SESSION OF THE DIVISION OF GENERAL PHYSICS AND ASTRONOMY, USSR ACADEMY OF SCIENCES

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A session of the Division of General Physics and Astronomy of the USSR Academy of Sciences was held in the Conference Hall of the P. N. Lebedev Physics Institute of the Academy. The following papers were presented at the session:

1. V. V. Sychev: Superconducting Magnets.
2. V. I. Rakhovskiĭ: Dynamics of the Near-electrode Regions in Electric Discharges.
3. Ya. A. Ryftin: Prospects for a Radical Increase of the Resolving Power in Television.

Published below are summaries of the papers.

V. V. Sychev: Superconducting Magnets (The Question of Reliability).

This paper is a review of the present state of the reliability of the coils of a superconducting magnetic system (SMS) from the point of view of the possibility of accidental or premature transition of the SMS to the normal state. The most detailed consideration is given to thermal (cryogenic) stabilization of superconductors.

As we know, stabilization of a superconductor is achieved by reinforcing the superconductor with a normal metal of high electrical and thermal conductivities. Such superconductors, placed in normal-metal matrices (substrates), have been named composite conductors.

The known model of composite conductors, due to Stekly, is the first approximation of the theory of these conductors, and is based on the assumptions that a) the coefficient of heat transfer from the surface of the conductor to the helium bath does not change with temperature*, b) the resistivity of the substrate material is independent of the temperature, and c) the temperature of the composite conductor is constant over its entire length. By taking into consideration the true nature of the variation of these quantities, we have been able to make a number of qualitatively new conclusions about the laws governing the behavior of composite conductors.

In[3,4], the influence of the nucleate-to-film boiling transition in helium, which sets in at a temperature differential $\sim 1°K$, and the true temperature dependence of the resistivity of copper, are taken into account in detailed computations of complete voltage-current characteristics of a composite conductor under isothermal conditions for the superconductor states which correspond to the current flowing both in the superconductor and the substrate as well as for the state when all the current is forced to flow the substrate. These calculations for the voltage-current characteristics were done for different values of critical temperature T_c (H, I = 0).

These characteristics differ considerably from the results obtained by Stekly in[1,2]. In particular, it has been established that full stabilization (i.e., when the minimum current necessary for the existence of the normal phase[1] I_m equals the critical current I_c) under the conditions considered corresponds to a stability parameter $\alpha \approx 0.03$. Furthermore, it has been established that for any given value of α greater than some limiting current value I^*, stable states of the conductor are impossible if the entire current flows only in the substrate; for $I > I^*$ the transition of the superconductor to the normal state leads to a subsequent unlimited rise in conductor temperature. A number of other regions of unstable state of the composite conductor have also been found[3,4].

The existence of unstable equilibrium states of the composite conductor in the region of the nucleate boiling of helium (stability parameter $\alpha > 1$) and in the region corresponding to the case when all the current flows only through the substrate $T > T_c$) and, also, the existence of the limiting current I^* have been experimentally confirmed.

Voltage-current characteristics have been obtained in these experiments for different types of composite conductors at different intensities of the external magnetic field under isothermal conditions (the temperature being constant along the part of the conductor under investigation).

It has been established that the true voltage-current characteristic of a composite conductor has just the features that had been established before by theoretical calculations.

A theoretical consideration of the case of non-uniform temperature distribution along a composite conductor was again carried out a few years ago[5], under the assumption that the heat-transfer coefficient is independent of the temperature on the basis of data obtained in[5], the idea of the so-called minimum propagation current (I_p), at which the velocity of propagation of the normal phase along the conductor (v) vanishes, was proposed. Naturally, $I_m < I_p < I_c$; $v = -\infty$ if $I = I_m$ and $v = 0$ if $I = I_c$. These results have been experimentally confirmed[6].

Recently, the voltage-current characteristics for the case of non-uniform temperature distribution have been improved by taking into account the influence of the nucleate-to-film boiling transition in helium. These characteristics have been unequivocally confirmed by experiment. The most important fact here is that even for conductor currents $I > I_p$, right up to the critical value I_c, the characteristics include sections with positive values of dV/dI. This is an indication of the stability of the obtained states - which is crucial for the solution of the problem of the reliability of opera-

*Subsequently, Stekly attempted [2] formally to take into account in his model the influence of the nucleate-to-film boiling transition in helium, but his approach was not quite correct and was inconsistent with the general principle of the method [3].

tion of a superconducting magnetic system (at currents $I > I_p$.

The concepts developed in these investigations described above make possible the formulation of conditions necessary for a safe and reliable operation of a stablized SMS. These concepts have, in particular, led to the establishment of the causes of the breakdown of large SMS, described in the literature in recent years, and the discovery of methods for eliminating the possibility of these breakdowns.

[1] Z. J. J. Stekly and J. L. Zar, IEEE Trans. Nucl. Sci. NS-12, 367 (1965).

[2] Z. J. J. Stekly, First Int. Cry. Eng. Conf., Kyoto (April 1967).

[3] M. G. Kremlev, V. B. Zenkevitch, and V. A. Al'tov, Cryogenics No. 3, 173 (1968).

[4] V. V. Sychev, V. B. Zenkevich, M. G. Kremlev, and V. A. Al'tov, Dokl. Akad. Nauk SSSR 188, 83 (1969) [Sov. Phys.-Doklady 188, 83 (1969)].

[5] V. E. Keilin, E. Y. Klimenko, M. G. Kremlev, and B. N. Samoilov, Les champs magnetiques Intenses, Coll. int., Grenoble (1966).

[6] V. B. Zenkevich and V. V. Sychev, Thermal Stabilization of Superconducting coils. Supplement to the translation of Laverick's "Superconducting Magnets" (Russ. Transl.) Mir (1968).

V. I. Rakhovskiĭ. The Dynamics of the Near-electrode Regions in Electric Discharges.

This paper deals with the systematic study of the dynamics of the development of strong-current-discharge cathode spots on different materials in wide ranges of pressure and current, with the object of establishing the basic laws governing the development of cathode spots as a function of the thermo-physical and atomic constants of the cathode material and the parameters of the external circuit: the formulation, as far as possible, of a simple physical model for the cathode region of the vacuum arc; an approximate theoretical description of the dynamics of the development of cathode spots, taking into as full consideration as possible the interrelated processes that ensure the continuity of transfer of current in this region; and a search for conditions for minimum erosive action of the cathode spots on the electrode.

For the study of the dynamics of the development of cathode region discharges ($I = 5$–4000 A, $P = 760$–10^{-5} mm Hg), we used an experimental setup which allowed us to make observations on the cathode spots with sufficient time resolution (10^{-8} sec.) by means of an electron-optical converter and at the same time determine the spectra of the cathode plasma by means of a diffraction spectrograph equipped with a special double-ray photoelectric attachment.

Erosion of the electrodes was investigated using optical and mechanical profilographic methods. As cathode materials we used Sn, Pb, Zn, Cd, Sb, Al, Cu, Pb, Au, Ag, Pt, Ni, Mo, and W.

The investigations showed that after a sparkover on the surface of the cathode there appear near the anode spots of high current density (10^6 A/cm^2) moving rapidly (10^2–10^4 cm/sec) in all directions. Each spot exists entirely independently. The characteristic time of stay of such spots (spots of the first kind) in one place varies, depending on the metal and the external conditions, from 5×10^{-7} sec to 10^{-5} sec. The lifetime of one spot did not exceed 10^{-5} sec. The duration of such conditions in the cathode region increases with increasing thermal conductivity and vapor pressure of the electrode material. The warming-up of localized sections of the surface of the electrode and the decrease in the pressure and in the atomic weight of the surrounding gas create conditions under which the necessary level of production of vapor in the near-cathode region becomes possible only when the individual spots coalesce, their velocity of motion decreases, and the so-called group or multiple spots (spots of the second kind) appear.

These spots appear after time lapses of 10^{-4}–10^{-3} sec from the instant of appearance of the discharge on the warmest part of the surface of the cathode, which, more often than not, is situated in the immediate vicinity of the anode. Spots of this kind are closely connected together: any individual spot, which leaves the boundary of the area occupied by the group, dies off. The current density in these pots is noticeably low (2×10^4–10^5 A/cm^2) and the velocity of motion is negligible (5×10^1 cm/sec) and what is more, these quantities decrease with increasing thermal conductivity and latent heat of vaporization of the cathode material.

The study of the erosion caused by the spots of the first and second kinds showed that while the former do not leave practically any noticeable traces of destruction, the existence of the latter leads to the appearance of considerable localized destruction of the material of the cathode.

On the basis of these experimental investigations, the following model for the development of the processes in the near-cathode region was proposed. Ions create near the surface of the cathode a region of positive space charge whose field acts on the potential barrier at the metal-vacuum boundary, lowering and narrowing the barrier and thereby facilitating the emission of electrons. The incident ions heat the cathode by transfering to it their kinetic and potential energy. The heating of the electrode causes the electrons to occupy energy levels above the Fermi level and, consequently, facilitates electron emission; besides, it causes the evaporation of the electrode material. When the emitted electrons are accelerated into the region of the positive space charge, they ionize the neutral atoms which, now as ions, move towards the cathode, whereby the cycle is completed.

Comparison of the results of theoretical calculations for copper, based on the proposed model, with experimental results gave good agreement and explained a number of peculiar features of the dynamics of the development of cathode spots.

The change from fast-moving to slow-moving spots is quite natural and is connected only with the heating of localized areas of the cathode and with the increase in size of the region of effective emission and evaporation and, consequently, with the decrease in current density, which, as experiment shows, decreases as the