OSCILLATION OF A CONDUCTING MICROPLATE IN A MAGNETIC FIELD

Indiaminov Muhammad Shukurovich
Samarkand district specialized school in the system of the Presidential Educational Institutions Agency, Samarkand, Uzbekistan
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Abstract. *The paper mathematically simulates the magnetoelastic vibration of non-ferromagnetic conductive microplates under the influence of non-stationary electromagnetic and mechanical forces. The plate magnetoelasticity problem is numerically solved taking into account the electrodynamic Lorentz forces.*
Keywords: *electromagnetic field, magnetoelasticity, Lorentz force, deformation.*

INTRODUCTION

The increasing interest in electromanito-elasticity from the problems of mechanics of connected fields arises from the requirements of ensuring the requirements of modern technical processes in various fields of production and the development of new technologies. Conducting research on the mechanics of coupled fields in deformable bodies is of both fundamental and practical importance and is of great relevance..

The connection effects of dynamic and mechanical displacements of electrically conductive bodies with the electromagnetic field are realized through electrodynamic Lorentz forces..

Magnetoelasticity is now very important in practical applications and is applied to various fields of modern technology. Including: in microsystem techniques, in microelectro-magnetomechanical systems, in calculations of real structural elements, in the creation of modern measurement systems, as well as, in electronic control machines of electronic automatic stations and microelectronics, radio electronics, in researching the oscillation, strength, and stress states of thin plate and shell-shaped structural elements operating under the influence of an electromagnetic field encountered in various fields of electrical engineering.

The integration of electronic crystal elements, mechanics, informatics and measuring systems has led to the convergence of these technologies and the creation of microsystems techniques, as well as the emergence of microelectromagnetic-mechanical systems.

RESEARCH MATERIALS AND METHODOLOGY

One of the areas of application of ECM is mathematical modeling of various processes and objects in nature. The method of computer modeling and research of processes is widely used in various fields of science. Mathematical modeling of the process of deformation of an electrically conductive body in a magnetic field and the study of electromagnetic effects appearing in the body are of practical importance. Computer-aided research of objects and processes shows the chain as follows: object-model-calculation algorithm-program for ECM-calculation results-analysis of calculation results-object management.

We write the mathematical model of the process of magnetoelastic oscillation of a non-ferromagnetic current-carrying body in a magnetic field under the influence of electromagnetic forces as follows [1-5]:

$$rot\ \vec{E} = -\frac{\partial \vec{B}}{\partial t},\ rot\ \vec{H} = \vec{J} + \vec{J}_{cm},\ div\ \vec{B} = 0,\ div\ \vec{D} = 0. \tag{1}$$

$$\rho \frac{\partial \vec{\upsilon}}{\partial t} = \rho\,(\vec{F} + F^{\wedge}) + div\ \hat{\sigma}. \tag{2}$$

$$\vec{B} = \mu\, \vec{H},\quad \vec{D} = \varepsilon\, \vec{E}. \tag{3}$$

$$\vec{J} = \sigma\ (\vec{E} + \vec{V} \times \vec{B}). \tag{4}$$

$$\rho\, \vec{F}^{\wedge} = \sigma\ (\vec{E} + \vec{V} \times \vec{B}) \times \vec{B}. \tag{5}$$

initial and boundary conditions, respectively:

$$\nu_k (t_{ki} + \tau_{ki})\Big|_{S_1} = [P_i + \nu_k \tau_{ki}^{(c)}]\Big|_{S_1}. \tag{6}$$

$$\vec{u} = 0,\ \ \dot{\vec{u}} = 0,\ \ \vec{B} = 0,\ \ \vec{B}^{(c)} = 0,\ \ \vec{H} = 0,\ \ \vec{H}^{(c)} = 0. \tag{7}$$

Here $\vec{E}$ - electric field strength vector; $\vec{H}$ - magnetic field strength vector; $\vec{D}$ - electric induction vector; $\vec{B}$ - magnetic induction vector; $\vec{J}_{cm}$ – extraneous electric current density; $\vec{F}$ – volumetric force; $\vec{F}^{\wedge}$ – volumetric Lorentz force; $\vec{J}$ – electric current density; $\hat{\sigma}$ – internal stress tensor; σ, ε, μ – electrical conductivity, dielectric and magnetic absorption of the current-carrying body, respectively; t_{ki} – stress tensor; $\tau_{ki}, \tau_{ki}^{(c)}$ – Maxwell tensors in matter and vacuum; P_i – organizers of surface forces; ν_k – unit normal vector components; S_1 – part of the boundary of the body given the stresses; $\vec{u}$ - displacement vector, (c) - the index shows that the quantities belong to the external environment.

Thus, relations (1), (2) and (3)–(5), as well as (6), (7) together form a model of magnetoelasticity of a non-ferromagnetic current-carrying elastic body..

RESEARCH RESULTS

We consider the problem of magnetoelastic oscillation of a non-ferromagnetic current-carrying elastic microplate under the influence of nonstationary electrodynamic and mechanical forces. The considered microplate is isotropic and homogeneous, and its material obeys Hooke's law.

The electromagnetic hypothesis is fulfilled in relation to electric field strength vector $\vec{E}$ and the magnetic field strength vector $\vec{H}$ [1]:

$$E_1 = E_1(\alpha,\beta,t),\ \ E_2 = E_2(\alpha,\beta,t),\ \ E_3 = \frac{\partial v}{\partial t}B_1 - \frac{\partial u}{\partial t}B_2,\ \ H_3 = H_3(\alpha,\beta,t), \tag{8}$$

$$H_1 = \frac{1}{2}\left(H_1^+ + H_1^-\right) + \frac{\gamma}{h}\left(H_1^+ - H_1^-\right),\qquad H_2 = \frac{1}{2}\left(H_2^+ + H_2^-\right) + \frac{\gamma}{h}\left(H_2^+ - H_2^-\right)$$

The mathematical model of the process of magnetoelastic oscillation of a non-ferromagnetic current-carrying microplate under the influence of electrodynamic forces in a magnetic field can be written as follows:

$$\frac{\partial u}{\partial r} = \frac{1-\nu^2}{Eh}N_1 - \frac{\nu}{r}\left(\frac{\partial v}{\partial \theta} + u\right);\qquad \frac{\partial v}{\partial r} = \frac{2(1+\nu)}{Eh}S - \frac{1}{r}\left(\frac{\partial u}{\partial \theta} - v\right);$$

$$\frac{\partial w}{\partial r} = -\vartheta_1; \qquad \frac{\partial \vartheta_1}{\partial r} = \frac{12(1-\nu^2)}{Eh^3} M_1 + \frac{\nu}{r^2}\frac{\partial^2 w}{\partial \theta^2} - \frac{\nu}{r}\vartheta_1;$$

$$\frac{\partial N_1}{\partial r} = \frac{1}{r}\left(N_1(\nu-1) + \frac{Eh}{r}\left(\frac{\partial v}{\partial \theta} + u\right) - \frac{\partial S}{\partial \theta}\right) - \left(P_1 + \rho F_1^{л}\right) + \rho h \frac{\partial^2 u}{\partial t^2};$$

$$\frac{\partial S}{\partial r} = -\frac{1}{r}\left(2S + \frac{Eh}{r}\left(\frac{\partial^2 v}{\partial \theta^2} + \frac{\partial u}{\partial \theta}\right) - \nu\frac{\partial N_1}{\partial \theta}\right) - \left(P_2 + \rho F_2^{л}\right) + \rho h \frac{\partial^2 v}{\partial t^2};$$

$$\frac{\partial Q_1^*}{\partial r} = -\frac{1}{r}Q_1^* - \frac{\nu}{r^2}\frac{\partial^2 M_1}{\partial \theta^2} - \frac{Eh^3}{12r^3(1+\nu)}\left(\frac{2}{r}\frac{\partial^2 w}{\partial \theta^2} + (3+\nu)\frac{\partial^2 \vartheta_1}{\partial \theta^2} - \frac{\nu+1}{r}\frac{\partial^4 w}{\partial \theta^4}\right) -$$
$$-\left(P_3 + \rho F_3^{л}\right) + \rho h \frac{\partial^2 w}{\partial t^2} - \frac{\rho h^3}{12r^2}\frac{\partial^4 w}{\partial t^2 \partial \theta^2}; \qquad (9)$$

$$\frac{\partial M_1}{\partial r} = Q_1^* + \frac{\nu-1}{r}M_1 - \frac{Eh^3}{12r^3}\left(\vartheta_1 - \frac{1}{r}\frac{\partial^2 w}{\partial \theta^2}\right) - \frac{Eh^3}{6r^2(1+\nu)}\left(\frac{1}{r}\frac{\partial^2 w}{\partial \theta^2} + \frac{\partial^2 \vartheta_1}{\partial \theta^2}\right) + \frac{\rho h^3}{12}\frac{\partial^2 \vartheta_1}{\partial t^2};$$

$$\frac{\partial e_2}{\partial r} = -\frac{1}{r}e_2 - \frac{\partial b_3}{\partial t} + \frac{1}{r^2\sigma\mu}\frac{\partial^2 b_3}{\partial \theta^2} - \frac{1}{r}\left(B_{30}\frac{\partial^2 v}{\partial t \partial \theta} - \frac{B_2^+ + B_2^-}{2}\frac{\partial^2 w}{\partial t \partial \theta}\right);$$

$$\frac{\partial b_3}{\partial r} = \sigma\mu\left(\frac{\partial u}{\partial t}B_{30} - e_2 - \frac{B_1^+ + B_1^-}{2}\frac{\partial w}{\partial t}\right) - \frac{B_1^+ - B_1^-}{h}.$$

Here $\rho F_i^{л}$ - Lorentz force [5].

We solve the problem of determining the stress-deformation state of a non-ferromagnetic current-carrying microplate under nonstationary magnetic and mechanical influences for fixed moments of time.

To do this, we divide the entire movement process of a non-ferromagnetic current-carrying microplate into small time steps and observe the deformation history, i.e., solving the problem sequentially in each time step..

We use the stationary finite difference Newmark scheme to separate the variables over time..

In solving nonlinear boundary value problems of a non-ferromagnetic current-carrying microplate, it is effective to use interactive processes in which a linear boundary value problem is solved at each step..

Such methods of solving non-linear boundary value problems include the method of linearization.

In the last step, each of the linear boundary value problems was solved by the discrete orthogonalization method [1-5].

DISCUSSION

We study the stress-deformation state of a non-ferromagnetic current-carrying microplate under nonstationary magnetic and mechanical influences, taking into account the electrodynamic Lorentz forces.

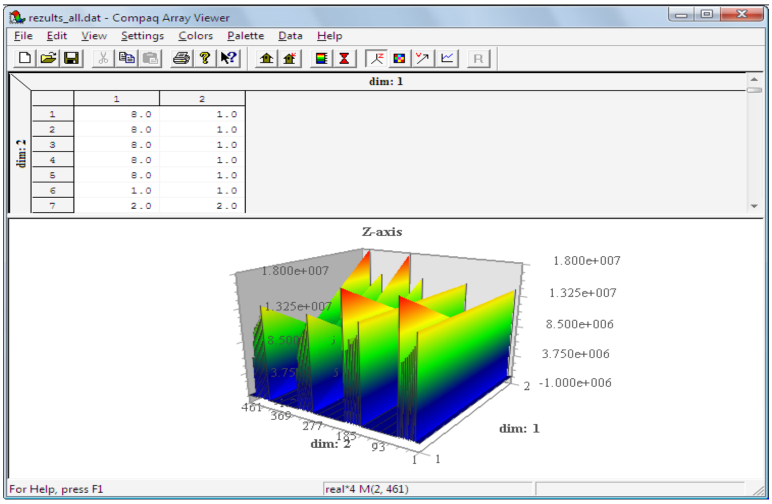

Figure 1. Deformation of a thin shell under the influence of electrodynamic forces

The obtained results show that the effect of electrodynamic forces on the magnetoelastic oscillation of a non-ferromagnetic conducting microplate is very significant (Fig. 1).

CONCLUSION

In the mechanics of dependent fields, the study of the movement of the surrounding medium taking into account electromagnetic effects occupies an important place. The development of modern new techniques and technologies has made it necessary to take these effects into account. When a stationary body moves in a magnetic field, a volumetric electrodynamic force acting on this body by the electromagnetic field, i.e. Lorentz force, appears. Lorentz forces depend on the speed of movement of the elements of the conducting medium and the external magnetic field, the direction and amount of the transfer current relative to the external magnetic field. The influence of these electrodynamic forces on non-ferromagnetic thin supporting flexible microplates is very significant.

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