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Thermomechanical Response of a Rotating Orthotropic Viscothermoelastic Medium with Two-Temperature and Hall Current Effects under Ramp-Type Thermal Loading

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Abstract:
This paper presents an analysis of a rotating orthotropic magneto-viscothermoelastic half-space subjected to ramp-type thermal loading within the framework of generalized thermoelasticity. The formulation is developed using Green–Naghdi type II and type III theories, and incorporates two-temperature theory, Hall current effects, and viscoelastic relaxation described by the Voigt model, enabling a coupled representation of thermal, mechanical, and electromagnetic fields.
The governing equations are formulated and solved using normal mode analysis in conjunction with Laplace and Fourier transform techniques. Numerical inversion is employed to obtain the spatial distributions of the physical field quantities. The results exhibit oscillatory behavior of the field variables, reflecting the coupled interactions among thermal, mechanical, and electromagnetic effects in the presence of rotation. Viscosity significantly influences the phase and magnitude of displacement, stress, and temperature fields.
Several special cases are derived as limiting forms of the general formulation, demonstrating the applicability of the model. The study provides insight into the behavior of rotating viscoelastic media under combined thermo-electromagnetic effects within the Green–Naghdi framework.

Keywords: Green–Naghdi theory II and III; Orthotropic; Magneto-viscothermoelasticity; Two-temperature theory; Hall current; Rotation.

1. Introduction:

In recent years, thermoelasticity has attracted significant attention due to its ability to describe the interaction between thermal and mechanical fields in solids. The classical theory based on Fourier's law predicts infinite speed of heat propagation, which is physically unrealistic. To overcome this limitation, generalized thermoelastic theories have been developed to account for finite thermal wave speeds and non-classical heat conduction effects.
A major breakthrough in this direction was introduced by Green and Naghdi [1], who reformulated the basic principles of thermomechanics and proposed a consistent framework for thermoelastic analysis. This work was extended in [2], where undamped thermal waves were introduced, eliminating energy dissipation. Further refinement in [3] led to the classification of thermoelastic models into three types (GN-I, GN-II, and GN-III), which differ in their treatment of thermal conductivity and energy dissipation.
Earlier, Chen and Gurtin [4] developed a two-parameter theory of heat conduction that generalized Fourier's law. Chen et al. [5] simplified the formulation for practical applications, while Chen et al. [6] extended the theory to include thermodynamic consistency for materials characterized by two distinct temperatures. Warren and Chen [7] later applied this theory to investigate wave propagation phenomena in two-temperature thermoelastic media, demonstrating the existence of thermal waves with finite speeds.

The theory of two-temperature thermoelasticity was further developed by Youssef [8], who formulated a generalized model incorporating dual-temperature effects. Youssef and Al-Lehaibi [9] applied a state-space approach to solve one-dimensional thermoelastic problems, providing analytical

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solutions. Youssef and Al-Harby [10] extended the analysis to infinite bodies with spherical cavities under thermal loading. Youssef [11] later proposed a formulation without energy dissipation, and subsequently, Youssef [12] established a variational principle for such systems.

Significant contributions have also been made toward extending thermoelasticity to more complex materials. Ezzat and Awad [13] developed constitutive relations for micropolar thermoelastic media with two temperatures and analyzed thermal shock problems. Kaushal et al. [14] investigated wave propagation in generalized thermoelastic continua with dual temperatures. Sharma [15] studied boundary value problems in thermodiffusive elastic media, while Sharma [16] analyzed deformation under inclined loading conditions. Kaushal et al. [17] examined temperature rate-dependent thermoelasticity, highlighting relaxation effects. Sharma et al. [18] investigated thermoelastic diffusion interactions due to inclined loading. Sharma and Marin [19] studied wave reflection in micropolar elastic half-spaces. Abbas et al. [20] examined the response of thermal sources in transversely isotropic thermoelastic media with two-temperature effects. Sharma and Sharma [21] studied the influence of heat sources and relaxation time on temperature distribution. Atwa and Jahangir [22] analyzed wave propagation in thermo-microstretch elastic solids with two-temperature effects.

In many engineering and geophysical applications, materials are subjected to rotation and electromagnetic fields. Kumar and Rupender [23] studied the effect of rotation in magneto-micropolar thermoelastic media. Kumar and Devi [24] investigated magnetothermoelastic interactions in half-space configurations. Mahmoud [25] analyzed the combined effects of magnetic fields and initial stress in rotating thermoelastic media. Das and Kanoria [26] studied thermal wave propagation in rotating magnetothermoelastic materials.

Parallel to thermoelastic developments, viscoelasticity has been widely explored to model time-dependent material behavior. Freudenthal [27] highlighted the role of rheological properties in thermal stress analysis. Ieşan and Scalia [28] developed fundamental theorems in thermoviscoelasticity. Borrelli and Patria [29] analyzed discontinuity waves in viscoelastic solids. Ezzat and Atef [30] studied magneto-thermo-viscoelastic materials with cavities. Abd-Allaa and Mahmoud [31] investigated magneto-thermo-viscoelastic interactions in non-homogeneous media. Kumar et al. [32] examined the effect of viscosity on wave propagation in anisotropic thermoelastic media using a three-phase-lag model.

Sharma et al. [33] analyzed the effect of viscosity on wave propagation in anisotropic thermoelastic materials Sharma et al. [34] studied wave motion in electro-microstretch viscoelastic solids. Sharma and Kumar [35] analyzed thermoviscoelastic media with voids. Sharma and Bhargava [36] investigated wave propagation across imperfect boundaries. Hilton [37] studied coupled thermo-viscoelastic wave propagation in temperature-dependent materials. Al-Basyouni et al. [38] examined the combined influence of rotation, magnetic field, and periodic loading on thermo-viscoelastic media. Yadav et al. [39] developed fractional-order thermoviscoelastic models under moving heat sources.

When strong magnetic fields are present, additional electromagnetic effects such as Hall currents become important. Zakaria [40] studied the effect of Hall current and rotation in magneto-micropolar thermoelastic media. Sarkar and Lahiri [41] investigated temperature rate-dependent thermoelasticity incorporating modified Ohm's law. Zakaria [42] extended the analysis of Hall current effects in micropolar thermoelastic solids. Kumar et al. [43] analyzed the combined influence of Hall current and rotation in generalized thermoelastic half-spaces.

Despite these extensive studies, relatively little work has been carried out on viscothermoelastic materials that simultaneously incorporate rotation, magnetic field, Hall current, and two-temperature effects within a unified framework. Therefore, the present study aims to investigate a two-dimensional problem in a transversely isotropic viscothermoelastic solid under the combined influence of these effects. The governing equations are formulated and solved using Laplace and Fourier transform techniques, and numerical inversion methods are employed to evaluate displacement, stress, temperature, and current density distributions. The results are presented graphically to illustrate the influence of various physical parameters.

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2. Basic equations:

For an anisotropic thermoelastic solid, the stress–strain–temperature relation may be represented as

$$t_{ij} = C_{ijkl}e_{kl} - \beta_{ij}T \tag{1}$$

When the medium rotates uniformly with angular velocity vector $\boldsymbol{\Omega} = \Omega\boldsymbol{n}$ where $\boldsymbol{n}$ defines the direction of rotation, and electromagnetic effects are included through the Lorentz force, the governing equations of motion can be formulated as

$$t_{ij,j} + F_i \ = \ \rho\{\ddot{u}_i + \left(\boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times u)\right)_i + (2\boldsymbol{\Omega} \times \dot{u})_i\ \} \tag{2}$$

Following Chandrasekharaiah [44] and Youssef [8], in the framework of generalized thermoelasticity with dual-temperature formulation, the heat transfer equation—covering both cases of energy dissipation and its absence—can be expressed as

$$K_{ij}\varphi_{,ij} + K_{IJ}^{*}\dot{\varphi}_{ij} = \beta_{ij}T_0\ddot{e_{iJ}} + \rho C_E\ddot{T} \tag{3}$$

For electrically conducting materials subjected to a magnetic field, and incorporating Hall current effects, the modified form of Ohm's law, Following Zakaria [40] is written as

$$\boldsymbol{J} = \frac{\sigma_0}{1+m^2}\left(\boldsymbol{E} + \mu_0\left(\dot{\boldsymbol{u}} \times \boldsymbol{H} - \frac{1}{en_e}\boldsymbol{J} \times \boldsymbol{H}_0\right)\right) \tag{4}$$

The infinitesimal strain tensor is related to the displacement components through the relation

$$e_{ij} = \frac{1}{2}\left(u_{i,j} + u_{j,i}\right) \quad i,j = 1,2,3 \tag{5}$$

Here

$F_i = \mu_0(\boldsymbol{J} \times \boldsymbol{H}_0)_i$ are the components of Lorentz force.

$\beta_{ij} = C_{ijkl}\alpha_{ij}$ and $T = \varphi - a_{ij}\varphi_{,ij}$

$\beta_{ij} = \beta_i\delta_{ij}, K_{ij} = K_i\delta_{ij},\ K_{ij}{}^{*} = K_i{}^{*}\delta_{ij},\ i$ is not summed

In the above formulation, $C_{ijkl}\left(C_{ijkl} = C_{klij} = C_{jikl} = C_{ijlk}\right)$ are elastic parameters,β_{ij} denotes the thermal modulus, while T and T_0correspond to the absolute and the reference temperature, respectively. The quantities $t_{ij}$and e_{kl} indicate the components of the stress and strain tensors. The displacement field is described by the components u_i and ρ stands for the mass density. The term C_E represents the specific heat capacity at constant strain.The coefficients K_{IJ}^{*} and K_{ij} are associated with heat conduction, where the latter accounts for additional material-dependent thermal effects. The parameters a_{ij}characterize the two-temperature, and α_{ij} corresponds to the linear thermal expansion coefficients. $\boldsymbol{\Omega}$ denotes the angular velocity, while H represents the magnetic field intensity. $\dot{\boldsymbol{u}}$, defines the particle velocity. **E** and $\boldsymbol{J}$ correspond to the electric field intensity and electric current density, respectively.The Hall parameter m $(= \omega_e t_e = \frac{\sigma_0\mu_0\boldsymbol{H_0}}{en_e})$, t_e is the mean collision time of electrons,$\omega_e = \frac{e\mu_0\boldsymbol{H_0}}{m_e}$ denotes the electron frequency , e and,m_e are the charge and mass of an

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electron, respectively, $\sigma_0 = \frac{e^2 t_e n_e}{m_e}$ is the electrical conductivity with n_e representing the number density of electrons.

3. **Formulation and solution of the problem**

A homogeneous, perfectly conducting orthotropic magneto-viscothermoelastic solid is considered, undergoing uniform rotation with angular velocity $\boldsymbol{\Omega}$. The medium is initially maintained at a constant reference temperature T_0. A rectangular Cartesian coordinate system (x, y, z) is employed such that the origin lies on the boundary surface z=*0*, with the z-axis pointing vertically downwards into the medium.

The bounding surface of the medium is exposed to a thermal load of ramp-type variation. Restricting the analysis to a two-dimensional configuration in the *xz*-plane, the field variables are a problem in *xz*-plane, we take

$$\boldsymbol{u} = (u, 0, w). \tag{6}$$

Taking

$$\boldsymbol{E}=0,\ \boldsymbol{\Omega} = (0, \Omega, 0),\ \boldsymbol{H}_0 = (0, \mathrm{H}_0, 0). \tag{7}$$

The generalized Ohm's law

$$J_y = 0\ , \tag{8}$$

the current density components J_x and J_z using (4) are given as

$$J_x = \frac{\sigma_0 \mu_0 H_0}{1+m^2}\left(m\frac{\partial u}{\partial t} - \frac{\partial w}{\partial t}\right), \tag{9}$$

$$J_z = \frac{\sigma_0 \mu_0 H_0}{1+m^2}\left(\frac{\partial u}{\partial t} + m\frac{\partial w}{\partial t}\right). \tag{10}$$

By applying suitable transformation, following Slaughter [45], on the set of equations (2) and (3) and with the aid of (6)-(10), the resulting system of equations describe the behavior of a orthotropic thermoelastic medium as

$$c_{11}\frac{\partial^2 u}{\partial x^2} + c_{13}\frac{\partial^2 w}{\partial x \partial z} + c_{55}\left(\frac{\partial^2 u}{\partial z^2} + \frac{\partial^2 w}{\partial x \partial z}\right) - \beta_1 \frac{\partial}{\partial x}\left\{\varphi - \left(a_1\frac{\partial^2 \varphi}{\partial x^2} + a_3\frac{\partial^2 \varphi}{\partial z^2}\right)\right\} - \mu_0 J_z H_0$$

$$= \rho\left(\frac{\partial^2 u}{\partial t^2} - \Omega^2 u + 2\Omega\frac{\partial w}{\partial t}\right),$$
(11)

$$(c_{13} + c_{55})\frac{\partial^2 u}{\partial x \partial z} + c_{55}\frac{\partial^2 w}{\partial x^2} + c_{33}\frac{\partial^2 w}{\partial z^2} - \beta_3\frac{\partial}{\partial z}\left\{\varphi - \left(a_1\frac{\partial^2 \varphi}{\partial x^2} + a_3\frac{\partial^2 \varphi}{\partial z^2}\right)\right\} + \mu_0 J_x H_0$$

$$= \rho\left(\frac{\partial^2 w}{\partial t^2} - \Omega^2 w - 2\Omega\frac{\partial u}{\partial t}\right), \tag{12}$$

$$\left(k_1 + {k_1}^*\frac{\partial}{\partial t}\right)\frac{\partial^2 \varphi}{\partial x^2} + \left(k_3 + {k_3}^*\frac{\partial}{\partial t}\right)\frac{\partial^2 \varphi}{\partial z^2} = T_0\frac{\partial^2}{\partial t^2}\left\{\beta_1\frac{\partial u}{\partial x} + \beta_3\frac{\partial w}{\partial z}\right\} + \rho C_E \ddot{T}\ , \tag{13}$$

and

$$t_{xx} = c_{11}e_{xx} + c_{13}e_{zz} - \beta_1 T\ , \tag{14}$$

$$t_{zz} = c_{13}e_{xx} + c_{33}e_{zz} - \beta_3 T\ , \tag{15}$$

$$t_{zx} = 2c_{55}e_{zx}\ , \tag{16}$$

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where

$$e_{xx} = \frac{\partial u}{\partial x}\ ,\ \ e_{zz} = \frac{\partial w}{\partial z}\ ,\ e_{zx} = \frac{1}{2}\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right),\quad T = \varphi - \left(a_1\frac{\partial^2\varphi}{\partial x^2} + a_3\frac{\partial^2\varphi}{\partial z^2}\right),$$

$$\beta_1 = c_{11}\alpha_1 + c_{13}\alpha_3\ ,\qquad \beta_3 = c_{13}\alpha_1 + c_{33}\alpha_3\ .$$

In the preceding relations, the fourth-order elastic tensor c_{ijkl} is reduced to a two-index form c_{mn} by employing the standard contracted notation, where the index pairs are mapped as follows:

$$11 \to 1, 22 \to 2, 33 \to 3, 23 \to 4, 31 \to 5, 12 \to 6$$

To incorporate the effect of material damping, the elastic coefficients c_{ij} are treated as operators dependent on time. Specifically, they are expressed in terms of the differential operator $\mathrm{D} = \frac{\partial}{\partial t}$, such that

$$c_{ij} = c_{ij}{}^{*}\quad \text{where}\quad c_{ij}{}^{*} = c_{ij}(D) \tag{17}$$

Assuming that the viscoelastic response of the material is described by the Voigt model of linear viscoelasticity (Kaliski [46]), we write

$$c_{11} = c_{11}{}^{*}\left(1 + R_1\frac{\partial}{\partial t}\right), c_{12} = c_{12}{}^{*}\left(1 + R_2\frac{\partial}{\partial t}\right),\ c_{13} = c_{13}{}^{*}\left(1 + R_3\frac{\partial}{\partial t}\right), c_{33} = c_{33}{}^{*}\left(1 + R_4\frac{\partial}{\partial t}\right),$$

$$c_{55} = c_{55}{}^{*}\left(1 + R_5\frac{\partial}{\partial t}\right). \tag{18}$$

where R_1, R_2, R_3, R_4 are viscoelastic relaxation times.

We assume that the medium is initially at rest and in thermal equilibrium at the reference temperature. Accordingly, the initial and regularity conditions are specified as:

$$u(x,z,0) = 0 = \dot{u}(x,z,0)\,,$$

$$w(x,z,0) = 0 = \dot{w}(x,z,0)\,,$$

$$\varphi(x,z,0) = 0 = \dot{\varphi}(x,z,0)\,,\qquad \text{For } z \geq 0,\quad -\infty < x < \infty$$

$$u(x,z,t) = w(x,z,t) = \varphi(x,z,t) = 0\ for\ t > 0\ when\ z \to \infty \tag{19}$$

For analytical convenience, the following non-dimensional variables are introduced:

$$x' = \frac{x}{L},\ z' = \frac{z}{L}\ ,\ u' = \frac{\rho c_1^2}{L\beta_1 T_0}u,\ \mathrm{w}' = \frac{\rho c_1^2}{L\beta_1 T_0}w,\ T' = \frac{T}{T_0}\,,\, t' = \frac{c_1}{L}t\,,\, t'_{xx} = \frac{t_{xx}}{\beta_1 T_0}\,,\, J' = \frac{\rho c_1^2}{\beta_1 T_0}J$$

$$t'_{zz} = \frac{t_{zz}}{\beta_1 T_0},\quad t'_{zx} = \frac{t_{zx}}{\beta_1 T_0}\quad ,\ \varphi' = \frac{\varphi}{T_0}\ ,\ a'_1 = \frac{a_1}{L}\ ,\ a'_3 = \frac{a_3}{L}\ ,\qquad h' = \frac{h}{H_0}\quad , M = \frac{\sigma_0\mu_0 H_0}{\rho c_1 L},\ \Omega' = \frac{L}{c_1}\Omega$$

(20)

Making use of (20) in equations (11)-(13) , after removing the primes, yield

$$\frac{\partial^2 u}{\partial x^2} + q_4\frac{\partial^2 w}{\partial x\partial z} + q_2\left(\frac{\partial^2 u}{\partial z^2} + \frac{\partial^2 w}{\partial x\partial z}\right) - \frac{\partial}{\partial x}\left\{\varphi - \left(\frac{a_1}{L}\frac{\partial^2\varphi}{\partial x^2} + \frac{a_3}{L}\frac{\partial^2\varphi}{\partial z^2}\right)\right\} - \frac{M}{1+m^2}\mu_0\, H_0\left(\frac{\partial u}{\partial t} + m\frac{\partial w}{\partial t}\right) = \frac{\partial^2 u}{\partial t^2} - \Omega^2 u + 2\Omega\frac{\partial w}{\partial t}, \tag{21}$$

$$q_1\frac{\partial^2 u}{\partial x\partial z} + q_2\frac{\partial^2 w}{\partial x^2} + q_3\frac{\partial^2 w}{\partial z^2} - \frac{\beta_3}{\beta_1}\frac{\partial}{\partial z}\left\{\varphi - \left(\frac{a_1}{L}\frac{\partial^2\varphi}{\partial x^2} + \frac{a_3}{L}\frac{\partial^2\varphi}{\partial z^2}\right)\right\} + \frac{M}{1+m^2}\mu_0 H_0\left(m\frac{\partial u}{\partial t} - \frac{\partial w}{\partial t}\right) = \frac{\partial^2 w}{\partial t^2} - \Omega^2 w - 2\Omega\frac{\partial u}{\partial t},$$

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(22) $p_1\left(1+\frac{\varepsilon_3}{\varepsilon_1}\frac{\partial}{\partial t}\right)\frac{\partial^2\varphi}{\partial x^2}+p_2\left(1+\frac{\varepsilon_4}{\varepsilon_2}\frac{\partial}{\partial t}\right)\frac{\partial^2\varphi}{\partial z^2}=p_5{\beta_1}^2\frac{\partial^2}{\partial t^2}\left(\frac{\partial u}{\partial x}+\frac{\beta_3}{\beta_1}\frac{\partial w}{\partial z}\right)+\frac{\partial^2}{\partial t^2}\left(\left\{\varphi-\frac{a_1}{L}\frac{\partial^2\varphi}{\partial x^2}+\frac{a_3}{L}\frac{\partial^2\varphi}{\partial z^2}\right\}\right)$, (23)

where

$q_1=\frac{(c_{13}+c_{55})}{c_{11}}$, $q_2=\frac{c_{55}}{c_{11}}$, $q_3=\frac{c_{33}}{c_{11}}$, $q_4=\frac{c_{13}}{c_{11}}$, $p_1=\frac{k_1}{\rho C_E c_1^2}$, $p_2=\frac{k_3}{\rho C_E c_1^2}$, $p_3=\frac{{k_1}^*}{L\rho C_E c_1}$,

$p_4=\frac{{k_3}^*}{L\rho C_E c_1}$, $p_5=\frac{T_0}{\rho^2 C_E c_1^2}$.

The Laplace and Fourier transforms are applied as defined below:

$$\bar f(x,z,s)=\int_0^\infty f(x,z,t)e^{-st}dt\ , \tag{24}$$

$$\hat f(\xi,z,s)=\int_{-\infty}^\infty \bar f(x,z,s)e^{i\xi x}dx\ . \tag{25}$$

Applying (24),(25) on equations(21)-(23) , determine a system of homogeneous equations in terms of $\tilde u,\tilde w$ and $\tilde\varphi$ which yield a non trivial solution if determinant of coefficient $\{\tilde u,\tilde w,\tilde\varphi\}^T$ vanishes and leads to the following characteristic equation

$$(QD^6+RD^4+SD^2+P)(\tilde u,\tilde w,\tilde\varphi)=0\ , \tag{26}$$

where

$Q=q_2q_3\mathrm{f}_7+p_6\mathrm{f}_5q_2$,

$R=\mathrm{f}_{10}\mathrm{f}_7q_3+q_2\mathrm{f}_7\mathrm{f}_{11}-q_3q_2\mathrm{f}_6-p_6{\beta_3}^2\mathrm{f}_4q_2-f_3^2\mathrm{f}_7-i\xi\mathrm{f}_3q_3\mathrm{f}_5p_6{\beta_1}^2+\xi^2p_6q_3\mathrm{f}_5{\beta_1}^2-i\xi p_6\mathrm{f}_5\beta_1\beta_3f_3-\xi^2p_6{\beta_1}^2q_3\mathrm{f}_5$,

$S=\mathrm{f}_{10}\mathrm{f}_{11}\mathrm{f}_7-\mathrm{f}_{10}q_3\mathrm{f}_6-p_6{\beta_3}^2\mathrm{f}_{10}\mathrm{f}_4-q_2\mathrm{f}_6\mathrm{f}_{11}+f_3^2\mathrm{f}_6+f_2^2\mathrm{f}_7+q_3\mathrm{f}_3\mathrm{f}_4p_6{\beta_1}^2i\xi+\mathrm{i}\xi\mathrm{f}_3\mathrm{f}_4\beta_1\beta_3p_6-\xi^2\mathrm{f}_5\mathrm{f}_{11}{\beta_1}^2p_6$,

$P=-\mathrm{f}_{10}\mathrm{f}_{11}\mathrm{f}_6-f_2^2\mathrm{f}_6+\xi^2\mathrm{f}_{11}{\beta_1}^2\mathrm{f}_4p_6$,

$f_1=-\left(\frac{M}{1+m^2}\mu_0H_0s+s^2\right)+\Omega^2$, $\mathrm{f}_2=-\frac{M}{1+m^2}\mu_0H_0ms-2\Omega s$, $\mathrm{f}_3=(\delta_4+\delta_2)i\xi$, $\mathrm{f}_4=1+\frac{a_1}{L}\xi^2$, $\mathrm{f}_5=\frac{a_3}{L}$, $\mathrm{f}_6=(p_1+p_3s)\xi^2+s^2(1+\frac{a_1}{L}\xi^2)$, $\mathrm{f}_7=p_2+p_4s-\frac{a_3}{L}s^2$, $\mathrm{f}_{10}=f_1-\xi^2$,

$$\mathrm{f}_{11}=\zeta_1-q_2\xi^2,\ p_6=\frac{T_0s^2}{\rho^2C_Ec_1^2}\ . \tag{27}$$

The solution of the equation (26) satisfying the radiation condition that $\tilde u,\tilde w,\tilde\varphi\to 0$ as $z\to\infty$, can be expressed as

$$\hat u=B_1e^{-\lambda_1 z}+B_2e^{-\lambda_2 z}+B_3e^{-\lambda_3 z}\ , \tag{28}$$

$$\hat w=n_1B_1e^{-\lambda_1 z}+n_2B_2e^{-\lambda_2 z}+n_3B_3e^{-\lambda_3 z}\ , \tag{29}$$

$$\hat\varphi=r_1B_1e^{-\lambda_1 z}+r_2B_2e^{-\lambda_2 z}+r_3B_3e^{-\lambda_3 z}\ , \tag{30}$$

where $\pm\lambda_i$, (i =1,2,3) , are the roots of (26) and n_i and m_i are given as

$$n_i=\frac{\lambda_i^2(\varepsilon_5 i\xi q_3-\mathrm{f}_3\beta_3\beta_1\xi\ )-\lambda_i(\xi\beta_1\beta_3\mathrm{f}_2)+\varepsilon_5 i\xi\mathrm{f}_{11}}{\lambda_1^4(q_3\mathrm{f}_7+\varepsilon_5\mathrm{f}_5{\beta_3}^2)+\lambda_1^2(\mathrm{f}_7\mathrm{f}_{11}-q_3\mathrm{f}_6-{\beta_3}^2\varepsilon_5\mathrm{f}_4)-\mathrm{f}_6\mathrm{f}_{11}}\quad i=1,2,3$$

$$r_i=\frac{-\lambda_i^3(\mathrm{f}_3\mathrm{f}_7+\varepsilon_5 i\xi\mathrm{f}_5\mathrm{q}_3)-\mathrm{f}_2\mathrm{f}_7\lambda_i^2+(\mathrm{f}_3\mathrm{f}_6+\varepsilon_5 i\xi\mathrm{q}_3\mathrm{f}_4)\lambda_i+\mathrm{f}_6\mathrm{f}_2}{\lambda_1^4(q_3\mathrm{f}_7+\varepsilon_5\mathrm{f}_5{\beta_3}^2)+\lambda_1^2(\mathrm{f}_7\mathrm{f}_{11}-q_3\mathrm{f}_6-{\beta_3}^2\varepsilon_5\mathrm{f}_4)-\mathrm{f}_6\mathrm{f}_{11}}\quad i=1,2,3$$

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4. Boundary conditions:

The boundary conditions are prescribed as follows:

1. The normal stress component at the boundary vanishes:

$$t_{zz}(x,0,t) = 0\,, \tag{31}$$

2. The shear stress component at the boundary also vanishes:

$$t_{zx}(x,0,t) = 0\,, \tag{32}$$

3. Additionally, the boundary is subjected to a ramp-type heating which depends upon co-ordinate x and time t of the form

$$\varphi(x,0,t) = F(t)\delta(x)\,, \tag{33}$$

where δ(x) is an dirac delta function of x and G(t) is a function defined as

$$F(t) = \begin{cases} 0 & t \le 0 \\ T_1 \frac{t}{t_0} & 0 < t \le t_0 \\ T_1 & t > t_0 \end{cases}\,, \tag{34}$$

Here, t_0 represents the time duration over which the temperature increases, and T_1 is a constant, this implies that the boundary of the half-space, which is initially at rest and has a fixed temperature t_0, is suddenly raised to a temperature equal to the function $F(t)\delta(x)$ and maintained at this temperature afterwards.

Applying the Laplace and Fourier transforms on (33) and (34), determine

$$\hat{\varphi}(\xi,0,s) = \hat{F}(s)\,, \tag{35}$$

where $$\hat{F}(s) = T_1 \frac{(1-e^{-st_0})}{t_0 s^2}\,. \tag{36}$$

Applying the Laplace and Fourier transforms defined in Eqs. (24)–(25) to the boundary conditions (31)–(34), and using Eqs. (14)–(16), (20), (28)–(30) and (36), we obtain the expressions for the displacement components, normal and tangential stresses, conductive temperature, and current density components.

$$\hat{u} = T_1 \frac{(1-e^{-st_0})}{\Delta t_0 s^2}\left(\Delta_0^*\ e^{-\lambda_1 z} + \Delta_1^* e^{-\lambda_2 z} + \Delta_3^* e^{-\lambda_3 z}\right), \tag{37}$$

$$\hat{w} = T_1 \frac{(1-e^{-st_0})}{\Delta t_0 s^2}\left(n_1\Delta_0^* e^{-\lambda_1 z} + n_2\Delta_1^* e^{-\lambda_2 z} + n_3\Delta_2^* e^{-\lambda_3 z}\right), \tag{38}$$

$$\hat{t}_{zz} = T_1 \frac{(1-e^{-st_0})}{\Delta t_0 s^2}\left(\Delta_{21}\Delta_0^* e^{-\lambda_1 z} + \Delta_{22}\Delta_1^* e^{-\lambda_2 z} + \Delta_{23}\Delta_2^* e^{-\lambda_3 z}\right), \tag{39}$$

$$\hat{t}_{zx} = T_1 \frac{(1-e^{-st_0})}{\Delta t_0 s^2}\left(\Delta_{21}\Delta_0^* e^{-\lambda_1 z} + \Delta_{22}\Delta_1^* e^{-\lambda_2 z} + \Delta_{23}\Delta_2^* e^{-\lambda_3 z}\right), \tag{40}$$

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$$\tilde{\varphi} = T_1 \frac{(1-e^{-st_0})}{\Delta t_0 s^2}\left(\Delta_{31}\Delta_0^* e^{-\lambda_1 z} + \Delta_{32}\Delta_1^* e^{-\lambda_2 z} + \Delta_{33}\Delta_2^* e^{-\lambda_3 z}\right), \tag{41}$$

$$\hat{J}_x = \frac{c_1\sigma_0 H_0\mu_0}{1+m^2} T_1 \frac{(1-e^{-st_0})}{\Delta t_0 s}\left((m-n_1)\Delta_0^* e^{-\lambda_1 z} + (m-n_2)\Delta_1^* e^{-\lambda_2 z} + (m-n_3)\Delta_2^* e^{-\lambda_3 z}\right), \tag{42}$$

$$\hat{J}_x = \frac{c_1\sigma_0 H_0\mu_0}{1+m^2} T_1 \frac{(1-e^{-st_0})}{\Delta t_0 s}\left((1+mn_1)\Delta_0^* e^{-\lambda_1 z} + (1+mn_2)\Delta_1^* e^{-\lambda_2 z} + (1+mn_3)\Delta_2^* e^{-\lambda_3 z}\right), \tag{43}$$

where,

$$(\Delta_{12}\Delta_{23} - \Delta_{13}\Delta_{22}) = \Delta_0^*,\ (\Delta_{13}\Delta_{21} - \Delta_{11}\Delta_{23}) = \Delta_1^*,\ (\Delta_{11}\Delta_{22} - \Delta_{12}\Delta_{21}) = \Delta_2^*$$

$$\Delta_{1j} = \frac{c_{13}}{\rho c_1^2} i\xi - \frac{c_{33}}{\rho c_1^2} n_j\lambda_j - \frac{\beta_3}{\beta_1} r_j + \frac{\beta_3}{\beta_1} a_3 r_j {\lambda_j}^2 - \frac{\beta_3}{\beta_1} r_j a_1 \xi^2 \quad j = 1,2,3$$

$$\Delta_{2j} = -\lambda_j + i\xi n_j \quad j = 1,2,3 \tag{44}$$

5. Particular Cases:

(i) When $a_1 = a_3 = 0$, Eqs. (37)–(43) reduce to the expressions for displacement components, stresses, conductive temperature, and current density components for a orthotropic magneto-viscothermoelastic medium, both with and without energy dissipation, including the effects of Hall current and rotation.

(ii) When ${c_{11}}^* = c_{11}$, ${c_{12}}^* = c_{12}$, ${c_{13}}^* = c_{13}$, ${c_{55}}^* = c_{55}$, yield the corresponding expressions for displacement, stresses, conductive temperature, and current density components in orthotropic magneto-thermoelastic medium with rotation, both in the presence and absence of energy dissipation incorporating two-temperature effects along with Hall current and rotation.

In addition, when $c_{11} = \lambda + 2\mu = c_{33}$, $c_{12} = c_{13} = \lambda$, $c_{55} = \mu$, $\beta_1 = \beta_3 = \beta$, $\alpha_1 = \alpha_3 = \alpha$, $K_1 = K_3 = K$ reduce to the corresponding expressions in a isotropic magnetothermoelastic medium.

(iii) When m=0, Eqs. (37)-(43) yield the expressions for displacement components, stresses, conductive temperature, and current density components for a orthotropic magneto-viscothermoelastic medium with rotation, both in the presence and absence of energy dissipation.

6. Inversion of the transforms:

To obtain the solution in the physical domain, it is necessary to invert the transforms appearing in Eqs. (37)–(43). The displacement components, normal and tangential stresses, and conductive temperature depend on the spatial variable x_3 and the transform parameters s (Laplace) and ξ (Fourier), and can therefore be represented in the form $f(\xi, z, s)$.

The corresponding physical function $f(x,z,t)$ is recovered by first performing the inverse Fourier transform, given by

$$\overline{f}(x,z,s) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-i\xi x} \hat{f}(\xi,z,s)d\xi = \frac{1}{2\pi}\int_{-\infty}^{\infty} |\cos(\xi x) f_e - i\sin(\xi x) f_o|\, d\xi \tag{45}$$

where f_e *and* f_o denote the even and odd parts of $\hat{f}$ (ξ, z, s). Thus the expression (35) gives the Laplace transform $\overline{f}(x,z,s)$ of the function $f(x,z,t)$. Following Honig and Hirdes [47], the Laplace transform function $\overline{f}(x,z,s)$ can be inverted to $f(x,z,t)$.

Finally, the integral appearing in (45) is evaluated numerically. The method for evaluating this integral is described in Press et al. [48]. It involves the use of Romberg integration with adaptive step size, which is based on successive refinements of the extended trapezoidal rule and extrapolation of the results as the step size approaches zero.

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7. Numerical results and discussion:

For the purpose of numerical evaluation, cobalt material has been chosen following Dhaliwal and Singh [49], as

$c_{11} = 3.071 \times 10^{11} Nm^{-2}, c_{33} = 3.581 \times 10^{11} Nm^{-2}$, $c_{13} = 1.027 \times 10^{11} Nm^{-2}$, $c_{55} = 1.510 \times 10^{11} Nm^{-2}$, $\rho = 8.836 \times 10^{3} Kgm^{-3}$, $T_0 = 298°K$, $C_E = 4.27 \times 10^{2} JKg^{-1} deg^{-1}$, $K_1 = .690 \times 10^{2} wm^{-1} deg^{-1}$, $K_3 = .690 \times 10^{2} wm^{-1} deg^{-1}$, $\beta_1 = 7.04 \times 10^{6} Nm^{-2} deg^{-1}$, $\beta_3 = 6.90 \times 10^{6} Nm^{-2} deg^{-1}$, $K_1^* = 0.02 \times 10^{2} Nsec^{-2} deg^{-1}$, $K_3^* = 0.04 \times 10^{2} Nsec^{-2} deg^{-1}$, $\mu_0 = 1.2571 \times 10^{-6} Hm^{-1}, H_0 = 1 Jm^{-1} nb^{-1}$, $\varepsilon_0 = 8.838 \times 10^{-12} Fm^{-1}$,

with non-dimensional parameter L=1 and $\sigma_0 = 9.36 \times 10^{5} col^{2}/Cal.cm$.sec, Ω=2, $t_0 = 0.02$, M=3.

Using the computed values, the graphical behavior of displacement components, stress components, conductive temperature, and current density components in a orthotropic magneto- viscothermoelastic medium subjected to ramp-type heating has been analyzed. The influence of viscosity on these physical quantities with respect to the spatial coordinate x is also illustrated.

For the viscoelastic medium, the parameters are taken as $R_1 = 0.5, R_2 = 0.75, R_3 = 1.0, R_4 = 1.5, R_5 = 2.0$ whereas for the non-viscoelastic case, $R_1 = R_2 = R_3 = R_4 = R_5 = 0$.

In all the figures, we have

(i) The solid line represents the orthotropic magneto-viscothermoelastic medium with viscosity (VS).

(ii) The solid line with circular markers represents the orthotropic magneto-thermoelastic medium without viscosity (WVS).

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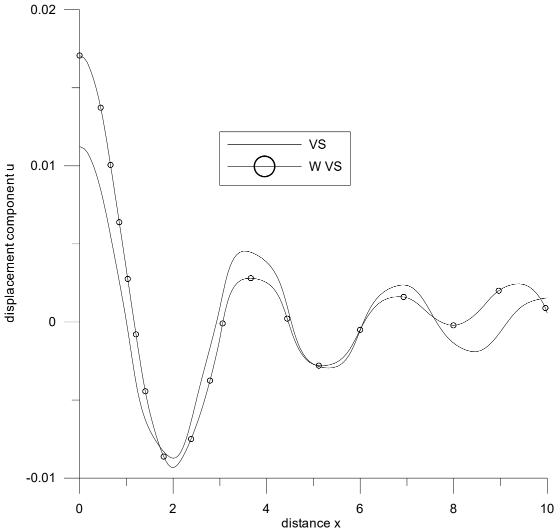

Fig 1.Variation of u with x

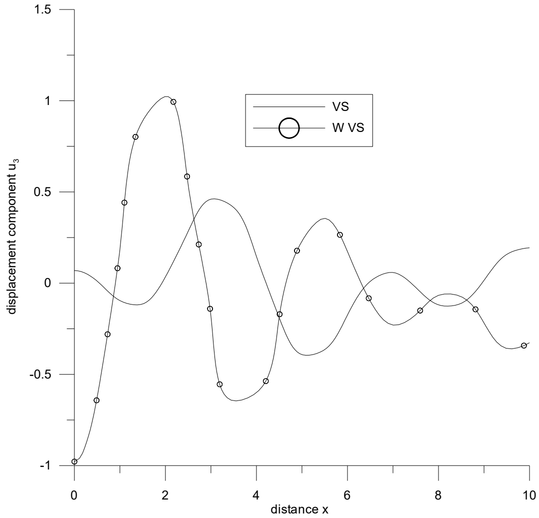

Fig 2.Variation of u_3(=w) with x

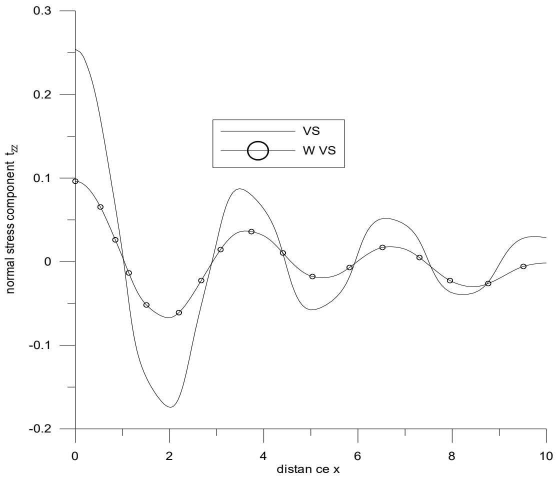

Fig 3. Variation of t_{zz} with x.

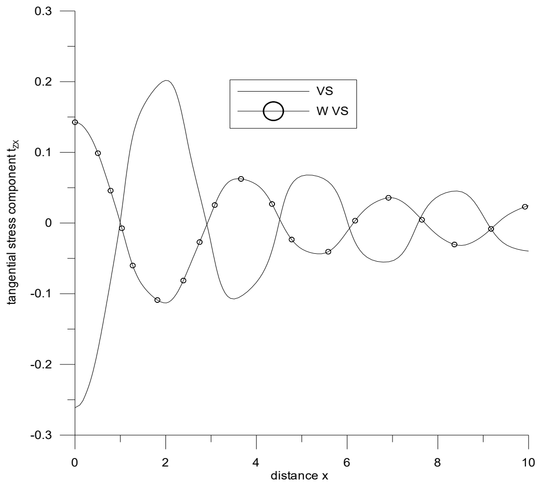

Fig 4. Variation of t_{zx} with x .

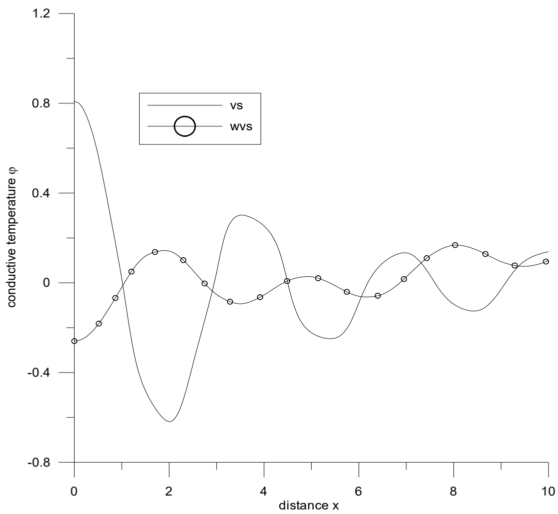

Fig 5. Variation of φ with x.

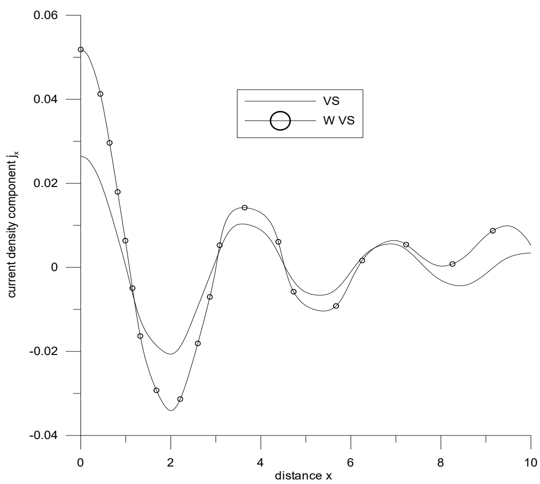

Fig 6. Variation of J_x with x.

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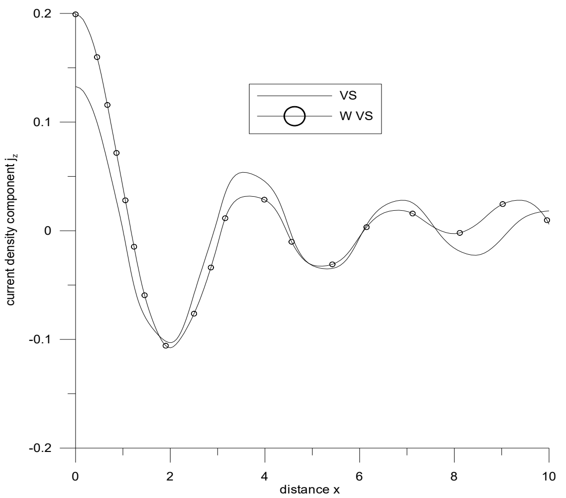

Fig 7. Variation of J_z with x .

Displacement Field

Figure 1 illustrates the variation of transverse displacement u with distance x. The response is oscillatory throughout the domain, with a pronounced reduction in amplitude occurring within the near-field region (x ≤3). Beyond this region, the oscillations persist with significantly diminished magnitude. The two profiles corresponding to the viscous and non-viscous cases are nearly indistinguishable, showing only minor deviations in peak values and no observable phase difference.

Fig. 2 demonstrates normal displacement w with x. It is noticed that u exhibits a more pronounced dependence on viscosity. Although the response remains oscillatory, a clear phase difference is observed between the two cases. In particular, within the region x ≈1–3, one profile attains a positive maximum while the other reaches a corresponding negative minimum, indicating an out-of-phase relationship. The amplitude is highest near the origin and decreases gradually with distance, with a slower decay compared to the transverse displacement. The divergence between the two curves is most evident in the intermediate region x ≈2–5), suggesting that viscosity significantly alters the normal deformation mode, particularly in terms of phase distribution.

Stress characteristics

The variation of normal stress t_{zz} with distance x is depicted in Fig. 3. The stress field exhibits strong oscillations near the origin, followed by a gradual attenuation as distance increases. A sharp initial drop is noticed, after which alternating peaks and troughs appear with decreasing amplitude. A key observation is that the viscous case consistently yields higher stress magnitudes, particularly within the first oscillation cycle (x ≤3). Although both cases converge toward low-amplitude oscillations at larger distances, the viscous response remains slightly elevated. The spatial frequency of oscillation appears unchanged, indicating that viscosity primarily influences the magnitude of stress rather than its wavelength**.**

Figure 4 presents the variation of tangential stress t_{zx} with distance x. The response is oscillatory with a gradual reduction in amplitude, similar to the normal stress component. However, a distinguishing feature is the strong phase opposition between the two cases across the domain. Peaks in one curve correspond closely to troughs in the other, particularly in the region x ≈1–4, indicating a reversal in

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shear stress direction. The amplitude is relatively high near the origin and decreases progressively with distance, reflecting attenuation effects. While the viscous case shows slightly larger peak values in the near-field region, this difference diminishes at larger distances.

Conductive Temperature and Electromagnetic Field Characteristics

Figure 5 shows the variation of φ with distance x. The temperature distribution exhibits an oscillatory behavior for both cases, with a distinct phase opposition observed throughout the domain. In the near-field region (x ≈0–3), one profile decreases sharply to a negative minimum, while the other simultaneously increases toward a positive maximum, confirming an out-of-phase relationship. The amplitude is highest near the origin and decreases progressively with distance, indicating attenuation of the thermal field. At larger distances, the oscillations diminish and approach small values around zero.

Figure 6 presents the variation of the current density component J_x with distance x. The response exhibits a clear oscillatory pattern, characterized by an initial decrease from a positive value near the origin to a pronounced negative minimum around $x \approx 2$. This is followed by successive oscillations with progressively decreasing amplitude as distance increases. The attenuation of amplitude is evident across the domain, with the oscillations becoming significantly weaker beyond $x \approx 6$.

Figure 7 shows the variation of the current density component J_z along the distance x. The response begins with a relatively high positive value near the origin, followed by a rapid decline leading to a negative minimum around $x \approx 2$. Beyond this point, the behavior transitions into an oscillatory pattern with decreasing amplitude as distance increases. The attenuation is gradual, with the oscillations becoming less pronounced at larger values of x.

Also, figures 6 and 7 exhibit closely matching profiles, with peaks and troughs aligned in position, indicating that there is no significant phase difference between them. The primary difference lies in the amplitude, where one case shows slightly higher magnitudes in the initial region. This difference reduces with increasing distance, and both responses tend toward small oscillations around zero

8. Conclusion

In this work, the behavior of a rotating orthotropic magneto-viscothermoelastic half-space under ramp-type thermal loading has been analyzed within the framework of GN II AND III thermoelasticity incorporating two-temperature theory and Hall current effects. The coupled governing equations were solved using normal mode analysis along with Laplace and Fourier transform techniques, and the physical fields were obtained via numerical inversion.

The results show that all field variables exhibit oscillatory behavior with attenuation as distance increases, reflecting the dissipative nature of the medium. The influence of viscosity is found to be non-uniform: transverse displacement remains largely unaffected, whereas normal displacement and tangential stress exhibit clear phase differences. The normal stress is significantly enhanced in magnitude in the presence of viscosity, while the conductive temperature shows a pronounced phase reversal. In contrast, the current density components J_x and $J_z$maintain similar oscillatory patterns, with variations primarily in magnitude.

Overall, viscosity, rotation, and electromagnetic effects significantly modify the coupled thermo-mechanical and electromagnetic responses, providing insights into wave propagation in advanced engineering and geophysical materials.

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