561. Compositional materials with controllable vibration damping parameters

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Abstract. The paper proposes laminated sandwich-elements containing electrorheological composite as a structural element, which enable designing novel thin-wall structures with a locally varying rigidity and vibrostability for aerospace engineering, ship-building, high-speed devices in mechanical engineering (machine tools, robots), in transport means (controlled springs), in instrument fabrication, etc.

Keywords: sandwich-element, electrorheological composite, viscoelastic properties.

Introduction

The problem of controlling and reducing noise and vibrations remains to be the key one in many branches of industry including automotive sector, shipbuilding, robotics and other manufacturing industries. Most of classical damping devices are passive, intended for specific operating and environmental conditions in a narrow range of parameters. Therefore very timely is the problem of creating new traditional "intellectual" materials and semiactive adaptive damping devices capable of changing their elastic characteristics in a real time and adapting to external operating conditions. They include electrorheological (ER) composites capable of varying their mechanical properties (including elastic ones) under the action of electric field. The possibility of controlling the viscoelastic properties in a broad range enable development of reliable vibration- and noise-absorbing structures using ER composites as a constitutive element.

Experiment

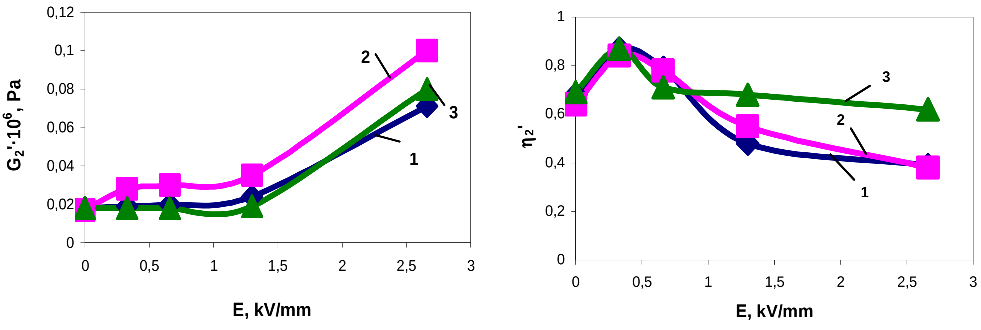
During investigations a construction was used that consists of two elastic deformable (sliding) electrodes with a layer of ER composite sandwiched between them (referred to as sandwich-element). By controlling the properties of the ER composite by means of electric field it is possible to alter the coefficient of losses by the sandwich-element and, consequently, the vibro-absorbing characteristics of structures. The electrodes can be made from flexible metal plates or nonmetallic plates having electrically conducting layers. The space between these layers is filled with an ER composite. When an electrical potential is set between the electrodes, the electrically sensitive disperse phase forms a bridge structure that connects the electrodes. In the presence of the electric field the rheological properties of the ER composite layer undergo a change, the viscosity and yield point increase, the viscoelastic properties appear and the cohesive force between the particles and electrodes increases, the complex shear modulus $G^* = G' + G''$ changes, including its real part G' (dynamic shear modulus) and imaginary part G'' (modulus of losses), as well as the loss factor G''/G'. As a result, the loaded sandwich-element demonstrates improved damping properties in the frequency range which depends on its constructions and rigidity. For the reproduction of the damping characteristics of the sandwich-element a constant optimal distance between the electrodes is to be maintained. At a smaller distance short-circuiting may occur, whereas at a larger distance the electric field strength in the gap decreases at a constant voltage supplied to the electrodes, and this considerably decreases the ER effect. Also, leakage of a fluid from the gap is possible. In [1] it was suggested to cement the edges of the sandwich-element to prevent the leakage, but this constitutes an additional uncontrolled damping factor. To preserve the homogeneity of the fluid layer it is suggested in [1] to separate the electrodes by a paste-like isolation spacer along the perimeter of the element. To prevent short-circuiting between the electrodes it is proposed to put a fabric or another porous material as mesh. The fabric increases the gap between the electrodes, which requires an increase in the electric field voltage potential for sustaining the needed field strength. The use of an insulating material decreases the contact area of the bridge structures of the ER fluid with the electrodes, and the influence of the electric field on the mechanical properties of the sandwich-element decreases. If as a controlled layer the ER composite is used which contains 70 wt. % of the ER active disperse phase in a mineral oil with addition of 5 wt. % of a surfactant, the possibility of accidental short-circuiting can be decreased by inserting into the composite large particles or dielectric fibers with a high electric resistance, which ensures the needed distance between the plates. Preliminarily calibrated and dried spherical polymeric or ceramic particles can be put into an ER composite before hand or directly into the layer deposited on to the plates. The diameter of the particles ranges from 100 to 500 μm. The quantity of particles can vary from 0.01 to 0.5 wt. %. An ER composite can be phased between two plates without creating a barrier for preventing the leakage of a suspension from the sandwich-element because of its high plasticity sandwich-elements can vary in size and shape, contain various compositions of ER composites, flexible plates, and the electrodes can be assembled in different configurations. The magnitudes of the dynamic shear modulus of sandwich-elements depend on the mechanical properties of the constituents of the flexible layers, their combinations, the force of cohesion between the particles and between the particles and electrode surfaces in an electric field.

Two series of experiments were carried out: in the first series the influence of the electric field on the forced oscillation of the sandwich-element was investigated and in the second series – on free oscillations. The sandwich-element consists of two thin flexible plates of size 20x240 mm between which where is a thin layer of an ER composite. The models of sandwich-elements differed in the constructions and in the types of the electrode plates. In one variant they were made from aluminum with anodic coatings of different thicknesses (from 0 to 300 μm) – the case where each of the plates represented a complete electrode. In the other series of experiments the plates were made from a dielectric material. On the working surface of one of the plates a comb of metal thin-layer electrodes was applied with leads to be connected to a high-voltage source, with the width of the electrodes being equal to 1.5 mm and the distance between them – 1.0 mm. The even electrodes were connected to a high-voltage source, whereas the add ones were grounded. The working surface of the other plate was coated by a layer of varnish of special composition. One end of such a sandwich-element is fixed in a special device, the other end is free. To excite oscillations in the free end, an electromagnet was used which was connected to a generator of oscillations. An induction displacement transducer placed opposite to the free end of the end of the bar generated a signal which was proportional to the amplitude of the sandwich-element oscillations, and this signal was fed into a recorder.

In the mode of periodic deformation the elasticity shear modulus (G_2') and the coefficient of losses (η_2) by the ER composite layer and the coefficient of losses whole sandwich-element (η) were determined by means of technique described in [2]. Investigations were carried out for different compositions and thicknesses of the ER composite layer, constructions of the sandwich, and the inherent resonance frequency of oscillations at the different electric field strengths.

Results and discussion

Figures 1 (a, b) present the dependences of the shear elasticity modulus G_2' and loss coefficient η_2 as a function of electric field strength E at T = 20 °C and the inherent resonance frequency of oscillations f = 18 Hz for one of the compositions of the ER composite with its layer thicknesses 150, 300 and 500 μm; aluminum plates were used as electrodes.



a) b)

Fig. 1. Dependences of the shear elasticity modulus G_2' (a) and loss coefficient η_2 (b) as functions of electric field strength E at T = 20 °C, f = 18 Hz; 1 – h = 150 μm, 2 – h = 300 μm, 3 – h = 500 μm

As Fig. 1 indicates with increase in the electric field strength in the gap the shear elasticity modulus G_2' increased 16.9 times, with the loss coefficient η_2 decreasing by a factor of 3.6, which is attributable to the strengthening of the structure in the ER composite layer with increase in the field strength and decrease in the shear flow dissipation.

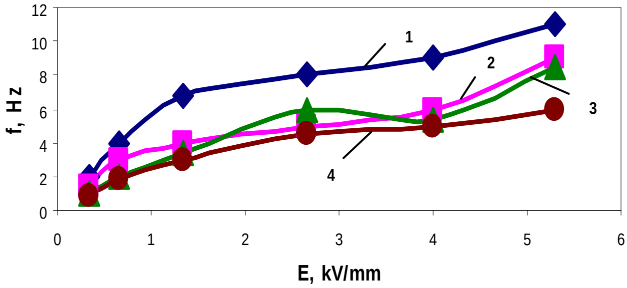
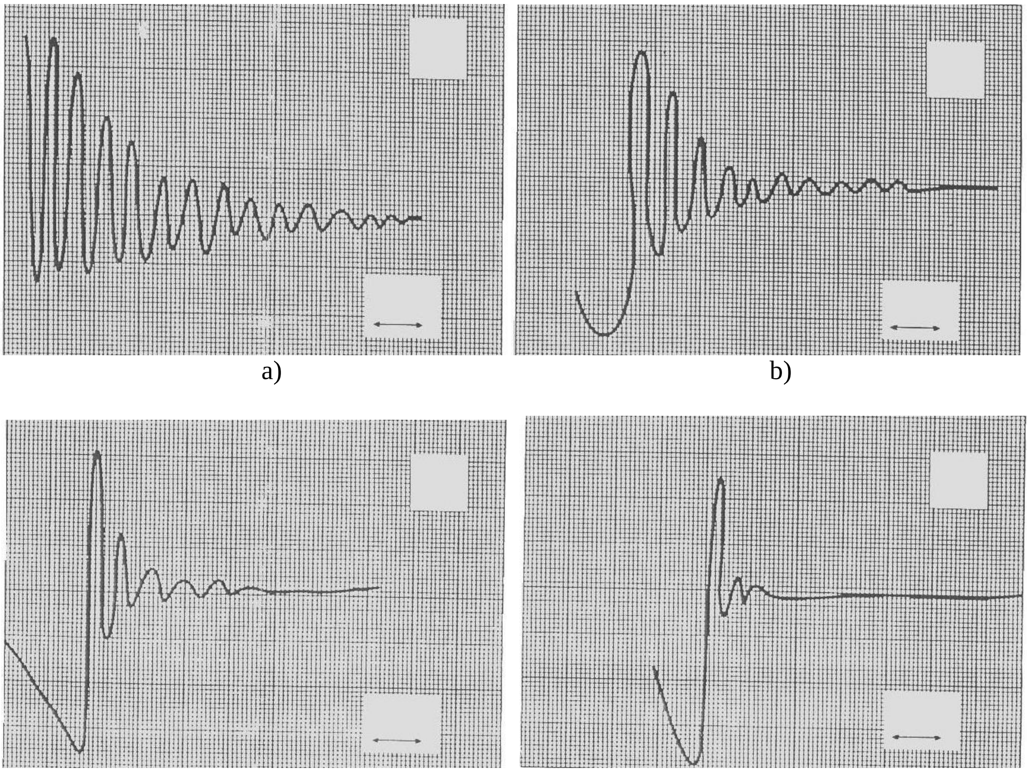


Fig. 2. Dependence of the shear in the resonance frequency Δf on the electric field strength at different resonance frequencies of oscillations; 1 – f = 18 Hz, 2 – f = 23 Hz, 3 – f = 32 Hz, 4 – f = 36 Hz

Figure 2 presents the dependence of the shear in the resonance frequency Δf as a function of electric field strength at different resonance frequencies of oscillations (f = 18, 23, 32, 36 Hz).

The resonance frequency of oscillations of the sandwich-element reciprocally shifted to the side of an increase by 10 – 12 Hz on decrease in the amplitude of oscillations and amounted to 28 – 30 Hz, i.e., the system gained rigidity. On removal of the field, the resonance frequency and the amplitude of oscillations recurred their initial values.



a) b)

c) d)

Fig. 3. The oscillograms of free oscillations of sandwich-elements (a – without an ER composite in the gap between the plates, b – with an ER composite without application of an electric field, c – with an ER composite with application of an electric field, E = 0.5 kV/mm, d – with an ER composite under an electric field of E = 0.8 kV/mm)

Figure 3 presents the oscillograms of free oscillations of sandwich-elements (a – without an ER composite in the gap between the plates, b – with an ER composite without application of an electric field, c – with an ER composite with application of an electric field, E = 0.5 kV/mm, d – with an ER composite under an electric field of E = 0.8 kV/mm). A comparison of the oscillograms reveals that the action of electric field on the ER composite layer induces more rapid damping of the free oscillations of the sandwich-element.

The logarithmic decrement of damping calculated for the sandwich-element under application of electric field of strength E = 0.8 kV/mm increase 3.5 times as compared to the damping decrement without a field, which is equivalent to an increase in the damping coefficient of the system by a factor of 3.5.

Conclusions

The results of investigations have demonstrated the possibility of a considerable increase in the shear elasticity modulus of the ER composite G_2' in an electric field. It has been determined that increase in the elasticity modulus depends directly on the construction of the sandwich-element and the electric field strength, with the loss coefficient η_2 decreasing in the process. The version of the sandwich-element construction with aluminum anodized plates has turned to be more efficient.

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