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NONLINEAR PHENOMENA IN COMPLEX SYSTEMS

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The Temperature Fields in Electrically Heated Wires at Crisis of Boiling

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The self-organization processes take place in several phenomena and physical objects and in particular they arise in metals in conditions of charge transfer. In [1-3] it is shown that at liquid helium temperature in conditions of the increase of direct current flowing through bismuth, indium and tungsten there arise unstabilities of charge carries flux and this process exhibits itself in electromagnetic oscillations generation. This instability the authors refer to the mutual influence of the current flowing through the sample and magnetic field of the current. With this heat flux density through the sample's surfaces didn't exceed 0.1 W/sm^2. Such a value of heat flux is close to the first boiling crisis but the author state that the nature of these phenomena is no case is connected with the heat removal specific features.

The arising on self-organized structure in metals one can observe as well in the processes of heat transfer from metallic sample heated by electric current to some liquid medium. For example in widely known electronic devices barretters used for filament current stabilization in different electronic valves is realized S-like dependence of heat removal function at linear dependence of heat generation [4,5]. In these devices is realized a specific feedback of heat generation control by means of sample resistance changing at fluctuations of voltage on load determined by source.

In this report the problem of the control of temperature self-organization in metallic medium in conditions of its heat up in the given current regime is discussed. As an external medium it was chosen cryogenic liquid-nitrogen and the sample was a molybdenum wire with length of 250 mm and diameter of 0 5 mm. The sample was placed horizontally in a container with liquid nitrogen and was powered from current generator. In the experimental procedure there was measured voltage-current characteristic, i.e. dependence of voltage drop on the sample upon the current flowing. Thus with the increase from zero of current flowing through the sample there takes place linear dependence of voltage drop that has the same horizontal axis slope up to current value of $I = 15.46\ A$ (the AB section of the figure 1). At the value $I = 15.46\ A$ there begins spontaneous voltage increase up to $8.3\ V$ (BV section). The decrease of the sample current is also accompanied by the non-linear dependence upon I (VG section). The decrease of the sample current is also accompanied by the non-linear voltage increase that doesn't coincide with the direct pass up to the current value of $I = 9\ A$ (GDE section). In E point the voltage spontaneously decreases to the value characteristic in the direct pass (EI section). If during the spontaneous voltage increase from B point current value would be decreased to some extend then transition will move on BD curve and the further current increase leads to DVG dependence with reverse pass on GDE section. With it when current value $I = 15.35\ A$ and voltage value $U = 8.34\ V$ self-organized structure is observed, i.e.luminous sections appear. Their number and positions depend on current value. Thus with current value growth the sections merge into continuous luminous zone that takes place beginning with the current value $I = 25\ A$. The AB dependence corresponds to the bubble boiling process when the surface temperature has a little change relative to environment of which bear witness the curves constant slope angle, but transition to the curve section indicates the strong dependences of sample temperature upon the current value. Obviously the temperature and voltage hysteresis indicates the appearance of sections with different boiling regime. Still it is problematic whether the transition regime takes place in this case, or spatial structure realizes in conditions of the film-boiling regime by means of stronger sample temperature dependence over heat removal. Therefore for the present case we have an example of dynamic system which has spatial distribution and the set of degrees of freedom of which is associated with temperature field in a long thin sample. With it conduction current value is determined by the current source and the power of system heat source is a function of temperature. In this case the main equation describing the evolution of the system with time has a traditional form:

$$c(\partial T/\partial t) = q_+ - q_- + \lambda \nabla^2 T, \qquad q_+ = \rho j^2.$$

where c - specific heat, q_+ - heat source power, q_- - heat remove process power, λ - heat conduction, ρ - resistivity, j - conduction current.

Heat remove process power is a complicated temperature function having N-like form that is hard to describe analytically. Resistivity of the heat generating element in a given regime one can represent in a following form $q \sim T$. It is worth noting that a set of variables describing temperature field is tied because spatial inhomogeneities lead to transport phenomena which lead to the appearance of the spatial derivatives in the given dynamic equation. For the analysis of system stability let us analyze the system characteristic equation that has the following form:

$$\omega = q_+^{'} - q_-^{'} + \nabla^2; \quad q' = \frac{\partial q}{\partial T};$$

$$\frac{dX}{dt} = ZX; \quad X = Ue^{\omega t},$$

here U is responsible for the X dependence on spatial coordinates.

Let us find the characteristic functions and the characteristic values of Laplacian of the given problem that has the following form:

$$\nabla^2 \varphi_m(x) + k_m \varphi_m(x) = 0$$

with boundary conditions

$$\left.\frac{d\varphi}{dx}\right|_{x=0} = \left.\frac{d\varphi}{dx}\right|_{x=L} = 0$$

in the following approximation

$$\varphi_m(x) = \cos\frac{2\pi m x}{L}; \quad k_m = \frac{2\pi m}{L}$$

In accordance with this the expression for the stability parameter is:

$$\omega = q_+^{'} - q_-^{'} - k_m^2$$

It is clear that the stability of system is determined by the correlation between all parameters $q_+^{'}$, $q_-^{'}$ and k_m^2. The temperature derivative $q_+^{'}$ is always positive function of temperature. Function $q_-^{'}$ has complicated non-monotonic behaviour appearing as a result of coexistence of different boiling regimes of cryogenic liquid (Fig.2). Thus the sections of bubble boiling OA and film boiling BC are characterized by positive temperature derivative of heat remove process power: $q'_- > 0$, and $| q'_- | \gg | q'_+ |$ because derivative of heat source power q'_+ is temperature independent. In accordance with it the stability parameter ω is negative at any values of characteristic magnitude k_m beginning from zero. This means the absence of spatial mode in stationary regime, i.e. the temperature is constant along the sample length. The boiling curve section AB is characterized by the negative derivative of heat remove process power $q'_- < 0$. In this middle of this range the $|q'_-| \gg |q'_+|$. Near the A and B points the correlation between $| q'_+ |$ and $| q'_- |$ may be more complicated. Thus stability parameter part $(q'_+ - q'_-)$ may have both positive and negative values. Naturally at the conditions when the $| q'_- | \geq | q'_+ |$ the decision describing system state with uniform temperature distribution along length sample is becoming unstable and system must go into new stable state with the appearance of spatial mode. Such state may take place at the conditions of quasi-state increase of heat source power that was organized in the experiment discussed. At high rates of heat power putting into the system there may exist the situation when the system goes into a new state with the absence of space mode. At this case the temperature fluctuation at some point of sample induces a temperature wave propagating with finite velocity. Therefore one can confirm that point A is a bifurcation point.

Thus the analysis of situation on the base of linear stability evidences the possibility of existence of stable space temperature structures during electrical heating of system at the regime of given current. The spatial structure stability in both transitive and film regimes of boiling is due to correlation between temperature derivatives of heat power generation and heat remove power functions at the conditions of cooperative heat exchange.

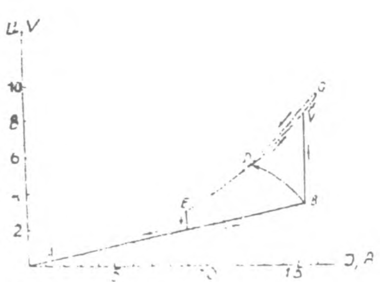

Fig.1. Voltage current characteristics of molybdenum wire placed as a function of temperature

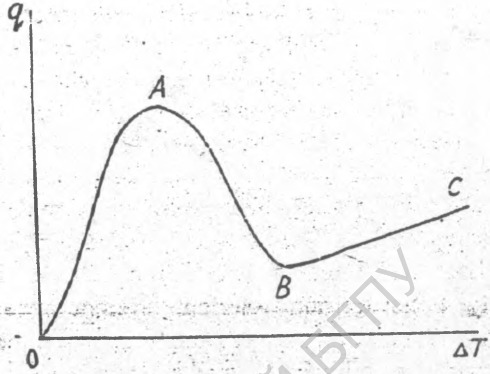

Fig.2. Boiling curve of liquid nitrogen as a function of temperature.

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