Resistive Shims for High-Field Resistive and Hybrid Magnets

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Introduction

The National High Magnetic Field Laboratory (NHMFL) has been funded by the National Science Foundation to construct a Series-Connected Hybrid (SCH) magnet system operated with a single 12 MW power supply which will produce 36 teslas and 10^{-6} field homogeneity and stability over a 1 cm diameter spherical volume [1]. The NHMFL presently operates a 25 T resistive magnet, referred to as the Keck magnet, which employs ferroshims that correct the field homogneity to 1.2 x 10^{-5} at 25 T over a 1 cm DSV [2]. The targeted SCH specification will extend the present boundary of the high-field, high-homogeneity experimental environment to 10^{-6} homogeneity at 36 T. As a first demonstration, a new shimming technique will be installed and operated in the Keck magnet to improve its homogeneity from 10^{-5} using ferroshims (10^{-4} unshimmed) to 10^{-6} at 25 T. Resistive shims have been selected for the SCH due to their operational flexibility. Unlike ferroshims, resistive shims can be adjusted to provide corrections throughout the range of available background field enabling scientific users to study the field dependence of various scientific phenomena such as nuclear magnetic relaxation. The resistive shims can also be adjusted as needed to optimize the field correction as resistive magnet coils are replaced over the system lifetime.

Novel Shimming Technique

A novel shimming technique (patent application no. 60/854654) is proposed for the SCH that locates resistive shims on the inner bore of the resistive magnet to allow cooling of the shims from the pre-existing resistive-magnet cooling water supply. The novel technique employs single-turns capable of carrying 150 A as opposed to, for example, 150 turns at 1 amp to minimize the electrical insulation that impedes cooling from the water channel. The traditional conductor locations and circuits for the transverse shims have been modified to allow a single conductor in a novel circuitry for both the X and ZX (and Y and ZY) terms. The modified transverse shim circuits in combination with the optimized conductor axial location resulted in elimination of any lengthwise overlap and the associated increase in thermal impedance. In addition, a Z0 coil is fabricated into the shim set as part of the system to correct for temporal field instabilities in the magnetic field. The resultant radial build of the shim assembly is less than 5.0 mm – a key parameter at the inner bore of a high-field magnet. As an important developmental step, a fully operational shim set will be installed in the Keck magnet to allow the system to be demonstrated and characterized by regular user operation before being employed in the SCH.

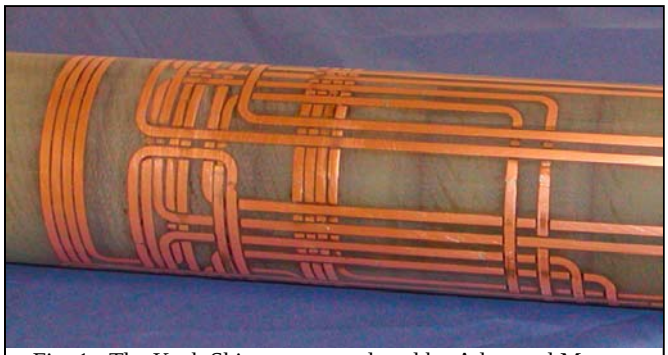

Fig. 1: The Keck Shims were produced by Advanced Magnet Lab to demonstrate and characterize performance and operation in a 25 T resistive magnet before integrating into the NHMFL SCH.

Conclusions

A novel shimming technique has been conceptualized, designed and built (Fig. 1) for correcting spatial inhomogeneities inside a high-field resistive or hybrid magnet system. The shimming technique uses resistive conductors located on the bore tube of the resistive magnet where (a) they can be cooled by a pre-existing flow of water required for the resistive magnet and (b) they require several orders of magnitude less ampere turns than superconducting shims traditionally located on the outer diameter of the superconducting magnet. A novel shim circuitry has been employed which allows the transverse shim terms to be divided and recombined to allow a minimum of turns. A complete working shim set with six terms has been built and will be installed in the 25 T Keck Magnet at the NHMFL in early 2008 to demonstrate the feasibility of this technique to meet the targeted objective of the SCH of 1 x 10^{-6} homogeneity in a 36 T central field region.

Acknowledgements

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References

[1] Miller, J.R., *et al*., *IEEE Trans. Appl. Supercond*., **14** (2), 1283-1286 (2004).
[2] Bird, M., *et al*., *IEEE Trans. Appl. Supercond.*, **12** (1), 447-451 (2002).