UDC 539.3

MATHEMATICAL MODELING OF THERMO-ELECTRO-MAGNIT-ELASTIC DEFORMATION PROCESSES OF THIN PLATES OF COMPLEX CONSTRUCTIVE FORM

Mirzaakhmedov M.K.
muhammadzohir1110@gmail.com
Andijan State University,
129, University Str., Andijan, 170100 Uzbekistan.

In this work, a mathematical model of the thermo-electro-magnetic-elastic deformation process of thin plates with a complex shape was developed and calculation experiments were carried out using the Hamilton-Ostrogradsky variational principle. Based on the Kirchhoff-Liav hypothesis, the three-dimensional mathematical model was transferred to a two-dimensional view. Cauchy's problem, physical law (Hook's law), Lawrence force and Maxwell's equations were used to find variational solutions of kinetic and potential energy and work done by external forces. The effects of electromagnetic field forces and temperature on the state of deformation stress of an electrically conductive plate were observed, as a result, the equation of motion in the form of a system of differential differential equations with initial and boundary conditions for displacement, i.e. mathematical model was developed. R-function, numerical methods (Bubnov-Galerkin, Newmark, Gauss and Gauss squares) were used to find the solutions of the unknown function, and a calculation algorithm was created. In the calculation experiments, numerical results were obtained by conducting calculation experiments based on the mechanical conditions of the plate and various conditions. A comparative analysis of the calculation results was presented.

Keywords: Hamilton-Ostrogradsky principle, Bubnov Galerkin method, Cauchy relation, Hooke's law, Maxwell's electromagnetic tensor, R-function.

Citation: Mirzaakhmedov M.K. 2024. Mathematical modeling of thermo-electro-magnit-elastic deformation processes of thin plates of complex constructive form. *Problems of Computational and Applied Mathematics.* 5(61): 31-42.

1 Introduction

Of plates with complex configuration in the world scientific research aimed at building mathematical models and developing calculation algorithms to solve the problems of thermo-electro-magnetic-elasticity deformation processes is being carried out.. Thin magnetoelastic structural elements are important structural elements of machine-building, aircraft-building, shipbuilding and construction facilities. In addition, it is widely used in the fields of working with radio signals.

Many scientists of the world and our country have conducted many studies on the processes of magnetoelastic deformation of thin electroconductive bodies. In particular, D.I. Bardzokas, S.A. Ambarsumyan, G.Ye. Bagdasaryan, M.V. Belubekyan, K.A. Rakhmatulin, V.K. Kobulov, B. Kurmanbaev, Sh.A. Nazirov, T. Yuldashev, A.A. Khaldjigitov, R.Sh. Indiaminov, F.M. Nuraliev etc. scientists are among them. The analysis of the literature shows that the problems of mathematical modeling of the thermo-electro-magnetic-elasticity deformation processes of thin plates with an electrically conductive complex shape under the influence of mechanical and electromagnetic forces and temperature are relevant. This determines how important the issue is and how relevant it is to conduct research.

Boundary problems of the general theory of thermoelectro-magneto-elasticity for homogeneous anisotropic bodies with cracks are studied in the work [2]. Using potential methods of pseudo-differential equations on finite manifolds, it is proved that the solutions are defined and unique based on their theory. Using potential methods and theory of pseudo-differential equations in finite manifolds, existence and uniqueness of solutions are proved. In the article [3], a nonlocal first-order deformable plate model is presented to study the buckling and subsequent buckling of magneto-electro-thermoelastic (METE) nanoplates under magneto-electro-thermo-mechanical loadings. The mathematical model is described by a system of nonlinear equations for temperature and displacement, and heat release occurs in the source subregion V. Vasileva et al. identified in the article [4].

The behavior of an anisotropic material under limited deformations under the influence of external force factors in a non-uniform stationary temperature field has been studied [5]. The description of these processes requires the formulation of a boundary value problem taking into account the interaction of force and temperature factors. A size-dependent nanoplate model was developed to describe the free vibrational and torsional motions of magneto-electro-thermo-elastic (METE) rectangular nanoplates [6]. Nonlocal elasticity theory, along with third-order shear deformation theory, has been applied to size-dependent mathematical modeling of nanoplates. Hamilton's principle, Galerkin's method and Duffing type ordinary differential equations are used.

2 Problem statement

Based on the Hamilton-Ostrogradsky variational principle, a mathematical model of the deformation process of a magnetoelastic plate was developed [1]. A three-dimensional mathematical model was converted to a two-dimensional view using the Kirchhoff-Liav hypothesis. A linear strain tensor was obtained using the Cauchy relation and Hooke's law. The general form of geometric linear deformation obtained according to the Cauchy relation is as follows [10]

$$\begin{aligned} e_{xx} &= \frac{\partial u}{\partial x} - z\frac{\partial^2 w}{\partial x^2}; \\ e_{yy} &= \frac{\partial v}{\partial y} - z\frac{\partial^2 w}{\partial y^2}; \\ e_{xy} &= \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} - z\frac{\partial^2 w}{\partial x \partial y}. \end{aligned} \tag{1}$$

$e_x x, e_y y, e_x y$ is deduced from the formula. Here the plates are joined by thickness. We derive this expression using the Duhamel-Neyman relation and Hooke's law

$$\begin{aligned} \sigma_{xx} &= \frac{E}{1-\mu^2}[\frac{\partial u}{\partial x} - z\frac{\partial^2 w}{\partial x^2} - \mu\frac{\partial v}{\partial y} + \mu z\frac{\partial^2 w}{\partial y^2}] - \alpha_T(T-T_0)\frac{1}{1-\mu}; \\ \sigma_{yy} &= \frac{E}{1-\mu^2}[\frac{\partial v}{\partial y} - z\frac{\partial^2 w}{\partial y^2} - \mu\frac{\partial u}{\partial x} + \mu z\frac{\partial^2 w}{\partial x^2}] - \alpha_T(T-T_0)\frac{1}{1-\mu}; \\ \sigma_{xy} &= \frac{E}{2(1+\mu)}(\frac{\partial u}{\partial y} + \mu\frac{\partial v}{\partial x} - 2z\frac{\partial^2 w}{\partial x \partial y}), \end{aligned} \tag{2}$$

where E - Young modulus, μ - Poisson's ratio, α_T - heat resistance coefficient, T_0 - initial temperature of the plate, T - temperature of the plate.

Lorenth force and Maxwell's electromagnetic tensor form were used [7] and the electromagnetic field forces of the magnetoelastic plate were developed. As a result, a mathematical model representing the process of deformation under the influence of electromagnetic field forces was developed [8].

$$\begin{cases} \rho h\dfrac{\partial^2 u}{\partial t^2}+\dfrac{Eh}{(1-\mu^2)}(\dfrac{\partial^2 u}{\partial x^2}+\mu\dfrac{\partial^2 v}{\partial x\partial y}+\dfrac{\alpha_T}{1-\mu}\dfrac{\partial T}{\partial x})+\dfrac{Eh}{2(1+\mu)}(\dfrac{\partial^2 u}{\partial y^2}+\mu\dfrac{\partial^2 u}{\partial x\partial y})+ \\ +R_x+N_x+q_x+\zeta_T+\xi_{zx}=0 \\ \rho h\dfrac{\partial^2 v}{\partial t^2}+\dfrac{Eh}{(1-\mu^2)}(\dfrac{\partial^2 v}{\partial y^2}+\mu\dfrac{\partial^2 u}{\partial x\partial y}+\dfrac{\alpha_T}{1-\mu}\dfrac{\partial T}{\partial y})+\dfrac{Eh}{2(1+\mu)}(\dfrac{\partial^2 u}{\partial x\partial y}+\dfrac{\partial^2 v}{\partial y^2})+ \\ +R_y+N_y+q_y+\zeta_T+\xi_{zy}=0 \\ \rho h\dfrac{\partial^2 w}{\partial t^2}+\dfrac{Eh}{(1-\mu^2)}\dfrac{h^3}{12}(\dfrac{\partial^4 w}{\partial y^4}+\dfrac{\partial^2 u}{\partial x^2\partial y^2}+(\dfrac{\partial^4 w}{\partial x^4})+R_z+N_z+q_z+\zeta_T+\xi_{zz}=0. \end{cases} \quad (3)$$

Initial conditions:

$$\rho h\frac{\partial u}{\partial t}\delta u|_t=0,\ \rho h\frac{\partial v}{\partial t}\delta v|_t=0,\ \rho h\frac{\partial w}{\partial t}\delta w|_t=0,\ T|_{t=0}=0, \quad (4)$$

where ρ - density of the material under consideration, h - thickness of the plate.

Boundary conditions:

$$\begin{cases} N_{xx}\delta u|_x=0, \dfrac{1}{2}N_{xy}\delta v|_x=0, -M_{xx}\delta\dfrac{\partial w}{\partial x}|_x=0, -\dfrac{1}{2}M_{xy}\delta\dfrac{\partial w}{\partial y}|_x=0, \\ N_{yy}\delta v|_y=0, \dfrac{1}{2}N_{xy}\delta u|_y=0, -M_{yy}\delta\dfrac{\partial w}{\partial y}|_y=0, \\ (-\dfrac{\partial M_{xx}}{\partial x}+\dfrac{1}{2}N_{xx}\dfrac{\partial w}{\partial x}+\dfrac{1}{2}N_{xy}\dfrac{\partial w}{\partial y})\delta w|_x=0, \\ (-\dfrac{\partial M_{yy}}{\partial y}+\dfrac{1}{2}N_y y\dfrac{\partial w}{\partial y}+\dfrac{\partial M_{xy}}{\partial x}+\dfrac{1}{2}N_{xy}\dfrac{\partial w}{\partial x})\delta w|_y=0, \\ -\dfrac{\partial T}{\partial n}+\alpha_t(T-T_0)=0 \text{ at the border}, \end{cases} \quad (5)$$

where N_{xx}, N_{yy}, N_{xy} -normal and impact forces, M_{xx}, M_{yy}, M_{xy} - bending and twisting moments, $\xi_{zx}, \xi_{zy}, \xi_{zz}, q_x, q_y, q_z$ - derivative external forces,ζ_T-constant temperature, $N_x, N_y, N_z, R_x, R_y, R_z$ - the organizers of the volume forces.

3 Computational algorithm

The bending of the middle surface of the plate along the x, y, zcoordinate axis is determined by the above numerical methods. In this case, finding $u(x, y, z), v(x, y, z), w(x, y, z)$ displacement points of the middle surface of a thin plate with a complex shape along the coordinate x, y, z axis includes the following steps [11]:

$$\frac{\partial^4 M_{xx}(w)}{\partial x^4}+2\frac{\partial^4 M_{xy}(w)}{\partial x^2\partial y^2}+\frac{\partial^4 M_{yy}(w)}{\partial y^4}=Q_z. \quad (6)$$

The displacement functions u, v, w are calculated in the following system of equations

$$\left\{\begin{array}{l} -\rho h\dfrac{\partial^2 u}{\partial t^2}+\dfrac{Eh}{(1-\mu^2)}(\dfrac{\partial^2 u}{\partial x^2}+\mu\dfrac{\partial^2 v}{\partial x\partial y}+\dfrac{\alpha_T}{1-\mu}\dfrac{\partial T}{\partial x})+ \\ +\dfrac{Eh}{2(1+\mu)}(\dfrac{\partial^2 u}{\partial y^2}+\mu\dfrac{\partial^2 u}{\partial x\partial y})+\dfrac{h}{4\pi}H_y^2(\dfrac{\partial^2 u}{\partial x^2}+\dfrac{\partial^2 u}{\partial y^2})+ \\ +\dfrac{h}{4\pi}H_z^2(\dfrac{\partial^2 u}{\partial x^2}+\dfrac{\partial^2 v}{\partial x\partial y})+\dfrac{h}{4\pi}H_xH_y(\dfrac{\partial^2 v}{\partial x^2}+\dfrac{\partial^2 v}{\partial y^2})- \\ -\dfrac{h}{4\pi}H_xH_z(\dfrac{\partial^2 w}{\partial x^2}+\dfrac{\partial^2 w}{\partial y^2})-\dfrac{h}{2\pi}H_yH_z\dfrac{\partial^2 w}{\partial x\partial y}=Q_x \\ -\rho h\dfrac{\partial^2 v}{\partial t^2}+\dfrac{Eh}{(1-\mu^2)}(\dfrac{\partial^2 v}{\partial x^2}+\mu\dfrac{\partial^2 u}{\partial x\partial y}+\dfrac{\alpha_T}{1-\mu}\dfrac{\partial T}{\partial x})+ \\ +\dfrac{Eh}{2(1+\mu)}(\mu\dfrac{\partial^2 u}{\partial x\partial y}-\dfrac{\partial^2 v}{\partial x^2})+\dfrac{h}{4\pi}H_x^2(\dfrac{\partial^2 v}{\partial x^2}+\dfrac{\partial^2 v}{\partial y^2})+ \\ +\dfrac{h}{4\pi}H_z^2(\dfrac{\partial^2 v}{\partial x^2}+\dfrac{\partial^2 v}{\partial x\partial y})+\dfrac{h}{4\pi}H_xH_y(\dfrac{\partial^2 v}{\partial x^2}+\dfrac{\partial^2 v}{\partial y^2})- \\ -\dfrac{h}{4\pi}H_yH_z(\dfrac{\partial^2 w}{\partial x^2}+\dfrac{\partial^2 w}{\partial y^2})-\dfrac{h}{2\pi}H_zH_z\dfrac{\partial^2 w}{\partial x\partial y}= \\ =Q_y.-\rho h\dfrac{\partial^2 w}{\partial t^2}-\dfrac{Eh}{(1-\mu^2)}\dfrac{h^3}{12}+\dfrac{\partial^4(w)}{\partial x^4}+ \\ +2\dfrac{\partial^4(w)}{\partial x^2\partial y^2}+\dfrac{\partial^4(w)}{\partial y^4}+\dfrac{h}{4\pi}H_xH_z(\dfrac{\partial^2 u}{\partial x^2}-\dfrac{\partial^2 v}{\partial x\partial y})- \\ -\dfrac{h}{4\pi}H_yH_z(\dfrac{\partial^2 v}{\partial x^2}-\dfrac{\partial^2 v}{\partial x\partial y})-\dfrac{h}{4\pi}H_y^2H_z(\dfrac{\partial^2 w}{\partial x^2}+\dfrac{\partial^2 w}{\partial y^2})+ \\ +\dfrac{h}{4\pi}H_x^2H_z(\dfrac{\partial^2 w}{\partial x^2}-\dfrac{\partial^2 w}{\partial y^2})+\dfrac{h}{\pi}H_xH_yH_z\dfrac{\partial^2 w}{\partial x\partial y}=Q_z. \end{array}\right. \tag{7}$$

where $Q_x = -(N_x + q_x + \xi_x + \zeta_T), Q_y = -(N_y + q_y + \xi_y + \zeta_T), Q_z = -(N_z + q_z + \xi_z + \zeta_T)$.

4 Computational experiments

To determine the coefficients of the unknowns in the equation of motion (1), the Bubnov-Galerkin variational method, Gaussian squares, Gaussian, Newmark, numerical methods are used together. In particular, the displacement coefficients of the magnetoelastic thin plate along the OZ axis $u_i(x, y), v_i(x, y), w_i(x, y)$ are determined.

The analytical equation of the area of complex structural form was constructed using the R-function method of V.L. Rivachov [9]. A symmetrical complex structural form (Fig. 2) was built during computational experiments. The borders (four sides) of the elastic plate are tightly fixed.

Using the R-function, the boundary equation for the symmetric complex field (Fig. 1) was constructed. Numerical results and a graphical representation of the bending of this symmetric complex magnetoelastic plate (Fig. 2) along the coordinate axis under the influence of external forces are presented in Fig. 3.

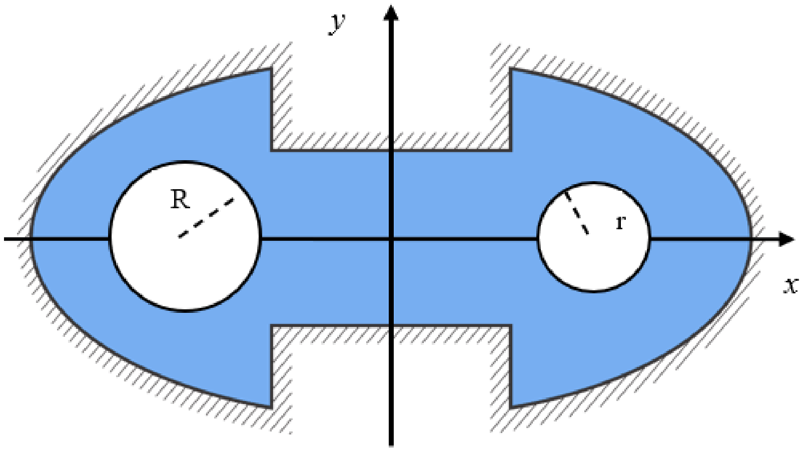

Figure 1 Complex form magnetoelastic symmetric thin plate

Based on the boundary conditions given above, we construct the analytical equations of the field with a complex configuration (expression 1).

$$\omega = \omega_1 \wedge (\omega_2 \vee \omega_3) \wedge (\omega_4 \wedge \omega_5),$$

$$\omega_1 = \frac{a^2b^2 - b^2x^2 - a^2y^2}{2ab\sqrt{a^2+b^2-x^2-y^2}} \geqslant 0,$$

$$\omega_2 = \frac{d^2-y^2}{2d} \geqslant 0; \omega_3 = \frac{x^2-c^2}{2c} \geqslant 0,$$

$$\omega_4 = \frac{(x-a)^2+y^2-R^2}{2R},$$

$$\omega_5 = \frac{(x-a)^2+y^2-r^2}{2r},$$

$$\omega_{23} = \omega_2 \vee \omega_3, \omega_{23} = \frac{d^2-y^2}{2d} + \frac{x^2-c^2}{2c} - \sqrt{(\frac{d^2-y^2}{2d})^2 + (\frac{x^2-c^2}{2c})^2},$$

$$\omega_{123} = \frac{a^2b^2 - b^2x^2 - a^2y^2}{2ab\sqrt{a^2+b^2-x^2-y^2}} + (\frac{d^2-y^2}{2d} + \frac{x^2-c^2}{2c})+$$
$$+\sqrt{(\frac{a^2b^2 - b^2x^2 - a^2y^2}{2ab\sqrt{a^2+b^2-x^2-y^2}})^2 + (\frac{d^2-y^2}{2d} + \frac{x^2-c^2}{2c})^2},$$

$$\omega_{45} = \omega_4 \vee \omega_5, \omega_{45} = (\frac{(x-a)^2+y^2-R^2}{2R}) + (\frac{(x-a)^2+y^2-r^2}{2r})+$$
$$+\sqrt{(\frac{(x-a)^2+y^2-R^2}{2R})^2 + (\frac{(x-a)^2+y^2-r^2}{2r})^2},$$

$$\omega = \omega_{123} \vee \omega_{45}.$$

In the process of calculation, we obtain the geometric and mechanical parameters as follows.

$$a = 1, b = 1,\ h = 0.01,\ R = 0.2,\ r = 0.1,\ \nu = 0.3,$$
$$t_0 = 0.1,\ H_x = H_y = H_z = 10kE,\ T = 40^0,\ Q_z = 1.$$

Table 1. Results obtained under conditions where the boundaries of the thin plate are rigidly fixed

x	y	Values of the function $W(x, y, t)t = 0.1$ when the mechanical forces	Values of the function $W(x, y, t)t = 0.1$ when the electromagnetic field forces	Values of the function $W(x, y, t)t = 0.1$ when the mechanical forces and electromagnetic field forces, when affected by temperature
-1	0	0	0	0
-0.9	0	0.000408	0.00449	0.00525
-0.8	0	0.000426	0.000468	0.00133
-0.7	0	0.000104	0.000114	0.000133
-0.6	0	0	0	0
-0.5	0	0	0	0
-0.4	0	0	0	0
-0.3	0	0.000086	0.000094	0.000110
-0.2	0	0.000404	0.000444	0.000519
-0.1	0	0.000814	0.000897	0.001049
0	0	0.001006	0.001107	0.001295
0.1	0	0.000814	0.000897	0.001049
0.2	0	0.000403	0.0004	0.000519
0.3	0	0.000086	0.000094	0.000110
0.4	0	0	0	0
0.5	0	0	0	0
0.6	0	0	0	0
0.7	0	0.000104	0.000114	0.000133
0.8	0	0.000426	0.000469	0.000548
0.9	0	0.000408	0.000449	0.000525
1	0	0	0	0

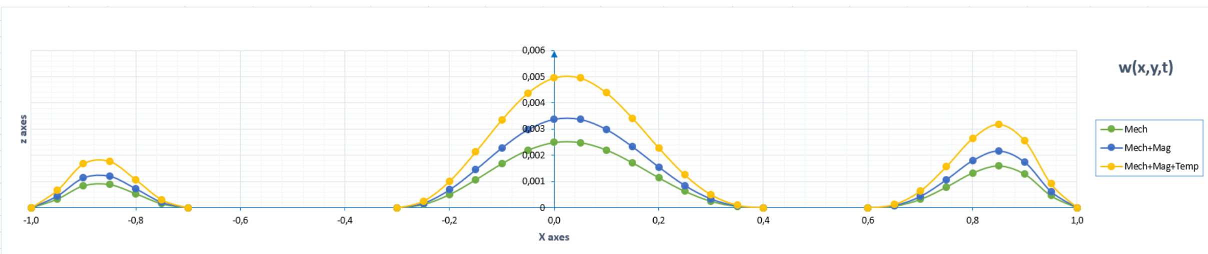

Figure 2 Graphic representation of a magnetoelastic symmetric thin plate with a complex configuration on the coordinate axis with the boundaries rigidly fixed

Table 2. Results obtained on $U(x, y, t)$ in the conditions where the boundaries of the thin plate are rigidly fixed

x	y	Values of the function $U(x, y, t)t = 0.1$ when the mechanical forces	Values of the function $U(x, y, t)t = 0.1$ when the electromagnetic field forces	Values of the function $U(x, y, t)t = 0.1$ when the mechanical forces and electromagnetic field forces, when affected by temperature
-1	0	0	0	0
-0.9	0	0.0000035	0.0000039	0.0000049
-0.8	0	0.0000036	0.0000041	0.0000051
-0.7	0	0.0000008	0.0000010	0.0000012
-0.6	0	0	0	0
-0.5	0	0	0	0
-0.4	0	0	0	0
-0.3	0	0.0000007	0.0000008	0.0000104
-0.2	0	0.0000034	0.000444	0.0000489
-0.1	0	0.0000066	0.0000079	0.0000987
0	0	0.0000087	0.0000098	0.0000122
0.1	0	0.0000069	0.000897	0.0000099
0.2	0	0.0000343	0.0000039	0.0000049
0.3	0	0.0000007	0.0000008	0.00000104
0.4	0	0	0	0
0.5	0	0	0	0
0.6	0	0	0	0
0.7	0	0.0000088	0.0000010	0.0000126
0.8	0	0.0000036	0.0000041	0.0000052
0.9	0	0.0000035	0.0000039	0.0000049
1	0	0	0	0

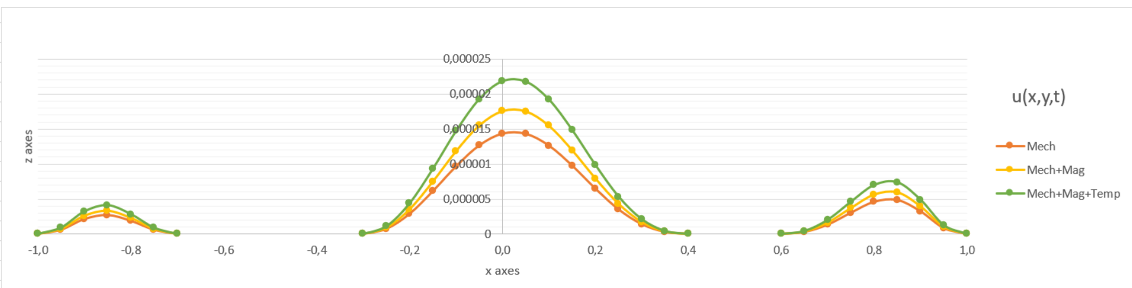

Figure 3 Graphic representation of a magnetoelastic symmetric thin plate with a complex configuration on the coordinate axis with the boundaries rigidly fixed

Table3. Results obtained on $V(x, y, t)$ in the conditions where the boundaries of the thin plate are rigidly fixed

x	y	Values of the function $V(x, y, t)t = 0.1$ when the mechanical forces	Values of the function $V(x, y, t)t = 0.1$ when the electromagnetic field forces	Values of the function $V(x, y, t)t = 0.1$ when the mechanical forces and electromagnetic field forces, when affected by temperature
-1	0	0	0	0
-0.9	0	0.0000026	0.0000031	0.0000037
-0.8	0	0.0000027	0.0000032	0.0000039
-0.7	0	0.0000066	0.0000078	0.0000094
-0.6	0	0	0	0
-0.5	0	0	0	0
-0.4	0	0	0	0
-0.3	0	0.0000005	0.0000007	0.0000078
-0.2	0	0.0000026	0.0000030	0.0000036
-0.1	0	0.0000052	0.0000061	0.0000074
0	0	0.0000064	0.0000076	0.0000091
0.1	0	0.0000052	0.0000061	0.0000074
0.2	0	0.0000026	0.0000030	0.0000037
0.3	0	0.0000005	0.0000006	0.0000008
0.4	0	0	0	0
0.5	0	0	0	0
0.6	0	0	0	0
0.7	0	0.0000066	0.0000008	0.0000009
0.8	0	0.0000027	0.0000032	0.0000039
0.9	0	0.0000026	0.0000030	0.0000004
1	0	0	0	0

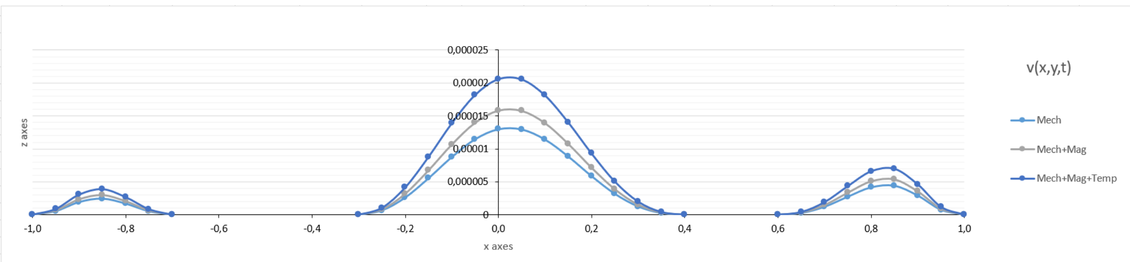

Figure 4 Results obtained on $V(x, y, t)$ in the conditions where the boundaries of the thin plate are rigidly fixed

In short, when calculating the effects of mechanical forces on an electroconductive thin plate and the magnetic field force difference of 9.1% and the effect of temperature on the mechanical forces (Table 1, Fig. 3), and the conclusion of the calculation experiments is as follows shows that their mutual difference was 14.5% [10]

The conclusion of the calculation experiments shows that the difference of mechanical forces, magnetic field forces was 12.3% and the mutual difference of temperature effect was 19.9%.

According to the results of the experiment, when calculating the effect of mechanical forces on the electrically conductive thin plate and the effect of magnetic field forces on the mechanical forces, the difference is 15.4% (Table 3, Figure 5) and the temperature Experiments show that the difference between them was 17.0%.

In the following experiment, the polynomial level $N = 2, N = 3, andN = 4$ were tested. As a result, $w(x, y, t)$ - numerical values of the function converged at levels $N = 3, N = 4$ (Fig.6).

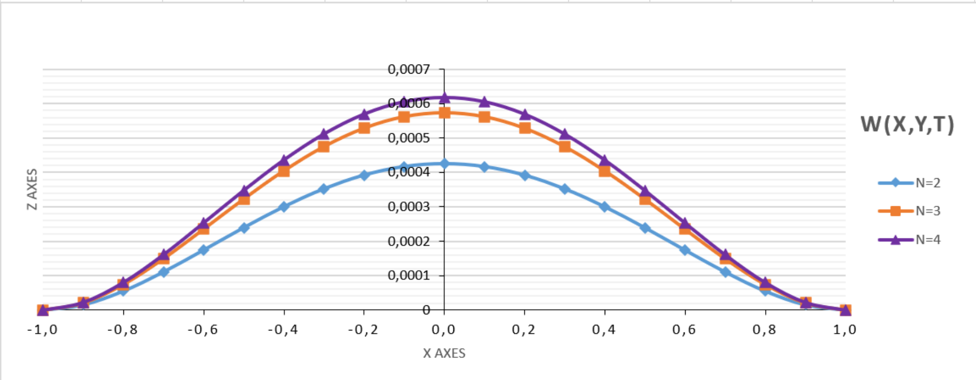

Figure 5 Comparison graph of degree polynomials obtained by the Bubnov-Galerkin method.

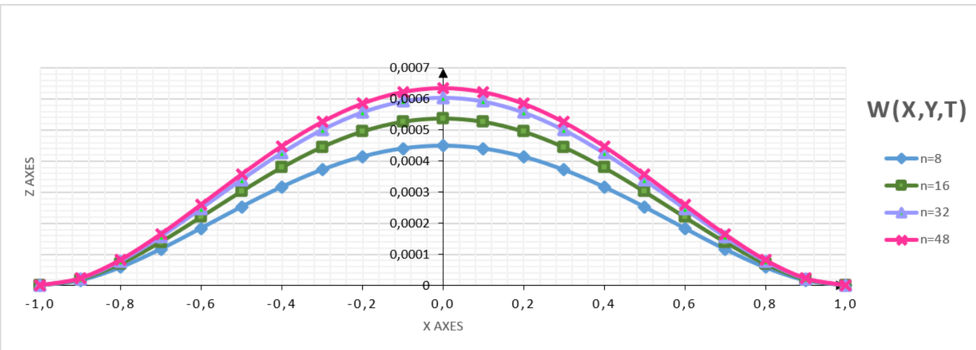

Figure 6 Gaussian node comparison plot.

In the next experiment (Fig. 6), the Gaussian quadrature formula was used to calculate the exact integral of the equation. Experiments were conducted at various points using the Kronrod polynomial. As a result, at values of Gauss nodes n=32, n=48, w(x,y,t) - numerical values of the function converged and approximate solutions close to the exact solution were obtained.

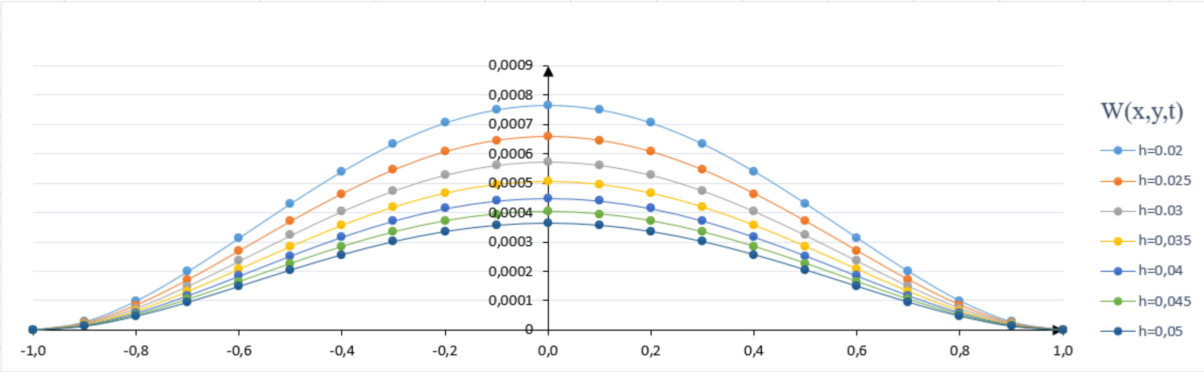

Figure 7 Experience obtained on plate thickness h results comparison graph

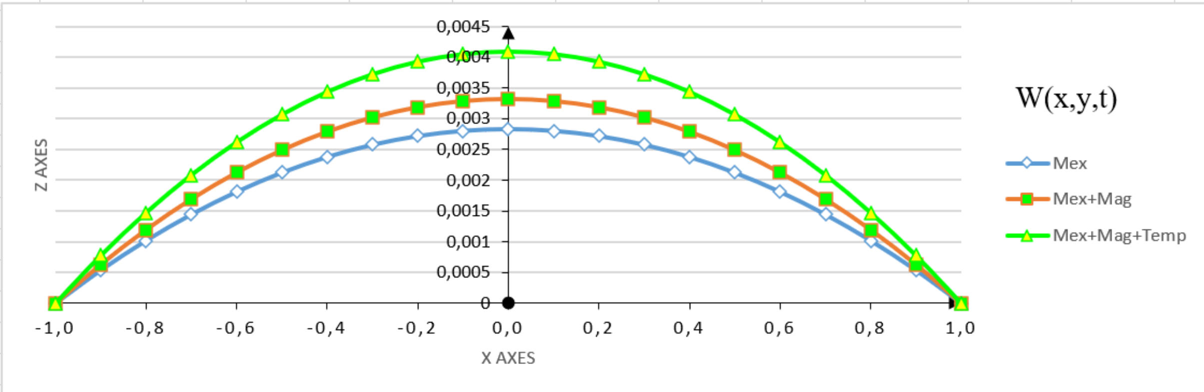

Figure 8 The boundaries of the plate are numerically obtained in the free state results graphd

5 Conclusion

A mathematical model in the form of a system of differential differential equations representing the processes of thermo-electro-magneto-elastic deformation of a thin plate with a complex shape was developed. A calculation algorithm was developed to determine the unknown coefficients in the mathematical model. The unknown coefficients of the mathematical model were found based on the deformation processes of the thin plate under the influence of electromagnetic forces and temperature under different conditions (the boundaries are tightly fixed, the hinge is fixed). Computational experiments were carried out to study the effect of mechanical forces, electromagnetic field forces and temperature on a thin plate of complex shape, and their comparative analysis was presented. The results of the experiment revealed that the influence of electro-magnetic field forces on thin magnetoelastic plates is small. The overall results prove that the plate with a complex structural shape has a direct effect on the thermo-electro-magneto-elastic deformation process.

References

[1] Kabulov V.K. 1966. *Algorithmization in the theory of elasticity and deformation theory of plasticity. Tashkent Science:.* – 392 p. (in Russian)

[2] Tengiz B., Ch. Otar, N. David 2016. Mixed boundary value problems of pseudo-oscillations of generalized thermo-electro-magneto-elasticity theory for solids with interior cracks *ScienceDirect. Transactions of A. Razmadze Mathematical Institute* 170(1), – P. 308–351.

[3] Ansari R., R. Gholami 2016. Size-Dependent Buckling and Postbuckling Analyses of First-Order Shear Deformable Magneto-Electro-Thermo Elastic Nanoplates Based on the Nonlocal Elasticity Theory *International Journal of Structural Stability and Dynamics* 16(10), 170–351.

[4] Vasilyeva M.V., P.Y. Zaxarov, P.V. Sivsev, D.A. Spiridonov 2017. Numerical modeling of thermoelasticity problems for a structure with an internal source *Mathematical notes of NEFU* 24(3) – P. 53–64.(in Russian)

[5] Markin A.A., D.V. Xritich, M.Y. Sokolova 2004. Relations of nonlinear thermoelasticity in variational form *Mathematical modeling and boundary value problems* 1 – P. 139–142. (in Russian)

[6] Gholami Y., R. Ansari, R. Gholami, F. Sadeghi 2004. Size-dependent free vibration and buckling analysis of magneto-electro-thermo-elastic nanoplates based on the third-order shear deformable nonlocal plate model *Juornal Mechanical Engineering Science* 236(14) – P. 8116–8133.

[7] Ambartsumyan S.A., M.V. Belubekyan 1991. Some problems of electromagneto elasticity of plates *Erevan* – 144 p.

[8] Nuraliyev F.M., M.K. Mirzaaxmedov, O.K. Abdulayev, B. Tohirov 1991. Mathematical model of thermo-electro-mangnite-elasticity of thin plate. *TUIT scientific-technical and information-analytical journal* 1 (69), – P. 12–28.

[9] Rvachev L.V.,L.V Kurpa 1987. R-Functions in Problems of the Theory of Plates *Russian (Naukova Dumka, Kiev) – P. 32–40.*

[10] Leibenzon L.S. 1977. *Course in the theory of elasticity.* Moscow. – 272 p. (in Russian)

[11] Nuraliyev F.M., N. Isayeva., M.K. Mirzaaxmedov 2024. Computational Algorithms For Solving Boundary Value Problems Of Magnetoelastic Plates With Complex Form *Bulletin of TUIT: Management and Communication Technologies* 1(10) – P. 13–20.

Received October 23, 2024

УДК 539.3

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССОВ ТЕРМО-ЭЛЕКТРО-МАГНИТОУПРУГОЙ ДЕФОРМАЦИИ ТОНКИХ ПЛАСТИН СЛОЖНОЙ КОНСТРУКТИВНОЙ ФОРМЫ

Мирзаахмедов М.К.

muhammadzohir1110@gmail.com

Андижанский государственный университет, 170100, Узбекистан, г. Андижан, ул. Университетская, 129.

Статья посвящена разработке математической модели процесса деформации тонких магнитоупругих пластин сложной структурной формы на основе вариационного принципа Гамильтона-Остроградского и проведению вычислительных экспериментов. При этом трехмерная математическая модель была переведена в двумерный вид с использованием гипотезы Кирхгофа-Лиава. Для определения кинетической и потенциальной энергии и работы внешних сил использовались соотношение Коши, закон Гука, сила Лоренца и электромагнитный тензор Максвелла. Исследовано влияние электромагнитного поля на деформационно-напряженное состояние магнитоупругой пластины, в результате чего создана математическая модель в виде системы дифференциальных уравнений с начальными и граничными условиями по перемещению. Для решения уравнения разработан алгоритм расчета с использованием методов R-функции, Бубнова-Галеркина, Ньюмарка, Гаусса, квадратов Гаусса и числа итераций. Проведены вычислительные эксперименты в различных механических состояниях магнитоупругой пластины, ее края жестко закреплены, одна сторона шарнирно закреплена, другая свободна, и получены численные результаты. Представлен сравнительный анализ результатов расчетов.

Ключевые слова: принцип Гамильтона-Остроградского, метод Бубнова-Галеркина, соотношение Коши, закон Гука, электромагнитный тензор Максвелла, R-функция.

Цитирование: *Мирзаахмедов М.К.* Математическое моделирование процессов термо-электро-магнитоупругой деформации тонких пластин сложной конструктивной формы // Проблемы вычислительной и прикладной математики. – 2024. – № 5(61). – С. 31-42.

ПРОБЛЕМЫ ВЫЧИСЛИТЕЛЬНОЙ И ПРИКЛАДНОЙ МАТЕМАТИКИ

№ 5(61) 2024

Журнал основан в 2015 году.
Издается 6 раз в год.

Учредитель:
Научно-исследовательский институт развития цифровых технологий и искусственного интеллекта.

Журнал зарегистрирован в Агентстве информации и массовых коммуникаций при Администрации Президента Республики Узбекистан.
Регистрационное свидетельство №0856 от 5 августа 2015 года.

ISSN 2181-8460, eISSN 2181-046X

Адрес редакции:
100125, г. Ташкент, м-в. Буз-2, 17А.
Тел.: +(998) 712-319-253, 712-319-249.
Э-почта: journals@airi.uz.
Веб-сайт: https://journals.airi.uz.

Дизайн и вёрстка:
Шарипов Х.Д.

Отпечатано в типографии НИИ РЦТИИ.
Подписано в печать 30.10.2024 г.
Формат 60x84 1/8. Заказ №7. Тираж 100 экз.

PROBLEMS OF COMPUTATIONAL AND APPLIED MATHEMATICS

No. 5(61) 2024

The journal was established in 2015.
6 issues are published per year.

Founder:
Digital Technologies and Artificial Intelligence Development Research Institute.

The journal is registered by Agency of Information and Mass Communications under the Administration of the President of the Republic of Uzbekistan.
The registration certificate No. 0856 of 5 August 2015.

ISSN 2181-8460, eISSN 2181-046X

Address:
100125, Tashkent, Buz-2, 17A.
Tel.: +(998) 712-319-253, 712-319-249.
E-mail: journals@airi.uz.
Web-site: https://journals.airi.uz.

Layout design:
Sharipov Kh.D.

DTAIDRI printing office.
Signed for print 30.10.2024
Format 60x84 1/8. Order No. 7. Printed copies 100.

Содержание

Contents