Design, Construction and First Testing of a 41.5 T All-Resistive Magnet

Toth, J. and Bole, S. (NHMFL)

Introduction

It has been over 10 years since the NHMFL has fully up-graded its all-resistive standard solenoid high field magnets. Over that time period it has been successfully operating four ~20 MW installations routinely providing fields up to 35 T in a 32 mm bore (cells 8 and 12) and 31 T in a 50 mm bore (cells 7 and 9) to its user program. The major common limiting factor of those designs for a substantial next generation up-grade was the outer diameter of the most outer coil being fixed at 610 mm. The presented upgrade [1] including a 6.5 T field increase from 35 T to 41.5 T in Tallahassee was primarily achieved by increasing the size of the outmost coil to 1 meter and taking advantage of its facility capable to supply over 33 MW of electric power to a single water cooled resistive magnet. This installation as shown on **Fig. 1** doubles the access to fields above 40 T to users in Tallahassee and presents the only DC magnet worldwide allowing a continuous sweep of the magnetic field from -41.5 T to 41.5 Tesla (within 8 minutes).

Results and Discussion

The NHMFL has developed the design of its next generation 32 mm bore Resistive Magnet. This new design employs a set of six state-of-the-art resistive coils (upgraded from four coils) including Florida-Bitter technology (invented at the NHMFL) as well as extensive axial current density grading for optimal stress and power management.

The resistive magnet winding has been designed to withstand all thermal loads at full operating current (48 kA) based on parametric hydraulic models providing estimates for the cooling conditions in the various cooling channels. All evaluations for peak temperatures in the winding are based on conservative thermal boundary conditions (friction coefficient of 0.05) with flows corresponding to a 25 bar pressure drop.

All disk geometries have been iteratively optimized to provide relatively uniform temperature distributions across each individual plate with peak temperatures not exceeding ~120 C in any part of the winding. Detailed parametric electromagnetic FEA was performed to determine the worst case combination of current density and magnetic field in each unique winding section of the six resistive coils. Structural loads based on these parameters have been calculated and imported into a coupled structural FEA evaluating structural deformations as well as stress distributions for each winding sections. All winding sections satisfy the structural design criteria of von Mises stresses not to exceed 660 MPa for the CuAg windings and 350/300 MPa for the 0.44/0.75 mm thick Cu disks. A summary of the final design parameters satisfying all requirements is listed in **Table 1**.

Fig.1 The new world record 41.5 T all-resistive magnet with completed user platform installed in cell 6 of the NHMFL DC user facility.

Table 1 General Coil Design Parameters

Coil	A1	A2	B	C	D	E
Inner Radius (IR) [mm]	19.0	33.1	69.1	119.3	220.0	343.0
Outer Radius [mm]	32.3	66.1	116.3	197.0	340.0	500.0
Midplane Winding Height [mm]	228.0	279.0	436.0	557.0	730.0	730.0
Total Winding Height [mm]	500.0	500.0	730.0	710.0	730.0	730.0
Midplane Winding Material	CuAg	CuAg	CuAg	Cu	Cu	Cu
Endturn Winding Material	Cu	Cu	Cu	Cu	Cu	Cu
EM Field Contribution [T]	5.16	8.23	8.81	7.50	8.32	3.46
ave IR Current Density [A/mm^2]	643	426	278	137	127	48
max Disk Temperature [C]	120	108	108	99	95	99
max ave Stress [MPa]	658	658	655	341	302	49

Conclusions

The NHMFL has finished the design and construction of its next generation 32 mm bore Resistive DC Magnet capable to generate up to 41.5 T peak field with an electric power consumption below 33.5 MW. This comprehensive upgrade was performed within an aggressive 2.5 year time frame from the start of the design process to successful first testing (conducted August 21, 2017).

Acknowledgements

This work was supported in part by the National Science Foundation, Cooperative Agreement No. DMR-1157490 and the State of Florida.

References

[1] J. Toth and S. Bole, “Design, Construction and First Testing of a 41.5 T All-Resistive Magnet at the NHMFL in Tallahassee”, *IEEE Trans. On Appl. Supercond.*, vol. 28, no. 3, April 2018, doi 10.1109/TASC.2017.2775578