EXPERIMENTAL STUDY OF TEMPERATURE OSCILLATIONS IN A VIBRATING SPIRAL HEATER

S. E. Nesis

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Mechanothermal self-oscillations of a spiral heater and their qualitative dependence on temperature head and spiral geometry are experimentally studied.

It is well known that under certain conditions intense transverse oscillations can be excited in an electrically heated wire [1]. The cause of these oscillations is a periodic change in the intensity of heat liberation from the moving hot wire to the surrounding air. Certain unique features of these oscillations were described previously by the present author [2, 3].

While conducting those previous experiments it was noted that a wire wound into a spiral form is much more prone to mechanothermal self-oscillations than the same wire in straight form, other conditions being equal. The first measurements revealed an important fact, that the amplitude of the temperature oscillations θ_0 in the spiral markedly exceeded the corresponding amplitude in the straight wire under certain conditions. It was thus decided to perform a more detailed experimental study of mechanothermal self-oscillation in spiral heaters.

The objects of study were wire spirals mounted horizontally between two steel arms, with a spiral length of 3 m. Nichrome and nickel wires with diameters of 10^{-4}–$4\cdot 10^{-4}$ m were used. A system of micrometer screws permitted continuous extension of the spiral, thus changing the number of turns per unit length, b (Fig. 1). A regulated dc voltage from a stabilized power supply was applied to the ends of the heater spiral. The sag in the wire i was about 0.1 m, and the mechanical oscillation frequency was in the range 1–5 Hz. The amplitude of these mechanical oscillations U_0 was determined to an accuracy of 10^{-3} m using a telescope with built-in micrometer scale. The amplitude of thermal oscillations in the spiral heater was measured to an accuracy of 0.5°K using a resistance thermometer located in the central portion of the spiral. Signals from the resistance thermometer and inductive sensors which fixed the heater position in space were applied to the inputs of an S1-18 dual trace oscilloscope, with scale calibrated in degrees of temperature (the measurement apparatus was described in detail in [2]).

Air temperature was measured by two mercury thermometers to an accuracy of 0.5°K.

Observations revealed that when the wire temperature head ΔT reached a value of the order of 80°K an insignificant initial displacement was sufficient to excite transverse vertical self-oscillations in the wire. Thereupon temperature oscillations developed in the wire, with amplitude of the order of magnitude of 5°K and frequency coinciding with the neutral oscillation frequency of the heater.

From general considerations it could be expected that the frequency of the temperature oscillations should be twice that of the transverse mechanical oscillations. However, numerous and varied experiments showed that such a frequency relationship occurred only for horizontal transverse oscillations of the heater [2].

In the case of vertical self-oscillations in both cylindrical and spiral heaters the frequencies of thermal and mechanical oscillations coincided within the limits of experimental uncertainty.

To explain this fact, we propose that the heat transfer conditions for heater motion upward and downward are different, due to the presence of ascending convective flows. This was verified experimentally by using the Topler shadow projection method. When the hot wire or spiral moves upward, the heated convective air flow rises simultaneously, and no cooling

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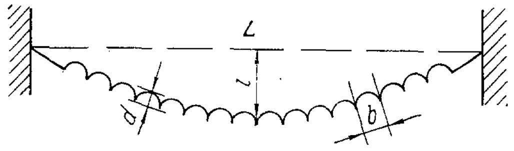

Fig. 1. Experimental specimen configuration.

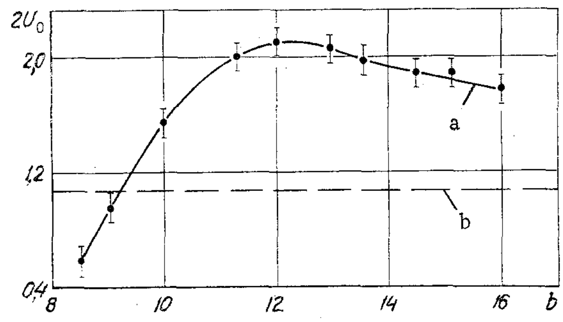

Fig. 2. Doubled mechanical oscillation amplitude $2U_0$ vs spiral turns/unit length (a). Dashed line (b) corresponds to maximum oscillation amplitude of straight wire with all other conditions equal. b, 10^{-3} m.

of the wire occurs during this half cycle. In the second half cycle, when the wire or spiral moves downward the convective flow breaks away from the heater, so that the latter is located in colder air layers and cools off.

Further proof of this supposition was provided by another experiment: upon applying an intense horizontal draft of air across a vertically oscillating wire the frequency of the temperature oscillations increased and became equal to twice the mechanical oscillation frequency.

The same shadow projection method was used to qualitatively study the temperature field about the vertically oscillating heater. It developed that the temperature of the air column within the spiral significantly exceeded the air temperature outside the spiral.

Further studies were performed of phase relationships, i.e., the value of the phase shift angle φ between the temperature and mechanical oscillations. The measurements performed revealed that the temperature oscillations are delayed relative to the mechanical heater oscillations by approximately 1/4 period, i.e., $\varphi \approx \pi/2$.

In the experiments the amplitudes of mechanical and thermal oscillations U_0 and θ_0 were measured as functions of temperature head ΔT, sag length l, turns/unit length b, and spiral diameter d, and the intensities of oscillations in a spiral and straight wire were compared (with wire material, cross section, temperature head, suspension length and sag for both types of heater constant).

The studies showed that in spiral heaters only vertical mechanical self-oscillations are excited, independent of the direction and magnitude of the initial mechanical oscillation amplitude. With increase in the current passed and temperature head ΔT the intensity of established mechanical oscillations increases, with the rate of increase of U_0 and θ_0 being greater the shorter the suspension length l. It was found that with increase in spiral diameter d (with other conditions unchanged) the amplitude of the transverse oscillations increased.

The number of turns per unit length b, or more precisely, the ratio b/d, has a great effect on the amplitude of mechanical and temperature oscillations.

Figure 2 shows a typical graph of the amplitude U_0 of steady state self-oscillations as a function of the turns/unit length b of a spiral at $d = 6 \cdot 10^{-3}$ m. The temperature head was equal to 90°K.

NOTATION

d, spiral diameter; l, sag; b, turns per unit length of spiral; ΔT, temperature head between heater and surrounding air; U_0, amplitude of mechanical oscillations; θ_0, temperature oscillation amplitude; φ, phase shift between thermal and mechanical oscillations.

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NUMERICAL ANALYSIS OF TRANSFER PROCESSES IN SEMICONDUCTING DEVICES AND STRUCTURES.

1. GENERAL PRINCIPLES OF CONSTRUCTING SOLUTIONS OF THE FUNDAMENTAL SYSTEM OF EQUATIONS

I. I. Abramov and V. A. Kharitonov

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The basic situation is considered of constructing effective methods and algorithms of numerical analysis of transfer processes of charge carriers in semiconducting devices and structures.

Most transfer processes of energy, mass, momentum, charge, etc. can be described within contemporary science and technology only by systems of nonlinear partial differential equations. Computational methods taking into account the specifics of given physical problems and being the subject of a new scientific discipline, computational physics [1], have been developed and widely used so as to model these processes, being of significant scientific and practical interest.

The study of charge transfer processes in semiconducting devices and structures is one of the most important problems. Its complexity consists of the fact that transfer of charged particles under the action of an external electric field occurs in the presence of immobile charges and the internal electric field due to these charges.

The need to solve this problem is related to the present transition to submicron technology of integrated circuits, and consequently, to the difficulties in performing a real physical experiment studying the internal processes in the semiconducting structures, being the basis of these circuits.

In the present paper we consider both the difficulties generated in numerical analysis of integrated semiconducting structures and the ways of overcoming them. It is shown that integral finite-difference formulations of the Sharfetter–Gummel [2] and Engl–Dirks [3] type for the continuity equation are special cases of a general integral formulation, obtained on the basis of the G. I. Marchuk integral identity under a number of physical assumptions. By using this identity one can also obtain integral formulations for the case of including Fermi statistics. Two-stage methods of vector relaxation systems (VRS) are developed in concluding the introduction of the physical balancing principle of the iteration solution of the problem.

Belorussian Institute of Highway Transport Engineering, Gomel. V. I. Lenin Belorussian State University, Minsk.

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