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# MATHEMATICAL MODELING OF THE PROCESSES OF NONLINEAR DEFORMATION OF CONSTRUCTIVE THERMO-MAGNETIC-ELASTIC PLATES

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**A B S T R A C T**

The article is devoted to the development of a mathematical model of the process of geometric nonlinear deformation of thin thermo-magnetic-elastic plates of a complex structural shape based on the Hamilton-Ostrogradsky variational principle and conducting calculation experiments. To solve the equation, a calculation algorithm was developed using R-function, Bubnov-Galerkin, Newmark, Gaussian, Gaussian squares, and Iteration number methods. Calculation experiments were carried out in various mechanical states of the magneto-elastic plate, its borders were tightly fixed, one side was hinged and the other side was free, and numerical results were obtained. A comparative analysis of the results of the calculations was presented.

**K E Y W O R D S**

Hamilton-Ostrogradsky principle, Bubnov Galerkin, Cauchy relation, Hooke's law, Maxwell's electromagnetic tensor, R-function, Gaussian, Iteration.Kirish

## Introduction

Nowadays, scientific research based on the nonlinear theories of electrical conductivity and magnetoelasticity of electromagnetic fields, in particular, the theories of the interdependence of two or more physical fields, is developing at a high pace. Thin magnetoelastic structural elements are important structural elements of machine-building, aircraft-building, shipbuilding and construction facilities.

Many studies have been conducted in the world on thermo-magnetic-elastic deformation processes of thin electroconductive bodies. In particular, such scientists as D.I.Bardzokas, S.A.Ambarsumyan, G.Ye.Baghdasaryan, M.V.Belubekyan, K.A.Rakhmatulin, V.K.Kobulov, B.Kurmanbaev, Sh.A.Nazirov, T.Yuldashev, A.A.Kholzhigitov, R.Sh.Indiaminov, F.M.Nuraliev including The analysis of the studied literature shows that the problems of mathematical modeling of the processes of geometric nonlinear deformation of magnetoelastic thin plates with an electrically conductive complex structural shape under the influence of an electromagnetic field have not been sufficiently studied to date. This determines how important the issue is and how relevant it is to conduct research.

**Mathematical model development**

Based on the Hamilton-Ostrogradsky variational principle, a mathematical model of the process of geometric nonlinear deformation of a magnetoelastic plate was developed [1,2]. A three-dimensional mathematical model was converted to a two-dimensional view using the Kirchhoff-Liav hypothesis. The geometric nonlinear strain tensor was obtained using the Cauchy relation and Hooke's law [3,4]. The electromagnetic field forces of the thermo-magnetic-elastic plate were developed using the Lorentz force and the Maxwell electromagnetic tensor. As a result, a mathematical model representing the process of geometric nonlinear deformation under the influence of electromagnetic field forces was developed [5].

$$\begin{cases} -\rho h\dfrac{\partial^2 u}{\partial t^2}+\dfrac{\partial N_{xx}}{\partial x}+\dfrac{\partial N_{xy}}{\partial y}+N_x+R_x+q_x+T_{zx}=0, \\ -\rho h\dfrac{\partial^2 v}{\partial t^2}+\dfrac{\partial N_{yy}}{\partial y}+\dfrac{\partial N_{xy}}{\partial x}+N_y+R_y+q_y+T_{zy}=0, \\ -\rho h\dfrac{\partial^2 w}{\partial t^2}+\dfrac{\partial^2 M_{xx}}{\partial x^2}+2\dfrac{\partial^2 M_{xy}}{\partial x\partial y}+\dfrac{\partial^2 M_{yy}}{\partial y^2}+N_{xx}\dfrac{\partial^2 w}{\partial x^2}+N_{yy}\dfrac{\partial^2 w}{\partial y^2}+N_{xy}\dfrac{\partial^2 w}{\partial x\partial y}+ \\ +\left(\dfrac{\partial N_{xx}}{\partial x}+\dfrac{\partial N_{xy}}{\partial y}\right)\dfrac{\partial w}{\partial x}+\left(\dfrac{\partial N_{yy}}{\partial y}+\dfrac{\partial N_{xy}}{\partial x}\right)\dfrac{\partial w}{\partial y}+N_z+R_z+q_z+T_{zz}=0. \end{cases} \quad (1)$$

Initial and boundary conditions:

$$\begin{cases} \rho h\dfrac{\partial u}{\partial t}\delta u\Big|_t=0,\ \rho h\dfrac{\partial v}{\partial t}\delta v\Big|_t=0,\ \rho h\dfrac{\partial w}{\partial t}\delta w\Big|_t=0, \\ \left(N_{xx}+N_{Px}+N_{Tx}\right)\delta u\Big|_x=0,\ \left(N_{xy}+N_{Py}+N_{Txy}\right)\delta v\Big|_x=0, \\ M_{xx}\delta\dfrac{\partial w}{\partial x}\Big|_x=0,\ M_{xy}\delta\dfrac{\partial w}{\partial y}\Big|_x=0, M_{yy}\delta\dfrac{\partial w}{\partial y}\Big|_y=0,\ M_{xy}\delta\dfrac{\partial w}{\partial x}\Big|_y=0, \\ \left(N_{yy}+N_{Fy}+N_{Tyy}\right)\delta v\Big|_y=0,\ \left(N_{xy}+N_{Fx}+N_{Tyx}\right)\delta u\Big|_y=0, \\ \left[N_{xx}\dfrac{\partial w}{\partial x}+N_{xy}\dfrac{\partial w}{\partial y}-\dfrac{\partial M_{xx}}{\partial x}-\dfrac{\partial M_{xy}}{\partial y}+N_{Pz}+N_{Txz}\right]\delta w\Big|_x=0, \\ \left[N_{yy}\dfrac{\partial w}{\partial y}+N_{xy}\dfrac{\partial w}{\partial x}-\dfrac{\partial M_{yy}}{\partial y}-\dfrac{\partial M_{xy}}{\partial x}+N_{Fz}+N_{Tyz}\right]\delta w\Big|_y=0. \end{cases}$$

where $N_{xx}, N_{yy}, N_{xy}$ - normal and impact forces on the thickness of the plate. $M_{xx}, M_{yy}, M_{xy}$ - bending and twisting moments of the plate, $\rho-$ body density, $h$- plate thickness, $R_x, R_y, R_z, N_x, N_y, N_z -$ volume forces, $q_x, q_y, q_z, T_{zx}, T_{zy}, T_{zz} -$ surface forces, $T_{xx}, T_{xy}, T_{xz}, T_{yy}, T_{yz}, T_{zx}, -$ contour forces.

**Algorithm for calculating the geometric nonlinear deformation processes**

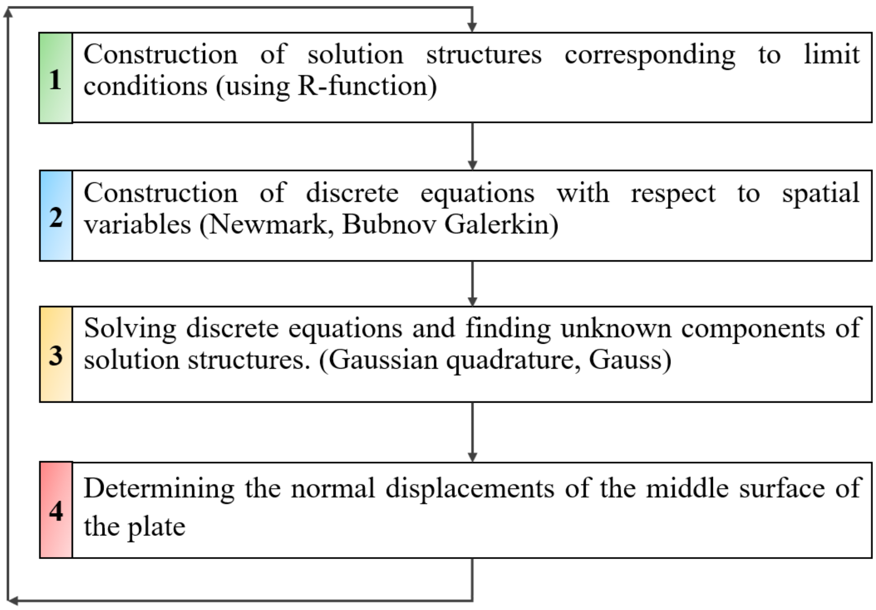


**Figure 1. Computational algorithm for solving the equation.**

## Computational experiments and analysis

To determine the coefficients of the unknowns in the equation of motion (1), the Bubnov-Galerkin variational method, Gaussian squares, Gaussian, Newmark, and Iteration number methods are used together [6]. In particular, the displacement coefficients of the thermo-magnetic-elastic thin plate along the OZ axis are determined.

The analytical equation of the field of complex structural form was constructed using the R-function method of V. L. Rivachev [7]. A symmetrical complex structural form (Fig. 2) was built during computational experiments. The borders (four sides) of the elastic plate are hinge fixed [8].

Using the R-function, the boundary equation for the symmetric complex field (Fig. 1) was constructed. Figure 3 shows a graphic representation of the bending of this symmetric complex magnetoelastic plate (Figure 2) along the coordinate axis under the influence of external forces [9].

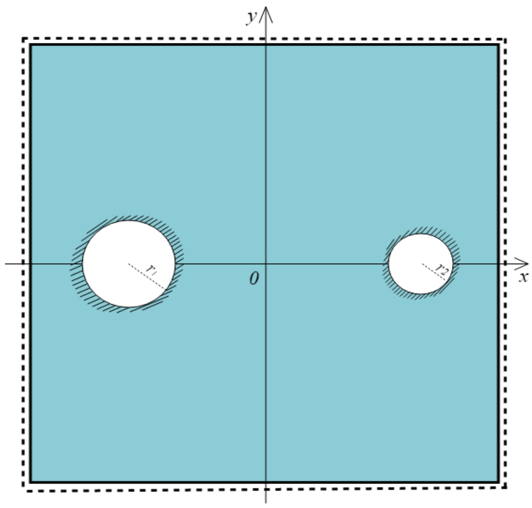


**Figure 2. Complex configurations of magnetoelastic symmetric thin plate boundaries are hinged**

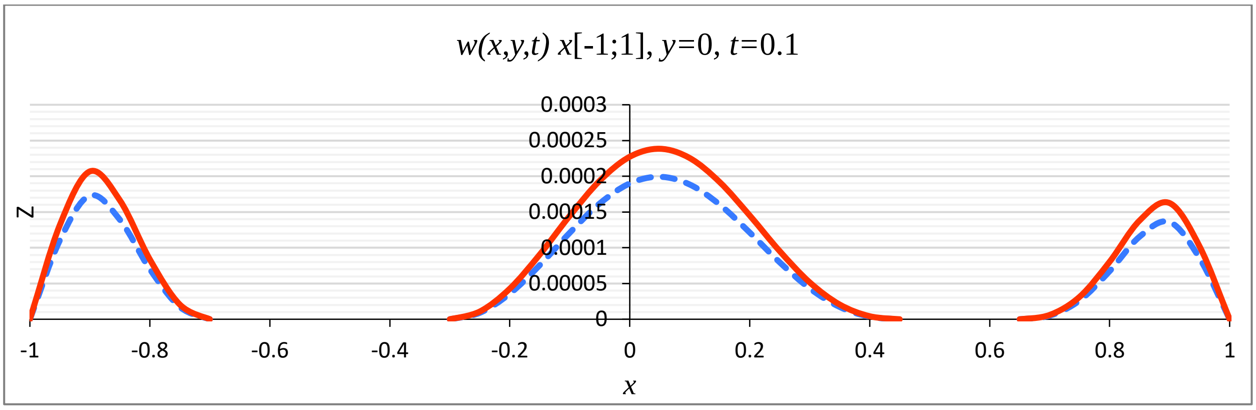


**Figure 3. Deformation graph of complex configuration thermo-magnetic-elastic thin plate boundaries when hinged**

When calculating the effect of mechanical force on a thin plate and the effect of magnetic field forces on mechanical forces (Fig. 3), the experimental results show that the deformation of the plate, taking into account the effect of magnetic field and temperature, is 18.4% was observed to increase [10]. Numerical results and graphical representation of bending along the axis of the thermo-magnetic-elastic plate (Moon) of complex shape in Fig. 1 (Fig. 4) are presented.

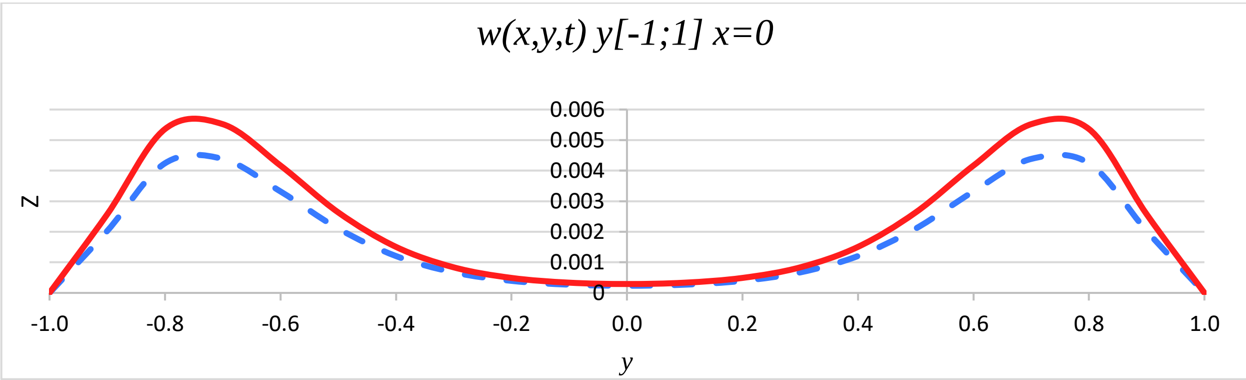


**Figure 4. Graphical representation of the complex configuration magnetoelastic symmetric thin plate boundaries on the coordinate axis when the hinge is fixed**

According to the results of the experiment, the effect of mechanical forces on the electroconductive thin plate and the effect of the magnetic field forces on the mechanical forces were calculated (Fig. 4), and the conclusion of the calculation experiments shows that their mutual difference It was 18.7%.

**Summary**

A mathematical model was created in the form of a system of differential equations with special derivatives, representing the processes of geometric nonlinear deformation of a thermo-magnetic-elastic thin plate of a complex structural form. A calculation algorithm was developed to find the unknown coefficients in the mathematical model. The unknown coefficients of the mathematical model were found on the basis of the conditions in which the boundaries of the geometric nonlinear deformation processes of thermo-magnetic-elastic thin plates of a complex structural form under the influence of electromagnetic forces are strictly fixed. The obtained numerical results were studied and their comparative analysis was presented. The results of the experiment show that the presence of magnetic field forces on thin magnetoelastic plates is small. This proves that the plate has a direct effect on the deformation process.

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