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DEPENDENCE OF THE HEAT TRANSFER COEFFICIENT ON THE VIBRATION AMPLITUDE AND FREQUENCY OF A VERTICAL THIN HEATER

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The effect of mechanical vibrations of a heated string on the heat transfer coefficient α at various heat fluxes has been studied experimentally. An empirical relation between the coefficient α and the vibration frequency and amplitude with unchanged q has been found.

It is known that the intensity of heat transfer between a thin heater and the environment increases markedly when the heater performs transverse vibrations [1, 2].

In recent years in our laboratory experimental and theoretical studies have been carried out, in practicular, on the dependence of the heat transfer coefficient α on the type of vibrations (natural, forced, parametric, thermomechanical, thermomagnetomechanical, etc.) and the parameters of the vibrations [1–5].

The present work is devoted to experimental determination of the functional dependence of the heat transfer coefficient α at various values of the heat flux q on the amplitude A and frequency ω of transverse vibrations of an electrical string heated by an electric current. A thin copper wire ($d = 0.375$ mm) with a length that could be varied over a wide range (1–4.75 m) was used as the string. One end of the string was fixed on a bracket with the aid of a micrometric worm mechanism that allowed smooth variation of the tension σ of the string and thereby of its natural vibration frequency ω_0.

The other end of the string passed through a freely rotating unit mounted on bearings and was attached to the movable core of an electromagnet supplied with a pulsed current with a controllable frequency ω. Because of this mounting, it was possible to parametrically excite free transverse vibrations of the string with various intensities: by varying the height of the current pulses, i.e., the depth of modulations of the parameter σ, it was possible to obtain vibrations of various amplitudes.

In some series of experiments we excited forced vibrations of the taut string. To do this, another electromagnet that was also supplied with a rectangular pulsed current was mounted to one side of the string at the level of its midsection. By selecting the frequency Ω of this current equal to the natural frequency ω_0 of the string, we obtained resonance of the forced vibrations, whose amplitude reached 1 cm or more.

Synchronized and in-phase forced vibrations generated by periodic disturbances of the lateral electromagnet, in which $\Omega = \omega_0$, were superposed on vibrations parametrically excited by the terminal magnet supplied with a pulsed current with $\omega = 2\omega_0$. As is known, in this case the amplitude of the resulting vibrations turns out to be equal to the sum of the amplitudes of the natural and forced vibrations.

In order to follow strictly the value of the amplitude of transverse vibrations, a sensitive photoelectronic sensor was incorporated into the setup. A light flux from a special incandescent lamp of an optical system was focused into a narrow intense beam directed to a photocell, which was blocked by a low-weight flag indicator mounted at the level of the midsection of the string, when the string vibrated. The light source and the photoelectronic sensor could be displaced parallel to the string, because of which it was possible to follow the vibrations of any point of the heater. An S1-93 double-beam electronic oscillograph was used as a recorder. Signals from the photoelectronic sensor were fed to one input of the S1-93, while the other input was used for recording the temperature at various points of the string (see below).

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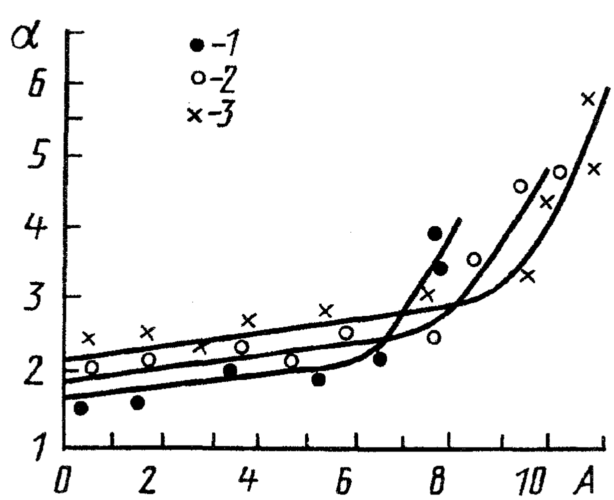

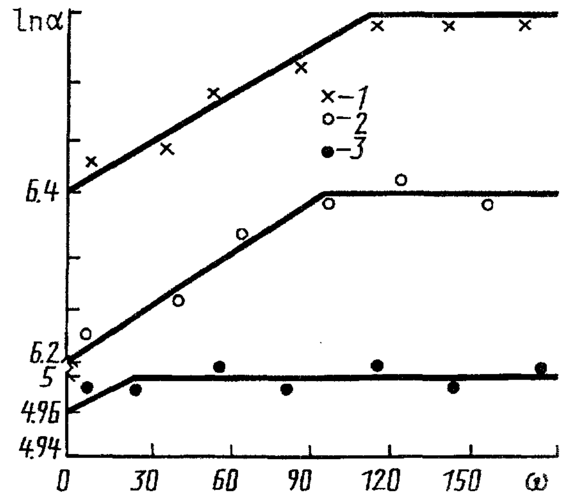

Fig. 1. Plot of the heat transfer coefficient versus the vibration amplitude of a wire heater: 1) $q_1 = 1.53 \cdot 10^3$ W/m^2; 2) $q_2 = 1.89 \cdot 10^3$ W/m^2; 3) $q_3 = 2.2 \cdot 10^3$ W/m^2. α, 10^2 W/(m^2·K); A, 10^{-3} m.

Fig. 2. Effect of the vibration frequency of a wire heater on the heat transfer coefficient: 1) $T = 102$ K; 2) 85; 3) 55. ω, sec^{-1}.

The wire was heated by supplying a controlled rectangular or constant voltage to the terminal from a stabilized rectifier. Parameters of the admitted current were measured by instruments of class 0.5.

Procedure of Temperature Measurement. Since determination of temperatures that change in time and along the length of a vibrating string by thermocouples or temperature sensors cannot provide reliable results, we used a resistance thermometer in the form of a nickel wire with a diameter of $2 \cdot 10^{-5}$ m installed on the heater in a double winding.

The largest amplitudes of oscillations of the temperature, velocity, and, consequently, the heat transfer coefficient occur in the central part of the wire, and therefore it is in this section with a length of 15 cm that the resistance thermometer was installed. The double winding suppressed induction currents that appeared when electric current was passed through the string.

The resistance thermometer was calibrated in heated and cooled oil. Mercury thermometers with a scale division of 0.1 K were used as reference standards. The scale of the S1-93 oscillograph was graduated in units of length by displacing the string statically by known distances and presetting vibration amplitudes of it.

The resistance thermometer was connected to a double bridge, the signal from which was fed to the open input of the S1-93 oscillograph, because of which the temperature of the wire could be recorded. A capacity filter was connected in parallel with the resistance thermometer to suppress high-frequency induction currents. The temperature of the ambient air was monitored by mercury thermometers accurate within 0.5 K. Thus, the experimental setup allowed us to record simultaneously the amplitude and frequency of mechanical vibrations and the instantaneous temperatures of the central part of the vibrating electric string.

Before presenting experimental results, it seems necessary to make some preliminary remarks.

A. From general considerations it may be suggested that at high vibration frequencies ω of the string, the function $\alpha(\omega)$ should be weak. Therefore, we studied thoroughly the effect of low-frequency vibrations on the heat-transfer coefficient α of a thin heater at various heat fluxes q and temperature heads ΔT.

B. In order to ascertain the effect of the amplitude A of transverse vibrations of a string heated by electric current on the heat transfer coefficient α at various heat fluxes over wide ranges of the amplitude, it was necessary to develop a method for controlling the vibration amplitude. The vibrations of the thin heater were especially strong when in-phase forced vibrations of resonance frequency were imposed on steady-state parametric natural vibrations of the heater.

Results of many experimental series allow the following conclusions:

1. At different (but constant within each experimental series) heat fluxes and vibration frequencies ω of a string heated by electric current in liquid and air, as the vibration amplitude increases, the heat transfer coefficient initially increases slowly, following a linear law, but starting from a certain critical value A_{cr} that depends on the heat flux q, the curve $\alpha(A)$ starts to rise rapidly, following an approximately parabolic law (Fig. 1). The critical value of A increases in direct proportion to q.

2. For a wide range of heat fluxes at a constant (A = const) amplitude and a certain temperature T of the heater, as the vibration frequency ω increases, the heat transfer coefficient α of a heated string vibrating in air initially increases proportionally to ω until the latter reaches a characteristic value $\omega(\Delta T)$ that depends on the temperature head ΔT; then, starting from this value, the coefficient α no longer changes (Fig. 2). The characteristic frequency ω is approximately proportional to the heat flux q.

A theoretical analysis of these results will be carried out in a separate work.

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