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DESIGN, FABRICATION AND PERFORMANCE OF LOW CURRENT SUPERCONDUCTING BEAM LINE DIPOLE

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ABSTRACT

A low current superconducting coil intended for use in a beam transport dipole magnet was built and tested. The coil design, fabrication, quench protection, and tests results are presented.

I. INTRODUCTION

We constructed and tested a low current prototype coil for the beam transport in the Fermilab High Intensity Laboratory. A low current configuration was achieved by winding the coil with a cable consisting of 15 electrically insulated strands which were ultimately connected in series.[1]

COIL PARAMETERS

Cable	15 insulated strands
Bare Strand Diameter	1.02 mm
Cu/NbTi Ratio	2.9/1.0
Strand Insulation	Triple Nyform
Cable Wrapping	B-Stage Glass Tape .177 mm thick
Coil Length	1.264 m
Cold Bore	.152 m
Operating Current	222 Amp (72% ss)
Number of Strand Turns	4920
Cable Current Density	1.6×10^4 A/cm^2
Central Field without Iron	3.4 tesla
Stored Energy	220 kilojoules
Coil Inductance	8.8 henries
Central Field with Iron (Expected)	4.3 tesla

II. COIL DESIGN AND FABRICATION

Our coil cross section is presented in Fig. 1. Four constant current density shells are wound about G-10 pole pieces approximating a cosθ current distribution.[2] The 15 strand cable is wrapped with a .178 mm B-Stage epoxy impregnated glass tape with a small space between wraps. This produces a pattern of radial cooling channels (typically .2mm x .2mm). Spacers between coil shells provide azimuthal passages of dimension .8 mm x 12.7 mm.

The shells are compressed to size and the B-Stage tape is cured on a mandrel before transfer to the stainless steel bore tube. After assembly of all shells, a final layer of Scotch-Ply Tape is applied and cured with the coil under radial compression. This layer is then machined to produce a .53 mm room temperature interference fit with the inner diameter of the aluminum support tube. The aluminum tube was heated to 120°C before sliding onto the coil package. Further radial clamping of the conductor is obtained from the differential thermal contraction between the stainless steel bore tube and the aluminum support tube. The aluminum pipe has ≈2.5 cm wall thickness with longitudinal helium passages on the inner wall at both ends.

The low current configuration is achieved by connecting the strands for each of four coil sections in series and then connecting the four sections in

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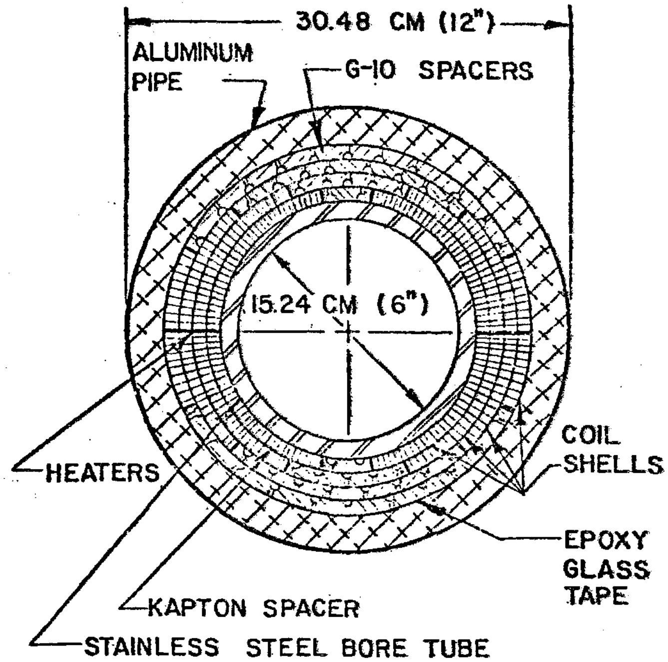

Fig. 1. Low Current Coil Cross Section

series. These connections are arranged to minimize the adjacent strand to strand voltages during quenching.

III. QUENCH PROTECTION

The basic quench protection scheme is presented in Fig. 2.

An AC bridge compares the voltages across coil sections A-B and C-D. Upon detection of a voltage imbalance signifying a quench, the power supply trips and the SCR quench switch turns off forcing the current to decay through the four external resistors. Lead voltage detectors will also trigger the protection circuitry.

Previous tests with a similar inductance racetrack coil demonstrated the ability of safety leads to shunt current around a quenched section. Therefore, in this test each coil had a pair of leads attached to its own external resistor, thereby reducing the danger of a local burnout. The protection system was designed to withstand the expected 900 volts across the magnet leads. The use of individual external resistors also limited the maximum voltage across each coil to one-fourth of this value or 225 volts. We have also learned from the racetrack and other small coils that our porous structure provided good stability against quenching. Consequently the quench propogation velocity was too low to effectively spread the internal energy dumped in the coil during a quench.

A small solenoid test coil was fabricated using an insulated cable consisting of 14 superconducting strands along with a single copper strand. Upon detection of a quench, the full magnet current was shunted through the copper strand which acted as a heater. This successfully quenched the coil at currents greater than 100 amp. However, below 100 amp the heat produced was not sufficient to quench the superconducting cable.

The dipole presently under discussion was out-

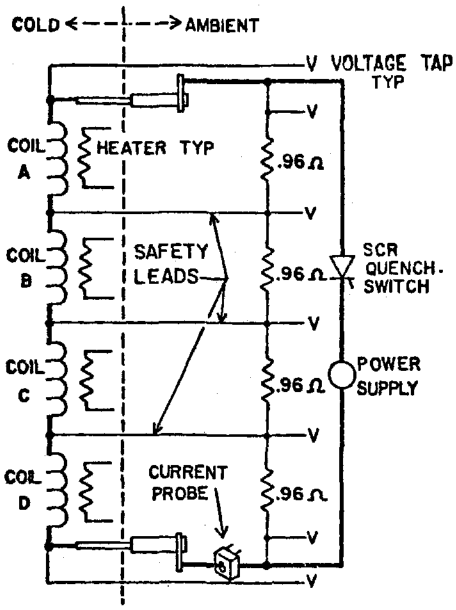

Fig. 2 Quench Protection Circuitry

fitted with four stainless steel heaters located in the magnet midplane between shells. A separate external power supply was energized at quench detection providing approximately 2 watts per centimeter along the length of the heaters.

IV. TEST PROCEDURES AND RESULTS

The coil was tested without iron in a vertical test dewar. The currents and voltages were recorded during training quenches in order to monitor the energy dumping specifically with regard to estimation of the maximum local coil temperature.[3]

The magnet training history during three cool downs is shown in Fig. 3. The coil reached its 222 amp operating current after approximately 25 training quenches and continued to train up to 239 amp. There is minimal tendency to retrain to reach this higher current on subsequent cool downs.

The estimated maximum local coil temperature during quenching is shown in Fig. 4. This is calculated from the time dependence of the current assuming no heat transfer to the helium or to the adjacent conductors. Furthermore, our safety lead system shunts current out of the loop in which the quench occurred. Hence the loop with the longest current decay time likely has minimal quenching.

The ability of the heaters to reduce the maximum temperature was tested by preventing the heaters from firing in the 215 amp region. They produce almost a 100°K difference in T_{max} and keep our maximum coil temperature always within safe limits.

Approximately 20-30% of the magnet's stored energy was dissipated internally in the coil. During two quenches at 238 and 239 amps, the SCR quench switch failed to turn off although the power supply tripped off. This removed the external resistors from the protection circuit. The heaters produced enough internal quenching so that the coil was able to safely absorb its total stored energy, raising the maximum estimated temperature to 550°K without damage.

V. CONCLUSION

A 8.8 henry low current coil has been built and successfully tested to design current. The energy dumping problems have been solved using individual external resistors for each of the four coil sections along with internal heaters to induce further quenching. We are presently installing the coil in its cryostat and iron shield and hope to install the complete system in the High Intensity Laboratory shortly.

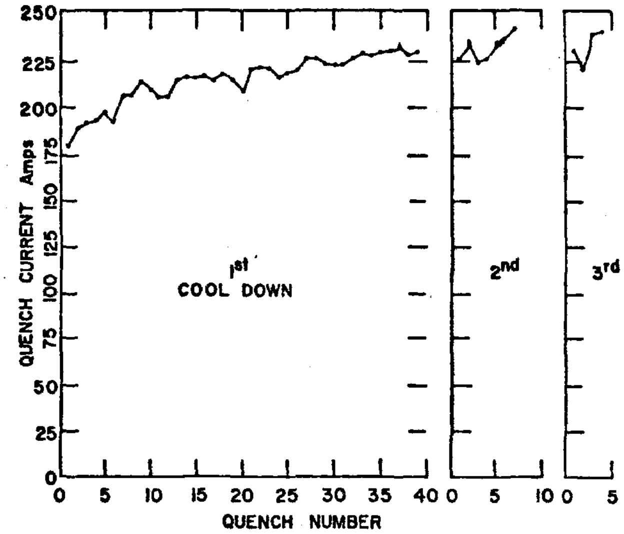

Fig. 3 Coil Training History

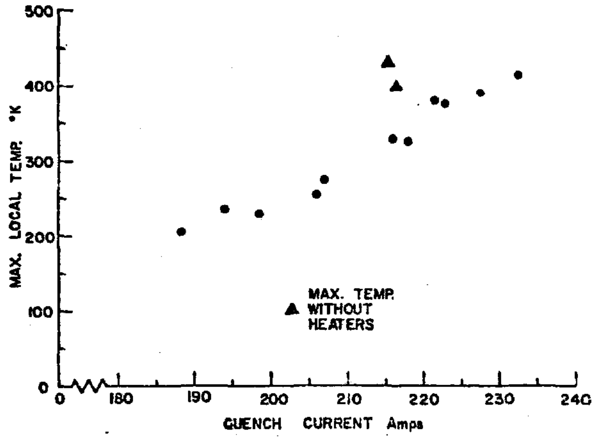

Fig. 4 Maximum Coil Local Temperature During Quench

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REFERENCES

1. J. A. Satti, "Superconducting Coil Manufacturing Method for Low Current DC Beam Line Magnets", IEEE Transactions on Nuclear Science, Vol. NS-24, No. 3, 1251, June 1977.

2. S. C. Snowdon, "Design of Superconducting High Energy Beam Line Dipole Magnetostatics", IEEE Transactions on Nuclear Science," Vol. NS-24, No.3, 1257, June 1977.

3. R. H. Flora, et. al., "Quench Development in Magnets Made with Multifilamentary Nbti Cable." IEEE Transactions on Magnetics, Vol. Mag.-13, No. 1, 28, January 1977.