Application of Flat Controlled Damping Constructions for Vibroprotection of Elements of On-board Precision Equipment

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Abstract. In the paper the results of investigations of mechanical deformations and damping characteristics of flat elements with magnetosensitive material are presented. Normal and tangential parts of the resistance force, appearing at the impact of the external mechanical force both in periodical sinusoidal oscillations mode and at continuous shear in the damping element in the magnetic field are determined.

1. Introduction

The work of modern surface transport, aircrafts, missiles, ships and submarines, etc. is accompanied by vibrations and shocks, which are not only adversely affect the health of people, but also affect the work of the existing on-board equipment. Namely, because of compliance and big weight of construction elements of on-board equipment of the aircraft there is a wide range of resonant frequencies at which vibration increases tenfold. Beside this, the range of internal and external mechanical influences is changed, for example, because of imbalance of aircraft's propeller or "oblique blowing" when performing aircraft's evolutions. All this may lead to malfunction of the electronic equipment and, consequently, adverse and even catastrophic consequences [1, 2]. The currently used methods for transport protection from vibrations, performing important functions, however, due to increasing demands on the protection of technical equipment and precision electronic devices require upgrades and new solutions for the implementation of a more efficient and directional damping effects of various vibration types [3].

One of the promising methods for targeted reduction of vibration exposure on the object is its vibroisolation, in particular, with the use of viscous damping. This method finds new control features through the use of modern intellectual damping materials with electric and magnetosensitive nanofillers [4, 5]. In the electro-and magnetorheological materials (ERM and MRM) containing non-colloidal particles as the dispersed phase, under the influence of external fields a strong structuring of particles is observed. Thanks to it, the material exhibits elastic and viscoplastic properties according to the level of external influence. This allows one to control its damping characteristics specifically and reversibly (response time less than 10^{-3}s). It is known, that ERM and MRM are used as fluids for flow hydraulic systems and fluid dampers, squeeze dampers. [6-8], including ground transportation systems and precision instruments. However, they hold a limited impact, as they are used for one-way damping vibration exposure. In the real world of application of damping elements for the protection of on-board high-precision equipment from external vibrations or in the suspension system of land vehicles, unidirectional oscillations are very rare. Only single (due to the complexity of implementation) attempts are known to improve the construction of existing flow damping devices with ERM and MPM, providing the possibility for the reduction of vibration on an object in several directions. For example, a construction of a flow cylindrical damper with electrosensitive fluid is developed, on the inner stock of which radially arranged electrodes are set [9],

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ensuring the realization of the objective. In the present time there is a very urgent task of creating plane multi-purpose damping elements, in particular for vibration protection of circuits of the equipment on-board of the aircraft and other flying objects. The use of electro-or magnetosensitive materials and combined effects of the electric and magnetic fields will allow [10] to implement tuning parameters of the damping unit to multidirectional vibrations in flying objects, arising as a result of the effects of internal (engine) and external (the impact of air flow and temperature stress) sources.

2. Materials and equipment

The aim of this study is to investigate the damping response to vibration and mechanical effects of different types of flat elements containing controlled layers of magnetosensitive components [11] under the influence of the external magnetic field.

Experiments were performed using the damping element which is schematically shown in fig.1. The measuring cell is presented in the form of two parallel plates, which are placed between the magnetosensitive material. The diameter of plates is 20mm, the clearance between them is 0.7mm. The upper plate can perform a rotary tangential (horizontal) shift with the constant speed mode and with the sinusoidal oscillations. Furthermore, it can be moved in the vertical direction at a constant speed. For the experiments, a magnetosensitive material which contains insulating oil and 16.0% of complex filler from iron, chromium oxide CrO_2 and silicon oxide SiO_2 was used. The values of the induction of the constant magnetic field have been varied in all experiments up to the value of B=1T.

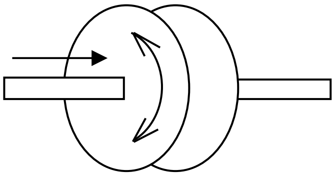

Figure 1. Scheme of damping element.

3. Experimental technique

In all modes of deformation the values of resistance force in a material to the shift of the upper plate F (normal F_N and tangential F_T components) were recorded. They were determined by pressure sensors on the top measuring plate of the experimental cell at material's shear. The impact on the shear force a shift of the external magnetic field was evaluated. The dependencies are presented in the form of specific values of force $F_{N,T}/S$, where S - area of the plate, i.e., normal τ_N and tangential τ_T values of shear stress on the magnetic field at various modes of deformation. Experiments were conducted in the following modes of vibrations on MRM:

1) Tangential sinusoidal vibration mode of the top plate at a constant frequency f=10Hz and strain amplitude γ_a in the range of 0.0001-0.1, corresponding to the range of amplitudes of a shear rate 0.0063-6.3s^{-1},

2) Tangential sinusoidal oscillation mode of the top plate at a frequency f=10Hz and strain amplitude γ_a=0.002 while continuously moving it vertically, which generates a compression to the material. The clearance d during 50s decreased from 0.7mm to 0.65mm with a corresponding relative deformation of the material $\varepsilon=\Delta d/d$ in the range of values 0-0.07.

3) Tangential shear mode of the top plate at a constant shear rate in the range of 0.01-1000s^{-1}.

4) Continuous vertical shift mode of the upper plate, wherein the clearance d during 50s decreased similarly to claim 2;

5) Continuous vertical movement mode of the upper plate (refer to claim 2) with a simultaneous tangential shear deformation at a constant shear rate of 10s^{-1}.

4. Results and discussion

Dependences of the shear stress τ_T vs. shear rate presented in Fig. 2a allow us to determine that with increasing the induction of the external magnetic field all the elastic and viscoplastic characteristics of the damping element increase sharply. First of all, limiting shear stresses, increasing which the plastic shift of the material appears, followed by a flow in the gap between the plates. It is characterized by the small range of relative deformations (less than 1%) and the growth of values τ_T in 3000 times in comparison with those without the field.

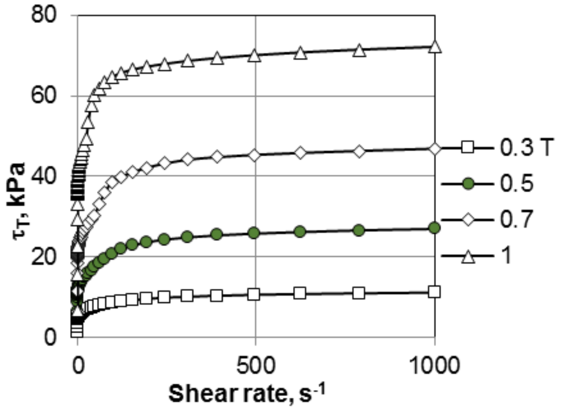

Figure 2a. Dependence of shear stress of MRM on shear rate in mode (3) at different magnetic field induction.

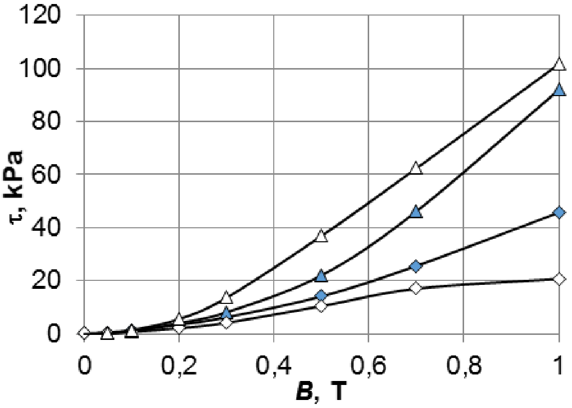

Figure 2b. Dependence of normal and shear stresses of MRM on magnetic field induction: open symbols – in mode (1), deformation amplitude – 0.011, filled symbols – in mode (3), shear rate – 11.5s^{-1}; rhombuses – τ_T, triangles – τ_N.

Normal shear stresses (fig. 2b) in the continuous deformation mode are practically independent of the shear rate in the range of shear rates about 30s^{-1}. At high shear rates, they increase in the magnetic field with induction of more than 0.1T. The normal stresses are approximately equal to the shear stresses in the range of the magnetic field up to 0.25T. At higher fields the normal stresses exceed the shear stresses, reaching values of 120kPa. It is established that in the regime of small forced sinusoidal oscillations and the tangential shear (corresponding to the viscoelastic response of the MRM) normal stresses τ_N are approximately equal to those obtained with a continuous deformation in the magnetic fields of the same induction. By increasing the amplitude of the deformation that creates a viscoplastic state of the material, they are about one and a half times higher (at B>0.5T).

The dependence of the normal stresses on the strain under compression of MRM according to the mode 4 is shown in fig. 3a. It is seen that the increase in the normal stresses is the most significant at the beginning of the compression. With the increase in the compressive strain the growth of τ_N slows down. The higher the intensity of the magnetic field, the smaller compression of the material can be achieved and the higher its resistance to the compression is. Similar relationships are observed for the normal stresses in the vertical compression mode with a continuous simultaneous tangential shear deformation, but τ_N magnitude is smaller (fig. 3b). The increase of the shear stress τ_T at compression is smaller than the increase of τ_N. (fig. 3c) The shear stresses grow linearly with deformation; they increase at the compression by about 60-70% (mode 5). In the sinusoidal forced tangential oscillations mode and vertical shear (mode 2), the normal stresses τ_N reach their maximum values (above 100kPa) (fig. 3d).

5. Conclusion

Thus, it has been experimentally shown that for certain modes of the magnetic field impact on the flat damping element comprising magnetosensitive dispersed material one can effectively increase the resistance to the external vibration influence both in the tangential and the normal directions.

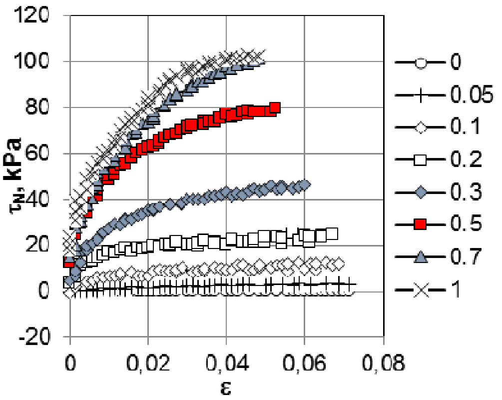

Figure 3a. Dependence of τ_N on compressive deformation of MRM (mode 4) at different magnetic field induction.

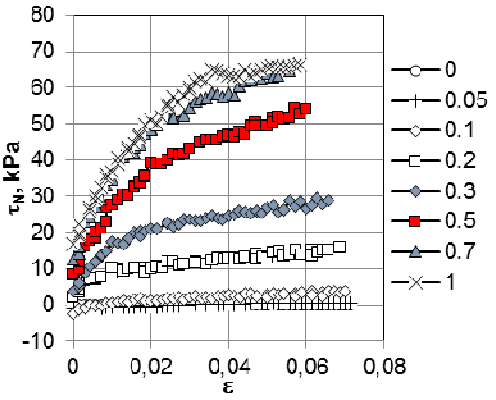

Figure 3b. Dependence of normal stress on compressive deformation of MRM (mode 5) at shear rate 10s^{-1}.

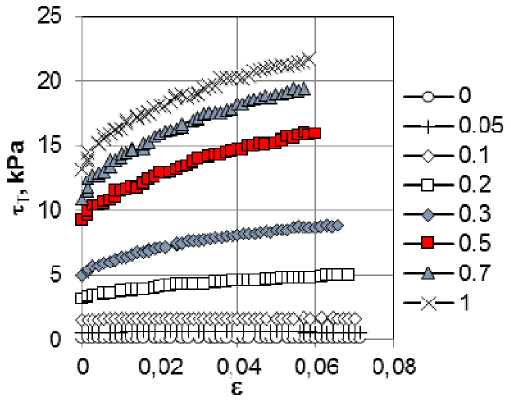

Figure 3c. Dependence of shear stress τ_T on compressive deformation at continuous shear deformation with shear rate 10s^{-1} and vertical compression (mode 5).

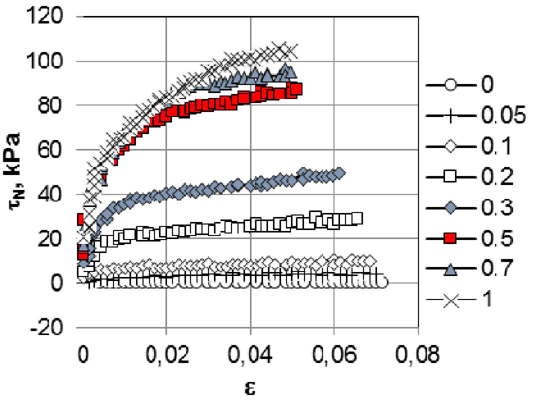

Figure 3d. Dependence of normal stress on compressive deformation at sinusoidal tangential deformation and vertical compression (mode 2).

References

[1] Roizman V P, Voronov C A, Bogorosh A T, Bubulis A and Yurgenas V 2010 *Space and Aviation Engineering and Technology* **8** pp 145–148

[2] Roizman V P and Korobko E V 2011 *Vibration in Machinery and Technology* **62** 97–101

[3] Dixon J C 2007 *The Shock Absorber Handbook*: Second Edition (New York) p 427

[4] Qiao Y et al 2007 *Smart Materials and Structures* **16** pp 332–339

[5] Korobko E V, Kolik V L and Korobko A O 2003 *Proceedings of the 10 th Annual Int. Symp. Smart Structures and Materials, Part Damping and Isolation* **5052** pp 445–50

[6] Han Y-M, Seong M-S, Choi S-B and Wereley N M 2010 *Proceedings of the Institution of Mechanical Engineers, Part C: J. Mechanical Engineering Science* **224** pp 293–304

[7] Zhu X, Jing X and Cheng L 2012 *J. Intel. Mater. Syst. and Struct.* **23** pp 839–873

[8] Wang J, Meng G, Feng N and Hahn E 2005 *Smart Materials and Structures* **14** pp529–539

[9] Khzhinskiy B P, Korobko E V and Koloskov A K *USSR Patent 1551872*/1990

[10] Korobko E V, Novikova Z A, Zhurauski M A, Borin D and Odenbach S 2012 *J. Intel. Mater. Syst. and Struct.* **23** pp 963–967

[11] Korobko E V, Dostanko A P, Korobko A O, Roizman V P, Novikova Z A, Globa A I and Zhurauski M A. 2011 *Nanosystems, nanomaterials, nanotechnologies* **9** pp 569–581