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Effect of Rotation Under the Influence of Gravity Due to Various Sources in a Generalized Thermoelastic Medium

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Abstract. The present problem is concerned with the study of deformation of a rotating generalized thermoelastic medium under the influence of gravity. The components of displacement, force stress and temperature distribution are obtained in Laplace and Fourier domain by applying integral transforms. These components are then obtained in the physical domain by applying a numerical inversion method. Some particular cases are also discussed in context of the problem. The results are also presented graphically to show the effect of rotation and gravity in the medium.

AMS subject classifications: 74F05

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1 Introduction

Generalized thermoelasticity theories have been developed with the objective of removing the paradox of infinite speed of heat propagation inherent in the conventional coupled dynamical theory of thermoelasticity in which the parabolic type heat conduction equation is based on fourier's law of heat conduction. This newly emerged theory which admits finite speed of heat propagation is now referred to as the hyperbolic thermoelasticity theory [9], since the heat equation for rigid conductor is hyperbolic-type differential equation.

There are two important generalized theories of thermoelasticity. The first is due to [23]. The second one is known as the theory with two relaxation times or the theory

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of temperature-rate-dependent thermoelasticity. [26], in a review of the thermodynamics of thermoelastic solid, proposed an entropy production inequality, with the help of which he considered restrictions on a class of constitutive equations. A generalization of this inequality was proposed in [21]. Green and Lindsay (G-L) obtained another version of the constitutive equations. These equations were also obtained independently and more explicitly by Suhubi in [42]. This theory contains two constants that act as relaxation times and modify all the equations of the coupled theory, not only the heat equations. The classical Fourier law violated if the medium under consideration has a centre symmetry.

Barber and Martin-Moran in [5] discussed Green's functions for transient thermoelastic contact problems for the half-plane. Barber in [6] studied thermoelastic displacements and stresses due to a heat source moving over the surface of a half plane. Sherief in [41] obtained components of stress and temperature distributions in a thermoelastic medium due to a continuous source. Dhaliwal et al. [20] investigated thermoelastic interactions caused by a continuous line heat source in a homogeneous isotropic unbounded solid. Chandrasekharaiah and Srinath in [10] studied thermoelastic interactions due to a continous point heat source in a homogeneous and isotropic unbounded body. Sharma et al. [33] investigated the disturbance due to a time-harmonic normal point load in a homogeneous isotropic thermoelastic half-space. Sharma and Chauhan [34] discussed mechanical and thermal sources in a generalised thermoelastic half-space. Sharma et al. [37] investigated the steady-state response of an applied load moving with constant speed for infinite long time over the top surface of a homogeneous thermoelastic layer lying over an infinite half-space. Deswal and Choudhary [18] studied a two-dimensional problem due to moving load in generalized thermoelastic solid with diffusion. The dynamic interaction of thermal and mechanical fields in solids has great practical applications in modern aeronautics, astronautics, nuclear reactors and high-energy particle accelerators, for example.

Some researchers in the past have investigated different problem of rotating media. Chand et al. [11] presented an investigation on the distribution of deformation, stresses and magnetic field in a uniformly rotating homogeneous isotropic, thermally and electrically conducting elastic half space. Many authors [12, 17, 31] studied the effect of rotation on elastic waves. [30] studied the effect of rotation and relaxation times on plane waves in generalized thermo-visco-elasticity. [43] investigated the interfacial waves in a rotating anisotropic elastic half space. Sharma and his coworkers [36, 38–40] discussed effect of rotation on different type of waves propagating in a thermoelastic medium. Othman and Song [28, 29] discussed the effect of rotation in magneto-thermoelastic medium. Othman in [28] investigated plane waves in generalized thermo-elasticity with two relaxation times under the effect of rotation.

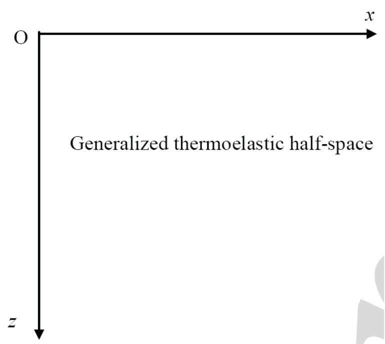
In classical theory of elasticity the gravity effect is generally neglected. The effect of gravity in the problem of propagation of waves in solids, in particular on an elastic globe, was first studied by Bromwich in [8]. Subsequently, investigation of the effect of gravity was considered by Love in [24] who showed that the velocity of Rayleigh waves is increased to a significant extent by the gravitational field when wavelengths are large. De and Sengupta in [14–16] studied the effect of gravity on surface waves, on the propagation of waves in an elastic layer and Lamb's problem on a plane. Sengupta and Acharya [32] studied the influence of gravity on the propagation of waves in a thermoelastic layer. Dey et al. [19] derived the velocities of longitudinal and transverse waves in an initially stressed medium. Das et al. [13] investigated surface waves under the influence of gravity in a non-homogeneous elastic solid medium. Abd-Alla and Ahmed in [1] investigated Rayleigh waves in an orthotropic thermoelastic medium under gravity field and initial stress. Abd-Alla and Ahmed [2] discussed wave propagation in a non-homogeneous orthotropic elastic medium under the influence of gravity. Ailawalia and Narah [4] depicted the effects of rotation and gravity in generalized thermoelastic medium. Recently Abd-Alla [3] presented the influences of rotation, magnetic field, initial stress and gravity on Rayleigh waves in a homogeneous orthotropic elastic half-space.

In the present investigation we have obtained the expressions for displacement, force stress and temperature distribution in a rotating generalized thermoelastic medium under the influence of gravity by applying Laplace and Fourier transforms. Such types of problems in the rotating medium are very important in many dynamical systems. Some particular cases are also derived from the present investigation.

2 Formulation of the problem

We consider a homogeneous generalized thermoelastic half-space rotating uniformly with angular velocity $\vec{\Omega} = \Omega\hat{n}$, where $\hat{n}$ is a unit vector representing the direction of the axis of rotation. All quantities considered are functions of the time variable t and of the coordinates x and z. The displacement equation of motion in the rotating frame has two additional terms [31]: centripetal acceleration, $\vec{\Omega} \times (\vec{\Omega} \times \vec{u})$ due to time varying motion only and $2\vec{\Omega} \times \vec{u}$, where $\vec{u} = (u_1, 0, u_3)$ the dynamic displacement vector and angular velocity is $\vec{\Omega} = (0, \Omega, 0)$. These terms do not appear in non-rotating media.

We consider normal source acting at the plane surface of generalized thermoelastic half space under the influence of gravity. A rectangular coordinate system (x, y, z) having origin on the surface $z = 0$ and z-axis pointing vertically into the medium is considered.



Geometry of the problem

3 Basic equations and their solutions

For a two dimensional problem (xz-plane) all quantities depend only on space coordinates x, z and time t. The field equations and constitutive relations in generalized linear thermoelasticity with rotation under the influence of gravity and without body forces and heat sources are [22,23,25,31]:

$$\frac{\partial t_{11}}{\partial x}+\frac{\partial t_{13}}{\partial z}+\rho g\frac{\partial u_3}{\partial x}=\rho\Big[\frac{\partial^2 u_1}{\partial t^2}-\Omega^2 u_1+2\Omega\frac{\partial u_3}{\partial t}\Big], \tag{3.1a}$$

$$\frac{\partial t_{31}}{\partial x}+\frac{\partial t_{33}}{\partial z}-\rho g\frac{\partial u_1}{\partial x}=\rho\Big[\frac{\partial^2 u_3}{\partial t^2}-\Omega^2 u_3-2\Omega\frac{\partial u_1}{\partial t}\Big], \tag{3.1b}$$

$$K^*\Big(n^*+t_1\frac{\partial}{\partial t}\Big)\nabla^2 T=\rho C_E\Big(n_1\frac{\partial}{\partial t}+\tau_0\frac{\partial^2}{\partial t^2}\Big)T+vT_0\Big(n_1\frac{\partial}{\partial t}+n_0\tau_0\frac{\partial^2}{\partial t^2}\Big)(\nabla\cdot\vec{u}), \tag{3.1c}$$

$$t_{11}=\lambda\Big(\frac{\partial u_1}{\partial x}+\frac{\partial u_3}{\partial z}\Big)+2\mu\frac{\partial u_1}{\partial x}-v\Big(1+\vartheta_0\frac{\partial}{\partial t}\Big)T, \tag{3.1d}$$

$$t_{13}=\mu\Big(\frac{\partial u_1}{\partial z}+\frac{\partial u_3}{\partial x}\Big), \tag{3.1e}$$

$$t_{33}=\lambda\frac{\partial u_1}{\partial x}+(\lambda+2\mu)\frac{\partial u_3}{\partial z}-v\Big(1+\vartheta_0\frac{\partial}{\partial t}\Big)T. \tag{3.1f}$$

Using Eqs. (3.1d)-(3.1f) in Eqs. (3.1a)-(3.1b), we obtain

$$\begin{aligned}&(\lambda+2\mu)\frac{\partial^2 u_1}{\partial x^2}+\mu\frac{\partial^2 u_1}{\partial z^2}+(\lambda+\mu)\frac{\partial^2 u_3}{\partial x\partial z}+\rho g\frac{\partial u_3}{\partial x}-v\Big(1+\vartheta_0\frac{\partial}{\partial t}\Big)\frac{\partial T}{\partial x}\\&=\rho\Big[\frac{\partial^2 u_1}{\partial t^2}-\Omega^2 u_1+2\Omega\frac{\partial u_3}{\partial t}\Big],\end{aligned} \tag{3.2a}$$

$$\begin{aligned}&\mu\frac{\partial^2 u_3}{\partial x^2}+(\lambda+2\mu)\frac{\partial^2 u_3}{\partial z^2}+(\lambda+\mu)\frac{\partial^2 u_1}{\partial x\partial z}-\rho g\frac{\partial u_1}{\partial x}-v\Big(1+\vartheta_0\frac{\partial}{\partial t}\Big)\frac{\partial T}{\partial z}\\&=\rho\Big[\frac{\partial^2 u_3}{\partial t^2}-\Omega^2 u_3-2\Omega\frac{\partial u_1}{\partial t}\Big].\end{aligned} \tag{3.2b}$$

Introducing dimensionless variables defined by

$$\{x',z'\}=\frac{\omega^*}{c_0}\{x,z\},\qquad \vartheta_0'=\omega^*\vartheta_0,\qquad t'=\omega^* t,\qquad \tau_0'=\omega^*\tau_0, \tag{3.3a}$$

$$\{u_1',u_3'\}=\frac{\rho c_0\omega^*}{vT_0}\{u_1,u_3\},\qquad T'=\frac{T}{T_0},\qquad t_{ij}'=\frac{t_{ij}}{vT_0},\qquad \Omega'=\frac{\Omega}{\omega^*}, \tag{3.3b}$$

where

$$\omega^*=\frac{\rho C_E c_0^2}{K^*},\qquad \rho c_0^2=\lambda+2\mu,$$

in Eqs. (3.1c), (3.2a) and (3.2b), we obtain the equations of motion in dimensionless form.

We define displacement potentials q and ψ which are related to displacement components u_1 and u_3 as

$$u_1=\frac{\partial q}{\partial x}-\frac{\partial \psi}{\partial z},\qquad u_3=\frac{\partial q}{\partial z}+\frac{\partial \psi}{\partial x}, \tag{3.4}$$

in the resulting dimensionless equations, and then applying the Laplace and Fourier transform defined by

$$\bar{f}(x,z,p)=\int_0^\infty f(x,z,t)e^{-pt}dt, \tag{3.5a}$$

$$\tilde{f}(\xi,z,p)=\int_{-\infty}^\infty \bar{f}(x,z,p)e^{i\xi x}dx, \tag{3.5b}$$

after neglecting the primes, we get

$$\Big[\frac{d^2}{dz^2}-\xi^2+\Omega^2-p^2\Big]\tilde{q}-\Big[2\Omega p+\frac{i\xi g}{c_0\omega^\bullet}\Big]\tilde{\psi}-(1+\vartheta_0 p)\tilde{T}=0, \tag{3.6a}$$

$$\Big[\frac{d^2}{dz^2}-\xi^2+a_1\Omega^2-a_1p^2\Big]\tilde{\psi}+\Big[2\Omega a_1 p+\frac{i\xi\rho g c_0}{\mu\omega^\bullet}\Big]\tilde{q}=0, \tag{3.6b}$$

$$\Big[\frac{d}{dz^2}-\xi^2-p\Big(\frac{n_1+\tau_0 p}{n^\bullet+t_1 p}\Big)\Big]\tilde{T}-\frac{n_1+\tau_0 n_0 p}{n^\bullet+t_1 p}(\varepsilon p)\Big[\frac{d^2}{dz^2}-\xi^2\Big]\tilde{q}=0. \tag{3.6c}$$

Eliminating $\tilde{T}$ and $\tilde{\psi}$ from Eqs. (3.6a)-(3.6c), we obtain

$$\big[\Delta^6-A\Delta^4+B\Delta^2-C\big]\tilde{q}=0, \tag{3.7}$$

where

$$\Delta=\frac{d}{dz},\quad a_1=\frac{\rho c_0^2}{\mu},\qquad \varepsilon=\frac{v^2T_0}{\rho K^*\omega^*},\quad c_1=\xi^2+p\Big(\frac{n_1+\tau_0 p}{n^\bullet+t_1 p}\Big), \tag{3.8a}$$

$$c_2=\xi^2-\Omega^2+p^2,\qquad c_3=\varepsilon p(1+\vartheta_0 p)\Big(\frac{n_1+n_0\tau_0 p}{n^\bullet+t_1 p}\Big), \tag{3.8b}$$

$$c_4=\xi^2-a_1\Omega^2+a_1p^2,\quad A=c_1+c_2+c_3+c_4, \tag{3.8c}$$

$$B=c_4\left(c_1+c_2+c_3\right)+c_1c_2+c_3\xi^2+4a_1\Omega^2p^2-\frac{g^2\xi^2\rho}{\mu\omega^{\bullet 2}}+\frac{4\Omega i\xi p\rho g c_0}{\mu\omega^\bullet}, \tag{3.8d}$$

$$C=c_4(c_1c_2+c_3\xi^2)+c_1\Big[4a_1\Omega^2p^2-\frac{g^2\xi^2\rho}{\mu\omega^{\bullet 2}}+\frac{4\Omega i\xi p\rho g c_0}{\mu\omega^\bullet}\Big]. \tag{3.8e}$$

The solutions of Eq. (3.7) satisfying the radiation conditions that $\tilde{q}$, $\tilde{\psi}$, $\tilde{T}\to 0$ as $z\to\infty$ are

$$\tilde{q}=D_1e^{-q_1z}+D_2e^{-q_2z}+D_3e^{-q_3z}, \tag{3.9a}$$

$$\tilde{\psi}=a_1^*D_1e^{-q_1z}+a_2^*D_2e^{-q_2z}+a_3^*D_3e^{-q_3z}, \tag{3.9b}$$

$$\tilde{T}=b_1^*D_1e^{-q_1z}+b_2^*D_2e^{-q_2z}+b_3^*D_3e^{-q_3z}, \tag{3.9c}$$

where q_i^2 are the roots of Eq. (3.7) and a_i^*, b_i^* are coupling constants defined by

$$a_i^*=\frac{q_i^4-(c_1+c_2+c_3)q_i^2+(c_1c_2+c_3\xi^2)}{\big[2\Omega p+i\xi g/c_0\omega^\bullet\big](q_i^2-c_1)}, \tag{3.10a}$$

$$b_i^*=\varepsilon p\Big(\frac{n_1+n_0\tau_0 p}{n^\bullet+t_1 p}\Big)\Big(\frac{q_i^2-\xi^2}{q_i^2-c_1}\Big), \tag{3.10b}$$

for $i=1,2,3$.

4 Boundary conditions

The boundary conditions at the plane surface $z=0$ are,

$$\text{(i)}\quad t_{33}=-F(x,t),\qquad \text{(ii)}\quad t_{31}=0,\qquad \text{(iii)}\quad T=0. \tag{4.1}$$

Using Eqs. (3.1d)-(3.1f), (3.3) and (3.4), in the boundary conditions (4.1), we obtain the boundary conditions in the dimensionless form. On suppressing the primes and applying the Laplace and Fourier transform defined by (3.5a) and (3.5b) on the dimensionless boundary conditions and using (3.9a)-(3.9c), in the resulting transformed boundary conditions, we get the transformed expressions for displacement, force stress, and temperature distribution in a rotating generalized thermoelastic medium under the influence of gravity as

$$\tilde{u}_1=\frac{\Big(\sum\limits_{m=1}^{3} b_m\Delta_m e^{-q_m z}\Big)}{\Delta},\quad \tilde{u}_3=\frac{\Big(\sum\limits_{m=1}^{3} l_m\Delta_m e^{-q_m z}\Big)}{\Delta},\quad \tilde{t}_{31}=\frac{\Big(\sum\limits_{m=1}^{3} s_m\Delta_m e^{-q_m z}\Big)}{\Delta}, \tag{4.2a}$$

$$\tilde{t}_{33}=\frac{\Big(\sum\limits_{m=1}^{3} r_m\Delta_m e^{-q_m z}\Big)}{\Delta},\quad \tilde{T}=\frac{\Big(\sum\limits_{m=1}^{3} k_m\Delta_m e^{-q_m z}\Big)}{\Delta}, \tag{4.2b}$$

where

$$\Delta=-\Big[\frac{r_1\Delta_1+r_2\Delta_2+r_3\Delta_3}{\tilde{F}(\xi,p)}\Big],\qquad \Delta_1=-\tilde{F}(\xi,p)[s_2k_3-k_2s_3], \tag{4.3a}$$

$$\Delta_2=\tilde{F}(\xi,p)[s_1k_3-k_1s_3],\qquad \Delta_3=-\tilde{F}(\xi,p)[s_1k_2-k_1s_2], \tag{4.3b}$$

$$s_i=\frac{\mu}{\rho c_0^2}\big(2i\xi q_i-(q_i^2+\xi^2)a_i^*\big),\qquad r_i=q_i^2-\frac{\lambda\xi^2}{\rho c_0^2}+\frac{2i\mu\xi a_i^\bullet q_i}{\rho c_0^2}-(1+\vartheta_0 p)b_i^\bullet, \tag{4.3c}$$

$$k_i=b_i^\bullet,\quad i=1,2,3,\quad m=1,2,3,\qquad b_i=a_i^\bullet q_i-i\xi,\qquad l_i=-(a_i^\bullet i\xi+q_i). \tag{4.3d}$$

5 Particular cases

Neglecting angular velocity (i.e., $\vec{\Omega}=0$), we obtain transformed components of displacement, stress forces and temperature distribution in a non-rotating generalized thermoelastic medium under the influence of gravity as

$$\tilde{u}_1=\frac{\Big(\sum\limits_{m=1}^{3} b'_m\Delta_m^{(1)} e^{-q'_m z}\Big)}{\Delta^{(1)}},\quad \tilde{u}_3=\frac{\Big(\sum\limits_{m=1}^{3} l'_m\Delta_m^{(1)} e^{-q'_m z}\Big)}{\Delta^{(1)}},\quad \tilde{t}_{31}=\frac{\Big(\sum\limits_{m=1}^{3} s'_m\Delta_m^{(1)} e^{-q'_m z}\Big)}{\Delta^{(1)}}, \tag{5.1a}$$

$$\tilde{t}_{33}=\frac{\Big(\sum\limits_{m=1}^{3} r'_m\Delta_m^{(1)} e^{-q'_m z}\Big)}{\Delta^{(1)}},\quad \tilde{T}=\frac{\Big(\sum\limits_{m=1}^{3} k'_m\Delta_m^{(1)} e^{-q'_m z}\Big)}{\Delta^{(1)}}, \tag{5.1b}$$

where

$$\Delta^{(1)} = -\Big[\frac{r_1'\Delta_1^{(1)} + r_2'\Delta_2^{(1)} + r_3'\Delta_3^{(1)}}{\tilde{F}(\xi,p)}\Big], \qquad \Delta_1^{(1)} = -\tilde{F}(\xi,p)[s_2'k_3' - k_2's_3'], \tag{5.2a}$$

$$\Delta_2^{(1)} = F(\xi,p)[s_1'k_3' - k_1's_3'], \qquad \Delta_3^{(1)} = -\tilde{F}(\xi,p)[s_1''k_2' - k_1's_2'], \tag{5.2b}$$

$$k_i' = b_i'^{\bullet}, \qquad c_2' = \xi^2 + p^2, \tag{5.2c}$$

$$r_i' = q_i'^2 - \frac{\lambda\xi^2}{\rho c_0^2} + \frac{2i\xi\mu q_i' c_i^{\bullet}}{\rho c_0^2} - (1+\vartheta_0 p)b_i'^{\bullet}, \qquad c_4' = \xi^2 + a_1 p^2, \tag{5.2d}$$

$$s_i' = \frac{\mu}{\rho c_0^2}[2i\xi q_i' - c_i^{\bullet}(q_i'^2 + \xi^2)], \qquad c_i^{\bullet} = \frac{i\xi\rho g}{c_0\omega^{\bullet}(c_4' - q_i'^2)}, \tag{5.2e}$$

$$b_i'^{\bullet} = \varepsilon p\Big[\frac{n_1 + n_0\tau_0 p}{n^{\bullet} + t_1 p}\Big]\Big[\frac{q_i'^2 - \xi^2}{q_i'^2 - c_1}\Big], \qquad b_i' = c_i^{\bullet} q_i' - i\xi, \tag{5.2f}$$

$$l_i' = -(i\xi c_i^{\bullet} + q_i'), \qquad A^{\bullet} = c_1 + c_2' + c_3 + c_4', \tag{5.2g}$$

$$B^{\bullet} = c_1c_2' + c_3\xi^2 + c_4'(c_1 + c_2' + c_3) - \frac{\rho\xi^2 g^2}{c_0^2\omega^{\bullet 2}}, \qquad C^{\bullet} = c_4'(c_1c_2' + c_3\xi^2) - \frac{c_1\rho\xi^2 g^2}{c_0^2\omega^{\bullet 2}}. \tag{5.2h}$$

The roots $q_i'^2$ are given by the sixth degree equation

$$\big[\Delta^6 - A^{\bullet}\Delta^4 + B^{\bullet}\Delta^2 - C^{\bullet}\big]\tilde{q} = 0.$$

Neglecting gravitational effect (i.e., $g = 0$) the expressions for displacements, force stresses and temperature distribution in a rotating thermoelastic medium reduce to

$$\tilde{u}_1 = \frac{\Big(\sum\limits_{m=1}^{3} b_m''\Delta_m^{(2)} e^{-q_m'' z}\Big)}{\Delta^{(2)}}, \quad \tilde{u}_3 = \frac{\Big(\sum\limits_{m=1}^{3} l_m''\Delta_m^{(2)} e^{-q_m'' z}\Big)}{\Delta^{(2)}}, \quad \tilde{t}_{31} = \frac{\Big(\sum\limits_{m=1}^{3} s_m''\Delta_m^{(2)} e^{-q_m'' z}\Big)}{\Delta^{(2)}}, \tag{5.3a}$$

$$\tilde{t}_{33} = \frac{\Big(\sum\limits_{m=1}^{3} r_m''\Delta_m^{(2)} e^{-q_m'' z}\Big)}{\Delta^{(2)}}, \quad \tilde{T} = \frac{\Big(\sum\limits_{m=1}^{3} k_m''\Delta_m^{(2)} e^{-q_m'' z}\Big)}{\Delta^{(2)}}, \tag{5.3b}$$

where

$$\Delta^{(2)} = -\Big[\frac{r_1''\Delta_1^{(2)} + r_2''\Delta_2^{(2)} + r_3''\Delta_3^{(2)}}{\tilde{F}(\xi,p)}\Big], \qquad \Delta_1^{(2)} = -\tilde{F}(\xi,p)[s_2''k_3'' - k_2''s_3''],$$

$$\Delta_2^{(2)} = \tilde{F}(\xi,p)[s_1''k_3'' - k_1''s_3''], \qquad \Delta_3^{(2)} = -\tilde{F}(\xi,p)[s_1''k_2'' - k_1''s_2''],$$

$$r_i'' = q_i''^2 - \frac{\lambda\xi^2}{\rho c_0^2} + \frac{2i\xi\mu a_i''^{\bullet} q_i''}{\rho c_0^2} - (1+\vartheta_0 p)b_i''^{\bullet}, \qquad k_i'' = b_i''^{\bullet},$$

$$b_i'' = a_i''^{\bullet} q_i'' - i\xi, \qquad s_i'' = \frac{\mu}{\rho c_0^2}[2i\xi q_i'' - a_i''^{\bullet}(q_i''^2 + \xi^2)],$$

$$l_i'' = -(q_i'' + i\xi a_i''^{\bullet}), \qquad b_i''^{\bullet} = \varepsilon p\Big(\frac{n_1 + n_0\tau_0 p}{n^{\bullet} + t_1 p}\Big)\Big(\frac{q_i''^2 - \xi^2}{q_i''^2 - c_1}\Big),$$

$$a_i''^{\bullet} = \frac{q_i''^4 - (c_1 + c_2 + c_3)q_i''^2 + (c_1c_2 + c_3\xi^2)}{2\Omega p(q_i''^2 - c_1)}, \qquad A_1 = c_1 + c_2 + c_3 + c_4,$$

$$B_1 = (c_1c_2 + c_3\xi^2) + c_4(c_1 + c_2 + c_3) + 4a_1p^2\Omega^2, \qquad C_1 = c_4(c_1c_2 + c_3\xi^2) + 4a_1c_1p^2\Omega^2.$$

In this case the roots $q_i''^2$ are given by the equation

$$\left[\Delta^6 - A_1\Delta^4 + B_1\Delta^2 - C_1\right]\tilde{q} = 0. \tag{5.4}$$

Neglecting both angular velocity and gravitational effect (i.e., $\Omega = g = 0$), we get the expressions for displacement, force stresses and temperature distribution in non-rotating thermoelastic medium as

$$\tilde{u}_1 = \frac{\left(\sum\limits_{m=1}^{3} b_m'''\Delta_m^{(2)} e^{-q_m''' z}\right)}{\Delta^{(2)}}, \quad \tilde{u}_3 = \frac{\left(\sum\limits_{m=1}^{3} l_m'''\Delta_m^{(2)} e^{-q_m''' z}\right)}{\Delta^{(2)}}, \quad \tilde{t}_{31} = \frac{\left(\sum\limits_{m=1}^{3} s_m'''\Delta_m^{(3)} e^{-q_m''' z}\right)}{\Delta^{(3)}}, \tag{5.5a}$$

$$\tilde{t}_{33} = \frac{\left(\sum\limits_{m=1}^{3} r_m'''\Delta_m^{(3)} e^{-q_m''' z}\right)}{\Delta^{(3)}}, \quad \tilde{T} = \frac{\left(\sum\limits_{m=1}^{2} k_m'''\Delta_m^{(3)} e^{-q_m''' z}\right)}{\Delta^{(3)}}, \tag{5.5b}$$

where

$$\Delta^{(3)} = -\left[\frac{r_3'''\Delta_3^{(3)}}{\tilde{F}(\xi,p)} + s_3'''(r_1'''k_2''' - k_1'''r_2''')\right], \qquad \Delta_1^{(3)} = \tilde{F}(\xi,p)k_2'''s_3''', \tag{5.6a}$$

$$\Delta_2^{(3)} = \frac{-\Delta_1^{(3)}k_1'''}{k_2'''}, \qquad \Delta_3^{(3)} = -\tilde{F}(\xi,p)[s_1'''k_2''' - k_1'''s_2'''], \tag{5.6b}$$

$$A_2 = c_1 + c_2' + c_3, \qquad B_2 = c_1c_2' + c_3\xi^2, \tag{5.6c}$$

$$q_{1,2}'''^2 = \frac{A_2 \pm \sqrt{A_2^2 - 4B_2}}{2}, \qquad q_3''^2 = \xi^2 + \frac{p^2\rho c_0^2}{\mu}, \tag{5.6d}$$

$$l_{1,2}^{\bullet} = \frac{q_{1,2}''^2 - c_2'}{1+\vartheta_0 p}, \qquad r_{1,2}''' = q_{1,2}'''^2 - \frac{\lambda\xi^2}{\rho c_0^2} - (1+\vartheta_0 p)l_{1,2}^{\bullet}, \tag{5.6e}$$

$$r_3''' = -i\xi q_3'''\left(1 - \frac{\lambda}{\rho c_0^2}\right), \quad s_{1,2}''' = \frac{2i\xi\mu q_{1,2}'''}{\rho c_0^2}, \qquad s_3''' = \frac{(q_3'''^2 + \xi^2)\mu}{\rho c_0^2}, \quad k_{1,2}''' = l_{1,2}^{\bullet}, \tag{5.6f}$$

$$b_{1,2}''' = -i\xi, \qquad b_3''' = q_3''', \qquad l_{1,2}''' = -q_{1,2}''', \qquad l_3''' = -i\xi. \tag{5.6g}$$

6 Types of sources

6.1 Concentrated source

For a concentrated source we take

$$F(x,t) = \delta(x)\delta(t), \quad \text{such that} \quad \tilde{F}(\xi,p) = 1. \tag{6.1}$$

6.2 Continuous source

For a continuous source acting along the interface, we have

$$F(x,t) = \delta(x)H(t), \quad \text{such that} \quad \tilde{F}(\xi,p) = \frac{1}{p}. \tag{6.2}$$

6.3 Distributed sources

6.3.1 Uniformly distributed source

The solution due to a uniformly distributed source in normal direction is obtained by setting

$$F(x,t) = \phi(x)\delta(t) \quad \text{and} \quad \tilde{F}(\xi,p) = \tilde{\phi}(\xi), \tag{6.3}$$

where

$$\phi(x) = \begin{cases} 1, & \text{if } |x| \leqslant a, \\ 0, & \text{if } |x| > a, \end{cases}$$

in Eq. (4.1). The Fourier transform with respect to the pair (x,ξ) for the case of a uniform strip load of unit amplitude and width $2a$ applied at the origin of the coordinate system $(x = z = 0)$ in a dimensionless form after suppressing the primes becomes

$$\tilde{\phi}(\xi) = \Big[\frac{2\sin(\xi a)}{\xi}\Big], \qquad \xi \neq 0. \tag{6.4}$$

6.3.2 Linearly distributed source

The solution due to a linearly distributed source in normal direction is obtained by substituting

$$\phi(x) = \begin{cases} 1 - \frac{|x|}{a}, & \text{if } |x| \leqslant a, \\ 0, & \text{if } |x| > a, \end{cases} \tag{6.5}$$

in Eq. (4.1). The Fourier transform of $\phi(x)$, in dimensionless form after suppressing the primes is

$$\tilde{\phi}(\xi) = \frac{2[1-\cos(\xi a)]}{\xi^2 a}. \tag{6.6}$$

The expressions for the components of displacement, force stress and temperature distribution are obtained as in Eqs. (4.2a)-(4.2b), (5.1a)-(5.1b), (5.3a)-(5.3b) and (5.5a)-(5.5b), by replacing $\tilde{\phi}(\xi)$ as $[2\sin(\xi a)/\xi]$ and $2[1-\cos(\xi a)]/(\xi^2 a)$, in the case of a uniformly distributed force and linearly distributed force in Eqs. (4.3d), (5.2), (5.4) and (5.6) for load in normal direction.

6.4 Moving source

In case of a source moving along the x-axis with uniform velocity U at the plane surface $z = 0$, we have

$$F(x,t) = H(t)\delta(x - Ut), \tag{6.7}$$

where

$$\tilde{F}(\xi,p) = \frac{1}{p - i\xi U}.$$

7 Special cases of thermoelastic theory

The equations of the coupled thermoelasticity (C-T theory) for a rotating media are obtained when

$$n^* = n_1 = 1, \qquad t_1 = \tau_0 = \vartheta_0 = 0. \tag{7.1}$$

The equations in this case are

$$\begin{aligned}
&(\lambda+2\mu)\frac{\partial^2 u_1}{\partial x^2} + \mu\frac{\partial^2 u_1}{\partial z^2} + (\lambda+\mu)\frac{\partial^2 u_3}{\partial x \partial z} + \rho g\frac{\partial u_3}{\partial x} - v\frac{\partial T}{\partial x} \\
&= \rho\Big[\frac{\partial^2 u_1}{\partial t^2} - \Omega^2 u_1 + 2\Omega\frac{\partial u_3}{\partial t}\Big], \qquad (7.2a)\\
&\mu\frac{\partial^2 u_3}{\partial x^2} + (\lambda+2\mu)\frac{\partial^2 u_3}{\partial z^2} + (\lambda+\mu)\frac{\partial^2 u_1}{\partial x \partial z} - \rho g\frac{\partial u_1}{\partial x} - v\frac{\partial T}{\partial z} \\
&= \rho\Big[\frac{\partial^2 u_3}{\partial t^2} - \Omega^2 u_3 - 2\Omega\frac{\partial u_1}{\partial t}\Big], \qquad (7.2b)\\
&K^*\nabla^2 T = \rho C_E\frac{\partial T}{\partial t} + vT_0\frac{\partial}{\partial t}(\nabla\cdot\vec{u}). \qquad (7.2c)
\end{aligned}$$

For Lord-Shulman (L-S theory),

$$n^* = n_1 = n_0 = 1, \qquad t_1 = \vartheta_0 = 0, \qquad \tau_0 > 0. \tag{7.3}$$

The equations for L-S theory are same as (7.2a) and (7.2b) and the heat conduction equation is

$$K^*\nabla^2 T = \rho C_E\Big(\frac{\partial}{\partial t} + \tau_0\frac{\partial^2}{\partial t^2}\Big)T + vT_0\Big(\frac{\partial}{\partial t} + \tau_0\frac{\partial^2}{\partial t^2}\Big)(\nabla\cdot\vec{u}). \tag{7.4}$$

For Green-Lindsay (G-L theory),

$$n^* = n_1 = 1, \qquad n_0 = 0, \qquad t_1 = 0, \qquad \vartheta_0 \geqslant \tau_0 > 0, \tag{7.5}$$

where ϑ_0, τ_0 are the two relaxation times. The equations of motion for G-L theory are same as (3.2a)-(3.2b) and the heat conduction equation is

$$K^*\nabla^2 T = \rho C_E\Big(\frac{\partial}{\partial t} + \tau_0\frac{\partial^2}{\partial t^2}\Big)T + vT_0\frac{\partial}{\partial t}(\nabla\cdot\vec{u}). \tag{7.6}$$

The equations of the generalized thermoelasticity for a rotating media, without energy dissipation (the linearlized GN theory of type II) are obtained when

$$n^* > 0, \quad n_1 = 0, \quad n_0 = 1, \quad t_1 = \vartheta_0 = 0, \quad \tau_0 = 1. \tag{7.7}$$

Eqs. (3.2a) and (3.2b) is the same and Eq. (3.1c) takes the form

$$K^*\nabla^2 T = \rho C_E\frac{\partial^2 T}{\partial t^2} + vT_0\frac{\partial^2 e}{\partial t^2}, \tag{7.8}$$

where n^* is constant which has the dimension of $[1/s]$ and

$$n^* k^* = K' = \frac{C_E(\lambda+2\mu)}{4},$$

is a characteristic constant of this theory.

8 Numerical results, inversion and discussions

For numerical computations the values of relevant parameters are taken at $T_0 = 23°C$

$$\lambda = 9.4 \times 10^{11}\ \text{dyne/cm}^2, \qquad \mu = 4.0 \times 10^{11}\ \text{dyne/cm}^2,$$
$$\rho = 1.74\ \text{gm/cm}^3, \qquad C_E = 0.23\ \text{cal/gm}°\text{C},$$
$$v = 1.78 \times 10^{-5}\ \text{dyne/cm}^2°\text{C}, \qquad K^\bullet = 0.6 \times 10^{-2}\ \text{cal/cms}°\text{C}.$$

The computations are carried out for $U < c_0$ on the surface $z = 1.0$ (in case of moving source). The graphically results for normal displacement u_3, normal force stress t_{33} and temperature distribution T are shown in Figs. 1-12 for

(a) Thermoelastic solid with rotation and under the influence of gravity (TESRG) by solid line (———).

(b) Thermoelastic solid without rotation and under the influence of gravity (TESWRG) by solid line with centered symbol (*—*—*).

(c) Thermoelastic solid with rotation and without gravity (TESR) by dashed line (- - - - - -).

(d) Thermoelastic solid without rotation and without gravity (TES) by solid line with centered symbol (*- - -*- - -*).

These graphical results represent the solutions obtained by using generalized theory with one relaxation time (L-S theory for $\tau_0 = 0.03$) by taking $\Omega = 0.5$ at $t = 1.0$.

The transformed displacements, microrotation and stresses are functions of z, the parameters of Laplace and Fourier transforms p and ξ respectively, and hence are of the form $\tilde{f}(\xi, z, p)$. To get the function in the physical domain, first we first invert the Fourier transform and then Laplace transform by using the method applied by Sharma and Kumar [35].

8.1 Concentrated source

The values of normal displacement for a non-rotating thermoelastic medium under the influence of gravity increase sharply in the range $0 \leq x \leq 2.0$ and then oscillate uniformly. The variations of normal displacement (for $g = 0$) are similar in nature for both rotating and non-rotating medium with difference in magnitude. These variations of normal displacement are shown in Fig. 1.

Under the influence of gravity, the values of normal force stress first decreases in the range $0 \leq x \leq 2.0$ and then oscillate uniformly. Also the values of normal force stress for a thermoelastic medium without rotation and independent of gravitational force lie in a very short range. These variations of normal force stress are shown in Fig. 2. It could be observed from Fig. 3 that the variations of temperature distribution are very similar to the variation of normal force stress with difference in magnitude.

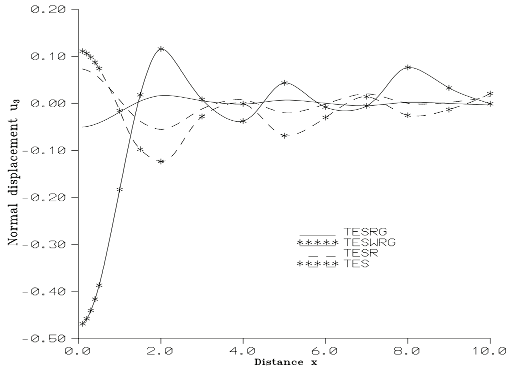


Figure 1: Variation of normal displacement u_3 with distance x due to concentrated source.

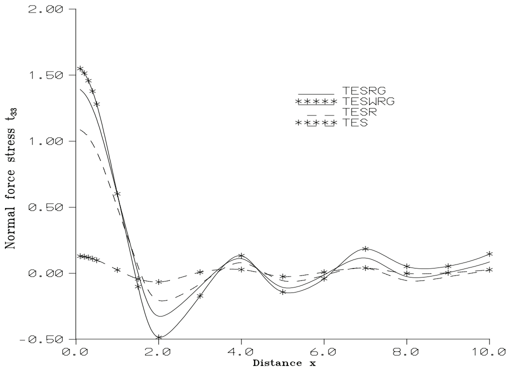


Figure 2: Variation of normal force stress t_{33} with distance x due to concentrated source.

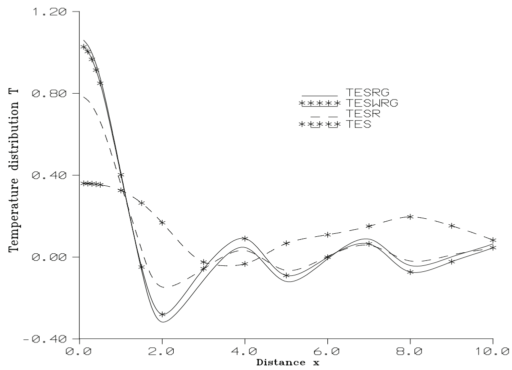


Figure 3: Variation of temperature distribution T with distance x due to concentrated source.

8.2 Continuous source

It is significant to observe that gravity play an important role on the variations of all the quantities when a continuous source is applied on the surface of the solid. From Figs. 4, 5 and 6 depicting the variations of normal displacement, normal force stress and temperature distribution, it is seen that the variations are highly oscillatory in nature for thermoelastic medium (with or without rotation), when the effect of gravity

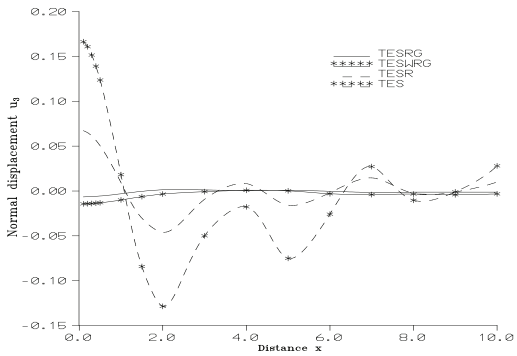


Figure 4: Variation of normal displacement u_3 with distance x due to continuous source.

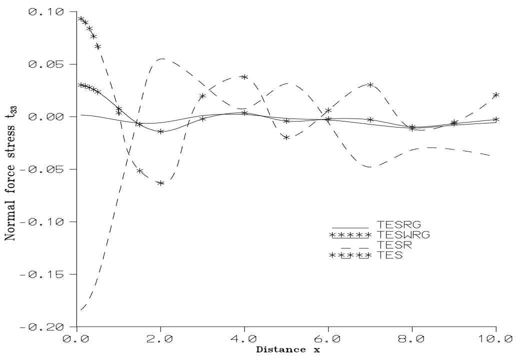


Figure 5: Variation of normal force stress t_{33} with distance x due to continuous source.

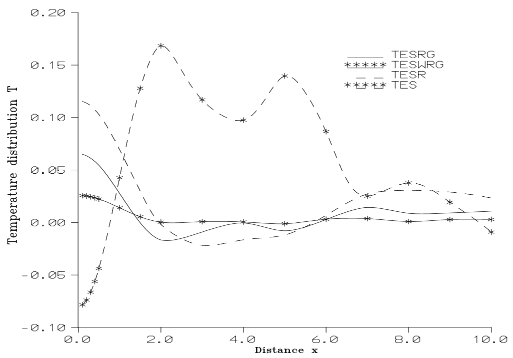


Figure 6: Variation of temperature distribution T with distance x due to continuous source.

is neglected whereas the values of all these quantities lie in very short range when we consider the effect of gravity.

8.3 Uniformly distributed source

The variations obtained for different quantities on application of uniformly distributed source are similar in nature to the variations obtained on application of concentrated source. However the magnitudes of the quantities differ in both cases. These

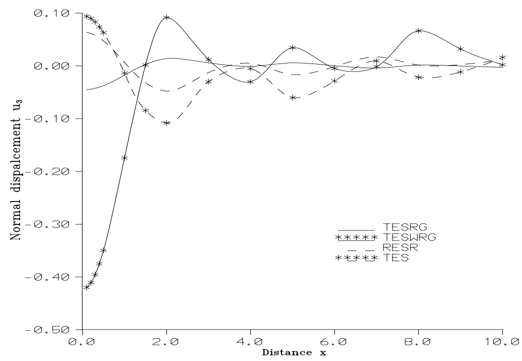


Figure 7: Variation of normal displacement u_3 with distance x due to uniformly distributed source.

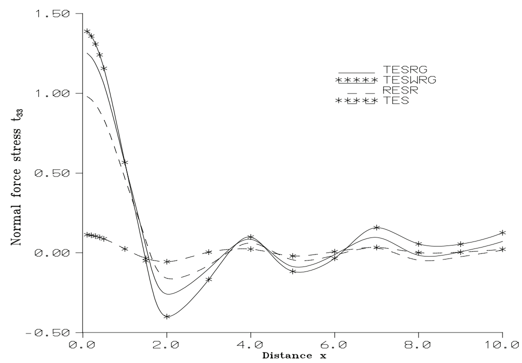


Figure 8: Variation of normal force stress t_{33} with distance x due to uniformly distributed source.

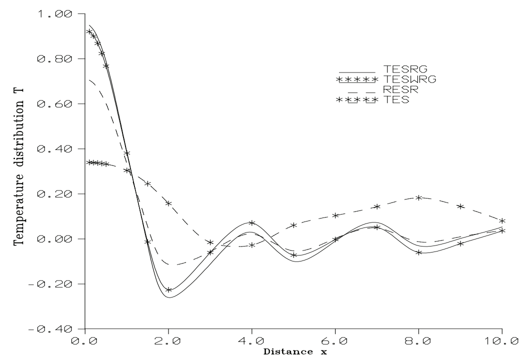


Figure 9: Variation of temperature distribution T with distance x due to uniformly distributed source.

variations are shown in Figs. 7, 8 and 9.

8.4 Moving source

When a source is moving on the surface of thermoelastic medium, the variations of thermoelastic medium are more oscillatory, if we neglect the effect of gravity. These variations under the effect of gravity are similar in nature to some extent for both rotating and non-rotating medium. These variations on application of a moving source

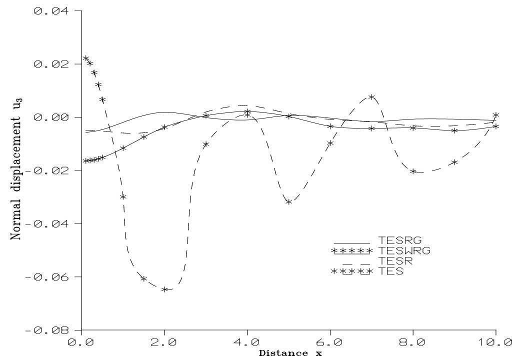


Figure 10: Variation of normal displacement u_3 with distance x due to moving source.

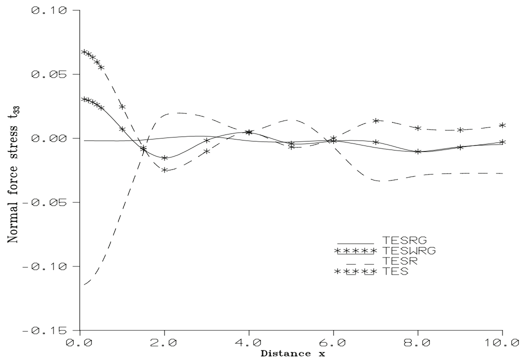


Figure 11: Variation of normal force stress t_{33} with distance x due to moving source.

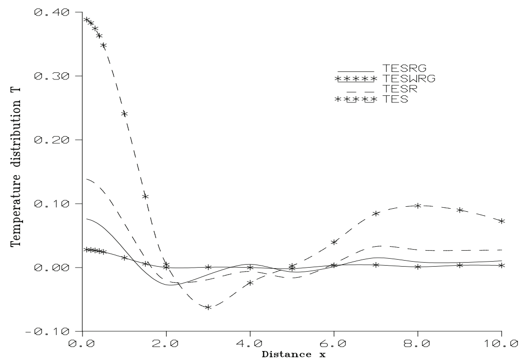


Figure 12: Variation of temperature distribution T with distance x due to moving source.

may be observed from Figs. 10, 11 and 12 respectively for normal displacement, normal stress and temperature distribution.

9 Conclusions

The effect of gravity, rotation and the source acting in the medium plays significant role in the study of deformation of a body; when a concentrated or a distributed source is applied in the medium, the variations of the quantities are smooth in nature which exactly is not the case for a continuous source and moving source; on the application of continuous source or moving source the variations of all the quantities shown in the graphical results are more oscillatory in nature when the effect of gravity is neglected; the variations of the quantities are similar in nature for different theories of thermoelasticity with difference in magnitude.

Nomenclature

λ, μ,	Lame's constants
ρ	Density
$\vec{u}$	Displacement vector
t_{ij}	Stress tensor
τ_0, ϑ_0	Thermal relaxation times
$v = (3\lambda + 2\mu)\alpha_t$	Linear thermal expansion
$e = div\vec{u}$	Dilatation
g	Acceleration due to gravity
K^*	Coefficient of thermal conductivity
C_E	Specific heat
T	Temperature distribution
T_0	Reference temperature

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