10. I. S. Berezin and N. P. Zhidkov, Computing Methods [in Russian], Moscow (1966) [translated by O. M. Blunn, Pergamon Press, London (1965)].
11. N. I. Nikitenko, "Investigation of nonsteady processes of heat and mass transfer by the grid method," Author's abstract of dissertation for degree in engineering sciences, Kiev (1969).
12. P. N. Tugunov and V. F. Novoselov, Transport and Storage of Oil and Gas [in Russian], Moscow (1975).

A NEW TYPE OF SELF-EXCITED THERMOMECHANICAL OSCILLATIONS

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A new type of self-excited thermomechanical oscillations of heaters with ferromagnetic properties is investigated. The conditions for the onset of such self-excited oscillations are analyzed qualitatively.

Temperature oscillations (generated, e.g., by an alternating current) in a body are known to induce oscillations of the dimensions and shape of the heater, along with mechanical vibrations. Such hybrid oscillations are now known as thermomechanical oscillations (TMO). A special kind of self-excited thermomechanical oscillations (SETMO) can also arise in the system under certain conditions [1].

Here we give the results of investigations of a new type of SETMO observed in ferromagnetic heaters.

Since the magnetization I decreases abruptly with increasing temperature near the Curie point T_C (Fig. 1a), strong pulsations of I can be produced in a ferromagnet by exciting thermal oscillations in it. If a ferromagnetic vibrator is introduced into a static nonuniform magnetic field, it begins to be subjected to a force [2]

$$F = I\frac{dH}{dx},$$

which varies periodically because of the pulsations of I. Clearly, such a perturbing force can excite steady-state SETMO under certain conditions.

Inasmuch as the attractive force F can be directed only in the direction of increasing magnetic field H, the temperature of the ferromagnetic vibrator must decrease as the magnet comes closer and, conversely, it must increase as the magnet moves away in order for the mechanical vibrations to be amplified. It should also be borne in mind that the field H decays rapidly with increasing distance x ($dH/dx < 0$).

In the final analysis three conditions are required in order for strong SETMO to be generated: 1) The frequency ω of the temperature oscillations must be a multiple of the natural frequency ω_0 of the vibrator; 2) the time shift τ between the temperature and mechanical oscillations must be such that the temperature of the ferromagnet drops sharply as the vibrator approaches the magnet; 3) the amplitude θ of the thermal oscillations must be large enough for the energy input into the oscillatory system to cover dissipative losses.

We have observed SETMO of this kind experimentally, using a ferromagnetic vibrator with the configuration shown in Fig. 1c.

The vibrator comprised a lightweight mica frame mounted in needle bearings; the frame was capable of executing torsional vibrations. A nickel wire coil ($d = 10^{-4}$ m) was wound on one side of the frame in a bifilar configuration. The coil-wound frame was placed in the field of a permanent magnet, which was situated either to one side (position I) or undernearth (position II) the coil.

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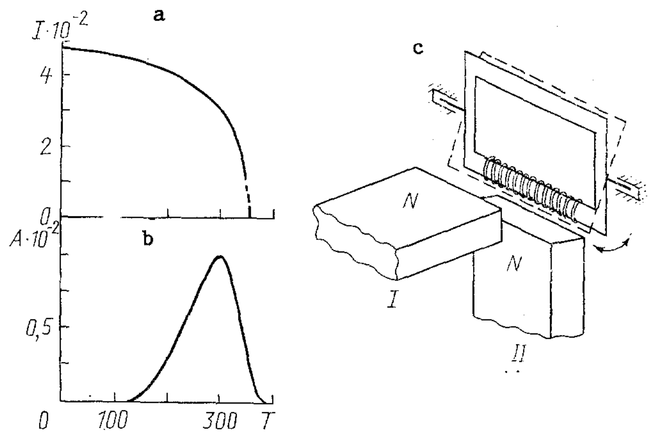

Fig. 1. Magnetization $I \cdot 10^{-2}$, Tl (a), and amplitude of self-excited mechanical vibrations $A \cdot 10^{-2}$, m (b), vs. temperature T, °C, of a nickel ferromagnetic vibrator (c).

The coil was heated by a pulsed current with a rectangular waveform, whose amplitude and frequency could be varied smoothly by means of an oscillator.

The temperature of the coil was measured with the use of a resistance thermometer. The role of the latter was taken by the middle part of the nickel coil, which was connected into the measurement arm of an R 3009 Kelvin bridge. The signal from the diagonal of the bridge was sent to the open input of one channel of an S1-93 oscilloscope calibrated in degrees of temperature.

The mechanical vibrations of the frame were recorded by an optical technique using a photomultiplier equipped with a micrometer slot; the photomultiplier signal was sent to the open input of the other channel of the S1-93 oscilloscope. The results of the measurements are shown in Fig. 2.

It follows from the oscillograms that the nature of the thermomechanical processes depends significantly on the spatial orientation of the magnetic field relative to the vibrator. For example, if the permanent magnet is in position I (corresponding to the oscillogram in Fig. 2a), strong SETMO are generated when the frequency ω of the temperature oscillations coincides with the natural frequency ω_0 of the mechanical vibrator ($\omega = \omega_0$).

On the other hand, if the magnet is in position II, SETMO are generated in two cases: when $\omega = \omega_0$ (Fig. 2b) or when $2\omega_0 = \omega$ (Fig. 2c).

As for the time shift τ between the mechanical and thermal oscillations, here the pattern is more complicated. For example, if the magnet is situated near the point of maximum displacement of the vibrator (Fig. 2a), the coil temperature T decreases once in each period of the mechanical vibrations, and the time τ between the minimum of T and the time of closest approach of the vibrator to the magnetic is ~1/4 period.

When the magnet is situated near the equilibrium position ($x = 0$) of the vibrator and $\omega = \omega_0$ (Fig. 2b), the temperature decreases once per period and attains its minimum value at the instant that the vibrator comes close to the magnet.

But if energy transfer takes place twice during each period of the mechanical oscillations, $\omega = 2\omega_0$ (Fig. 2c), then the time shift τ is ~1/8 period.

It should also be noted that if the magnet is in position I, mechanical vibrations are excited spontaneously (since the attractive force F causes the vibrator to be displaced somewhat from the equilibrium position even before the actual oscillatory process begins), whereas in position II the vibrator must be initially disengaged from the equilibrium state.

An analysis of many experiments shows that the amplitude A of the mechanical vibrations associated with steady-state SETMO of a ferromagnetic vibrator does not only depend strongly on the magnitude and direction of the field H, but also on the parameters of the thermal oscillations: their frequency ω and amplitude θ, and the mean temperature $\bar{T}$ about which the thermal pulsations take place. As an example, Fig. 1b shows the function $A = f(\bar{T})$ for the case in which $\omega = \omega_0$ and $\theta = 25°C$. The maximum of the curve occurs in the interval of tem-

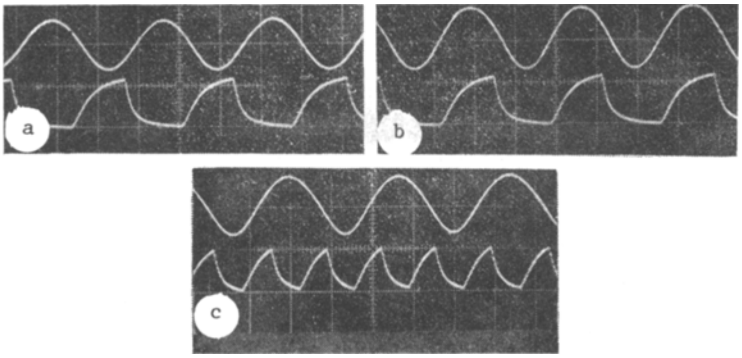

Fig. 2. Oscillograms of mechanical vibrations (upper curves) and temperature oscillations (lower curves) of a ferromagnetic vibrator for various orientations of the magnetic field. a) The maximum distance from the magnet corresponds to the uppermost positions (a) and amplitude values (b, c) of the mechanical vibration curves, $H = 1.5\cdot10^3$–$5\cdot10^3$ A/m. a, b) $\bar{T}$ = 302°C; c) 298°C. Sweep time 0.5 sec/div. Sensitivity of channel I: $1.5\cdot10^{-2}$ m/div; of channel II: 40°C/div.

peratures T where the magnetization I depends linearly on the temperature T, in good agreement with the theoretical considerations.

To confirm the thermal nature of the observed self-excited oscillations, the vibrator was placed in the chamber of a vacuum station, permitting the degree of rarefaction of the air to be varied over a broad range.

It was found that when the pressure in the chamber was lowered to values of the order of $0.1P_{atm}$, the mechanical vibrations of the frame ceased altogether. The vibrations reappeared when air was admitted into the chamber.

This result can be attributed to the fact that the rate of convective heat transfer falls off sharply in vacuum, thereby decreasing the amplitude θ of the thermal oscillations, which constitute a kind of "channel" for the input of energy from the external magnetic field into the self-excited system.

Finally, we should call attention to the potential usefulness of the observed phenomenon in engineering applications that utilize thermomagnetic materials with low Curie points.

NOTATION

I, magnetization of ferromagnet; F, force of interaction of ferromagnet with magnetic field; H, magnetic field strength; T, temperature of ferromagnet; T_C, Curie point; θ, amplitude of thermal oscillations; $\bar{T}$, mean temperature about which thermal oscillations take place; ω, frequency of thermal oscillations; ω_0, natural frequency of mechanical vibrations; A, amplitude of mechanical vibrations; x, displacement of system from equilibrium position; τ, time shift between mechanical and thermal oscillations.

LITERATURE CITED

1. E. I. Nesis and S. E. Nesis, Inzh.-fiz. Zh., 55, No. 4, 673-691 (1988).
2. S. V. Vonsovskii, Magnetism [in Russian], Moscow (1971).