FINAL REPORT

on

FLUX PINNING AND STABILIZER STUDIES

U.S. Department of Energy, Division of High Energy Physics
Contract No. DE-AC02-86ER40296
(8/28/86 to 11/31/92)

to the

Advanced Technology Research and Development Branch
Division of High Energy Physics
U.S. Department of Energy
Washington, DC 20585

by

E.W. Collings
Principal Investigator

BATTELLE
505 King Avenue
Columbus, OH 43201
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A synopsis of the results of the flux-pinning and stabilizer studies that form the central theme of the subject contract is followed by a list of papers that were published during its time period -- 8/28/86 to 11/31/92.

FLUX-PINNING RELATED STUDIES IN NbTi

Physical and Superconducting Properties of NbTi and NbTiMn: Transport measurements of residual electrical resistivity, ρ_n , and superconducting transition temperature, T_c , have been made on a series of NbTi alloys both with and without the addition of 0.5 wt% Mn. Wires that had already experienced cold drawing followed by a single precipitation heat treatment were measured after further cold drawing (CW), again after a second precipitation heat treatment (CW+PHT), then again after further cold drawing (CW+PHT+CW). ρ_n measurements were also made on samples taken from ingots that had been quenched from the bcc phase (βQ). **Resistivity:** From βQ (ingot) to CW (wire) a decrease in ρ_n was noted; this was followed by a further decrease from CW to CW+PHT; subsequent CW then raised ρ_n . The results of PHT could be interpreted in terms of α -phase precipitation and the concentrations of Nb and Mn solutes within those precipitates. **Superconducting Transition Temperature:** For reference the T_c s of calorimetrically measured βQ ingots were noted. From βQ to CW an increase in T_c was observed; this was followed by a further increase in T_c from CW to CW+PHT; subsequent CW then

decreased T_c . ***Beta-Stabilizing Strength of Mn:*** Using a simple model calculation for the resistivity of a two-phase alloy we interpreted the difference between the concentration dependences of ρ_n of the NbTi and NbTiMn series in terms of differences in α -phase precipitate concentration. It was concluded that as a stabilizer of the β phase (suppressor of α -phase precipitation) Mn is 4-6 times stronger than Nb, in agreement with earlier results.

PROPERTIES OF THE MATRIX (STABILIZER)

Filament Surface effects: Although the effect of surface superconductivity on hysteresis losses in longitudinal orientations have been studied extensively, not so in the transverse case. For bulk superconductors, surface superconductivity has a negligible influence on the hysteretic loss. However, in fine filament materials, since the surface comprises a rather large portion of the superconductor this will no longer be the case. Magnetic hysteresis measurements have been made on fine multifilamentary NbTi/Cu and NbTi/CuMn composites, both as constructed and with the matrix etched away. Hysteresis loss comparisons have been made for both transverse and longitudinal orientations, and for a range of filament diameters.

PROXIMITY EFFECT

Position and Amplitude of Proximity Effect Peaks: High resolution magnetization studies of low-field proximity-effect enhanced magnetization of NbTi/Cu composites have been made. Particular emphasis was placed on the displacement ΔH , of the proximity effect peak from the origin. A previously observed dependance of ΔH on the field-sweep amplitude, H_M , has been more thoroughly investigated. The H_M dependance of ΔM can be described in three different regimes: (1) below the H_{C1} of the filaments, (2) $H_{C1} < H < 2H^*$, and (3) $H > 2H^*$ where H^* is the field at which full penetration occurs. In region 1, ΔM is characteristic of a type II superconductor with weak pinning. In regions 2 and 3 the H_M dependance of ΔM can be explained in terms of demagnetization effects and their role in creating a local minimum in the interfilamentary field. Such Field minima occur when, after full field penetration (i.e. $H > H^*$), the applied field is reduced to near zero. The proximity effect, being highly field dependant, becomes greatest at this B field minimum. In region 2 the magnetization of the NbTi is a rapidly varying function of H_M in the region of the minimum, and thus so is ΔH . In region 3 ΔH has saturated, since full penetration has been reached and the NbTi magnetization is slowly varying in the region of the proximity peak. A model for the H_M dependance of ΔH has been developed.

PROXIMITY EFFECT AND STRAND DESIGN

Advanced Strand Design: Nonsuperconducting saddle magnets can in principle be designed to produce an undistorted dipolar magnetic field. But if the coils are wound from superconducting strands, residual magnetization, M_R , resident in the strand material itself is responsible for multipolar distortions of the desired field. It is well known that the height of the $M(H)$ hysteresis loop, viz. $\Delta M(H) \equiv (M_{R+} - M_{R-})$, where the signs refer to the trapping (paramagnetic) and shielding (diamagnetic) branches of $M(H)$, respectively, is proportional to the product of filament diameter, d , and critical current density, $J_c(H)$. Thus in an attempt to reduce strand magnetization (in the presence of high J_c) and the attendant field distortion, a strong effort has been under way to produce, on a commercial scale, multifilamentary strands with smaller and smaller filaments. In order to preserve filament quality in small filaments (i.e. to prevent thickness undulations, or "sausaging"), it has been suggested necessary to confine the ratio of filament spacing (s) to filament diameter (d) to $s/d \leq 0.15 \pm 0.02$. The combination of small d with low s/d results in interfilamentary spacings sufficiently close to proximity-effect couple the filaments. For example, at an s/d of 0.15, Cu-matrix filaments that have been reduced to $5\frac{1}{2} \mu\text{m}$ in diameter are beginning to exhibit coupling; and the coupling becomes worse as d is still further reduced. But if the interfilamentary matrix is alloyed with $\sim 0.5 \text{ wt.}\%$ Mn, coupling is barely perceptible even with $1 \mu\text{m}$ diameter filaments. Next, having disposed of an excess magnetization due to proximity-effect coupling one is still faced with the inherent magnetization of the NbTi filaments themselves. During the operating cycle (field-increasing) of the SSC magnet, this magnetization is diamagnetic; accordingly it can be neutralized by including in the superconducting strand a material with a large positive magnetization, such as Ni. To be sure, Ni barriers have been incorporated into multifilamentary strands to eliminate proximity-effect interfilamentary coupling, and bulk Ni inserts have been recommended for magnetization compensation in SSC dipoles, but the idea of associating Ni directly with the strand for local magnetization compensation is relatively new. It may turn out to be convenient to add the Ni as an electroplated layer on the outside of the strand, or to include it within the strand in the form of replacement- or extra filaments. In this work some strand designs have been recommended and developed.

MULTIFILAMENTARY STRAND DESIGN

Magnetically Compensated Strands: Nonsuperconducting saddle magnets can in principle be designed to produce an undistorted dipolar magnetic field, but if they are wound from *superconducting* strands, residual magnetization, M_R , (i.e. "persistent current") resident in the filaments causes a multipolar distortion of the desired field. Numerous ways of reducing this magnetization or its effect, at both the strand-design and magnet-design levels, have been proposed. Central to the various possible "magnetization-compensation" approaches is the fact that during the

operating (field-increasing or "shielding") branch of the SSC magnet's excitation cycle, M_R is mostly diamagnetic. Such a negative magnetization can obviously be neutralized by the inclusion within the magnet of strategically placed ferromagnetic-Ni elements. Early studies have suggested that magnetization compensation could be achieved through the insertion of bulk Ni into the dipole "wedge". But in this work we have ascertained that the Ni can be associated with the composite strand itself, either in the form of replacement filaments or as an electroplated coating on the outside surface.

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RESEARCH PUBLICATIONS
FOR THE PERIOD
8/28/86 TO 11/31/92

**PUBLICATIONS FOR THE PERIOD
8/28/86 TO 11/31/92**

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EFFECT ON THE MAGNETIZATION SEXTUPOLE AND DECAPOLE IN
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