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Белгіленулер: Tu– құбырдағы ағын турбуленттілігінің деңгейі, %; U_∞– ағын жылдамдығы, м/с; d–аэродинамиканы зерттеуге арналған дене диаметрі,мм; *l*–жалпақ бүйірлі орталық цилиндрдің ұзындығы, м; *l/d*– жалпақ бүйірлерімен цилиндрге арналған ұзындықтың диаметрге қатынасы; $(l+d)/d$ –сфералық бүйірлермен цилиндр үшін ұзындықтың диаметрге қатынасы; Re – Рейнольдс саны; *L/d*–айналымдық аймақтың ұзындығы; $d_{эф}$ – қысқа цилиндрдің миделдік қимасының ауданына тең ауданмен дөңгелектің тимді диаметрі; м; λ– соплоның ұзару параметрі ; $x_н$– ағыстың бастапқы учаскесінің ұзындығы, м; *b* – соплоның шығыс қимасының ені, м.

Индекстер: н-бастапқы; эф-тиімді; 0- соплоның жиегіндегі параметрдің мәні; ∞- ағындағы параметрдің мәні.

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The solution of problems of the propagation of elastic longitudinal and thermal waves in anisotropic medium of cubic system

Introduction: The urgency of studying the regularities of wave actions in elastic media with thermomechanical effect is associated with the need to solve theoretical and applied problems of geophysics, seismology, mechanics of composite materials, etc. The coupled motion equation and thermal conductivity equation are notable for the complexity and abundance of physical and mechanical parameters. In this connection, the section of the mechanics of the deformed solid, thermoelasticity, is developing intensively. Based on the use of certain physical properties of natural crystals and artificial ceramics, this direction studies the mechanics of coupled thermal and mechanical fields [1, 2].

Heterogeneity and anisotropy are the most common properties of real media. Wave phenomena in crystals, i.e. in media with pronounced anisotropy of a number of physical properties, are characterized by more complicated regularities as compared to the isotropic case.

In this connection, the plane wave method, which is obvious and effective for homogeneous and isotropic media, turned out to be complex in the case of anisotropic media. Generally, the existing analytical methods for studying wave actions are used for isotropic media and media with high symmetry. In the case of an anisotropic medium, these methods either do not lead to the necessary quantitative and qualitative results or the solutions obtained on their basis are practically vast and of little use.

Which means that the development of study methods and the formation of concepts of wave behavior in anisotropic media should be treated as one of the top–priority and urgent problems of the mechanics of a deformable solid.

Method of study: The method of study is analytical and is based on the development of matrix methods for studying the dynamics of elastic stratified media.

The method is about reducing the initial motion equations based on the variable separation method (representation of the solution in the form of plane waves) to the equivalent system of ordinary differential equations of the first order with variable coefficients and the construction of the matriciant structure (normalized matrix of fundamental solutions).

In the case of the consistent approach, the matrix method allows considering the propagation of waves in a wide class of media. Another advantage of this method is that the expressions obtained by the matrix method have a very compact form, which proves to be convenient both for analytical studies and for numerical calculations.

Problem and basic relations: The wave propagation in anisotropic inhomogeneous medium is considered. A new method of matricant has been developed. The method of matricant allows to investigate wave processing in anisotropic medium with various physical and mechanical properties[3-8].

The structure of matricant for the equation motion elastic media equations, equations of thermo-mechanical medium has been established. Wave propagation in infinite and finite periodical inhomogeneous media are studied.

The application of matricants method for non-destructive testing and wave propagation in thermo elastic media is considered[9].

In the paper [10], waves propagating along an arbitrary direction in a heat conducting orthotropic thermoelastic plate are presented by utilizing the normal mode expansion method in generalized theory of thermoelasticity with one thermal relaxation time. In the paper [11], authors studied the interaction of free harmonic waves with multilayered media in generalized thermoelasticity by utilizing the combination of the linear transformation formation and transfer matrix method approach. Solutions obtained are generaland pertain to several special cases. Of these mention: (a) dispersion characteristics for a multilayered.

In the example of propagation of elastic longitudinal waves, in the present work the propagation of heat waves in an anisotropic medium of cubic crystal system are considered in the presence of the symmetry axis of even order.

The motion equation for the elastic longitudinal wave propagating along one of spatial coordinates in an anisotropic layer of the cubic syngony is as follows:

$$\frac{\partial \sigma_z}{\partial t} = \rho \frac{\partial^2 U_z}{\partial z^2} \qquad (1)$$

where

$\sigma_z = c_{11}\dfrac{\partial Uz}{\partial z}$ - z-component of the stress tensor σ_{ij}, ρ - medium density, U_z – z-component o the displacement vector of medium, c_{33} - isothermal elastic modulus.

Based on the method of separation of variables in the case of a harmonic function of time:

$$[U_z;\sigma_z] = [U_i(z), \sigma_{ij}(z)]\, e^{i\omega t} \tag{2}$$

The system of equations (1) reduced to a system of differential equations of second ord describing the propagation of harmonic waves:

$$\frac{d\vec{W}}{dz} = B\vec{W} \tag{3}$$

Here - $\vec{W}$ a column vector of the boundary conditions.
The result is the differential equation system of the first order:

$$\left.\begin{aligned} \frac{dU_z}{dz} &= \frac{1}{c_{11}}\sigma_z \\ \frac{d\sigma_z}{dz} &= -\omega^2 \rho U_z \end{aligned}\right\} \Rightarrow \frac{d}{dz}\begin{pmatrix} U_z \\ \sigma_z \end{pmatrix} = \begin{pmatrix} 0 & b_{12} \\ b_{21} & 0 \end{pmatrix}\begin{pmatrix} U \\ \sigma \end{pmatrix} \tag{4}$$

Solution of the problem: Let's find the determinant [5]:

$$\det|B - \lambda E| = 0 \tag{5}$$

where B - coefficient matrix whose elements contain the parameters of the medium, in which an elastic longitudinal wave propagates. The elements of this matrix are contained in (4) and have the form:

$$b_{12} = \frac{1}{c_{11}};\ b_{21} = -\omega^2 \rho$$

Which results in obtaining the characteristic equation (5):

$$\lambda^2 = \pm i\omega\sqrt{\frac{\rho}{c_{33}}}$$

The last relation leads to the conclusion that the wave spectrum is equal to:

$$k_{1,2} = \pm i\omega\sqrt{\frac{\rho}{c_{33}}} \tag{6}$$

This problem can be solved as follows:

$$\varphi = Ae^{\lambda_1 z} + Be^{\lambda_2 z} \Rightarrow \varphi = Ae^{i\omega\sqrt{\frac{\rho}{c_{33}}}z} + Be^{-i\omega\sqrt{\frac{\rho}{c_{33}}}z} \tag{7}$$

Let's take the above mentioned as an example to consider the thermal wave propagation in an anisotropic medium of the cubic syngony.

Let's assume that harmonic thermal expansion waves with the circular frequency ω occur in an unlimited thermoelastic medium.

The one–dimension equation of thermal conductivity is as follows:

$$c_\varepsilon \frac{\partial \theta}{\partial t} = \lambda_{33} \frac{\partial^2 \theta}{\partial z^2} \tag{8}$$

which in matrix form is written as follows:

$$\frac{d}{dz}\begin{pmatrix} \theta \\ q_z \end{pmatrix} = \begin{pmatrix} 0 & b_{78} \\ b_{87} & 0 \end{pmatrix}\begin{pmatrix} \theta \\ q_z \end{pmatrix} \tag{9}$$

where c_ε-heat capacity at constant strain, $\theta = T - T_0$ temperature increase compared to the temperature T_0 of the natural state, λ_{33} - thermal conductivity tensor, q_z- vector component of heat [2].

Coefficients of the matrix B in (9) look as follows:

$$b_{78} = -\frac{1}{\lambda_{33}};\ b_{87} = -i\omega\, c_\varepsilon$$

In this case the characteristic equation (5) can be represented as follows:

$$\delta^2 - i\omega\frac{c_\varepsilon}{\lambda_{33}} = 0 \tag{10}$$

from which it follows that

$$\delta_{1,2} = \pm\sqrt{\frac{i\omega}{a}} \tag{11}$$

where $a = \frac{\lambda_{33}}{c_\varepsilon T_0}$ - thermal diffusivity.

The roots of (11) have the form:

$$\delta_1 = \sqrt{\frac{\omega}{a}}e^{i\frac{\pi}{4}}; \qquad \delta_2 = \sqrt{\frac{\omega}{a}}e^{i\frac{\pi}{4}+\pi}$$

$$\Rightarrow \quad \delta_1 = \sqrt{\frac{\omega}{a}}\left(\frac{1}{\sqrt{2}} + \frac{i}{\sqrt{2}}\right) = \sqrt{\frac{\omega}{2a}}(1+i) \tag{12}$$

$$\delta_2 = -\sqrt{\frac{\omega}{2a}}(1+i) \tag{13}$$

Subtracting (12) from (13), we obtain

$$\delta_2-\delta_1=-\sqrt{\frac{\omega}{2a}}(1+i) \qquad (14)$$

then

$$\delta_1=-\delta_2 \Rightarrow \delta_2=-\delta_1 \qquad (15)$$

Solution of the problem of the heat wave propagation in one dimension will be:

$$T_m=\frac{B-\delta_2E}{\delta_1-\delta_2}e^{\delta_1 z}+\frac{B-\delta_1E}{\delta_2-\delta_1}e^{\delta_2 z} \qquad (16)$$

Numerator on the right side of (16), using (14) and (15), will be:

$$\frac{B-\delta_1E}{2\delta_2}=\begin{pmatrix} \frac{1}{2} & \frac{1}{2\sqrt{\frac{2\omega}{a}}(1+i)} \\ \frac{i\omega c_\varepsilon}{2\sqrt{\frac{2\omega}{a}}} & \frac{1}{2} \end{pmatrix}$$

The coefficient matrix B can be represented as follows:

$$B=\begin{pmatrix} \frac{1}{2} & \frac{1-i}{4\sqrt{\frac{2\omega}{a}}} \\ \frac{\omega c_\varepsilon}{4\sqrt{\frac{2\omega}{a}}} & \frac{1}{2} \end{pmatrix}+\begin{pmatrix} 0 & -\frac{1}{4\sqrt{\frac{2\omega}{a}}} \\ \frac{\omega\, c_\varepsilon}{4\sqrt{\frac{2\omega}{a}}} & 0 \end{pmatrix}$$

Consequently, the coefficient matrix B is separated into the real and the imaginary parts:

$$B=\operatorname{Re}\ B+\operatorname{Im}\ B$$

that corresponds to thermal wave propagation in a solid body.

In the general case, considering the above relations, the solution (16) can be represented as follows:

$$T_m=\operatorname{Re}Be^{-\sqrt{\frac{\omega}{2a}}z}Cos\sqrt{\frac{\omega}{2a}}z+\operatorname{Im}Be^{-\sqrt{\frac{\omega}{2a}}z}Sin\sqrt{\frac{\omega}{2a}}z \qquad (17)$$

The solution of the thermal wave propagation problem in the one–dimensional case coincides with the classic solution, which is as follows [12, p. 287]:

$$f=e^{-\sqrt{\frac{\omega}{2a}}z}e^{i\left(\omega t-\sqrt{\frac{\omega}{2a}}z\right)} \qquad (18)$$

For physical reasons, from the two roots δ_1, δ_2, it is necessary to retain the root, which includes the negative real part.

Consequently, the solution for the thermal wave is obtained as follows:

$$\theta=\theta_0 e^{-\sqrt{\frac{\omega}{2a}}z} Cos\omega\left(t-\frac{z}{\sqrt{2a\omega}}\right) \tag{19}$$

Conclusion: In this paper, based on the analytical method of matriciant, the solution of problems of the one-dimensional propagation of elastic longitudinal and thermal waves in anisotropic medium of cubic crystal system.

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СЕКЦИЯ 3.

Жылу- масса- алмасу бейсызық процестердің динамикасы

Dynamics of nonlinear processes of heat and mass transfer

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