17. A. B. Coppens and J. U. Sanders, "Finite-amplitude standing waves in rigid-walled tubes," J. Acoust. Soc. Am., 43, No. 3, 516 (1968).
18. D. B. Cruikshank, "Experimental investigation of finite-amplitude acoustic oscillations in closed tubes," J. Acoust. Soc. Am., 52, No. 3, 1024 (1972).
19. Boa-Te-Chu, "Analysis of self-sustained thermally driven nonlinear vibrations," Phys. Fluids, 6, No. 11, 1638 (1963).
20. R. G. Zaripov and M. A. Ilhamov, "Nonlinear gas oscillations in a pipe," J. Sound Vib., 46, No. 2, 245 (1976).
21. J. J. Keller, "Subharmonic nonlinear acoustic resonances in closed tubes," Z. Angew. Math. Phys., 26, 395 (1975).
22. J. J. Keller, "Third-order resonances in closed tubes," Z. Angew. Math. Phys., 27, 303 (1976).
23. J. J. Keller, "Nonlinear acoustic resonances in shock tubes with varying cross-sectional area," Z. Angew. Math. Phys., 28, 107 (1977).
24. A. I. Gulyaev and V. M. Kuznetsov, "Large-amplitude gas oscillations in a closed pipe," Inzh. Zh., 3, No. 2, 236 (1963).
25. I. L. Povkh, G. P. Eremin, V. M. Shkredov, and V. G. Kondratenko, Prib. Sist. Upr., No. 5, 43 (1976).
26. K. Bremhorst and D. B. Gilmore, "Comparison of dynamic and static hot-wire anemometer calibrations for velocity perturbation measurements," J. Phys. E., 9, No. 12, 1098 (1976).

EXPERIMENTAL STUDY OF THERMOMECHANICAL OSCILLATIONS OF A CYLINDRICAL HEATER IN AN AIR MEDIUM WITH FREE CONVECTION

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It is demonstrated experimentally that when appropriate conditions are fulfilled, oscillations in the heat liberation coefficient of an electrically heated wire vibrating in air are capable of parametrically exciting intense mechanical oscillations in the wire.

The effect of low-frequency oscillations of a heater on its heat liberation to the surrounding medium have been studied by a number of authors [1-3]. In [4-6] it was observed that in an electrically heated wire with a weight suspended from its midpoint nondamping transverse oscillations may develop under certain conditions. The authors explained this by the phenomenon of thermoparametric amplification.

The present authors have performed further studies of thermomechanical oscillations of a thin cylindrical heater, and of the role of heat exchange in the parametric resonance mentioned above.

We will enumerate the basic results obtained.

1. It has been shown experimentally that the presence of a suspended weight is not necessary for excitation of nondamping wire oscillations. Experiments were performed on a wire held rigidly at both ends ($l = 4.3$ m, $d = 4 \cdot 10^{-4}$ m) carrying dc current, the amplitude of which could be varied over a wide range. It was also possible to adjust the tension in the wire τ with a micrometer worm mechanism. The mean temperature T over the wire volume was determined from the wire's electrical resistance.

It developed that for each value of T there corresponded some interval of tension, in which wire oscillations were self-exciting. The amplitude of the oscillations A increased rapidly, reaching a limiting value A°, which was a function of the temperature difference ($\Delta T = T - T_0$) between the wire and the surrounding air: initially with increase in ΔT the

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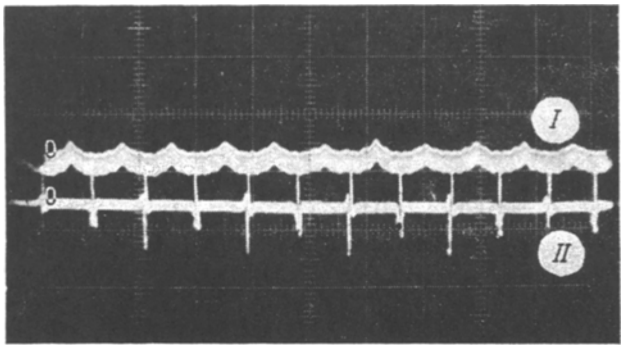

Fig. 1. Wire temperature oscillations (I) and mechanical oscillations (II), pips denote equilibrium position. Sweep rate, 1 sec/cm.

amplitude A^0 increased, taking on the maximum value A^0_{max} for limiting ΔT, after which it began to drop slowly (in our experiments $A^0_{max} = 6 \cdot 10^{-2}$ m). The wire oscillation frequency varied with T and τ, but in all cases was in the range of several Hz. It should be noted that in the experiments with dc current the wire oscillations occurred at the fundamental frequency (the string was one half wavelength long); when ac current was passed through the wire a higher harmonic was sometimes superposed on the fundamental oscillation (7-8 half waves along the wire). Measurements showed that when the wire was in oscillation its mean temperature decreased, the decrease being greater, the larger the range of the mechanical oscillations.

2. It was established by direct experiments that excitation of intense oscillations is produced by convective heat exchange between the hot wire and surrounding medium.

A copper wire (l = 1.07 m, d = $2 \cdot 10^{-4}$ m) was mounted along the axis of a glass tube (L = 1.1 m, D = 0.07 m) in a manner such that the tension in the wire could be varied. A constant 24-V dc was applied to the wire from a UIP-1 regulated power supply. By varying the value of τ, nondamping wire oscillations could be produced with a steady-state amplitude A^0 of the order of 0.01 m (frequency about 5 Hz). Then a forevacuum pump was used to evacuate the tube, so that the pressure fell gradually. The maximum oscillation amplitude A^0 then decreased slowly. When the decreasing air pressure reached a value of $P = 5 \cdot 10^{-4}$ Pa or less, the wire oscillations damped out rapidly. When the pressure in the tube was increased again the oscillations recommenced and increased in amplitude with growth in P. A similar damping of the wire oscillations was observed when the temperature of the surrounding medium was increased (thus decreasing ΔT). Subsequent increase in ΔT by cooling of the medium led to reestablishment of the oscillations. Thus, with degradation in heat liberation due to rarefaction of the surrounding air or decrease in temperature difference ΔT the depth of the temperature modulation, and thus, the wire stress modulation, decreases. As a result the quantity of energy supplied to the system per period becomes less, and parametric excitation of wire oscillations is hindered.

3. In the following series of experiments the relationship between frequencies and phases of the mechanical and thermal oscillations was studied. A nichrome wire was used (l = 7 m, d = $32 \cdot 10^{-5}$ m). A dc voltage was applied to the wire (U = 200 V, I = 1.2 A) from three UIP-1 supplies connected in parallel. A pi-network LC-filter was used to suppress line noise. A weight with a permanent magnet attached to it was suspended from the midpoint of the wire on asbestos filaments. Total mass of the suspended mass was 0.25 kg. The wire and weight could undergo horizontal thermomechanical oscillations, which were modulated by periodic changes in the wire sag due to temperature oscillations. A coil was mounted below the wire and connected to one input of an S1-18 dual trace oscilloscope. As the wire passed through its equilibrium position the pulse from the coil was displayed on the oscilloscope screen. Wire temperature oscillations were recorded by the change in electrical resistance of the middle portion of the wire. To do this two fine copper wires were attached to the main wire and connected to the second oscilloscope input. A capacitive filter was connected in parallel with the measurement section to suppress high-frequency interference. The steady-state amplitude of the wire's mechanical oscillations reached 0.3 m, with a frequency of 1.8 Hz. The temperature of the wire at rest was 70°C, with oscillation amplitude of the order of 5°C. An oscillogram of the temperature oscillations is shown in Fig. 1. As may be seen from the figure, the frequency of the temperature oscillations ω is twice the frequency of the wire mechanical oscillations ω_0 ($\omega = 2\omega_0$), i.e., the most favorable condition for excitation of parametric resonance is satisfied.

The series of experiments performed also permitted determining the magnitude of the phase shift. As is evident from the oscillograms, as the wire passes the temperature equilibrium position, the wire length, and with it, the sag distance, are decreasing, which is a necessary condition for parametric pumping of pendulum oscillations [7].

NOTATION

l, wire length; L, tube length; d, wire diameter; D, tube diameter; T, mean wire temperature over volume; T_0, temperature of surrounding medium.

LITERATURE CITED

1. Penney and Jefferson, Teploperedacha, No. 4 (1966).
2. O. A. Kremnev, A. L. Satanovskii, and V. V. Lopatin, Heat and Mass Transfer [in Russian], Vol. 1, A. V. Lykov and B. M. Smol'skii (editors) (Materials of the Third Conference on Heat and Mass Exchange, Minsk, 1968), Énergiya, Moscow (1968), p. 301.
3. B. M. Galitseiskii, Yu. A. Ryzhev, and E. V. Yakush, Thermal and Hydrodynamic Processes in Oscillating Flows [in Russian], Mashinostroenie, Moscow (1977).
4. D. I. Penner, Ya. B. Duboshinskii, et al., in: Some Questions on the Excitation of Nondamping Oscillations [in Russian], 1st ed., Vladimir State Pedagogical Institute, Vladimir (1974), p. 168.
5. A. S. Vermel', in: Questions on the Excitation of Nondamping Oscillations [in Russian], 2nd ed., Vladimir State Pedagogical Institute, Vladimir (1974), p. 90.
6. A. S. Vermel', in: Questions on the Excitation of Nondamping Oscillations [in Russian], 2nd ed., Vladimir State Pedagogical Institute, Vladimir (1974), p. 104.
7. E. I. Nesis, in: Studies in the Physics of Boiling [in Russian], 2nd ed., Stavropol, State Pedagogical Institute, Stavropol' (1974), p. 3.

CALCULATION OF GAS–GAS PHASE EQUILIBRIUM FOR THE MIXTURE He–F12

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Equilibrium conditions are determined by use of the Redlich–Kwong equation of state and two different methods for numerical calculation of the mixture phase behavior.

By analyzing the geometric properties of the F–v–x surface with the aid of the theory of folds proposed by Korteveg, using his own approximate equation of state for the mixture, Van der Waals arrived at the conclusion [1] that the existence of a longitudinal (relative to the v axis) fold on this surface corresponds to the condition of equilibrium of two fluid phases at some fixed value of molar volume. This simple approach also permitted a qualitative description of all the experimentally observed variants of behavior of the critical curve of a binary system in P–T–x space. The calculation of phase behavior of a fluid mixture is usually refined by introducing a more complex equation of state and solving a quite cumbersome system of nonlinear equilibrium equations. It will be shown below that use of the Van der Waals approach (i.e., direct analysis of F), together with refinement of the mixture equation of state, permits equilibrium calculations with results comparable in accuracy to traditional methods.

The Redlich–Kwong equation of state was used to describe the properties of the coexisting phases. This equation is one of the most useful variants of the semiempirical approach to construction of a unified equation of state for pure materials and mixtures. The specifics of the problem in question here require reliable determination of the mixture thermodynamic properties over a narrow temperature interval somewhat above T_{cF12}, at pressures above P_{cF12}. Accordingly, the constants a and b in the Redlich–Kwong equation of state

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