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Axisymmetric thermomechanical analysis of transversely isotropic magneto thermoelastic solid due to time-harmonic sources

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Abstract. The present research deals with two-dimensional axisymmetric deformation in transversely isotropic magneto thermoelastic solid with and without energy dissipation, with two temperature and time-harmonic source. The proposed model is helpful for finding the type of relations between mechanical and thermal fields as most of the structural elements of heavy industries are frequently related to mechanical and thermal stresses at a higher temperature. The Hankel transform has been used to find a solution to the problem. The displacement components, stress components, and temperature distribution with the horizontal distance in the physical domain are calculated numerically. The effect of time-harmonic source and two temperature is depicted graphically on the resulting quantities.

Keywords: transversely isotropic Magneto thermoelastic; mechanical and thermal stresses; time harmonic source

1. Introduction

A lot of research and attention has been given to deformation and heat flow in a continuum using thermoelasticity theories during the past few years. It is well known that all the rotating large bodies have angular velocity, as well as magnetism, therefore, the thermoelastic interactions in a rotating medium under magnetic field is of importance. When sudden heat/external force is applied in a solid body, it transmits time-harmonic wave by thermal expansion. The change at some point of the medium is beneficial to detect the deformed field near mining shocks, seismic and volcanic sources, thermal power plants, high-energy particle accelerators, and many emerging technologies. The study of a time-harmonic source is one of the broad and dynamic areas of continuum dynamics. Therefore, in an unbounded rotating elastic medium with angular velocity, with rotation and relaxation time and without energy dissipation in generalized thermoelasticity has been studied in this research.

Rehbinder (1987) discussed thermally induced vibrations in an elastic body with a spherical cavity. Marin (1997) proved the Cesaro means of strain and kinetic energies of dipolar bodies with finite energy. Erbay (1991) investigated the thermally induced vibrations in a generalized

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thermoelastic solid with a cavity. Salam *et al.* (2007) discussed the magneto-thermoelastic problem in a non-homogeneous isotropic cylinder by the finite-difference method. Argeso and Eraslan (2008) investigated the thermomechanical calculations for a solid and hollow cylinder. Hou *et al.* (2008) discussed a point heat source on a semi-infinite transversely isotropic piezothermoelastic material by four harmonic functions. Khalili *et al.* (2010) gave an analytical solution for two-dimensional magneto-thermo-mechanical response in FG hollow sphere. Ailawalia *et al.* (2010) had studied a rotating generalized thermoelastic medium in the presence of two temperatures beneath hydrostatic stress and gravity with different kinds of sources using integral transforms. Singh and Yadav (2012) solved the transversely isotropic rotating magnetothermoelastic medium equations by cubic velocity equation of three plane waves without anisotropy, with rotation, and thermal and magnetic effects. Banik and Kanoria (2012) studied the thermoelastic interaction in an isotropic infinite elastic body with a spherical cavity for the TPL(Three-Phase-Lag) heat equation with two-temperature generalized thermoelasticity theory and has shown variations between two models: the two-temperature GN theory in presence of energy dissipation and two-temperature TPL model and has shown the effects of ramping parameters and two-temperature.

Mahmoud (2012) considered the impact of rotation, relaxation times, magnetic field, gravity field and initial stress on Rayleigh waves and attenuation coefficient in an elastic half-space of granular medium and obtained the analytical solution of Rayleigh wave velocity by using Lame's potential techniques. Abd-alla and Alshaikh (2015) discussed the influence of magnetic field and rotation on plane waves in a transversely isotropic thermoelastic medium under the GL theory in presence of two relaxation times to show the presence of three quasi-plane waves in the medium. Marin *et al.* (2013) have modelled a micro stretch thermoelastic body with two temperatures and eliminated divergences among the classical elasticity and research. Sharma *et al.* (2015) investigated the 2-D deception in a transversely isotropic homogeneous thermoelastic solids in presence of two temperatures in GN-II theory with an inclined load (linear combination of normal load and tangential load). Kumar *et al.* (2016a) investigated the impact of Hall current in a transversely isotropic magnetothermoelastic in presence and absence of energy dissipation due to the normal force. Kumar *et al.* (2016b) studied the conflicts caused by thermomechanical sources in a transversely isotropic rotating homogeneous thermoelastic medium with magnetic effect as well as two temperature and applied to the thermoelasticity Green–Naghdi theories with and without energy dissipation using thermomechanical sources. Ezzat *et al.* (2017) proposed a mathematical model of electro-thermoelasticity for heat conduction with a memory-dependent derivative. Kumar *et al.* (2017) analyzed the Rayleigh wave in a transversely isotropic homogeneous magnetothermoelastic medium in the presence of two temperature, with Hall current and rotation. Kordkheili (2017) discussed the axisymmetric analysis of a thermoelastic isotropic half-space under burried source in displacement and temperature potentials.

Lata (2018) studied the impact of energy dissipation on plane waves in sandwiched layered thermoelastic medium of uniform thickness, with two temperature, rotation, and Hall current in the context of GN Type-II and Type-III theory of thermoelasticity. Lata (2019) studied time-harmonic interactions in fractional thermoelastic diffusive thick circular plate. Ezzat and El-Bary (2017) had applied the magneto-thermoelasticity model to a one-dimensional thermal shock problem of functionally graded half-space based on a memory-dependent derivative. Despite of this several researchers worked on different theory of thermoelasticity as Marin (1998; 1999), Abbas & Youssef (2009; 2012), Mohamed *et al.* (2009), Abbas *et al.* (2009), Abd-Alla and Mahmoud (2011), Bouderba *et al.* (2013), Atwa (2014), Zenkour & Abbas (2014), Abbas (2015), Marin

(2016), Bijarnia and Singh (2016), Marin and Craciun (2017), Ezzat *et al.* (2012), Othman & Marin (2017), Hassan *et al.* (2018), Ezzat and El-Bary (2017), Kumar *et al.* (2016d), Ezzat *et al.* (2017), Chauthale *et al.* (2017) and Shahani and Torki (2018). Farhan & Khder (2019), Lata and Kaur (2019 a,b,c,d,e,f), Attia *et al.* (2018),

In spite of these, not much work has been carried out in thermo-mechanical interactions in transversely isotropic magneto thermoelastic solid with rotation and with and without energy dissipation, with two temperature due to time-harmonic sources. Keeping these considerations in mind, analytic expressions for the displacement components, stress components, and temperature distribution in two-dimensional homogeneous, transversely isotropic magneto-thermoelastic rotating solids with two temperature and various frequencies of time-harmonic source have been derived

2. Basic equations

Following Lata *et al*. (2019d) the constitutive relations and field equations for an anisotropic thermoelastic medium with and without energy dissipation in absence of body forces and heat sources are

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

$$K_{ij}\varphi_{,ij} + K_{ij}^{*}\dot{\varphi}_{,ij} = \beta_{ij}T_0\ddot{e}_{ij} + \rho C_E\ddot{T} \tag{2}$$

and equation of motion as described by Schoenberg and Censor (1973) for a transversely isotropic thermoelastic medium rotating uniformly with an angular velocity $\mathbf{\Omega} = \Omega\boldsymbol{n}$, where $\mathbf{n}$ is a unit vector representing the direction of the axis of rotation and taking into account Lorentz force is

$$t_{ij,j} + F_i = \rho\{\ddot{u}_i + (\Omega \times (\Omega \times \mathrm{u})_i + (2\Omega \times \dot{u})_i\}, \tag{3}$$

where $\mathbf{\Omega} = \Omega\boldsymbol{n}$, $\mathbf{n}$ is a unit vector representing the direction of the axis of rotation. The term $\Omega \times (\Omega \times \mathrm{u})$ is the additional centripetal acceleration due to the time-varying motion only, and the term $2\Omega \times \dot{u}$ is the Coriolis acceleration.

$$F_i = \mu_0(\vec{J} \times \vec{H}_0) .$$

where

$$T = \varphi - a_{ij}\varphi_{,ij}, \tag{4}$$

$$\beta_{ij} = C_{ijkl}\alpha_{ij}, \tag{5}$$

$$e_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}).\ i = 1,2,3 \tag{6}$$

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

3. Formulation of the problem

Consider a transversely isotropic magneto thermoelastic homogeneous medium with an initial

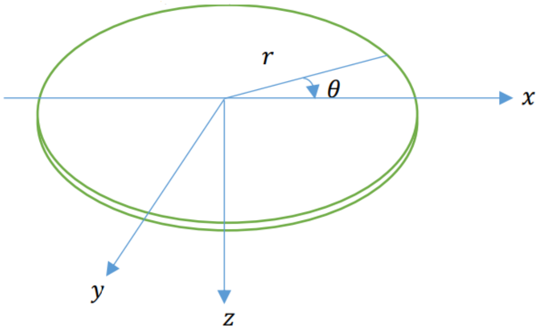

Fig. 1 Geometry of the problem

temperature T_0 and rotating uniformly with an angular velocity $\boldsymbol{\Omega} = \Omega\boldsymbol{n}$. We take a cylindrical polar coordinate system (r, θ, z) with symmetry about z-axis. Consider that the problem is plane axisymmetric, so the field component$(v = 0)$, and $(u, w,$ and $\varphi)$are independent of θ.

In addition, we consider that

$$\boldsymbol{\Omega} = (0, \Omega, 0).$$

From the generalized Ohm's law (Kumar, Sharma, & Lata, 2016)

$$J_2 = 0.$$

The density components $J_1$and J_3 are given as

$$J_1 = -\varepsilon_0\mu_0 H_0 \frac{\partial^2 w}{\partial t^2}, \tag{7}$$

$$J_3 = \varepsilon_0\mu_0 H_0 \frac{\partial^2 u}{\partial t^2}. \tag{8}$$

Using the appropriate transformation following Slaughter (2002) on the set of Eqs. (1)-(3) to derive the equations for transversely isotropic thermoelastic solid with two temperatures and with and without energy dissipation we get

$$C_{11}\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} - \frac{1}{r^2}u\right) + C_{13}\left(\frac{\partial^2 w}{\partial r\partial z}\right) + C_{44}\frac{\partial^2 u}{\partial z^2} + C_{44}\left(\frac{\partial^2 w}{\partial r\partial z}\right) - \beta_1\frac{\partial}{\partial r}\left\{\varphi - a_1\left(\frac{\partial^2\varphi}{\partial r^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r}\right) - a_3\frac{\partial^2\varphi}{\partial z^2}\right\} - \mu_0 J_3 H_0 = \rho\left(\frac{\partial^2 u}{\partial t^2} - \Omega^2 u + 2\Omega\frac{\partial w}{\partial t}\right), \tag{9}$$

$$(C_{11} + C_{44})\left(\frac{\partial^2 u}{\partial r\partial z} + \frac{1}{r}\frac{\partial u}{\partial z}\right) + C_{44}\left(\frac{\partial^2 w}{\partial r^2} + \frac{1}{r}\frac{\partial w}{\partial r}\right) + C_{33}\frac{\partial^2 w}{\partial z^2} - \beta_3\frac{\partial}{\partial z}\left\{\varphi - a_1\left(\frac{\partial^2\varphi}{\partial r^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r}\right) - a_3\frac{\partial^2\varphi}{\partial z^2}\right\} + \mu_0 J_1 H_0 = \rho\left(\frac{\partial^2 w}{\partial t^2} - \Omega^2 w - 2\Omega\frac{\partial u}{\partial t}\right), \tag{10}$$

$$\left(K_1 + K_1^*\frac{\partial}{\partial t}\right)\left(\frac{\partial^2\varphi}{\partial r^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r}\right) + \left(K_3 + K_3^*\frac{\partial}{\partial t}\right)\frac{\partial^2\varphi}{\partial z^2} = T_0\frac{\partial^2}{\partial t^2}\left(\beta_1\frac{\partial u}{\partial r} + \beta_3\frac{\partial w}{\partial z}\right) + \rho C_E\frac{\partial^2}{\partial t^2}\left\{\varphi - a_1\left(\frac{\partial^2\varphi}{\partial r^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r}\right) - a_3\frac{\partial^2\varphi}{\partial z^2}\right\}. \tag{11}$$

Constitutive relations are

$$t_{rr} = c_{11}e_{rr} + c_{12}e_{\theta\theta} + c_{13}e_{zz} - \beta_1 T,$$
$$t_{zr} = 2c_{44}e_{rz},$$
$$t_{zz} = c_{13}e_{rr} + c_{13}e_{\theta\theta} + c_{33}e_{zz} - \beta_3 T,$$
$$t_{\theta\theta} = c_{12}e_{rr} + c_{11}e_{\theta\theta} + c_{13}e_{zz} - \beta_3 T, \tag{12}$$

where

$$e_{rz} = \frac{1}{2}\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial r}\right),$$
$$e_{rr} = \frac{\partial u}{\partial r},$$
$$e_{\theta\theta} = \frac{u}{r},$$
$$e_{zz} = \frac{\partial w}{\partial z},$$
$$T = \varphi - a_1\left(\frac{\partial^2\varphi}{\partial r^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r}\right) - a_3\frac{\partial^2\varphi}{\partial z^2},$$
$$\beta_1 = (c_{11} + c_{12})\alpha_1 + c_{13}\alpha_3,$$
$$\beta_3 = 2c_{13}\alpha_1 + c_{33}\alpha_3.$$

We consider that the medium is initially at rest. Therefore, the preliminary and symmetry conditions are given by

$$u(r,z,0) = 0 = \dot{u}(r,z,0),$$
$$w(r,z,0) = 0 = \dot{w}(r,z,0),$$
$$\varphi(r,z,0) = 0 = \dot{\varphi}(r,z,0) \text{for } z \geq 0, -\infty < r < \infty,$$
$$u(r,z,t) = w(r,z,t) = \varphi(r,z,t) = 0 \; for \; t > 0 \text{ when } z \to \infty.$$

Assuming the time-harmonic behavior as

$$(u,w,\varphi)(r,z,t) = (u,w,\varphi,)(r,z)e^{i\omega t}, \tag{13}$$

where ω is the angular frequency. To facilitate the solution, the following dimensionless quantities are introduced

$$r' = \frac{r}{L},\; z' = \frac{z}{L},\; t' = \frac{c_1}{L}t,\; u' = \frac{\rho c_1^2}{L\beta_1 T_0}u,\; w' = \frac{\rho c_1^2}{L\beta_1 T_0}w, T' = \frac{T}{T_0}, t'_{zr} = \frac{t_{zr}}{\beta_1 T_0}, t'_{zz} = \frac{t_{zz}}{\beta_1 T_0}, \varphi' = \frac{\varphi}{T_0}, a'_1 = \frac{a_1}{L^2}, a'_3 = \frac{a_3}{L^2}. h' = \frac{h}{H_0},\; \Omega' = \frac{\mathrm{L}}{C_1}\Omega. \tag{14}$$

Using the dimensionless quantities defined by (14) in equations (9)-(11) and after that suppressing the primes and applying Hankel transforms defined by

$$\tilde{f}(\xi,z,\omega) = \int_0^\infty f^*(r,z,\omega) r J_n(r\xi)dr. \tag{15}$$

on the resulting quantities, we obtain

$$(-\xi^2 + \delta_2 D^2 + \omega^2\delta_7 + \Omega^2)\tilde{u} + (\delta_1 D\xi - 2\Omega \mathrm{i}\omega)\tilde{w} + (-\xi(1 + a_1\xi^2) + a_3\xi D^2)\tilde{\varphi} = 0, \tag{16}$$

$$(\delta_1 D\xi + 2\Omega \mathrm{i}\omega)\tilde{u} + (\delta_3 D^2 - \delta_2\xi^2 + \omega^2\delta_7 + \Omega^2)\tilde{w} - \left(\frac{\beta_3}{\beta_1} D[(1+\xi^2 a_1) - a_3 D^2]\right)\tilde{\varphi} = 0, \quad (17)$$

$$\delta_6\omega^2\xi\tilde{u} + \frac{\beta_3}{\beta_1}\delta_6\omega^2 D\tilde{w} + \left(\delta_8\omega^2(1+\xi^2 a_1 - a_3 D^2) - \xi^2(K_1 + \delta_4\omega i) + D^2(K_3 + \delta_5\omega i)\right)\tilde{\varphi} = 0. \quad (18)$$

where

$$\delta_1 = \frac{c_{13}+c_{44}}{c_{11}}, \quad \delta_2 = \frac{c_{44}}{c_{11}}, \quad \delta_3 = \frac{c_{33}}{c_{11}}, \quad \delta_4 = \frac{K_1^* C_1}{L}, \delta_5 = \frac{K_3^* C_1}{L},$$

$$\delta_6 = -\frac{T_0\beta_1^2}{\rho}, \delta_7 = \frac{\varepsilon_0\mu_0^2 H_0^2}{\rho} + 1, \delta_8 = \rho C_E C_1^2,$$

$$\delta_{10} = \frac{C_{12}}{C_{11}}, \delta_{11} = \frac{C_{13}}{C_{11}}, i = \sqrt{-1}.$$

The non-trivial solution of (14)-(16) by eliminating $\tilde{u}$, $\tilde{w}$, and $\tilde{\varphi}$ yields

$$AD^6 + BD^4 + CD^2 + E = 0 \quad (19)$$

where

$$\mathrm{A} = \delta_2\delta_3\zeta_{11} - \zeta_9\delta_2\zeta_7,$$

$$\mathrm{B} = \delta_2\zeta_3\zeta_{11} + \delta_3\zeta_1\zeta_{11} + \delta_2\delta_3\zeta_{10} - \delta_2\zeta_7\zeta_{10} - \zeta_7\zeta_1\zeta_9 - \zeta_2^2\zeta_{11} + \zeta_2\zeta_4\zeta_9 + \zeta_8\zeta_7\zeta_2 - \delta_3\zeta_4\zeta_8,$$

$$C = \zeta_1\zeta_3\zeta_{11} + \delta_2\zeta_{10}\zeta_5 + \delta_3\zeta_3\zeta_{10} - \zeta_9\zeta_1\zeta_6 - \zeta_2^2\zeta_{10} + \zeta_2\zeta_6\zeta_8 + \zeta_3\zeta_2\zeta_9 - \zeta_3\zeta_8\delta_3 - \zeta_4\zeta_8\zeta_5 - 4\Omega^2\omega^2\zeta_{11},$$

$$E = \zeta_5\zeta_1\zeta_{10} - \zeta_8\zeta_5\zeta_3 - 4\Omega^2\omega^2\zeta_{10}.$$

$$\zeta_1 = -\xi^2 + \omega^2\delta_7 + \Omega^2,$$

$$\zeta_2 = \delta_1\xi,$$

$$\zeta_3 = -\xi(a_1\xi^2 + 1),$$

$$\zeta_4 = a_3\xi,$$

$$\zeta_5 = -\delta_2\xi^2 + \omega^2\delta_7 + \Omega^2,$$

$$\zeta_6 = -\frac{\beta_3}{\beta_1}(1 + a_1\xi^2),$$

$$\zeta_7 = a_3\frac{\beta_3}{\beta_1},$$

$$\zeta_8 = \xi\delta_6\omega^2,$$

$$\zeta_9 = \frac{\beta_3}{\beta_1}\delta_6\omega^2,$$

$$\zeta_{10} = \delta_8\omega^2(1 + a_1\xi^2) - \xi^2(K_1 + \delta_4\omega i),$$

$$\zeta_{11} = (K_3 + \delta_5\omega i) - \delta_8\omega^2 a_3.$$

The roots of the Eq. (19) are ±λj, (j = 1, 2, 3), which is calculated by using the radiation conditions that $\tilde{u}, \tilde{w}, \tilde{\varphi} \to 0 \; as \; z \to \infty$ yields

$$\hat{u}(\xi, z, \omega) = \sum_{j=1}^{3} A_j e^{-\lambda_j z}, \tag{20}$$

$$\hat{w}(\xi, z, \omega) = \sum_{j=1}^{3} d_j A_j e^{-\lambda_j z}, \tag{21}$$

$$\hat{\varphi}(\xi, z, \omega) = \sum_{j=1}^{3} l_j A_j e^{-\lambda_j z}, \tag{22}$$

where $A_j(\xi, \omega), j = 1, 2, 3$ being arbitrary constants and d_j and l_j are given by

$$d_j = \frac{\delta_2 \zeta_{11} \lambda_j^4 + (\zeta_{11}\zeta_1 - \zeta_4\zeta_8 + \delta_2\zeta_{10})\lambda_j^2 + \zeta_1\zeta_{10} - \zeta_8\zeta_3}{(\delta_3\zeta_{11} - \zeta_7\zeta_9)\lambda_j^4 + (\delta_3\zeta_{10} + \zeta_5\zeta_{11} - \zeta_9\zeta_6)\lambda_j^2 + \zeta_5\zeta_{10}},$$

$$l_j = \frac{\delta_2\delta_3\lambda_j^4 + (\delta_2\zeta_5 + \zeta_1\delta_3 - \zeta_2^2)\lambda_j^2 + \zeta_1\zeta_5 - 4\Omega^2\omega^2}{(\delta_3\zeta_{11} - \zeta_7\zeta_9)\lambda_j^4 + (\delta_3\zeta_{10} + \zeta_5\zeta_{11} - \zeta_9\zeta_6)\lambda_j^2 + \zeta_5\zeta_{10}}.$$

$$\widetilde{t_{zz}} = \sum A_j(\xi, \omega)\eta_j \, e^{-\lambda_j z}, \tag{23}$$

$$\widetilde{t_{rz}} = \sum A_j(\xi, \omega)\mu_j e^{-\lambda_j z}, \tag{24}$$

$$\widetilde{t_{rr}} = \sum A_j(\xi, \omega) Q_j \, e^{-\lambda_j z}, \tag{25}$$

where

$$\eta_j = \delta_{11}\xi - \delta_3\lambda_j d_j - \frac{\beta_3}{\beta_1}(1 + a_1\xi^2)l_j + \frac{\beta_3}{\beta_1} a_3 l_j \lambda_j^2, \; \mu_j = \delta_2(-\lambda_j + \xi d_j),$$
$$Q_j = (\delta_{10} + 1)\xi - \delta_{11}\lambda_j d_j - l_j(1 + a_1\xi^2) + a_3 l_j \lambda_j^2, \qquad i = 1, 2, 3. \tag{26}$$

4. Boundary conditions

Thermal source and normal force are applied to the half-space (z = 0).

$$t_{zz}(r, z, t) = -F_1\psi_1(r)e^{i\omega t}, \tag{27}$$

$$t_{zz}(r, z, t) = -F_1\psi_1(r)e^{i\omega t}, \tag{28}$$

$$\frac{\partial\varphi(r, z, t)}{\partial z} + h\varphi(r, z, t) = F_2\psi_2(r)e^{i\omega t}, \tag{29}$$

where F_1 is the magnitude of the force applied, F_2 is the thermal source applied on the boundary,

$$\sum A_j(\xi, \omega)\eta_j = -F_1\psi_1(\xi)e^{i\omega t}, \sum A_j(\xi, \omega)\mu_j = 0, \sum A_j\,(\xi, \omega)P_j = F_2\psi_2(\xi)e^{i\omega t},$$

where $P_j = l_j\left(-\lambda_j + h\right)$.

Solving the Eqs. (27)-(29) with the aid of (20)-(22) and we obtain

$$\tilde{u} = \frac{F_1\widetilde{\psi_1}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}\Lambda_{1j}e^{-\lambda_j z}\right] + \frac{F_2\widetilde{\psi_2}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}\Lambda_{2j}e^{-\lambda_j z}\right], \tag{30}$$

$$\widetilde{w} = \frac{F_1\widetilde{\psi_1}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}d_j\Lambda_{1j}e^{-\lambda_j z}\right] + \frac{F_2\widetilde{\psi_2}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}d_j\Lambda_{2j}e^{-\lambda_j z}\right], \tag{31}$$

$$\tilde{\varphi} = \frac{F_1\widetilde{\psi_1}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}l_j\Lambda_{1j}e^{-\lambda_j z}\right] + \frac{F_2\widetilde{\psi_2}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{i=1}^{3}l_j\Lambda_{2j}e^{-\lambda_j z}\right], \tag{32}$$

$$\widetilde{t_{rr}} = \frac{F_1\widetilde{\psi_1}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}Q_j\Lambda_{1j}e^{-\lambda_j z}\right] + \frac{F_2\widetilde{\psi_2}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}Q_j\Lambda_{2j}e^{-\lambda_j z}\right], \tag{33}$$

$$\widetilde{t_{zr}} = \frac{F_1\widetilde{\psi_1}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}\mu_j\Lambda_{1j}e^{-\lambda_j z}\right] + \frac{F_2\widetilde{\psi_2}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}\mu_j\Lambda_{2j}e^{-\lambda_j z}\right], \tag{34}$$

$$\widetilde{t_{zz}} = \frac{F_1\widetilde{\psi_1}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}\eta_j\Lambda_{1j}e^{-\lambda_j z}\right] + \frac{F_2\widetilde{\psi_2}(\xi)e^{i\omega t}}{\Lambda}\left[\sum_{j=1}^{3}\eta_j\Lambda_{2j}e^{-\lambda_j z}\right], \tag{35}$$

where

$$\Lambda_{11} = -\mu_2 P_3 + P_2\mu_3,$$

$$\Lambda_{12} = \mu_1 P_3 - P_1\mu_3,$$

$$\Lambda_{13} = -\mu_1 P_2 + P_1\mu_2,$$

$$\Lambda_{21} = \eta_2\mu_3 - \mu_2\eta_3,$$

$$\Lambda_{22} = -\eta_1\mu_3 + \mu_1\eta_3,$$

$$\Lambda_{23} = \eta_1\mu_2 - \mu_1\eta_2,$$

$$\Lambda = -\eta_1\Lambda_{11} - \eta_2\Lambda_{12} - \eta_3\Lambda_{13}, \quad j = 1,2,3.$$

5. Special cases

a. Mechanical force on a half-space surface

By taking F2 = 0 in Eqs. (30)-(35), we obtain the components of displacement, normal stress, tangential stress and conductive temperature due to mechanical force.

b. Thermal source on the half-space surface

By considering F1 = 0 in Eqs. (30)-(35), we obtain the components of displacement, normal stress, tangential stress and conductive temperature due to a thermal source.

5.1 Concentrated normal force/ thermal point source

F_1 is the magnitude of the force applied, F_2 is the magnitude of the constant temperature applied on the boundary. We obtain the solution with concentrated normal force on the half-space by taking

$$\psi_1(r) = \frac{\delta(r)}{2\pi r}, \psi_2(r) = \frac{\delta(r)}{2\pi r} \tag{36}$$

Applying Hankel transform we get

$$\hat{\psi}_1(\xi) = \frac{1}{2\pi\xi}, \hat{\psi}_2(\xi) = \frac{1}{2\pi\xi} \tag{37}$$

Using (37) in (30)-(35), the components of displacement, stress and conductive temperature can be obtained.

5.2 Normal force over the circular region/ Thermal source over the circular region

Let a uniform pressure of total magnitude F_1/ constant temperature F_2 be applied over a uniform circular region of radius a. We obtain the solution with uniformly distributed force applied on the half-space by taking

$$\psi_1(r) = \psi_2(r) = \frac{H(a-r)}{\pi a^2} \tag{38}$$

where $H(a-r)$ is a Heaviside function. The Hankel transforms of $\psi_1(r)$ and $\psi_2(r)$is given by

$$\hat{\psi}_1(\xi) = \hat{\psi}_2(\xi) = \left\{\frac{J_1(\xi a)}{2\pi a\xi}\right\}, \ \xi \neq 0. \tag{39}$$

Using (39) in (30)- (35), the components of displacement, stress and conductive temperature can be obtained.

6. Particular cases

a) If we take $K_{ij}^* \neq 0$, the equation (2) is GN-III theory or GN theory with energy dissipation and thus we obtain the components of displacement, normal stress, tangential stress and conductive temperature from(30)-(35)for transversely isotropic magneto-thermoelastic solid with rotation and GN III theory (thermoelasticity with energy dissipation).

b) The equation (2) becomes GN-II theory or GN theory without energy dissipation if we take $K_{ij}^* = 0$, we obtain the components of displacement, normal stress, tangential stress and conductive temperature from (30)-(35) for transversely isotropic magneto-thermoelastic solid with rotation and GN II theory (generalized thermoelasticity without energy dissipation).

c) If we take $K_{ij} = 0$ the equation of GN theory of type III reduce to the GN theory of type I, which is identical with the classical theory of thermoelasticity and thus we obtain the components of displacement, normal stress, tangential stress and conductive temperature from (30)-(35) for transversely isotropic magneto-thermoelastic solid with rotation and GN I theory.

d) If $C_{11} = C_{33} = \lambda + 2\mu, C_{12} = C_{13} = \lambda, C_{44} = \mu,\ \alpha_1 = \alpha_3 = \alpha',\ a_1 = a_3 = a,\ b_1 = b_3 = b$, $K_1 = K_3 = K,\ K_1^* = K_3^* = K^*$ we obtain the components of displacement, normal stress, tangential stress and conductive temperature from (30)-(35) for magneto-thermoelastic isotropic materials with rotation and with and without energy dissipation.

7. Inversion of the transformation

To find the solution of the problem in physical domain following Sharma *et al.* (2016b), invert the transforms in equations (30)-(35) by inverting the Hankel transform using

$$f^*(r, z, s) = \int_0^\infty \xi \tilde{f}(\xi, z, s) J_n(\xi r) d\xi \tag{40}$$

The last step is to calculate the integral in Eq. (40). The method for evaluating this integral by using Romberg's integration with adaptive step size is described in Press *et al.* (1986).

8. Numerical results and discussion

To demonstrate the theoretical results and effect of frequency, and two temperature, the physical data for cobalt material, which is transversely isotropic, is taken from Dhaliwal & Singh (1980) is given as

$$c_{11} = 3.07 \times 10^{11} Nm^{-2},\ c_{33} = 3.581 \times 10^{11} Nm^{-2},\ c_{13} = 1.027 \times 10^{10} Nm^{-2},\ c_{44} = 1.510 \times 10^{11} Nm^{-2},\ \beta_1 = 7.04 \times 10^6 Nm^{-2} deg^{-1},\ \beta_3 = 6.90 \times 10^6 Nm^{-2} deg^{-1},\ \rho = 8.836 \times 10^3 Kgm^{-3},\ C_E = 4.27 \times 10^2 jKg^{-1} deg^{-1},\ K_1 = 0.690 \times 10^2 Wm^{-1} Kdeg^{-1},\ K_3 = 0.690 \times 10^2 Wm^{-1} K^{-1},\ \mathrm{T}_0 = 298\,\mathrm{K}, \mathrm{H}_0 = 1\mathrm{Jm}^{-1}\mathrm{nb}^{-1},\ \varepsilon_0 = 8.838 \times 10^{-12} \mathrm{Fm}^{-1},\ \mathrm{L} = 1,\ \Omega = 0.5.$$

Using the above values, the graphical representations of displacement component u, normal displacement w, conductive temperature φ, normal force stress t_{zz}, tangential stress t_{zr}, radial stress t_{rr}, for a transversely isotropic magneto-thermoelastic solid with and without energy dissipation, with two temperature and frequency of time-harmonic sources has been depicted.

i. The solid black line with a square symbol corresponds to frequency. $\omega = 0.25$ and $a_1 = 0.0$, $a_3 = 0.0$,

ii. The solid blue line with a circle symbol corresponds to frequency. $\omega = 0.50$ and $a_1 = 0.0$, $a_3 = 0.0$,

iii. The solid red line with triangle symbol corresponds to frequency $\omega = 0.25$ and $a_1 = 0.02$, $a_3 = 0.04$,

iv. The solid green line with diamond symbol corresponds frequency $\omega = 0.5$ for $a_1 = 0.02$, $a_3 = 0.04$.

Case 1: Concentrated normal force with time-harmonic source frequency and two temperature

Figs. 2-7 show the variations of the displacement components (u and w), conductive

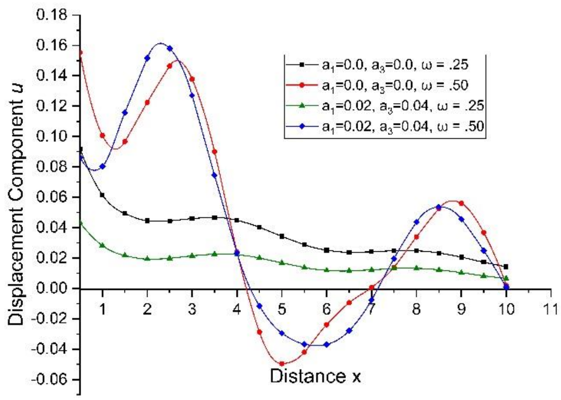

Fig. 2 Variations of displacement component u with distance x

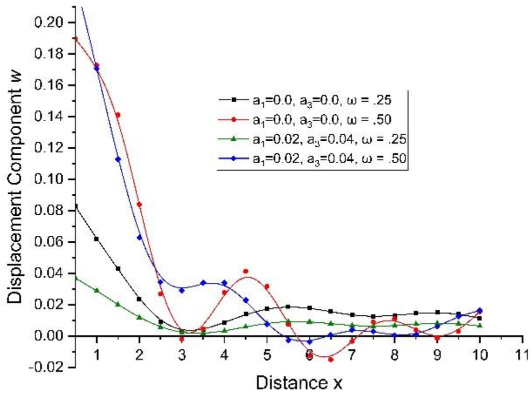

Fig. 3 Variations of displacement component w with distance x

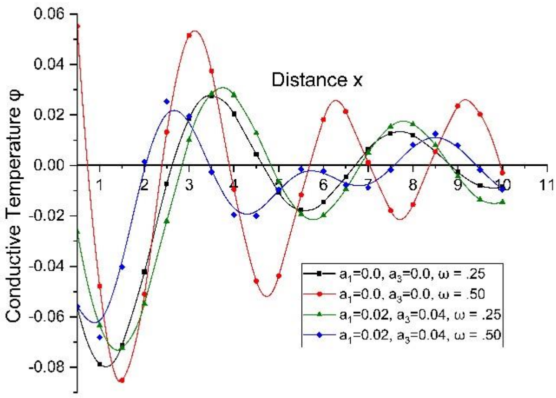

Fig. 4 Variations of temperature φ with distance x

temperature φ and stress components (t_{rr}, t_{rz} and t_{zz}) for a transversely isotropic magneto-thermoelastic medium with and without energy dissipation, with Mechanical and Concentrated normal force, with rotation, and with time-harmonic source frequency. The displacement

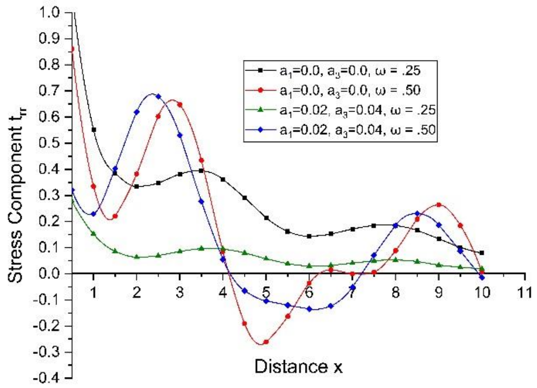

Fig. 5 Variations of stress component t_{rr} with distance x

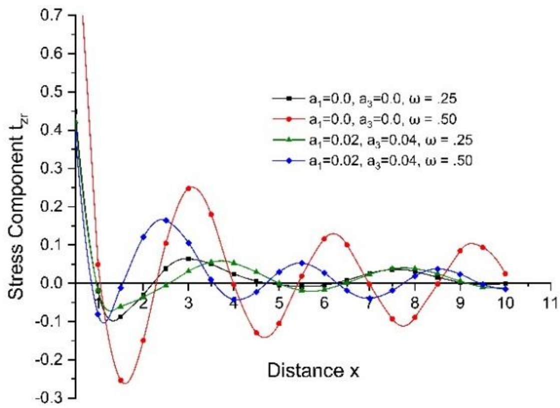

Fig. 6 Variations of the stress component t_{rz} with distance x

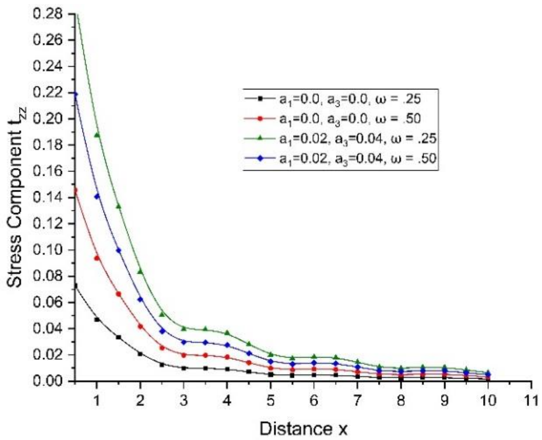

Fig. 7 Variations of the stress component t_{zz} with distance x

component u illustrate the different pattern for $\omega = .25, and\ \omega = 0.5$ but a similar pattern for the same value of two temperature having different magnitudes. The displacement component w also

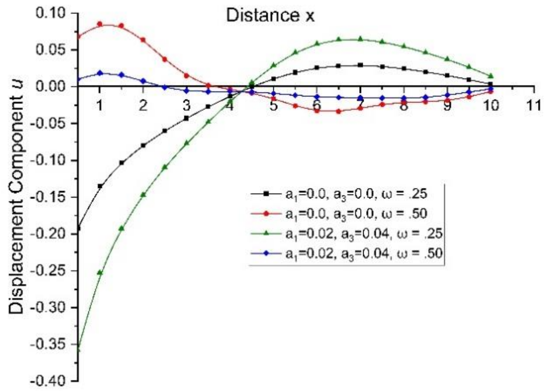

Fig. 8 Variations of displacement component u with distance x

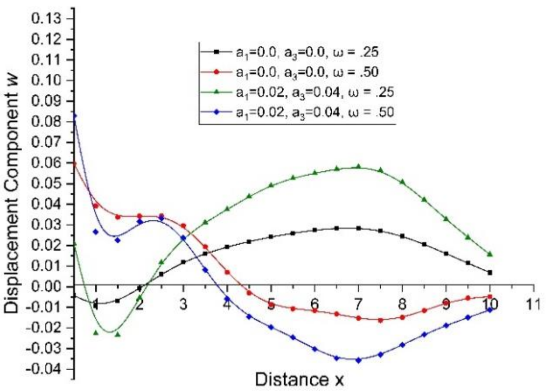

Fig. 9 Variations of displacement component w with distance x

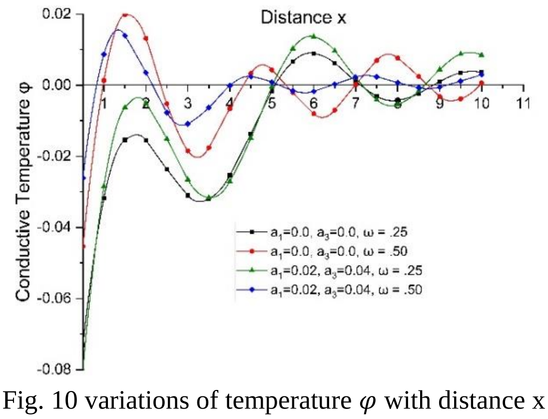

Fig. 10 variations of temperature φ with distance x

illustrate the same pattern with different magnitude for different value of frequency and two temperature. Conductive temperature φ shows an oscillatory pattern with a difference in magnitude for different values of ω. Stress components (t_{rr}, t_{rz} and t_{zz}) in Figs. 5-7 varies (increases or decreases) during the initial range of distance near the loading surface of the time-

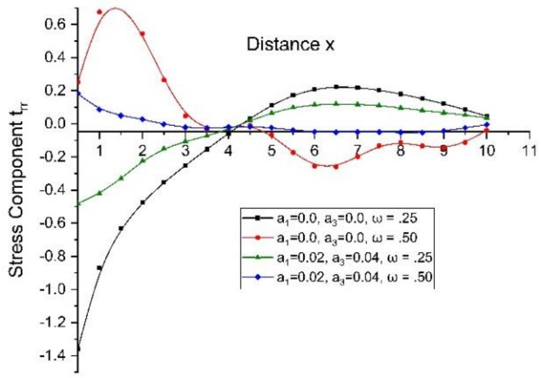

Fig. 11 Variations of stress component t_{rr} with distance x

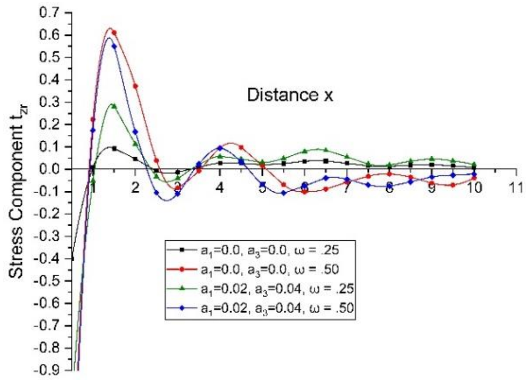

Fig. 12 Variations of the stress component t_{zr} with distance x

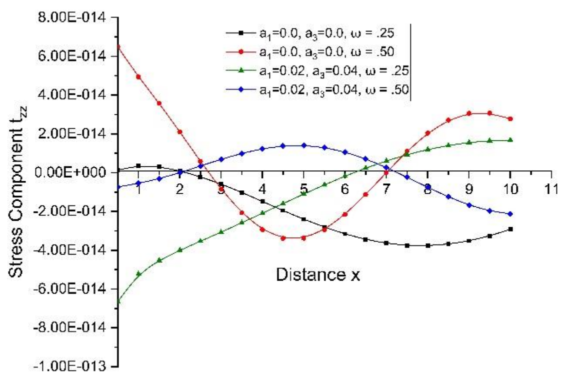

Fig. 13 Variations of the stress component $t_{zz}$with distance x

harmonic source and follow a small oscillatory pattern for rest of the range of distance showing the effect of two temperature and frequency.

Case II: Concentrated Thermal source with time-harmonic source frequency and two temperature

Figs. 8-13 show the variations of the displacement components (u and w), conductive

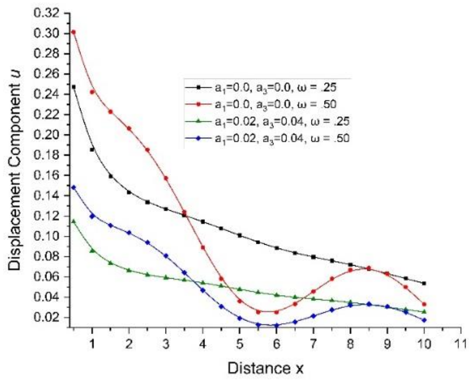

Fig. 14 Variations of displacement component u with distance x

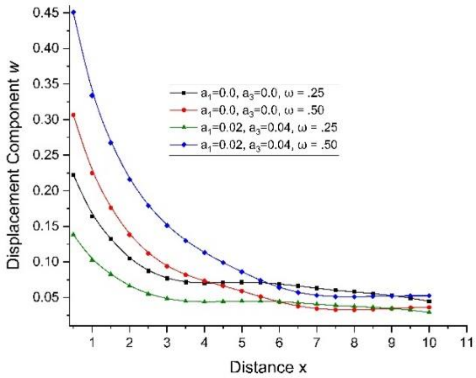

Fig. 15 Variations of displacement component w with distance x

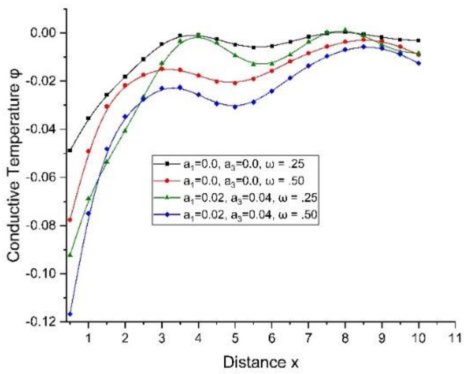

Fig. 16 Variations of temperature φ with distance x

temperature φ and stress components (t_{rr}, t_{rz} and t_{zz}) for a transversely isotropic magneto-thermoelastic medium with and without energy dissipation, with concentrated thermal source and with rotation, time-harmonic source frequency. The displacement components (u and *w)* and temperature φ illustrate the variation in the initial range of distance and then shows the small oscillatory pattern. Stress components (t_{rr}, t_{rz} and t_{zz}) in Figs. 11-13 vary (increases or

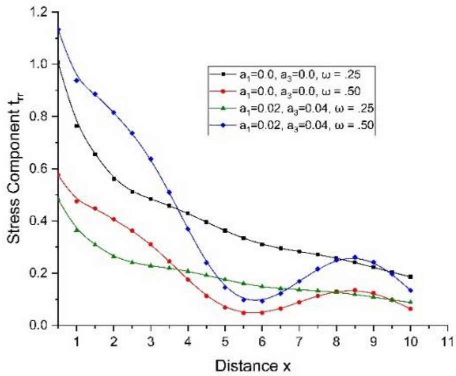

Fig. 17 variations of stress component t_{rr} with distance x

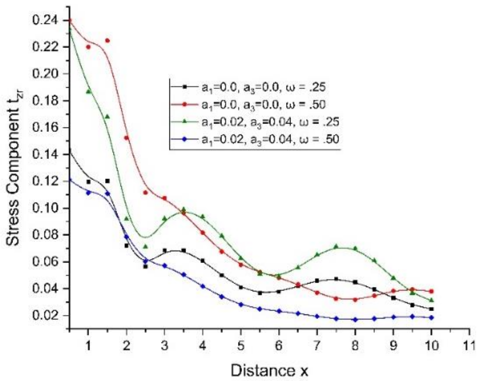

Fig. 18 Variations of the stress component t_{zr} with distance x

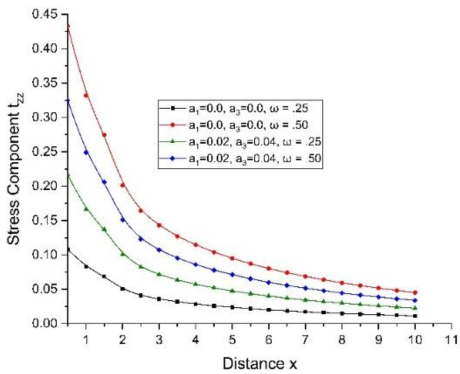

Fig. 19 Variations of the stress component $t_{zz}$with distance x

decreases) during the initial range of distance near the loading surface of the time-harmonic source and follow a small oscillatory pattern for rest of the range of distance. A small value of ω shows more stress near the loading surface. For two temperature and without two temperature the pattern is opposite showing effect of two temperature.

Case III: Normal force over the circular region with time-harmonic source frequency and two temperature

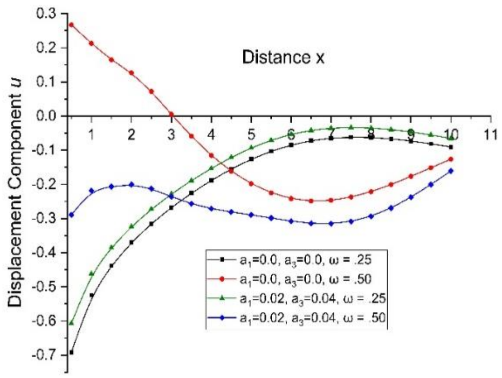

Fig. 20 Variations of displacement component u

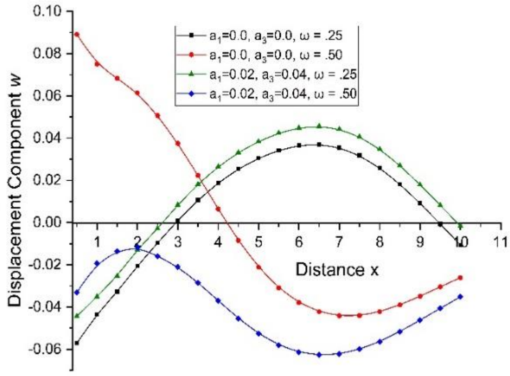

Fig. 21 Variations of displacement component w with distance x

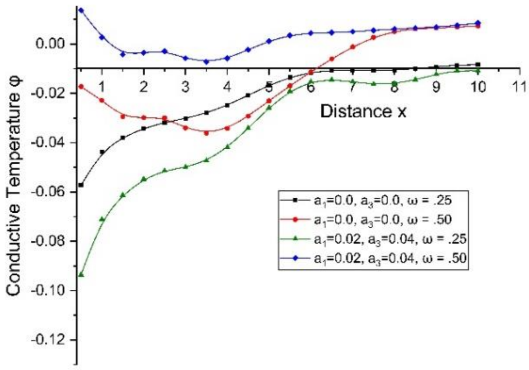

Fig. 22 Variations of temperature φ with distance x

Figs. 14-19 show the variations of the displacement components (u and w), conductive temperature φ and stress components (t_{rr}, t_{rz} and t_{zz})for a transversely isotropic magneto-thermoelastic medium with and without energy dissipation, with mechanical force and uniformly distributed load and with rotation, and with a time-harmonic source. The displacement components (u and w), and Stress components t_{rz} t_{rr} and t_{zz} illustrate the same pattern but having different

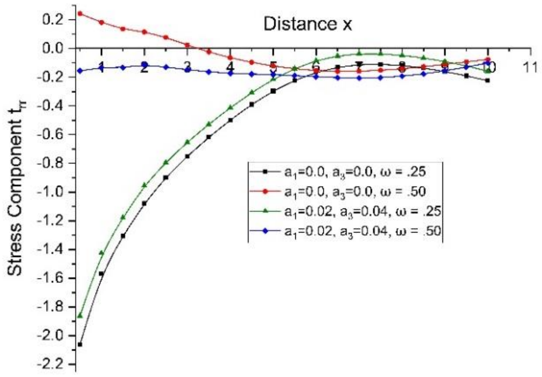

Fig. 23 Variations of stress component t_{rr} with distance x

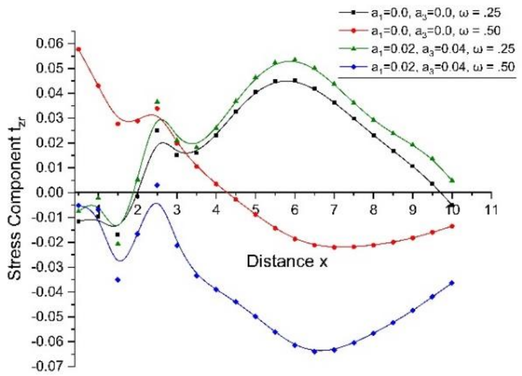

Fig. 24 Variations of the stress component t_{zr} with distance x

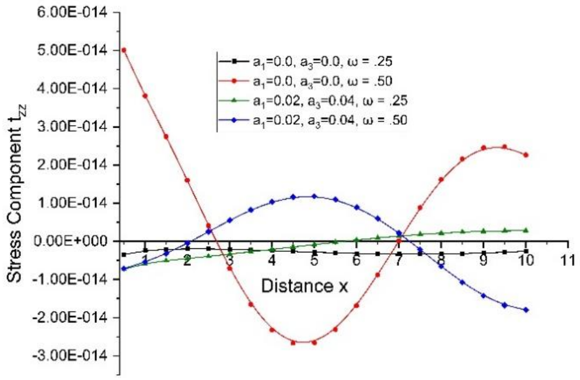

Fig. 25 Variations of the stress component t_{zz} with distance x

magnitudes with frequency and with and without two temperature while conductive temperature φ show opposite trends for frequency ω and also for two temperature.

Case IV: Thermal source over the circular region with time-harmonic source frequency and two temperature

Figs. 20-25 show the variations of the displacement components (u and w), temperature φ and stress components (t_{rr}, t_{rz} and t_{zz}) for a transversely isotropic magneto-thermoelastic medium with and without energy dissipation, with thermal source and concentrated load and with rotation and time-harmonic source. The displacement components (u and w) conductive temperature φ and stress component t_{rz} t_{rr}, t_{zz} illustrate the same pattern for all the four cases.

9. Conclusions

From the above investigation,

• The displacement components, stress components, and temperature distribution for transversely isotropic magneto thermoelastic solid with and without energy dissipation, with two temperature and time-harmonic source, are calculated numerically. The effect of time-harmonic source and two temperature is depicted graphically on the resulting quantities.

• It is observed that frequency of time-harmonic source and two temperature plays a key role for the oscillation of physical quantities both near to the point of use of source and away from the source. The physical quantities differ with the change in angular frequency and two temperature.

• The result gives the inspiration to study magneto-thermoelastic materials as an innovative domain of applicable thermoelastic solids. The shape of curves shows the impact of different angular frequencies and fixed relaxation time and rotation on the body and fulfills the purpose of the study.

• The outcomes of this research are extremely helpful in the 2-D problem with dynamic response of time-harmonic sources in transversely isotropic magneto-thermoelastic medium with rotation which is beneficial to detect the deformation field such as geothermal engineering; advanced aircraft structure design, thermal power plants, composite engineering, geology, high-energy particle accelerators and in real life as in geophysics, auditory range, geomagnetism etc. The proposed model in this research is relevant to different problems in thermoelasticity and thermodynamics.

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CC

Nomenclature

δ_{ij} Kronecker delta

C_{ijkl} Elastic parameters

β_{ij} Thermal elastic coupling tensor

T Absolute temperature

T_0 Reference temperature

φ Conductive temperature

t_{ij} Stress tensors

e_{ij} Strain tensors

u_i Components of displacement

ω Frequency

τ_0 Relaxation Time

Ω Angular Velocity of the Solid

F_i Components of Lorentz force

$\vec{H}_0$ Magnetic field intensity vector

$\vec{J}$ Current Density Vector

$\vec{u}$ Displacement Vector

μ_0 Magnetic permeability

ε_0 Electric permeability