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# Wed-Af-Po.04-05: Development of 600 A-class current leads for cryocooler-cooled devices using copper and REBCO wires

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To achieve a controllable operating temperature for superconducting magnet devices, the development of cryocooler-cooled superconducting magnets has garnered significant attention. Typically, the excitation current of commercially available cryocooler-cooled superconducting magnets ranges from approximately 100 to 200 A. However, increasing the excitation current of superconducting magnets is desirable for applications such as superconducting magnetic energy storage (SMES) systems in electric power systems. Achieving a high-current coil winding requires careful design and development of current leads that connect the room-temperature and low-temperature sections.

To address the challenges and design considerations associated with achieving high current flow through cryocooler-cooled current leads, the authors developed and tested 600 A-class current leads for cryocooler-cooled devices. In this research, the authors utilized a two-stage GM cryocooler, with a cooling capacity of approximately 60 W at 70 K in the first stage and about 15 W at 20 K in the second stage.

The current leads are composed of copper and high-temperature superconducting (HTS) components to minimize heat transfer to the low-temperature section. Initially, the copper parts were placed between the first stage of the cryocooler and the room temperature section. The optimal length-to-cross-sectional area ratio is typically determined through numerical analysis, using the average resistivity and thermal conductivity values over the temperature range to reduce conductive and Joule heating of the copper current leads. However, experimental results revealed that such designs might lead to localized overheating of the current leads. To address this issue, the authors substituted the physical property values at each temperature into a differential equation to obtain the temperature distribution through numerical analysis, thereby optimizing the shape ratio. With this new design approach, the optimal length-to-cross-sectional area ratio was $6.32 \times 10^3\ \mathrm{m}^{-1}$ at the operating current of 600 A, between 300 K and 60 K. To prevent overheating caused by Joule heating, the length of the copper parts should be designed to be 90 % of the optimal length. The authors demonstrated that a flat braided copper current lead with an effective cross-sectional area of $60\ \mathrm{mm}^2$ and an effective length of 341 mm could prevent localized overheating, as confirmed through experimental testing.

The authors conducted a short-circuit current test on the copper parts assembly of the current leads. The test results showed that the temperature at the low-temperature end, connected to the first stage of the cryocooler, remained below 70 K even when a current of 600 A was applied for 300 seconds. These findings demonstrate the feasibility of a 600 A-class cryocooler-cooled current lead and suggest that the research outcomes could serve as a model for cooling current leads in high-current applications.

On the other hand, for the HTS current leads connecting the first and second stages of the cryocooler, it is essential to limit conductive heat to 15 W at 20 K. This requirement is met using two strands of 12 mm-wide REBCO tape wires manufactured by Fujikura Ltd. The critical current of the REBCO wires is 719 A at 77 K in a self-magnetic field. This paper summarizes the design conditions and the test results of the 600 A-class cryocooler-cooled current leads using copper and REBCO wires.

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