Thermohydraulic Analysis of Helium Flow in the NHMFL SCH Magnet Outsert Coil

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Introduction
The NHMFL has finalized the design of the Series Connected Hybrid magnet system (SCH), a vertical bore, 36 T low-resolution NMR magnet to be installed at the NHMFL. The SCH has been developed over last few years and consists of a resistive insert (a group of concentric nested Florida-Bitter magnets) and a superconducting outsert layer-wound with a graded cable-in-conduit-conductor (CICC) with Nb$_3$Sn/Cu strands forced-flow-cooled with supercritical helium at about 4.7 K and 3.4 bar (at the inlet) delivered by a helium refrigerator. The superconducting outsert is definitely the most demanding part of the SCH. Reliability and stability of the outsert during normal operation and its behavior predictability in emergency situations as well are critical to the whole project success. The main challenge lies in the fact that one operational scenario is a so-called cyclic operation when the magnet is linearly ramped up to a desired field (typically to the full field of 36T) and then ramped down, typically to zero field, cycle after cycle (Fig. 1), at a rather high rate, resulting in very significant AC losses in the coil and thus reducing the temperature margin. In order to withstand such challenging operational loads with a predetermined stability margin, the CICC and the coil have been properly designed. To do so, a sophisticated and complex thermohydraulic analysis was required. The results of this analysis then played a critical role in specifying the SCH cryogenic system design.

Approach to the Thermohydraulic Analysis
Over last few years we have developed an effective approach to model realistically all the thermohydraulic operating conditions including normal cyclic operation fast discharge, quench, etc. To do this, we heavily modified the code GANDALF developed by CERN. To better predict AC losses, magnetic field and strain variations. Also, we used our latest experimental data for the AC loss level in the cable and the cable current carrying capacity depending on the field, temperature, and strain, and the Twente scaling law was used to fit the $I_c$-dependence [2,3]. Assumptions on critical current degradation based on numerical modeling [4] were appropriately included along with the friction factor fit [1] derived from our special experiment [3]. A block to model the electrical circuit in all possible situations was also added. Numerous comparable analyses were conducted to justify the approach. All this made it a very effective tool enabling us to proceed with the outsert design.

Results and Conclusions
The results of thermohydraulic analysis showed that the magnet can be safely discharged if required at predetermined rates and the quench protection system developed is efficient enough. A regular thermohydraulic regime was discovered, enabling one to continuously cycle the magnet at a rather high current ramp rate (up to almost 40 A/s) without waiting time intervals between the cycles [1]. The temperature margin can be maintained at higher ramp rates, up to about 55 A/s, if short idle current periods between the cycles (Fig. 1) are allowed [1].

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References