Reports of the Academy of Sciences of the USSR

PHYSICS

1964

SovietRxiv

Abstract

Full Text

Reports of the Academy of Sciences of the USSR
1964. Volume 159, No. 1

PHYSICS

V. V. SYCHEV, V. B. ZENKEVICH, V. V. ANDRIANOV, V. A. ALTOV

ON THE JUMP IN THE CRITICAL ALTERNATING CURRENT OF A SUPERCONDUCTING SOLENOID IN HELIUM UPON PASSING THROUGH THE λ-POINT

(Presented by Academician V. A. Kirillin, 17 VI 1964)

Questions concerning the behavior of superconductors when an alternating current is passed through them have recently been attracting the attention of many researchers. This is connected with the prospects for the practical use of superconducting devices operating on alternating current, and also with the fact that the study of phenomena arising when an alternating current flows through a superconductor is of undoubted interest from the standpoint of the physics of the process.

Superconductors of the second kind, when an alternating current of even comparatively low frequency is passed through them, have an active resistance which, although quite small, is nevertheless measurable (two orders of magnitude smaller than the resistance of copper at these temperatures ([1])). This applies fully also to superconducting alloys based on niobium, which are now widespread. Electrical losses in small Nb—Zr solenoids were studied in work ([2]), and the critical currents for small Nb—Zr and Nb—Ti solenoids at various frequencies—in work ([3]). Both of these investigations were carried out at a temperature of 4.2°K.

The value of the alternating-current strength at which a superconducting solenoid passes into the normal state (I_{cr}) is determined by various factors. In view of the presence of Joule heating in a superconducting solenoid supplied with alternating current, it is obvious that the process of removal of the released Joule heat from the inner regions of the solenoid should have a substantial influence on the value of I_{cr}. The intensity of this process determines the amount by which the temperature inside the solenoid exceeds the temperature of the helium bath and, consequently, the difference between the critical temperature of the given superconducting alloy and the temperature of the inner regions of the solenoid (when this temperature difference passes through zero, the solenoid leaves the superconducting state). Heat removal from the central regions of the solenoid is effected by thermal conduction through the

Fig. 1. Temperature dependence of the critical current density for a solenoid with a brass frame

Figure 1: Fig. 1. Temperature dependence of the critical current density for a solenoid with a brass frame

winding material and by heat transfer to the helium from the surface of the solenoid. A certain role may also be played by the process of heat removal due to heat exchange during evaporation of helium penetrating into the interturn space of the solenoid. It is at present difficult to estimate quantitatively the relative influence of each of the factors mentioned on the value of I_{cr}. In this connection, in order to reveal in more detail the qualitative features of the process, it appeared expedient to study the nature of the variation of I_{cr} with decreasing temperature. The present work is devoted to this aim.

Experiments on measuring the value of I_{cr} in superconducting solenoids were carried out with alternating current of industrial frequency (50 cps), which is of greatest interest from the standpoint of practical applications.

In the experiments, the effective values of the current were recorded. The experimental solenoids were made of wire fabricated from the superconducting alloy 65BT (a multicomponent alloy based on niobium and titanium), developed at the Central Scientific Research Institute of Ferrous Metallurgy. The wire was insulated with viniflex lacquer.

The diameter of the wire without insulation was 0.25 mm, and with insulation 0.30 mm. The packing factor of the solenoid coils with active material was on average 0.60, while the packing factor with the material including insulation was 0.85. The current leads were also made of superconducting material in order to eliminate completely the possibility of their heating during the experiments. The design of the experimental apparatus made it possible to carry out experiments at a reduced pressure of helium vapor in the cryostat. In this way it was possible to lower the temperature in the cryostat to a value of the order of 2°K. In view of the fact that during operation with alternating current the heat release in the cryostat was relatively large, lower temperatures could not be attained with this apparatus.

Fig. 1. Temperature dependence of the critical current density for a solenoid with a brass frame

The first series of experiments was carried out with solenoid I, wound on a thin-walled frame of L62 brass. Parameters of solenoid I: number of turns $n = 6200$, inner diameter of the winding $d_{\text{in}} = 16$ mm, outer diameter $d_{\text{out}} = 45$ mm, winding height $h = 35$ mm. The dependence obtained in the experiments of the critical current density j_{cr} on temperature for this solenoid is shown in Fig. 1.

As can be seen from the figure, up to the temperature of the helium λ-point the value of j_{cr} remains practically constant, while at a temperature of about

Fig. 2. Solenoid with a fluoroplastic frame

Figure 2: Fig. 2. Solenoid with a fluoroplastic frame

Fig. 3. Temperature dependence of the critical current density for solenoids with a fluoroplastic former. 1 –solenoid II, 2 –solenoid III

Figure 3: Fig. 3. Temperature dependence of the critical current density for solenoids with a fluoroplastic former. 1 –solenoid II, 2 –solenoid III

2.17°K the value of j_{cr} increases discontinuously. It should also be noted in passing that, since the transition process to the normal state is determined in this case by heating of the inner regions of the solenoid, a considerable time (not less than 5 min) was required in order to make sure that no transition occurred at the given value of the current.

Fig. 2. Solenoid with a fluoroplastic frame

From the point of view of the possibility of generalizing the results, the experiments carried out on solenoid I were not sufficiently rigorous because of possible heat generation in the brass frame of the solenoid due to eddy currents. Therefore, the subsequent series of experiments were carried out on solenoids II and III with a fluoroplastic frame; the geometrical dimensions of the frame and the design of the solenoid are shown in Fig. 2. Parameters of solenoid II: $n = 5000$ turns, $d_{in} = 16$ mm, $d_{out} = 39$ mm, $h = 35$ mm. Parameters of solenoid III: $n = 2700$ turns, $d_{in} = 16$ mm, $d_{out} = 29$ mm, $h = 35$ mm. The measurement results are presented in Fig. 3.

As can be seen from the data presented in Fig. 3, the value of j_{cr} increases sharply as the dimensions of the solenoid decrease. In the temperature interval from 4.20 to 2.18°K the value of j_{cr} decreases somewhat with decreasing temperature. This decrease, amounting to 2–3% per 1°, is evidently due mainly to a decrease in the thermal conductivity of the winding material with decreasing temperature. It should also be borne in mind that the heat-transfer coefficient to helium decreases with decreasing temperature ([4]). Some increase in the temperature difference between the critical temperature of the alloy and the temperature of the helium bath apparently does not compensate for the influence of the factors indicated above.

At the temperature of the helium λ-point, a jump in the value of j_{cr} is observed. Ne-

a large decrease in temperature below the λ-point leads to an approximately twofold increase in the critical current. At the same time, it is characteristic that, for the solenoid with the smaller winding thickness (solenoid III), the values of j_{cr} increase more sharply as the temperature is lowered below the λ-point.

Fig. 3. Temperature dependence of the critical current density for solenoids

with a fluoroplastic former. 1 –solenoid II, 2 –solenoid III

The results obtained in this work show that the magnitude of the critical density of alternating current depends strongly on the possibility of liquid helium penetrating into the inner regions of the solenoid winding. Apparently, helium vapors formed in the inner regions of the winding do not hinder (at least in the helium-II region) the penetration of liquid helium into these regions. In fact, the results obtained cannot be satisfactorily explained simply by a change in the conditions of heat removal from the surface of the solenoid winding on passing through the λ-point, since above the λ-point as well the heat-transfer coefficient to boiling helium is very large (4), and consequently the temperature difference between the winding surface and the helium bath is very small even at $T > T_{\lambda}$.

The observed effect of a jump-like change in the critical current density in a superconducting solenoid operating on alternating current is of undoubted practical interest, since in a number of cases this effect can be used in the creation of appropriate superconducting devices.

Scientific Research Institute of High Temperatures
of the Moscow Power Engineering Institute

Received
15 VI 1963

CITED LITERATURE

1. J. L. Zar, *J. Appl. Phys.*, **35**, No. 5, 1610 (1964).
2. C. H. Jones, H. L. Schenk, *AC Losses in Hard Superconductors*, Adv. Cryogenic Eng., **8**, N. Y., 1963.
3. E. J. Young, H. L. Schenk, *J. Appl. Phys.*, **35**, No. 3, 980 (1964).
4. M. D. Reeber, *J. Appl. Phys.*, **34**, No. 3, 481 (1963).

Note: Figure translations are in progress. See original paper for figures.