ON He II MICROSTABILIZATION OF Nb_3Sn*

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The Abrikosov-Mendelssohn[1] theory describes the hard superconductor of the second kind in the mixed state as a multiply connected structure of supercurrent filaments orthogonally penetrated by an array of flux vortices of diameter of the coherence length. The coexistence of the normal and superconducting phase has become possible through the "hardening process," which made the surface energy for boundaries between the two phases negative. On the one hand, this has improved the current-carrying capacity in these materials to such a degree that superconducting magnets became feasible. But, on the other hand, it also enhanced their instability since no positive boundary energy inhibits the propagation and growth of the normal phase zones propagating as "flux jumps" in the superconductor.

With changing field and/or current density, the density of fluxoids changes and the vortices move through the superconductor in or against the direction of the Lorentz force. This flow is not a continuous movement but an erratic one, since the vortices display an affinity to crystal defects and lattice imperfections. Within the course of this discontinuous, rapid movement, joule heat is being dissipated, heating the superconductor locally. If this heat is allowed to accumulate, it can form macroscopic normal zones — macroscopic in terms of the coherence lengths — which propagate as "flux jumps" through the superconductor until their propagation is impeded by the rapidly rising specific heat, or until they have driven the total superconductor normal.

The condition limiting the formation of macroscopic normal zones is that the electromagnetic diffusivity has to be smaller than the thermal diffusivity. The importance of these two quantities was first discussed by Furth[2] in connection with pulsed magnets. Kim[3] discusses their relationship macroscopically for superconducting magnets. It is also essential to secure this condition on a microscopic scale compatible with the coherence length.

One approach in this direction is to divide the superconductor into very fine filaments embedded in a metal matrix of high thermal capacity and thermal and electric conductivity. This approach finds its limitations in the Wiedemann-Franz law, which governs the ratio of thermal to electrical conductivity in metals; the low strength of ultrapure metals used as stabilizers on superconductors, which introduce severe mechanical support problems in high field magnets; and fabrication technology, since a metallurgical bond of high electrical and thermal conductivity is required between the

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1. A.A. Abrikosov, J. Exp. Theor. Phys. 32, 1442 (1957);
   R.A. French, J. Lowell, and K. Mendelssohn, in Proc. 9th Intern. Conf. Low Temperature Physics (Plenum, New York, 1965), Part A. p. 540;
   R.A. French, J. Lowell, and K. Mendelssohn, Cryogenics 7, 83 (1967).
2. H.P. Furth, M.A. Levine, and R.W. Waniek, Rev. Sci. Instr. 28, 949 (1957).
3. Y.B. Kim, Phys. Today 17, No. 9, 21 (1964).

superconductor and its stabilizing metal. This approach usually leads to average current densities within the coil-winding body, which do not exceed 10% of the current densities within the superconductor itself, at the same field and temperature conditions. Voluminous coil windings with their inherent mechanical and thermal problems are the consequence.

There appears to be a second intriguing possibility. We have seen above that the basic problem of stability is the heat of dissipation associated with the discontinuous movement of the fluxoids. Stabilizing a superconductor means to remove this heat before it can accumulate into macroscopic normal regions. The principal question, therefore, is how to extract this heat most expediently. It has been pointed out — for instance, by Hancox[4] — that the thermal capacity of liquid helium is more than one hundred times greater than that of Nb_3Sn. Several experimenters[4,5] have demonstrated that porous sintered cylinders of Nb_3Sn could be stable against flux jumping for field changes up to 50 kG if liquid helium is admitted freely to the pores. Within the sintered material, Claude achieved 150 kA/cm^2 current density at 50 kG in such a sintered cylinder by circulating liquid helium through the material, without any flux jumps occurring. These results should encourage one to attempt stabilization of Nb_3Sn by supercritical helium, but we believe that before one should proceed in this direction, one should first investigate the unique possibility nature has provided us for this very problem. One should attempt to exploit the unique heat transport mechanism of superfluid helium, which can set up heat flows of several W/cm^2 over temperature gradients of only millidegrees with very small losses, and possibly even no losses at all.

One has to separate carefully the above effects from those which are due to the increase in current-carrying capacity with decreasing temperature.

We have started experiments aiming at the observation of He II microstabilization of Nb_3Sn. As a first step, we have constructed two identical solenoids, consisting of two counterwound spirals of 100 turns each. The over-all dimensions are 2 in. i.d., 3½ in. o.d., and 1-1/32 in. axial length. The first solenoid was wound with RCA-R-60322 silver-plated 1200 A at 100 kG niobium-tin vapor-deposited superconductor. This ribbon was wound interleaved with a stainless-steel ribbon of 0.001 in. × 0.4 in.[6] In the second coil, we removed the silver-plating completely — by chemical means — laying bare the niobium tin. The space vacated by the silver and stainless-steel ribbon was filled by fiberglass cloth. The first coil was initially operated at 4.2°K in boiling He I. The coil could be charged up to about 50 kG at a current density of 40 kA/cm^2. During the charging process, "flux jumps" could be observed with a magnitude of up to 50 mV. In the second experiment, the coil was again charged, but at a temperature of 1.85°K in superfluid helium. The most pronounced difference between these two experiments was the noise reduction during the charging process.[7] Only small "flux jumps" with an amplitude of about 1 mV could be observed. This noise level experienced further reduction below the limit of detectability of our system, which was about 10 μV, during the charging of the second coil at 1.85°K in superfluid helium. We have not yet attained with the second coil any higher current densities or fields than with the first one, since we had to leave the silver on the very ends of the superconductor ribbons in

4. R. Hancox, Phys. Letters 13, 208 (1965).

5. M.L. Claude and M. Williams, in Proc. 2nd Intern. Conf. Magnet Technology, Oxford, 1967, p. 497.

6. Kindly supplied to us by W.B. Sampson of Brookhaven National Laboratory.

7. W.B. Sampson, M. Strongin, A. Paskin, and G.M. Thompson, Appl. Phys. Letters 8, 191 (1966).

order to solder the joints and possibly because the superfluid had access only to the surface of the vapor-deposited layer. We have evidence that the second coil was quenched from "flux jumps" propagating from these joints into the spirals, but we feel that the most significant observation of this experiment is the complete elimination of "flux jumps" propagating partially through the coil during charging operations, which suggests to us that we may have been successful in preventing the development of macroscopic normal zones. Further investigations are in progress to clarify whether this interpretation is justified.

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