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ON THE PREPARATION AND STUDY OF SUPERCONDUCTORS

By

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The research activities in progress at the Department of Superconducting Materials and at the Department of Applied Superconductivity of the Electrotechnical Institute, Slovak Academy of Sciences, are reported.

The following problems are investigated in two Departments of EI SAS:

I. Department of Superconducting Materials:
  1. Current transport in superconducting materials
  2. Preparation and study of superconducting materials

II. Department of Applied Superconductivity:
  1. Electrodynamic properties of hard superconductors
  2. Superconducting magnets
  3. Magnetometry at low temperature

I.1. Current transport in superconductors

The main theoretical problems concerning the current transport in superconductors are as follows:

I.1.1. Calculation of the volume pinning force and other quantities of the mixed state with model as well as realistic interaction potentials (in the last two years: including the periodicity of the interaction potential) [1]. It was shown that the function volume pinning force F_v vs maximum elementary interaction force K_m depends on the shape and the character (attractive, repulsive) of the interaction potential. The periodicity of the interaction potential leads to the linear dependence of F_v on the maximum elementary force K_m for large K_m. More complicated potentials (attractive + repulsive combinations) were also considered. Some problems concerning the statistically distributed point defects [2], are of basic interest for problems of pinning.

I.1.2. Anisotropy of the critical currents in type II superconductors

a) in transverse magnetic fields ($j \perp B$) [3]
b) in longitudinal magnetic fields (more exactly: with nonzero $j \parallel B$ component) [4].

For the case a), some details will be given below. The calculations in non-transverse magnetic fields show that in superconductors with elongated defects the Labusch's quadratic $F_v(K_m)$ dependence is true, which implies the importance of the elastic response of the flux line lattice on the volume pinning force.

I.1.3. The critical currents in superconductors with rigidly pinned flux line lattice [5]. Taking into account the changes of the distribution function of normal excitations in the energy gap of the superconductor and the changes of the "kinetic" energy of the supereconducting electrons under the influence of an electric current, we have re-examined the basic assumptions and the applicability of the critical-velocity model for the rigidly pinned vortex lattice. The same magnetic-field and temperature dependence of the critical current density has been obtained as in the model of BYČKOV et al, but without any assumption about the field dependence of the density of superconducting electrons. The right value of the characteristic length λ is obtained, thus also allowing a quantitative comparison with the experiments. The new model is applicable for all magnetic fields, in contradistinction to the narrow validity range of the initial model in the immediate vicinity of the upper critical magnetic field.

I.1.4. The processes in forming the flux lines near surfaces of superconductors. These processes were studied by means of time-dependent Ginzburg—Landau equations [6]. We have outlined the first steps of an iteration procedure for obtaining some analytical results of the very complicated system of time-dependent GL equations and solved analytically the equation for the order parameter. The solutions can be used in the theory of the Josephson effect in structures with vortices, too.

I.1.5. The properties of long superconducting bridges with Josephson behaviour [7]. These bridges show the a.c. and d.c. Josephson effect (as well as all effects accompanied by them, such as harmonics and subharmonics of the Josephson radiation, subharmonic gap structure and satellites of these structures) in some extreme conditions (extremely large magnetic fields, large temperature interval). For these investigations, more precise calculations of the structure of the mixed state in thin superconducting films were needed and actually performed. It was shown that the one-dimensional vortex structure (with vortices in the slab centre) is stable in a relatively large magnetic field interval not only for films with a thickness smaller than the penetration depth, but also for films up to approximately 5-times the penetration depth.

I.2. Preparation and study of superconducting materials

In the past few years the aim of research at the Department of Superconducting Materials has been mainly to develop materials for magnets. The following materials were prepared and their basic properties studied:

a) Nb_3Sn tape prepared by diffusion technology;
b) Nb_3Sn tape prepared by CVD;
c) Nb_3Ge tape prepared by CVD;
d) multifilamentary Nb_3Sn.

The technology of these materials is described to some extent in the literature [8]. The following properties were studied:

I.2.1. The I_c vs B characteristics (with B growing up to 20 *T).* A strong dependence upon the technological parameters and the structure of materials has been found [8].

I.2.2. The critical currents anisotropy. It has been found that the critical currents depend upon the external transverse magnetic field vector orientation [3]. From theoretical calculations the conclusion was drawn that this type of anisotropy is caused mainly by the structural grain shape. The influence of this anisotropy upon critical currents of magnetic coils wound of such tape was also studied [9].

I.2.3. Transition temperatures. Two methods were employed, the resistive and the inductive as well. Continuous lengths of the order of 10 m of Nb_3Ge tape were lately prepared with T_c onset being around 20 K [8].

I.2.4. The influence of some mechanical properties upon the critical current of superconductors. Especially, the influence of mechanical loading, cooling and bending has been studied and some empirical conclusions have been drawn.

I.2.5. Stabilization of superconductors. Problems of current flowing between stabilizing material and the superconductor both from the theoretical and technological point of view have been investigated. We have also studied the heat transfer to liquid helium for both open pools and narrow channels under static and/or dynamic conditions as well [10]. Some of the first results have been obtained concerning the flow of liquid—gas mixture under critical conditions.

II. 1. Electrodynamic properties of hard superconductors

II.1.1. Current density distribution in technical superconductors. The current density distribution was studied in monofilamentary and multifilamentary conductors of circular cross-section subjected to various sequences of setting the current and the external field as shown in Fig. 1. The sequence responsible for the self field effect, is to preset a bias field and then to increase the current. Another one is to supply the current in zero field and then to increase the field. The sequence really occurring in a coil is to increase current and field simul-

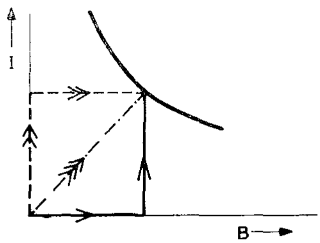

Fig. 1

taneously and proportionally. In all cases the voltage across the sample length of about 2 m was measured and compared with theoretical prediction based on a simplified model (J_c = const) [11, 12]. Calculations and experimental results are in reasonable agreement, especially in the case of pure self field effect, which field proves that the model proposed for field profiles and current distribution is suitable.

II.1.2. Critical current — field characteristics. We have studied the influence of the following parameters on $I_c - B$ characteristics

— temperature [13];
— field orientation with respect to the conductor axis [14];
— anisotropy of the rectangular cross-section conductors [15, 16].

II.1.3. Losses. Two magnetization techniques are used for the measurement of the losses:

— pick-up coils with an electronic integrator;
— Hall plates method based on the measurement of the field created by the magnetization of the sample [17].

We have studied theoretically and experimentally the losses in different types of multifilamentary superconductors and cables for pulsed field magnets [18, 19, 20]. The a.c. losses in Nb_3Sn strips for superconducting power transmission lines are investigated theoretically [21]. A device for measuring the a.c. losses at 50 Hz und 4.2 K in short samples of Nb_3Sn tapes with sensitivity of 0.1 $\mu W/cm^2$ has been developed.

II.2. Superconducting magnets

In the field of superconducting magnets the research work at the Electrotechnical Institute of the SAS has been concerned with the development of solenoids producing very homogeneous magnetic fields (with the aim to use them for EPR or NMR) and with the study of problems connected with their design, building and performance [22, 23]. The problem of suitable coil forms producing very homogeneous magnetic fields has been treated in many detailed papers [24—27] and summed up in [28] with emphasis upon the specific characteristics of the superconductors and their economics. The study of mechanical stress in cylindrical coils culminated in a complex theory of stress due to the pretension at winding, to the unequal thermal expansion of materials at cooling to helium temperatures and due to magnetic forces from current flowing in the turns [29]. Theoretical calculations were compared with experimental results from several superconducting solenoids and an attempt has been made to explain degradation by mechanical reasons [20].

Special attention has been given to the time stability of the magnetic field in coils under persistent current mode operation. The fast initial change of the magnetic field after the current had been frozen-in, was succesfully explained by a transformer model between the transport current in the coil and the eddy currents in the superconductors [31, 32]. In connection with their influence on the homogeneity of the magnetic field the magnetic properties of several construction materials at helium temperatures have been investigated [33]. The economics of the design of large special magnets is the essential point in paper [34]. The critical current of solenoids wound with strip formed superconductors depends greatly on the relative direction of flux lines and the strip surface due to the anisotropy of the critical current density [35]. The study of the normal zone propagation in quenched superconducting windings under various conditions [35] has been performed with the aim to protect the coils. The study culminated in the construction of a special thyristor switch acting when a defined voltage occurred in the winding after the beginning of quenching. This work has been extended to the protection of short circuited coils, too [37]. To measure the homogeneity of the magnetic field a simple compensation method using Hall probes and a Kelvin bridge has been elaborated [38]. A complex experimental diagnostic system for laboratory superconducting magnets has been proposed [39]. The last research work in the field of superconducting magnets is done in the analysis of magnetic forces in various types of superconducting coils for magnetic separators in view of the restrictions following from the characteristics of the superconductors and the influence of iron cores [40, 41]. The first successful attempt to build a superconducting coil producing a low 50 Hz alternating field and measure its losses was made several years ago [42].

II.3. Magnetometry at low temperature

Several types of Hall plates suitable for operation from room down to liquid helium temperatures have been developed [43]. They are characterized by the good linearity of the Hall voltage — magnetic field characteristics as well as by the very small temperature coefficient of the Hall voltage.

Further, the precision of measurements of magnetic field vector components with Hall plates with respect to the planar Hall effect has been studied [44].

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