SIMULATION OF HEAT TRANSFER IN A CONDUCTIVE HEAT EXCHANGER OF LOOP HEAT PIPES BY A FINITE-ELEMENT METHOD

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An analysis of a conductive heat exchanger used for joining links of coolant loop piping utilized in thermal regime systems of spacecraft is carried out. An indirect variant of the finite-element method specially modified for this case was used for the numerical solution. Temperature fields in the heat exchanger and dependences of the heat transfer coefficient on main parameters are obtained.

1. Presently, loop heat pipes (LHP) that provide heat transfer from operating spacecraft-borne equipment to a source of cold have found wide applications in systems of the thermal regime support of spacecraft. Heat exchangers of various types are used in this case. For example, an investigation of a radiation heat exchanger has been carried out in [1].

In order to ensure leak-proof LHP lines (when they must be joined), conductive heat exchangers consisting of two detachable boards are used. In one of the boards, the condenser of the first HP is situated, and the evaporator of the second HP is situated in the other one. The condenser and evaporator are most frequently manufactured in the form of a ring slot. The geometry of the heat exchanger makes it possible to consider the problem in a plane formulation. In view of that fact, and owing to the symmetry of the problem, the region of calculations has a rectangular shape with two semicircular notches (Fig. 1). External surfaces of the heat exchanger are heat-insulated, and therefore the value of the heat flux on them is considered to equal zero. The total heat flux is assumed to be known. Then, by setting up the temperature on the condenser (left notch) and the heat flux density on the evaporator, one can determine the heat transfer coefficient of the whole construction. The coefficient of thermal conductivity on the contact surface, whose value depends on a number of factors (pressure of board constriction, the degree of the finishing treatment of the surface, characteristics of the medium in the gap, etc.), is considered to be known. A similar method of calculation is presented in [2].

Thus, the mathematical formulation of the problem is as follows. It is necessary to find a solution of a steady-state heat conduction equation, i.e., the Laplace equation

$$\frac{\partial^2 T}{\partial x_i \partial x_j} = 0, \quad i = 1, 2,$$

under the following boundary conditions:

$$q = 0, \quad x \in \Gamma_1, \Gamma_3,$$

$$T = T_1, \quad x \in \Gamma_2,$$

$$q = q_0, \quad x \in \Gamma_4,$$
Equation (1) with boundary conditions (2)–(4) and condition on the contact surface (5) are written in dimensionless variables. The board height and the temperature on the condenser wall are chosen as length and temperature scales.

2. An indirect variant of the finite-element method [3] was used to solve the problem. In doing this, we used a singular solution of the Laplace equation for the case of a single concentrated source:

\[ T^* (x, \xi) = - \ln r / (2\pi) , \]

\[ q^* (x, \xi) = y_i n_i / (2\pi r^2) . \]

We consider fictitious sources of unknown power to be distributed over the boundary of the region, including the contact surface. The left and right subregions will be treated separately, as independent zones interconnected by conditions on the contact (5), which consist in continuity of the heat flux and setting a temperature jump in accordance with the value of the thermal conductivity \( U \). In view of the linear character of the problem, values of the temperature and flux at any point in the first and second zones can be found by convoluting the fundamental solutions (6), (7) with the corresponding distributions of the sources \( \phi_i(\xi) \) and \( \phi_2(\xi) \):

\[ T_i (x) = \int_{S_i} \phi_i (\xi) T^* (x, \xi) dS (\xi) + C_i , \quad x \in \Omega_i , \quad \xi \in S_i , \]

\[ q_i (x) = \int_{S_i} \phi_i (\xi) q^* (x, \xi) dS (\xi) , \quad x \in \Omega_i , \quad \xi \in S_i . \]

where \( i = 1, 2 \) is the zone number. Constants \( C_i \) appear due to the logarithmic behavior of the fundamental solution for the temperature.

By passing to the limit \( x \to x_0 (x_0 \in S_i) \) in (8), (9), we obtain a system of boundary integral equations equivalent to the boundary-value problem (1)–(5), and, by solving the system, we can find the distribution of the unknown intensities of the sources \( \phi_i(\xi) \):

\[ T_i (x_0) = \int_{S_i} \phi_i (\xi) T^* (x_0, \xi) dS (\xi) + C_i , \quad x_0 \in (S_i \cap \Gamma_S) . \]