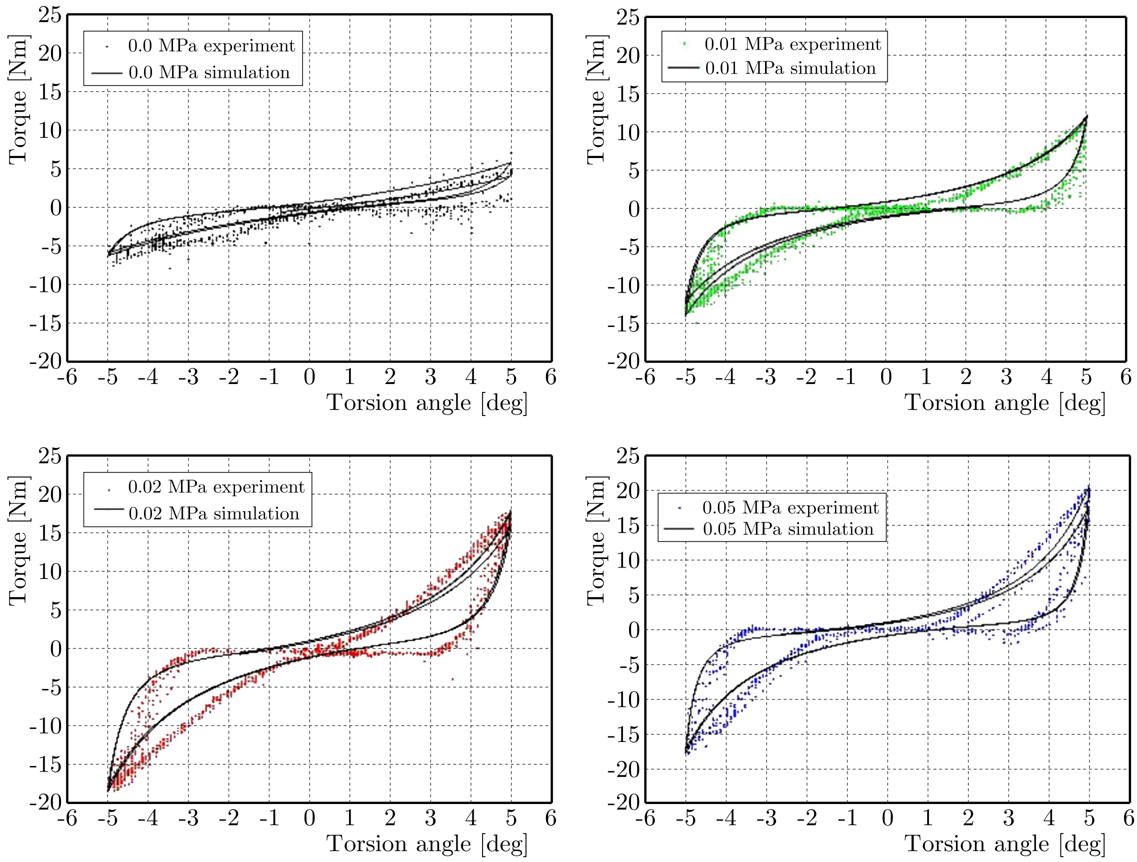

Fig. 4. Experimental and numerical data

Table 1. The model parameters for various values of the underpressure

p	ω_n	ξ	α	γ	A	β	n
0	0.85	3	10.79	28	1.64	−45	1.02
0.01	0.045	30	709.86	9	32.97	−15	1.4
0.02	0.0121	300	3755.27	9	106.47	−15	1.29
0.05	0.0088	300	4148.3	8	144.74	−15	1.3

At the preliminary stage of investigations, the authors did not apply sophisticated methods for the model calibration process. The values of the Bouc-Wen model parameters were captured using the simplest Monte-Carlo method. The range of variations in the model parameter values was adopted based on the data presented in (Zalewski and Szmidt, 2014). The main objective of the modeling section at this stage of research was to confirm the ability to capture the real response of the VPP torsional damper prototype with the Bouc-Wen rheological model. The convergence between the experimental and numerical data encourages the authors to carry out further research on innovative granular dampers.

4. Conclusions

In the paper, the authors presented a novel and original design of a semi-active, controlled by the value of underpressure, Vacuum Packed Particles torsional damper. Analyzing the data presented in Fig. 4, relatively large differences were noted in the responses of the numerical model and experimental data. Nevertheless, the qualitative answers are quite comparable. This fact, in the authors opinion, confirms the reliability of the applied mathematical model. In order to apply the described prototype of the VPP torsional damper to improve real engineering structures, an appropriate methodology for controlling the device response to external loading should be additionally developed. To propose an efficient controlling strategy, it is crucial to determine universal relationships between the Bouc-Wen model parameters values and the value of the control factor which, in the case of the VPP torsional damper, is the value of partial vacuum generated inside the device.

References

1. Bartkowski P., Zalewski R., Chodkiewicz P., 2019, Parameter identification of Bouc-Wen model for vacuum packed particles based on genetic algorithm, *Archives of Civil and Mechanical Engineering*, DOI:10.1016/j.acme.2018.11.002

2. Bzura P., 2012, Reliability model of the crankshaft – piston assembly, *Journal of KONES Powertrain and Transport*, **19**, 1

3. Graczykowski C., Pawłowski P., 2017, Exact physical model of magnetorheological damper, *Applied Mathematical Modelling*, DOI: 10.1016/j.apm.2017.02.035

4. Ivanovic G., Popovic P., 2007, Reliability design of power transmission, *Journal of KONES Powertrain and Transport*, **14**, 2

5. Loeve A.J., Van de Ven O.S., Vogel J.G., Breedveld P., Dankelman J., 2010, Vacuum packed particles as flexible endoscope guides with controllable rigidity, Granular Matter, **12**, 6, 543-554

6. Singh S.S.K., Abdullah S., Mohamed N.A.N., 2015, Reliability analysis and prediction for time to failure distribution of an automobile crankshaft, *Eksploatacja i Niezawodność – Maintenance and Reliability*, **17**, 3

7. Wen Y.K., 1976, Method for random vibration of hysteretic systems, *Journal of Engineering Mechanics, Division*, *ASCE 102*, EM2, 193-199

8. Zalewski R., Pyrz M., 2013, Experimental study and modeling of polymer granular structures submitted to internal underpressure, *Mechanics of Materials*, DOI:10.1016/j.mechmat.2012.11.002

9. Zalewski R., Szmidt T., 2014, Application of Special Granular Structures for active damping of lateral beam vibrations, *Engineering Structures*, **65**, 13-2

Manuscript received March 27, 2020; accepted for print October 30, 2020