Control of Damping for Multi-layer Vibration Insulators with Dry Friction on Contact Surfaces

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Abstract. Possibilities of development of multi-layer vibration insulators with controller elastic-damping characteristics are considered. Examples of vibration insulators design with the highest efficiency of damping are given. It is shown that multi-layer elastic-damping elements of these vibration insulators should have pressure load equal on a length and wideness of elements. This load should be controlled during vibration. Friction pairs in the layer contact should have a second degree dependency of friction coefficient on height of elastic-damping element.

Key words: Hysteresis, multi-layer dampers, structure damping.

Introduction

It is known many researches devoted to problem of energy dissipation in motionless connections – structure damping. The most completely analysis of this problem is presented in [1]. One of the most important articles which discovered a phenomenon of structure damping is Goodman and Clump research [2]. In this article a problem of cyclic deformation under concentrated force of two-layer cantilever beam which layers are clasped to each other by known constant pressure was solved. For this two-layer beam an elastic-hysteretic loop in a shape of parallelogram was obtained theoretically and proved experimentally. Area of this loop depends linearly on force amplitude and has parabolic dependency on clasp layer pressure. An optimal clasp layer pressure p, for which energy dissipation during a cycle is maximal, was obtained:

$$p = \frac{3P}{8\,fbh}, \tag{1}$$

here P is amplitude of force; f is friction coefficient between layers; b is wideness of layer; h is thickness of each layer.

Analogous results were obtained in [3] for multi-layer beam pressed by constant pressure. In researches [2, 3] it is shown that in two-layer beam a slip of layers takes place instantly when concentrated force achieves any value, however in multi-layer beam an exfoliation takes place at once on each contact surface but it spreads gradually from surface to surface by any dependency.

In a research [4] on a basement of theory of similarity and dimension a wide analysis of energy dissipation in different structure damping systems is undertaken for rope vibration insulators, vibration insulators with elastic-damping elements made of pressed wire material, multi-layer dampers with different pressure distribution diagrams between layers. It is obtained that the best damping properties has multi-layer structures with instant slip and uniform pressure between layers. This conclusion allowed developing many high-efficiency structures of dampers for aircraft industry and mechanical engineering.

The simplest realization of this principle of uniformity of clasp pressure on a length of multi-layer element is in rope vibration insulators [5]. Here elastic-damping element contains of one or several elastic metal rope strands braided by wire with tightness and connected with two plates with fixing bolts.

An analogous idea for multi-layer band damper of aircraft gas-turbine engine damper is realized in a structure described in [6]. Here multi-layer group of bands is placed between a support frame and outer bearing ring. Uniformity of layer pressing in the group is provided by elastic rigs with special profile. In the same time these rings are damper supports.

Experimental [4] and theoretic [7] research of structures [5, 6] show its high efficiency: the maximal value of energy dissipation coefficient is $\psi = W/\Pi$ = 6…7.3 (here W is energy dissipated during one cycle of load, Π is potential energy of elastic deformation).

Problem and its solution.

Unfortunately in the mentioned structures [5, 6] a maximal value of energy dissipation coefficient $\psi_{\max}$ is realized on exactly determined amplitude only and can't be controlled during a process of changing of vibrations for transient speeds of engine. On this reason it is interesting to obtain a structure of multi-layer vibration insulator with structure damping with controlled characteristics. As a parameter of control the pressure on contact surfaces (1) is chosen.

Some variants of vibration insulator structures are developed on this principle. In the first one [8] (Fig. 1) a group of elastic elements 1 with square section is enclosed by clamps 2. Inside of these clamps there are washers 3 made of electrostrictive material which can change its transversal size under voltage on electrodes of washers 3. Thus washers 3 change pressure between layers of vibration insulator and shape of elastic-hysteretic loop. To control a level of vibration of damped object in two perpendicular directions differently, each of two opposite pairs of electrostrictive elements is connected with independent source of voltage which is controlled by signal of vibration sensor.

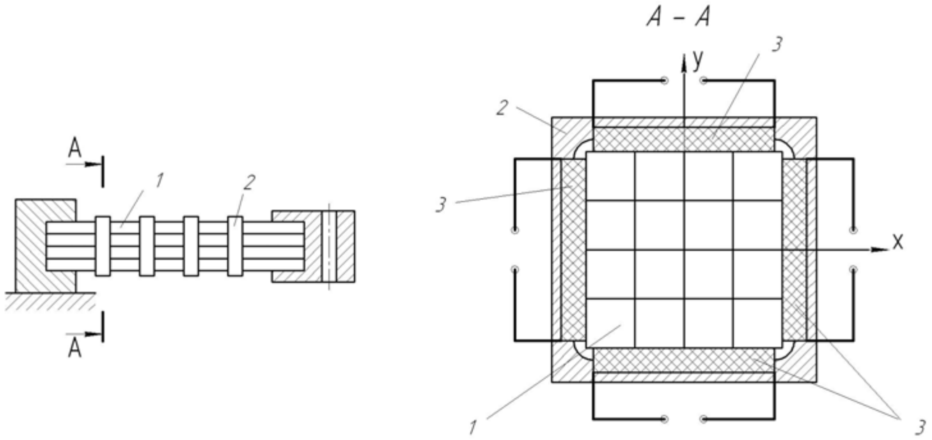
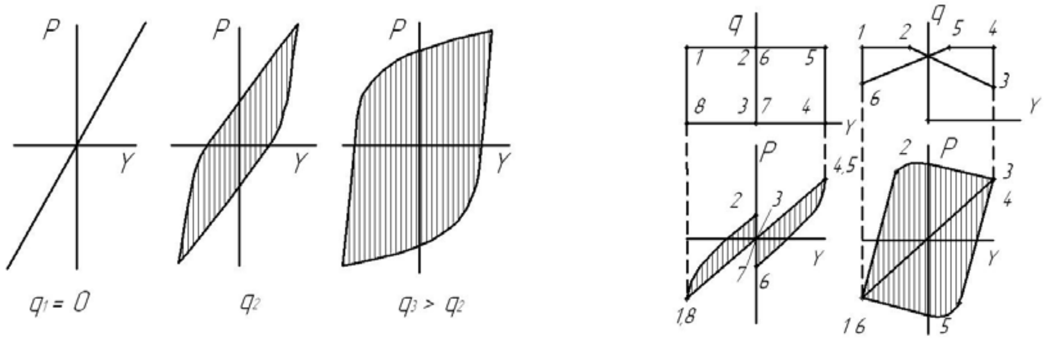


Fig. 1. Structure of vibration insulator [8] with controlled damping

Elastic-hysteretic loops of vibration insulator with different values of pressure q_1, q_2, q_3, which are constant on the beam length, are presented on Fig. 2, a. It is possible to see that for the changing of pressure shape of the elastic-hysteretic loop changes, and beside it middle-cycle stiffness and damping (dissipated energy) change too. If by system of feedback it is possible to change the pressure between layers depending on displacement of movable end of vibration insulator, we can control by elastic-hysteretic loop shape, as it is shown on Fig. 2, b, c. By numbers it is shown a consecution of pressure changing rule forming and detour of loop parts during cyclic deformation of vibration insulator.



a b c

Fig. 2. Changing of vibration insulator elastic-hysteretic loops for different pressure on contact surfaces

For structure is shown on Fig. 3 good preciseness of calculation can be obtained by method [3] for arbitrary number of layers and method [2] for two-layer beam. However the principle of control of clasping load level is different of [8]. Changing of the clasped load is provided by air pressure in inner cavities of elastic elements [9].

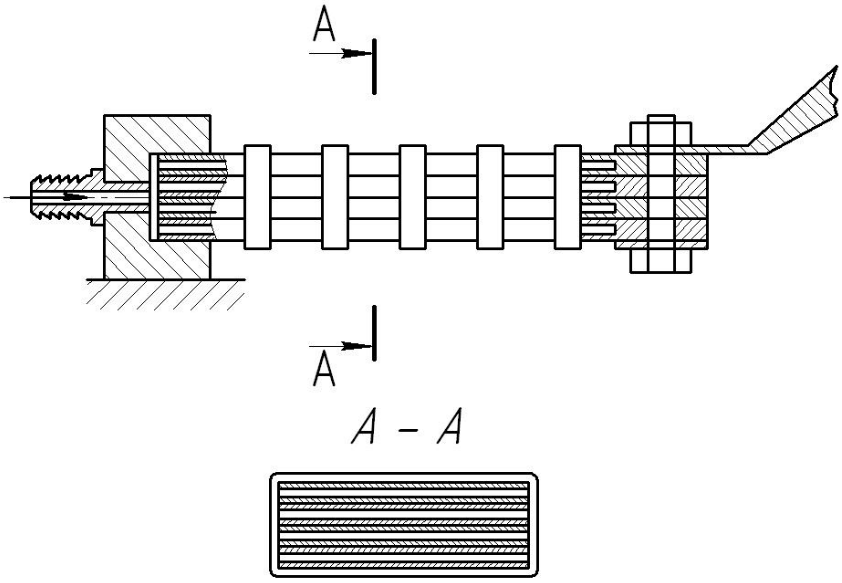


Fig. 3. Structure of vibration insulator [9] with controlled hysteresis

As it was mentioned, damping properties of multi-layer vibration insulators [8, 9, 11 – 14] are on the high level. However it is possible to increase damping more [10]. It is necessary to have on contact surfaces of layer groups (Fig. 1, 3) the friction pairs which friction coefficient is reducing in both of sides relatively a neutral axis in accordance to a rule

$$f = \frac{3}{2}\frac{P}{bqhn}\left[1 - \frac{4y^2}{n^2h^2}\right], \tag{2}$$

here P is amplitude of transversal force which provides an exfoliation of layers;

y is distance from neutral axis to respective contact surface, m;

q is intensity of clasping load (it has dimension of pressure, N/m^2);

n is number of layers in a group along of the present axis.

In this case if tangential stress reach a level of distributed friction forces $q_0 = fq$, all layers of group slip at once. Hysteretic loop for bending of this elastic-hysteretic element for constant clasping pressure q has a shape of parallelogram with two distinctive stiffnesses: initial (non-exfoliated), which is obtained as

$$\tilde{n}_0 = \frac{\mu E n^3 I}{l^3}, \tag{3}$$

and exfoliated

$$\tilde{n}_p = \frac{\mu E n I}{l^3}, \tag{4}$$

here μ is coefficient depending on boundary conditions of beam movable end displacement; E is elastic modulus of layer material; $I = bh^3/12$ is inertia moment of cross-section of one layer; l is length of beam. In this case an energy dissipation coefficient ψ is obtained as

$$\psi = 16bqhf_0(1 - \frac{1}{n})/3P, \tag{5}$$

here f_0 is maximal value of friction coefficient in the friction pair on the neutral axis of layer group. It is seen from this equation that it is possible to control a value of energy dissipation coefficient ψ by changing of value of clasped load q. For example, it is possible to provide a constancy of energy dissipation coefficient $\psi = \psi_0 =$ const and make it independent on force amplitude P. In this case it is necessary to obtain the rule for clasping load as

$$q = \frac{3P\psi_0}{16bhf_0(1 - \frac{1}{n})}. \tag{6}$$

Conclusions

The second degree dependency of friction coefficient on height of elastic-damping element is possible to obtain technologically by different surface smoothness, or by plasma spraying of different materials on surfaces, or by different chemical or galvanic coating. Thus it is possible to use dampers and vibration insulators with structure damping for development of active systems with controlled vibration condition.

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