PERFORMANCE OF COMPOSITE COPPER–SUPERCONDUCTOR SOLDERED CONDUCTORS

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INTRODUCTION

The stabilization technique of superconducting coils, which has been introduced by Laverick [1], Stekly [2], and Whetstone et al. [3], has been successfully applied to the practical construction of large superconducting coils. This paper touches on the concept of quasi-stable superconducting coils, the maximum allowable disturbance that can be associated with these coils, and presents information on some basic experiments using small pancake coils which are made of composite copper–superconductor soldered conductors (ribbon type). Voltage drop, heat dissipation, and temperature rise of the coils submerged in liquid helium were measured, and these experimental data are compared with theoretical predictions.

THEORETICAL CONSIDERATIONS

A small pancake coil (7 cm ID and 14 cm OD) was made of a copper conductor (0.1 cm in thickness and 1 cm in width) and submerged in liquid helium. The top surface of the pancake coil was kept in direct contact with liquid helium while the bottom surface of the coil was covered with an epoxy resin and thermally insulated. Current was supplied to the coil and both voltage drop (Joule heat) and temperature rise vs coil current were measured. The average heat dissipation vs temperature rise of the conductor was evaluated and is shown in Fig. 1. The resulting curve depicts the heat transfer characteristics of liquid helium and is similar to the curve obtained by Lyon [4] and Wilson [5]. Curve a–b is associated with nucleate boiling of liquid helium while curve c–d is associated with film boiling of liquid helium.

This experimental result permits one to obtain an approximate prediction of the performance of a stabilized superconducting coil submerged in liquid helium [5]. When the conductor current I is increasing, the voltage drop V per unit length of a stabilized conductor is given by

\[ V = 0 \quad \text{if } I < I_c \]  
\[ V = r_b (I - I_c) \quad \text{if } I_c < I < I_u \]  
\[ V = r_u I \quad \text{if } I_u < I \]
where

\[ r_b = \text{resistance of the copper ribbon of the stabilized conductor per unit length (1 m) at 4.2^\circ K} \]

\[ I_u = \frac{1}{2} \left[ I_c + \sqrt{I_c^2 + 4h\Delta T_{\text{max}}S/r_b} \right] \]

\[ h\Delta T_{\text{max}} = \text{maximum nucleate heat flux} \]

\[ S = \text{cooling surface per unit length of the conductor} \]

When the current is decreasing, the voltage drop is given by

\[ V = r_b(I - I_u) \quad \text{if } I_e > I > I_r \quad (5) \]

\[ V = 0 \quad \text{if } I_c > I_r > I \quad (6) \]

where

\[ I_r = \sqrt{h\Delta T_{\text{min}}S/r_b} \]

\[ h\Delta T_{\text{min}} = \text{minimum film-boiling heat flux} \]

Therefore, performances of stabilized superconductors are classified as follows: the absolutely stable region \((I < I_e)\); the quasi-stable region \([I_r < I < I_s < I_u]\); and the absolutely resistive region \((I_u < I)\).

The design current of large superconducting coils tend to be limited by the recovery current \(I_r\). In the quasi-stable region the voltage drop defines two possible states: (1) the superconducting state \((V = 0)\) or partially superconducting state \([V = r_b(I - I_u)]\); and (2) the resistive state \((V = r_bI)\).

**MAXIMUM ALLOWABLE DISTURBANCE**

The quasi-stable superconducting coil is expected to have reversible terminal characteristics when the coil current is raised slightly above the critical current. However, there is always the possibility that the coil might undergo sudden transition from the superconducting to the resistive state because of external and/or internal disturbances.* The maximum allowable disturbance which may be applied to the

* Current pulse, current ripple, heat pulse, wire movement, flux jumps, etc.