CURRENT LEAD DEVELOPMENT

H.W. Weijers, G. Miller, S. Kenney, J. Miller (NHMFL)

Introduction

Current leads with steel-shunted HTS lower parts and nitrogen-vapor-cooled resistive upper sections are envisioned for the Series Connected Hybrid outsert. The same technology is also considered for the rebuild of the existing 45T Hybrid outsert. An innovative aspect is the structure of the upper lead, which is constructed by rolling up a stabbed copper sheet. This creates a tortuous network of narrow passages axially and radially that provides a very large heat exchange surface area. The construction techniques used to fabricate these leads are convenient, moderately inexpensive, amenable to commercialization and especially appropriate for high-current applications (5 to 20 kA and higher). The lower end of the resistive element in the lead is kept near 77 K through a small reservoir for liquid nitrogen built into the lead. Boil-off from this reservoir provides the vapor for cooling the upper lead, which reduces heat load to the reservoir by about half. The intent of the research reported here is twofold:

(1) Establish the upper lead-voltage and nitrogen mass-flow characteristics versus operating current.
(2) Validate and tune the LN_2-supply system to automatically maintain a small amount of LN_2 in the chamber at all operating current levels

Experimental

The experiment was performed in Cell 16, the Large Magnet Component Test Facility. A single upper lead section was mounted through the top flange and ends above the LN_2 level in a cryostat. The return path for the current was provided by a solid copper bar that passes through the cryostats LN_2 bath and a solid copper rod parallel to the vapor cooled lead. An array of fiber-optic sensors was used to detect the liquid level in a reservoir at the bottom of the lead section. Level information was fed into a unit that controls a valve between a LN_2 supply vessel and the reservoir. One of the NHMFL magnet power supplies provided the current.

Results and Discussion

Vapor-cooled current leads operated in self-demand mode have an optimum current. Above or below that current, the required cooling is larger than what could be achieved by an improved design. For a given material used to fabricate the lead, the voltage drop across the lead is a unique value when operating at the optimum current. This feature greatly simplifies a determination of the optimum current for a particular lead. For the present lead, the calculated voltage at optimum current is 52 mV. The projected optimum current was 10 kA with a vapor flow of 1.9 g/s. When operated continuously at 10 kA, however, the lead voltage remained ≤38 mV, even though the flow rate was maintained in the range 1.6-1.8 g/sec. On the other hand, after 0.5 hours at 13 kA the voltage drop and flow rate exceeded the design values by ~10% and the temperature of the upper end of the lead slowly kept going up. The head pressure in the LN_2 supply tank at this point was insufficient to provide adequate flow to the lead, even with the control valve fully open, explaining at least part of the temperature rise. It is expected that, with a relatively simple improvement of the LN_2 supply vessel head pressure, the upper lead would operate at the design voltage and gas flow for continuous operating currents around 11-12 kA.

Conclusions

Measured lead voltage and gas flow show that the 10 kA specification is conservative for the resistive lead element tested. This was as expected and validates the design and construction of the upper lead. Experimental conditions that are not typical for the intended application caused the temperature of the upper end of the lead to deviate from design conditions. This limits the accuracy in comparing the actual and design parameters. Better control of the head pressure in LN_2 supply vessel is required to keep up with demand for extended amounts of time when the upper lead is operated at or near the maximum operating current. The minimum heat load/current ratio for this lead of this lead is interpolated to be in the 11-12 kA range.

Reference

Miller, J.R. *et al.*, IEEE Transactions on Applied Superconductivity, **15**, No.2, 1492-1495 (2005).