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SOI: [1.1/TAS](#) DOI: [10.15863/TAS](#)

International Scientific Journal Theoretical & Applied Science

p-ISSN: 2308-4944 (print) e-ISSN: 2409-0085 (online)

Year: 2022 Issue: 01 Volume: 105

Published: 30.01.2022 <http://T-Science.org>

QR – Issue



QR – Article



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SIMULATION OF MAGNETOELASTIC DEFORMATION OF A PLATE IN AN ALTERNATING MAGNETIC FIELD

Abstract: A conductive flexible annular plate under the influence of a time-varying mechanical force and a time-varying external electric current, taking into account anisotropic electrical conductivity, is mathematically simulated in the article. The effect of an external magnetic field on the stress state of an annular plate is studied.

Key words: plate, magnetic field, magneto elasticity.

Language: English

Citation: Indiaminov, R. Sh., & Abdullaev, A. (2022). Simulation of magnetoelastic deformation of a plate in an alternating magnetic field. *ISJ Theoretical & Applied Science*, 01 (105), 751-755.

Soi: <http://s-o-i.org/1.1/TAS-01-105-55> **Doi:**  <https://dx.doi.org/10.15863/TAS.2022.01.105.55>

Scopus ASCC: 2200.

Introduction

Solid electrical materials can have different structures - crystalline, amorphous, and composite. Crystals are characterized by strict repetition of identical spatial cells and periodicity of the electrostatic field. Crystals are an example of purity and order in the world of atoms; they differ in the shape of spatial lattices and have different types of symmetry. Single crystals have anisotropy; their reactions to electrical, magnetic, light, mechanical and other influences depend on the direction of these influences relative to the crystallographic planes and axes of the crystal.

Single crystals are distinguished by a more perfect structure, they are the most studied ones, the physical phenomena occurring in them are easily calculated; they provide greater reliability and identity of the parameters of semiconductor devices. In magnetic semiconductors, the processes of generation of charge carriers and the passage of electric current depend on the direction and value of the magnetic field induction.

Metallic magnetic materials conduct electricity. In alternating fields, eddy currents arise in them, which increase with increasing frequency, therefore, the frequency range of their use is limited to direct current devices, as well as industrial and audio frequency currents.

Microminiaturization of electronic devices is a powerful stimulus for the development of nanotechnology, and microelectronics is turning into nanoelectronics before our very eyes.

In recent decades, considerable attention in the literature has been paid to the study of the process of deformation of electrically conductive bodies placed in an external alternating magnetic field under the influence of non-stationary force, thermal and electromagnetic loads [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21].

Interest in research in this area is associated with the importance of quantitative studying and evaluating the observed effects of the relationship of non-stationary mechanical, thermal and electromagnetic processes and their practical application in various

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fields of modern technology in the development of new technologies, in the field of nanotechnology and microelectronics, and in modern measuring systems, etc.

I. BASIC MAGNETOELASTIC EQUATIONS OF A FLEXIBLE CONDUCTIVE ANNULAR PLATE.

Based on the magnetoelasticity relations of a thin shell [3] and using the nonlinear elasticity relations, as well as Ohm's law and Maxwell's equations, the basic equations of a conductive annular plate can be obtained as follows:

The magnetoelastic kinetic equations have the following form

$$\begin{aligned} \frac{\partial(rN_r)}{\partial r} - N_\theta + r(F_r + \rho F_r^\wedge) &= r\rho h \frac{\partial^2 u}{\partial t^2}; \\ \frac{\partial(rQ_r)}{\partial r} + r(F_z + \rho F_z^\wedge) &= r\rho h \frac{\partial^2 w}{\partial t^2}; \\ \frac{\partial(rM_r)}{\partial r} - M_\theta - rQ_r - rN_r \vartheta_r &= 0. \end{aligned} \quad (1)$$

Equations of electrodynamics:

$$\begin{aligned} -\frac{\partial B_z}{\partial t} &= \frac{1}{r} \frac{\partial(rE_r)}{\partial r}; \\ \sigma_2 \left[E_\theta + 0,5 \frac{\partial w}{\partial t} (B_r^+ + B_r^-) - \frac{\partial u}{\partial t} B_z \right] &= \\ -\frac{\partial H_z}{\partial t} + \frac{H_r^+ - H_r^-}{h}. \end{aligned} \quad (2)$$

Expressions for deformations:

$$\begin{aligned} \varepsilon_r &= \frac{\partial u}{\partial r} + \frac{1}{2} \vartheta_r^2; \quad \varepsilon_\theta = \frac{u}{r}; \\ \chi_r &= \frac{\partial \vartheta_r}{\partial r}; \quad \chi_\theta = \frac{1}{r} \vartheta_\theta. \end{aligned} \quad (3)$$

where $\vartheta_r = \partial w / \partial r$ is the angle of rotation of the normal;

Elasticity ratio:

$$\begin{aligned} N_r &= \frac{e_r h}{1 - \nu_r \nu_\theta} (\varepsilon_r + \nu_\theta \varepsilon_\theta); \\ N_\theta &= \frac{e_\theta h}{1 - \nu_r \nu_\theta} (\varepsilon_\theta + \nu_r \varepsilon_r); \\ M_r &= \frac{e_r h^3}{12(1 - \nu_r \nu_\theta)} (\chi_r + \nu_\theta \chi_\theta); \\ M_\theta &= \frac{e_\theta h^3}{12(1 - \nu_r \nu_\theta)} (\chi_\theta + \nu_r \chi_r). \end{aligned} \quad (4)$$

In equations (1)–(4) the following parameters are accepted: $\nu_r = \nu_{\theta r}$, $\nu_\theta = \nu_{r\theta}$, $e_r \nu_\theta = e_\theta \nu_r$; ν_r ,

ν_θ – Poisson's ratios; e_r , e_θ – Young's modulus; u , w – displacements; N_r , N_θ – tangential forces; M_r , M_θ – bending moments; Q_r –

generalized cutting force; χ_r , χ_θ – the main curvatures of the middle surface of the plate; N_r , B_r^\pm – known values of the tangential components of magnetic induction on the surfaces of the plate.

The expressions for the Lorentz force have the form

$$\begin{aligned} \rho F_r^\wedge &= \sigma_1 h \left[E_\theta B_z - \frac{\partial u}{\partial t} B_z^2 + 0,5 \frac{\partial w}{\partial t} (B_r^+ + B_r^-) B_z \right]; \\ \rho F_z^\wedge &= -\sigma_2 h \left[0,5 E_\theta (B_r^+ + B_r^-) - 0,25 \frac{\partial w}{\partial t} (B_r^+ + B_r^-)^2 - \right. \\ &\quad \left. + \frac{1}{12} \frac{\partial w}{\partial t} (B_r^+ - B_r^-)^2 - 0,5 \frac{\partial u}{\partial t} (B_r^+ + B_r^-) B_z \right]. \end{aligned} \quad (5)$$

II. METHODS FOR SOLVING A COUPLED PROBLEM.

The developed methods for the numerical solution of coupled problems of magnetoelasticity of orthotropic plates with orthotropic electrical conductivity are based on the consistent application of the Newmark finite difference scheme, the linearization method and discrete orthogonalization [2-6,9].

III. ANALYSIS OF ELECTROMAGNETIC EFFECTS.

Consider the nonlinear behavior of an annular boron aluminum plate of variable thickness, changing in the meridional direction according to the following law $h = 5 \cdot 10^{-4} (1 - \gamma r^2 / r_0) m$. We assume that the plate is under the influence of mechanical force $P_\zeta = 5 \cdot 10^3 \sin \omega t N/m^2$, external electric current $J_{\theta CT} = 3 \cdot 10^7 \sin \omega t A/m^2$, and external magnetic field $B_{S0} = 0.1 T$, and that the plate is elastic orthotropic and has a finite orthotropic electrical conductivity $\sigma(\sigma_1, \sigma_2, \sigma_3)$. Let the problem of magnetostatics for the unperturbed state be solved, that is, the magnetic induction vectors of the initial state for the outer and inner regions are known.

We assume that the external electric current in the unperturbed state is uniformly distributed over the plate, i.e. the external current density does not depend on the coordinates. In this case, the plate is subjected to a combined loading consisting of the Lorentz ponderomotive force and mechanical force.

Let us study the effect of an external magnetic field on the stress state of an annular plate.

The boundary conditions are $s = r_0 = 0: u = 0, w = 0, \vartheta_r = 0, B_z = 0.5 \sin \omega t$;

$s = r_N = 0.0009m: N_r = 0, Q_r = -100, M_r = 0, E_\theta = 0$.

The initial conditions are

$$\vec{N}(s, t) \Big|_{t=0} = 0, \quad \dot{u}(s, t) \Big|_{t=0} = 0, \quad \dot{w}(s, t) \Big|_{t=0} = 0$$

The parameters of the plate and the material are:

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$r_0 = 0.005m; r_1 = 0.009m; h = 5 \cdot 10^{-4}(1 - \gamma r^2 / r_0)m; \gamma = 0.7,$
 $\sigma_1 = 0.454 \cdot 10^8 (\Omega \times m)^{-1}, \sigma_2 = 0.200 \cdot 10^8 (\Omega \times m)^{-1}, \nu_r = 0.262;$
 $\nu_\theta = 0.320; e_r = 22.9 \cdot 10^{10} N/m^2; e_\theta = 10.7 \cdot 10^{10} N/m^2;$
 $\omega = 314.16 \text{ sec}^{-1}; P_z = 5 \cdot 10^3 \sin \omega t H/m^2; P_r = 0;$
 $\tau = 1 \cdot 10^{-2} \text{ sec}; \mu = 1.256 \cdot 10^{-6} H/m; \rho = 2600 \text{ kg/m}^3;$
 $J_{\theta CT} = 3 \cdot 10^7 \sin \omega t A/m^2; B_r^\pm = 0.5Tn;$
 $B_{r0} = 0.5 \sin \omega t; \Delta t = 1 \cdot 10^{-3} \text{ sec}; 0 \leq t \leq 1 \cdot 10^{-2} \text{ sec}.$
 The solution to the problem is determined over time

interval $\tau = 10^{-2} \text{ sec}$, the integration step over time is taken as $\Delta t = 1 \cdot 10^{-3} \text{ sec}$ at one hundred points of integration over the length of the shell. The maximum values are obtained at time step $t = 5 \cdot 10^{-3} \text{ sec}$. Fig. 1 shows graphs of the change in time of the normal component of the Lorentz force $F_r^\wedge(t)$ for three values of magnetic induction. Graphs 1÷3 correspond to magnetic induction 1. $B_{z0} = 0.1$; 2. $B_{z0} = 0.2$; 3. $B_{z0} = 0.5$, respectively.

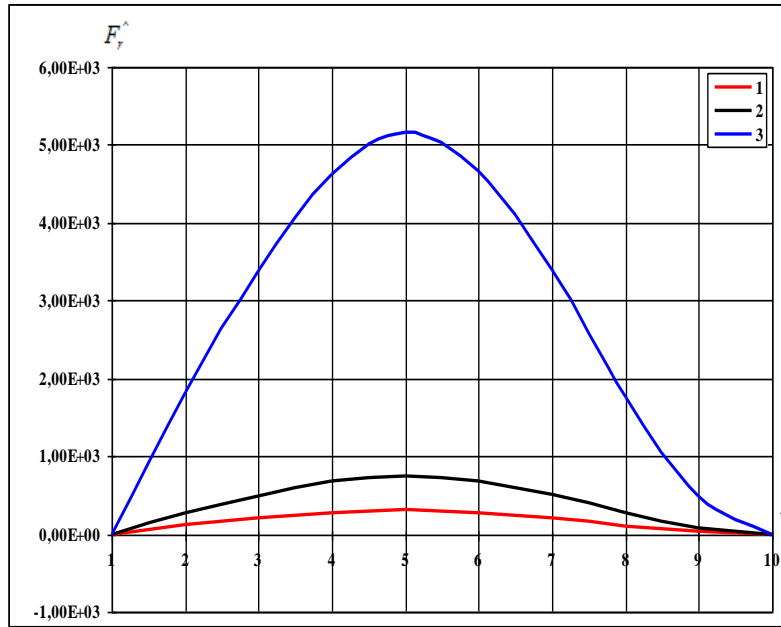


Figure 1. Graphs of changes in time of the normal component of the Lorentz force $F_r^\wedge(t)$ for the values of the normal component of external magnetic induction.

Analyzing the numerical results obtained, it can be seen that with an increase in the values of the normal component of external magnetic induction, the Lorentz force increases.

It was found that with an increase in the value of external magnetic induction, the stresses on the outer surface of the plate change depending on the change in the direction of the Lorentz ponderomotive force and the interaction with the mechanical load.

IV. CONCLUSION.

The article deals with the coupled problem of magnetoelasticity for a flexible orthotropic

conductive annular plate taking into account the anisotropy of the conductive properties. A solution was obtained for the nonlinear problem of magnetoelasticity of an annular plate taking into account anisotropic electrical conductivity.

The analysis of the results obtained allows us to evaluate the influence of the normal components of magnetic induction on the stress state of a flexible orthotropic annular plate. Based on the results presented, the magnetoelastic nonlinear problem for a conductive annular plate must be considered in a coupled form.

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