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Experimental Investigation of Vibration Parameters of Sandwich Beam with Viscoelastic Core

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Abstract. This study deals with the vibrational measurement of a sandwich beam with carbon-epoxy composite skins and a viscoelastic core made of magnetorheological elastomer (MRE). The forced vibration measurements at different frequencies were performed under the action of gradually increasing magnetic field intensity. The stiffness and damping properties of the active constrained MRE core layer and the dynamic properties of the sandwich beam were evaluated. The experimental results show a reduction of mechanical vibrations together with the shift of the natural frequencies and vibration amplitude caused by the change of magnetic field intensity.

Introduction

Magnetorheological elastomers (MREs) are smart composites that are made of micro-sized magnetic particles dispersed in a non-magnetic elastomeric matrix. The mechanical and rheological properties of MREs can be controlled rapidly and reversibly by the application of an external magnetic field which leads to the so-called magnetorheological (MR) effect [1]. The control of MREs enabling the immediate change of their properties in the real time has made them very promising for a wide range of applications, such as damping elements in the vibration absorbers, vibration isolators, sensing devices, vehicle seat suspension, engine mounts, actuators to control the flow, and adaptive stiffness devices [2].

Matrices of MREs are made usually of soft viscoelastic materials such as silicone rubber, natural rubber, polyurethane, and thermoplastic elastomers [3]. The common type of fillers for MREs are carbonyl iron particles of micrometer size with high saturation magnetization. The properties of MREs strongly depend on the distribution of iron particles which can be either random or aligned in chains. The distribution structure of particles is determined by whether or not the magnetic field is applied during the cross-linking. The isotropic MREs have randomly distributed particles and the anisotropic MREs have the chain-like particle structure caused by the applied magnetic field during the cross-linking. The MR effect is far more pronounced in the anisotropic MREs [4].

The dynamic properties of isotropic and anisotropic MREs are usually measured using DMA tests in order to determine their suitability for potential use in vibration damping [4]. The dynamic properties as the storage and loss moduli and the loss factor depend on different frequencies and amplitudes and on the magnitude of the applied external magnetic field. A number of constitutive models have been developed to describe the rheological properties of MREs and the dependence of their dynamic properties on the frequency and amplitude of vibration and on the intensity of the magnetic field. Recently, the constitutive models based on fractional calculus have been used for viscoelastic modelling the behavior of MREs. The model parameters are determined by fitting the experimental data [4].

Beam-type structures are widely used in the fields of mechanical engineering. An optimum structural design requires an accurate analysis of their dynamic characteristics [5]. Sandwich beams with the core made of smart material such as MRE enable the continuous change of stiffness and damping properties with varying external magnetic field [6,7]. This study investigates the dynamical response of an exciting sandwich beam with an MRE core layer in the presence of an externally applied magnetic field.

Experiment

A sandwich beam 145 × 20 × 7 mm^3 consists of a 5 mm thick MRE core glued between the outer layers with 1 mm thickness and of an aluminum insert serving to attach the beam to a shaker. The outer layers are of carbon-epoxy composite and were made by hand-laying of 4 layers of KC 200g / m^2 plain carbon fabric and LH 289 epoxy resin with H289 hardener supplied by Havel Composites.

Components of MRE core are carbonyl iron particles of spherical shapes with 2–5 μm in diameter supplied by Sigma-Aldrich and liquid silicone ZA13 and its catalyst produced by Zhermack S.P.A. The core layer is of isotropic MRE with 27% volume fraction of carbonyl iron particles. The detailed procedure for the fabrication of the MRE core layer and its dynamic properties are given in previous articles by the authors [3,4]. The core was glued between the two composite layers by Loctite Super Attak Activator Adhesive.

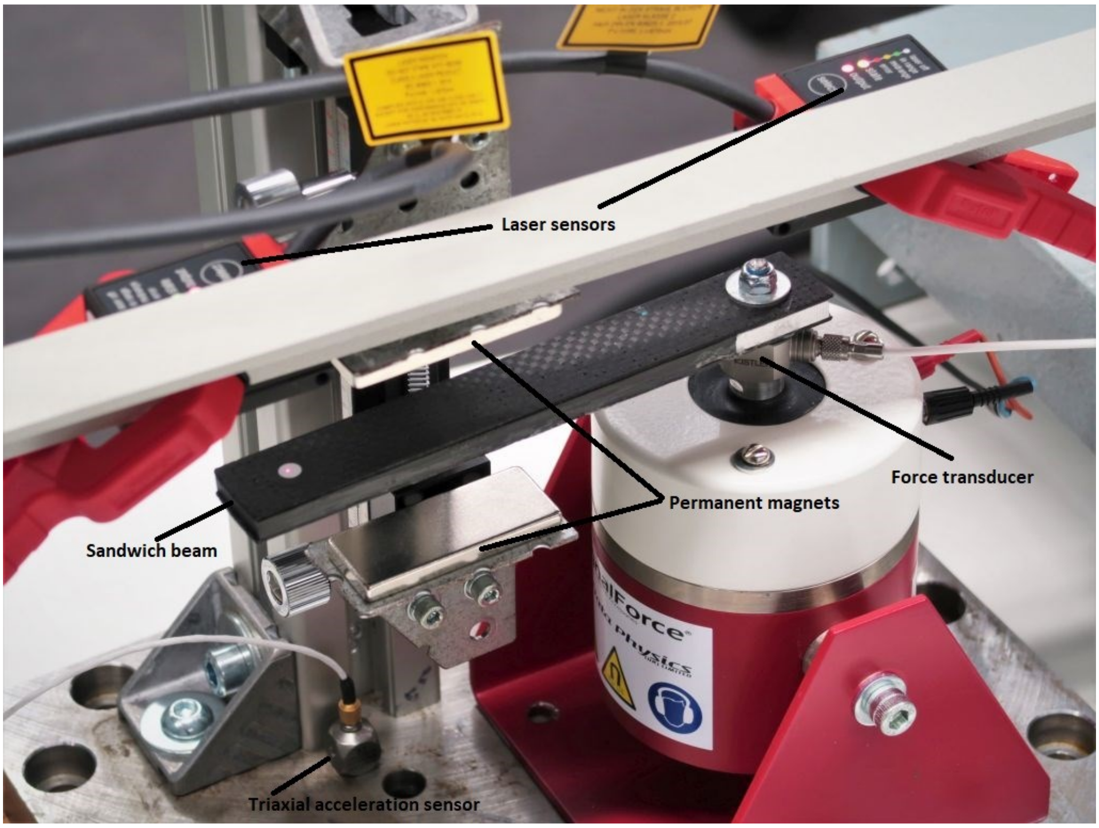

Fig. 1: Experimental setup: the sandwich beam is attached to the shaker at one end - two permanent magnets creating a magnetic field perpendicular to the beam

Experimental setup. Tested sandwich composite beam in Fig. 1 is fixed at its end to Permanent Magnet Shaker SignalForce GW-V4 with PA30E Power Amplifier supplied by

DataPhysics. Kistler force transducer 220 N is placed between the end of the beam and the shaker to monitor the excitation force and to prevent damage of the shaker whose maximum allowed sine force is 17.8 N. The shaker is firmly attached to a heavy steel plate, which rests on a cork board that dampens vibrations and this base lies on a solid table. Kistler Triaxial acceleration sensor is fixed on the steel base plate. The real-time signal from this sensor is used to verify that the transmission of unwanted vibrations is eliminated.

The excitation signal for the SignalForce GW-V4 shaker is generated using the Spider-80X dynamic signal analyzer with Spider-DSA software (Crystal Instruments) and amplified with PA30E Power Amplifier. The amplification is tuned manually using 50 Hz sine excitation signal until the shape of the force signal is sinusoidal with amplitude 1 N.

The external magnetic field is generated by two permanent magnets NdFeB 50x25x12 mm type N35 supplied by WAMAG spol. s r.o. The magnetic field acts in the vertical direction perpendicularly to the skin layers of the beam. The magnets are fixed on high-precision dovetail slides which move synchronously on the vertical rack by a pinion mechanism. This device allows to precisely adjust the distance between the magnets and thus the gradually change of the intensity of the magnetic field. The magnetic flux density is measured with portable Bell-5180 Gauss/Tesla meter with Standard Transverse Probe STD18-0404 supplied by Magnetic Sciences.

Two laser triangulation displacement sensors ILD1420-10 provided by Micro-Epsilon are placed above the tested beam. The first sensor reads the displacement of the target placed at the point of beam fixation to the shaker and the second sensor measures the displacement of the target at the free end of the beam.

Experimental procedure. Forced vibration tests were performed using sinusoidal harmonic loading over a range of frequencies in order to determine the resonant frequencies at different magnitudes of the external magnetic field. The input signal was linear sine sweep in Fig. 2 between the frequencies f_1=1 Hz and f_2=100 Hz and of time duration T=200 s

$$f(t) = f_1 + \frac{f_2 - f_1}{T} t \tag{1}$$

The intensity of the magnetic field was gradually increased between tests. The magnetic field depends on the distance of two permanent magnets and also on the magnetic properties of the beam that is inserted between them. The measured magnetic field for the different distances of magnets is presented in Fig. 3.

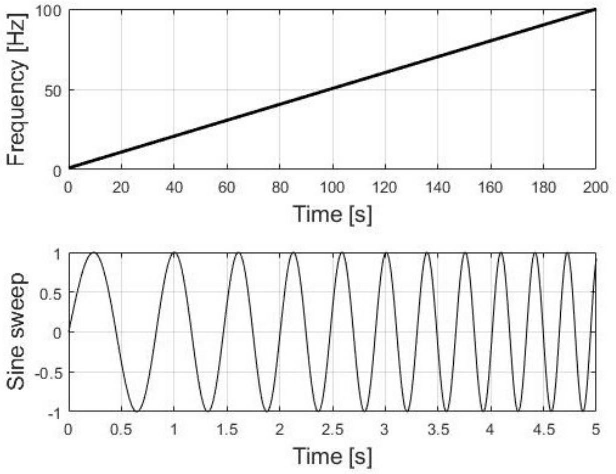

Fig. 2: Sine sweep of forced vibration signal

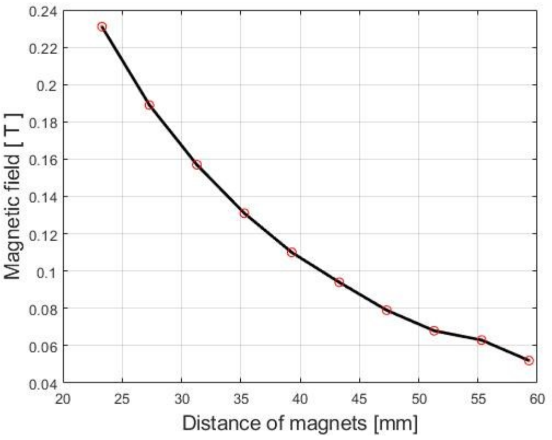

Fig. 3: Magnetic field vs magnets distance

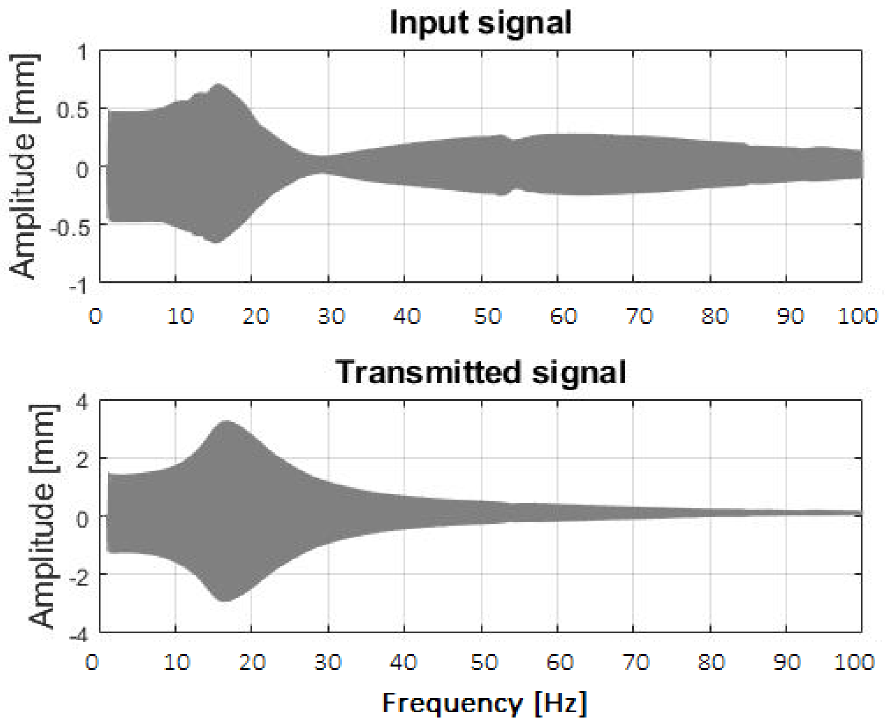

Fig. 4. Displacements of points at the shaker head (above) and at the end of beam (below) measured by laser sensors with sampling frequency 4 kHz

A total of 20 frequency sweep tests were performed with the values of magnetic flux density increasing gradually from 0.0 T to 0.236 T. The displacements of two points of the beam were measured by the laser sensors with the sampling frequency of 4 kHz. Point 1 is on the head of the shaker and point 2 is on the free end of the beam.

Evaluation of experimental data. Amplitude transmissibility was determined for each test based on the recorded data of displacements (deflection) of two points see Fig.4. The amplitude transmissibility is the ratio of the amplitude a2(f_i) of the deflection at the free end of the beam and the amplitude a1(f_i) of the displacement of the shaker head. Both amplitudes are evaluated in Matlab at the same time which corresponds to the selected excitation frequency as can be seen in Fig. 5. The transmissibility was evaluated for frequencies f_i=1,2,3,...,100 Hz.

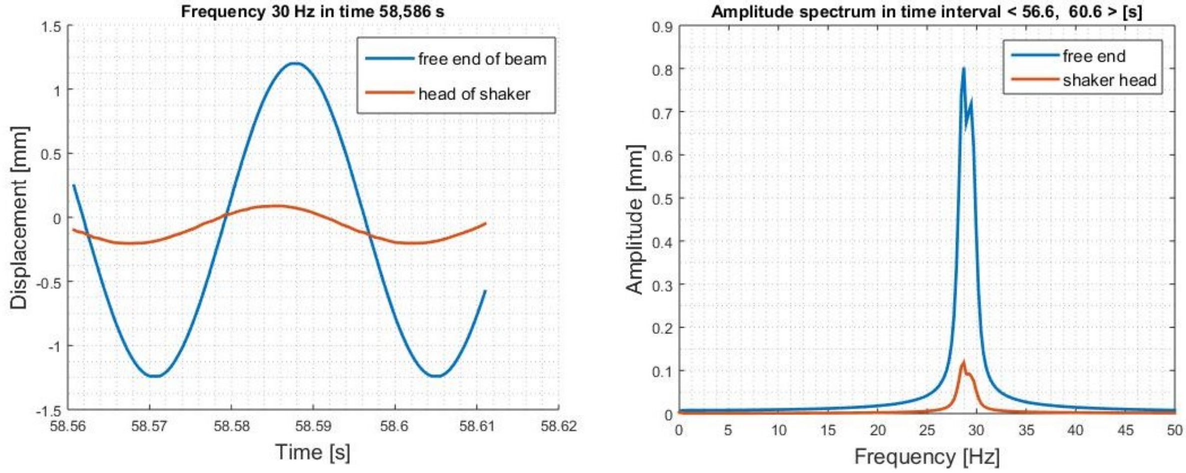

Fig. 5. Amplitudes of the displacements and amplitude spectrum for frequency around 30 Hz

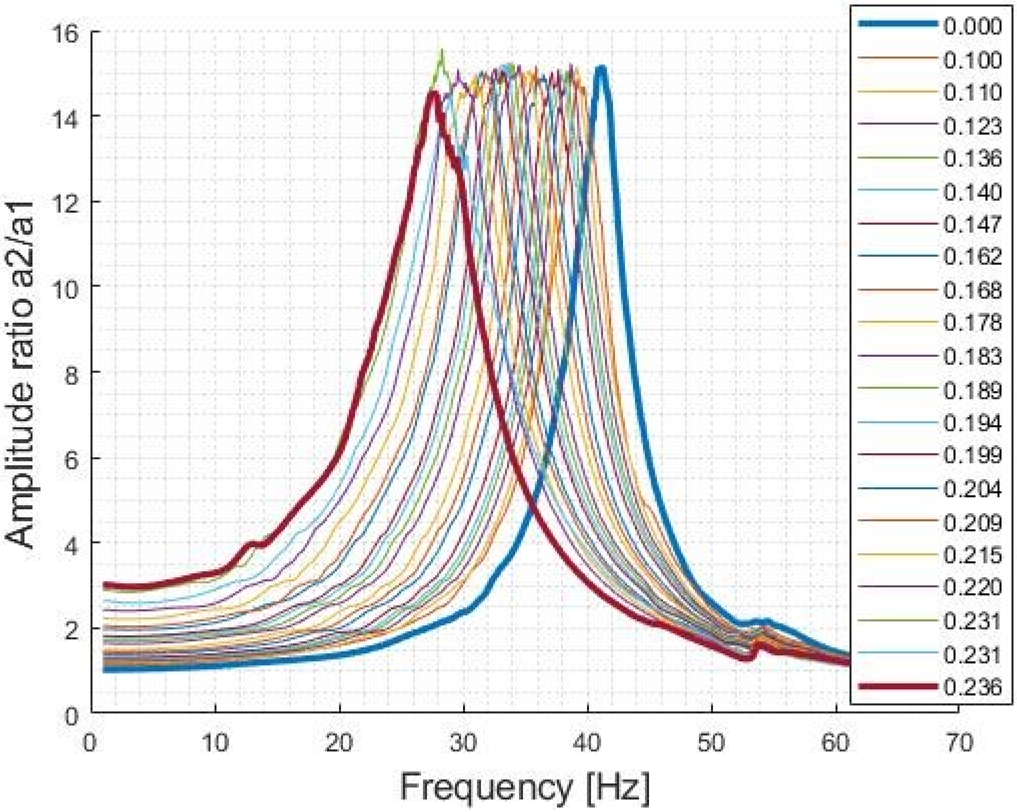

Fig. 6. Amplitude transmissibility a2/a1 in the frequency range 1-70 Hz for the magnetic field increasing gradually from 0 to 0.236 T.

The peaks of amplitude transmissibility curves shift to the lower frequencies as the magnetic field increases as is depicted in Fig. 7.

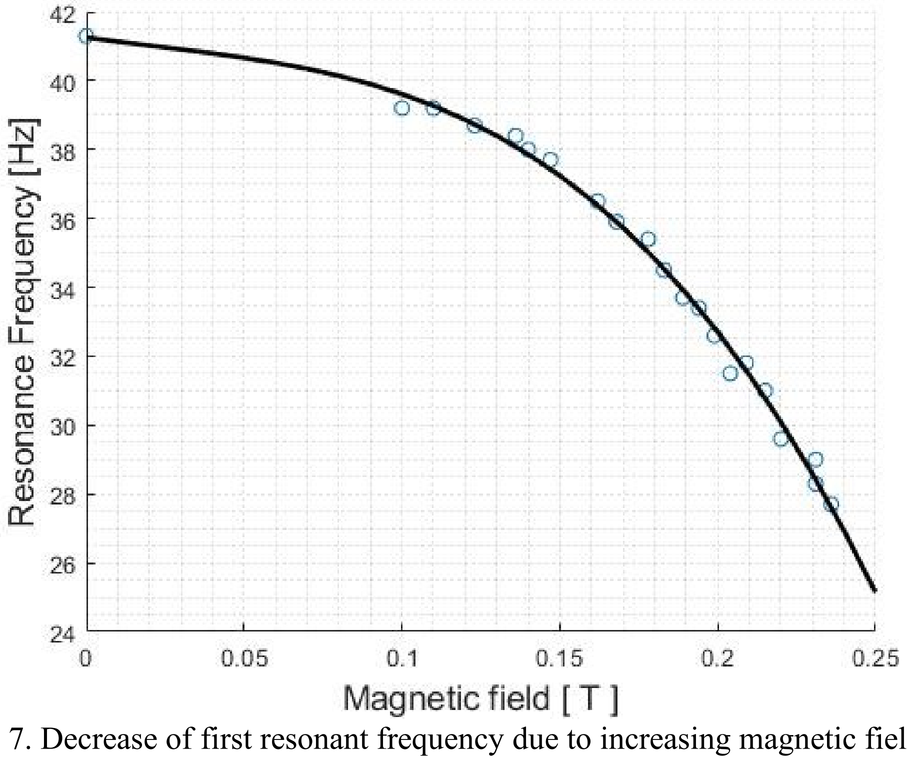

Fig. 7. Decrease of first resonant frequency due to increasing magnetic field

Conclusions

The forced vibration of the sandwich beam with carbon-epoxy composite skins and a viscoelastic MRE core has been examined. The results of experimental research of the forced vibration of the sandwich beam with the constrained layer show that the amplitude and velocity of the beam vibration have changed with varying the external magnetic field. The stiffness and damping properties of the beam vary due to a change in the rheological properties of the MRE in the magnetic field. The stiffness of the beam and the damping of the active constrained layer increased.

We can conclude that the first resonant frequencies of the beam decreased with increasing intensity of the magnetic field as can be seen from the graph in Fig.7. The decrease in frequency is quite significant and is around 35%.

The forced harmonic motion of the three-layer beam in which the damping constrained core layer core is sandwiched between two elastic layers can be described by differential wave equation of sixth-order [8,9]. In this equation the material of viscoelastic core is characterised by complex shear modulus $G^*=G(1+i\beta)$. The dynamic parameters of MRE core material are already determined by authors [3,4]. The numerical modeling of vibrations of sandwich beams with MRE core will be the subject of further research.

The experimental research and numerical modelling of the vibrations of sandwich beam with MRE constrained layer is the promising direction in the search of application of this smart magnetorheological material.

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