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An approach to the modeling and simulation of multi-layered and multi-stimulable material for application in soft robots

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Abstract: The behaviour of magnetically stimulable materials is considered. The investigations focus on multi-layered one-dimensional continua where the respective stimulability is based on discrete layers. Vibrations of two-layered elastic Timoshenko's beam are investigated. One of the layers consists of a magneto-sensitive material. Young and shear module in this layer depend on the magnitude of the applied magnetic field those changes periodically in time. A lumped force is applied to the beam. The expressions for the amplitude and phase of the steady-state vibrations of the beam are obtained by the method of averaging. Using the analytical expressions and the measurement data for the amplitude and frequency of the beam vibrations, one can identify the application point of the lumped force. The investigated system can be considered as a model of a tactile sensor for soft robotics.

Keywords: soft robots, sandwich beam, beam vibrations, tactile sensors

1. Introduction

For soft robots the development of compliant smart materials with controllable properties is one of the key problems. Thus, the use of smart materials whose shape and properties can be controlled by external fields is in the focus of research [1], [2]. There are a number of publications that deal with theoretical investigations of multi-layered (sandwich) structures. As a rule, the objects of such investigations are cantilever beams or plates that consist of several layers of different materials, with at least one layer of a smart material [3], [4]. In our study, the vibrations of a two-layered Timoshenko's beam acted upon by a lumped force and a magnetic field are investigated by means of the averaging technique. One of the layers of the beam is non-magnetic, while the material of the other layer is a magneto-sensitive elastomer.

2. Results and Discussion

Vibrations of a two-layered beam of a length L, in which one layer is a magneto-sensitive elastomer, are studied. The beam is acted upon by a lumped force applied at some distance away from the end of the beam. The beam is subjected to a magnetic field that is periodically (harmonically) changing in time (Fig. 1). The dynamics of the vibrations are studied on the basis of Timoshenko's beam model. The vibrations of the beam are governed by the equations

$$\begin{aligned} m_0\partial_{tt}w - Q(\partial_{xx}w - \partial_x\varphi) &= f - m_0\partial_{tt}a, \\ \partial_t(J\partial_t\varphi) - P\partial_{xx}\varphi - Q(\partial_x w - \varphi) &= 0. \end{aligned} \tag{1}$$

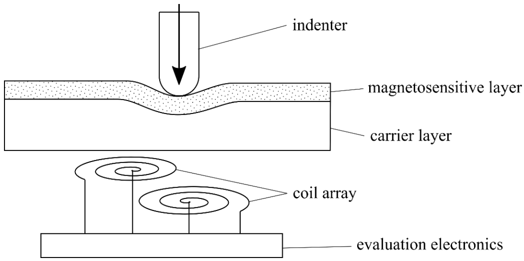

Fig. 1. Concept of a tactile sensor based on a two-layered design

Here, $w(x,t)$ is the transverse deflection of the beam, $\varphi(x,t)$ is the angle of the rotation of the cross section, m_0 is the mass of the beam per unit length, $f(x,t)$ is the external load per unit length, $J(t)$, $P(t)$, $Q(t)$, $a(t)$ are given functions that depend of the elastic constants and densities of the beam materials, as well as on the amplitude and frequency of the pariodically changing magnetic field. The boundary conditions are given by

$$w(0,t) = w(L,t) = \partial_x \varphi(0,t) = \partial_x \varphi(L,t) = 0. \quad (2)$$

Assuming that the amplitude is small and neglecting the rotational inertia of the beam cross-section, we found the expressions for the amplitude and phase of the steady-state vibrations. These expressions were obtained by the method of averaging applied to the system of equations of (1) subject to the boundary conditions of (2). Using these expressions, one can identify the application point of the force, if the amplitude is known.

3. Concluding Remarks and Outlook

A model of a tactile sensor that consists of two deformable layers, one of which is magneto-sensitive, is presented. The analytical solution obtained on the basis of the averaged equations demonstrates good agreement with the numerical solution. This model can be used for the development of a tactile sensor, allowing the identification of a force application point on the basis of measured vibration data. The results of the experiments with a sensor prototype that have been performed agree with the conclusions that have been drawn on the basis of the proposed mathematical model. By using additional thermoplastic particles in an elastomer matrix, further controllable effects can be achieved.

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