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Two-temperature heat transfer in a metal and a longitudinal elastic wave generation

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Abstract: A new version of the classic Danilowskaya's problem is presented. To describe the formation of a longitudinal elastic wave in the metal by a laser beam, we use a two-temperature theory of heating such a metal. In this theory of thermoelasticity, there are two temperatures simultaneously, the temperature of the electron gas T_e and the temperature of the ionic lattice T_i, and both are functions of position and time. The energy transferred by electrons to the lattice per unit volume of the crystal per unit time is proportional to the difference T_e - T_i. We give the equations of energy conservation and entropy production, whose thermodynamic consistency is verified. The equations of the problem are quasi-linear, since the specific heat of the electron gas in the considered temperature range depends on the temperature (degenerate electron gas). The one-dimensional process of transmitting thermal energy to the crystal lattice and the formation of mechanical wave is analyzed by the numerical method and illustrated in the pictures for various exemplary cases.

Keywords: electron gas, photon-electron interaction, energy balance, entropy growth

1. Introduction

In Danilowskaya problem the surface of an elastic half-space is suddenly heated, and due to the thermoelastic effect a longitudinal elastic wave is created, [1]. In our case we use a pulse laser beam to heat the metal crystal half-space surface. The energy transfer of the laser beam to the ionic lattice of the metal occurs in two stages. First, the electron gas is heated and this one, in turn, transfers part of the acquired energy to the crystal lattice. In this second stage it follows a thermal deformation of the crystal lattice, what means formation of a longitudinal thermoelastic wave. Emerging of equilibrium between electrons and the lattice in crystals, in particular in metals, is realized by relaxation processes. During the relaxation processes crystal must be looked upon as a two-temperature system. Estimates based on the electrical conductivity of metals give values of α of the order 10^{10}J/(cm^3 s K). The relaxation time for the phonon temperature is of the order of 10^{-10} s. For laser pulses of shorter duration, the violation of equilibrium between the electrons and the lattice becomes important. After estimating the contribution of individual components, [2-4], we arrive to the system of equations for temperatures T_e and T_i ,and displacement u

$$c_e(T_e)\frac{\partial T_e}{\partial t} = \chi\frac{\partial^2 T_e}{\partial x^2} - \alpha\,(T_e - T_i)$$

$$c_a(T_i)\frac{\partial T_i}{\partial t} = \alpha\,(T_e - T_i)$$

$$\partial^2 u \qquad \partial^2 u \qquad \gamma\,\partial T_i$$

The coefficients in this equation are constants or given functions. The problem given by this system is nonlinear and requires numerical solution.

2. Results and Discussion

The exemplary results of calculation for some values of parameters are presented in the following figures:

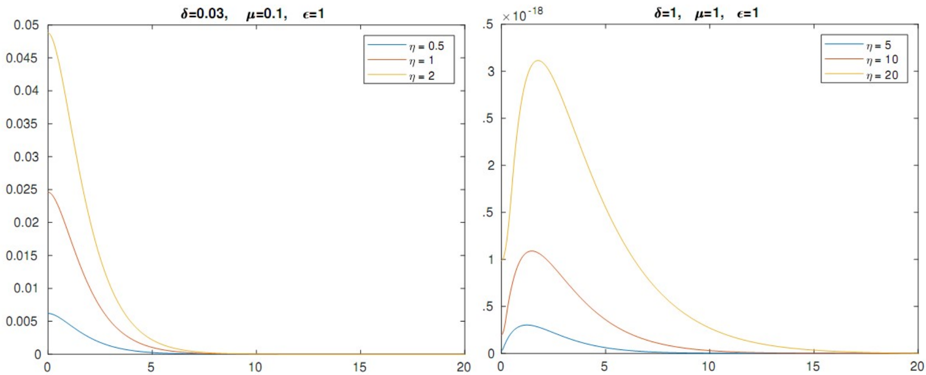

Fig. 1. The ionic lattice temperature (left) and the displacement (right) propagations

3. Concluding Remarks

The two-temperature non-equilibrium system in metal was considered, and two temperatures and displacement fields are found. Moreover, it is shown that for a rectangular in time laser pulse, the temperature and stress are continuous function of time *t*, while their time derivatives suffer jumps on the *t*-axis.

References

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