Final Report on Design and Construction of a Radiation Resistant Quadrupole using Metal Oxide Insulated CICC

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INTRODUCTION

Producing magnets that survive in high radiation environments is a concern for RIA (FRIB) and several other high-intensity projects under consideration, such as the Neutrino Factory and FAIR project at GSI.

Different approaches were used to try to boost the current density that is available from resistive-magnet technology. The first approach was to find a radiation resistant epoxy and to fabricate coils the same way we have been doing it for twenty years. The next way was to make cryostable magnets, like the S800 Spectrograph dipole, but using all-inorganic materials. The final approach was to develop radiation resistant Cable-In-Conduit-Conductor (CICC), like the conductor used in the fusion magnets. It should be noted the CICC approach used in fusion magnets is not radiation resistant because some type of organic insulator is used. The approach taken here is to produce a CICC with an inner electrically isolated part (conductor and liquid helium) and an outer skin to use to form the coil. This is illustrated in Fig. 1. One final note that the nuclear radiation heating of the first quadrupoles in the RIA Fragment Separator is so high the iron will have to be at room temperature and the cold mass minimized.

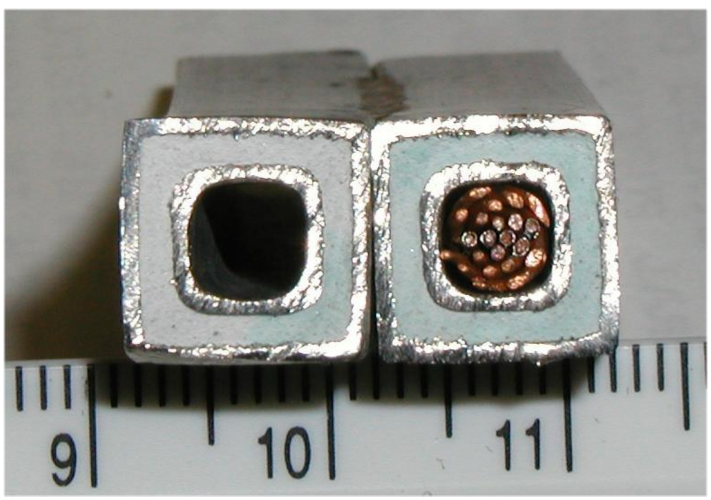

Fig. 1. Sample of metal oxide insulated CICC.

CICC

What makes the metal oxide insulated cable radiation resistant is that structural strength is obtained by brazing the coils together. Similarly, the radiation resistance of the resistive coils is obtained by potting the coil in solder. However, unlike the resistive conductor, the amount of stainless steel in both the inner and out sheaths needs to be minimized to give the maximum current density. Because of the large forces on the coils, the brazing is not strong enough to support the forces, so a backing system is used to provide the necessary strength.

In addition, it’s known that synthetic spinel (MgAl oxide) is more radiation resistant than magnesium oxide or aluminum oxide. Therefore, we changed the insulation in the CICC to spinel. Tyco Thermal Controls (Pyrotenax), who provides the standard metal oxide insulated copper conductor, has been able to provide the conduit in the necessary lengths.

QUADRUPOLE DESIGN

The coil design uses two flat race-track coils per each quadrant. The large coil is a double pancake of five turns per layer and the small coil is two turn per layer double pancake. This arrangement is shown in Fig. 2. The vendor was able to supply lengths sufficient to wind the coils without additional splices. The conductor consists of 60 strands of superconducting wire that have a copper to superconductor ratio of 2:1. The magnet load line is shown in Fig. 3. The operating current to produce the required field is about 6 kA.

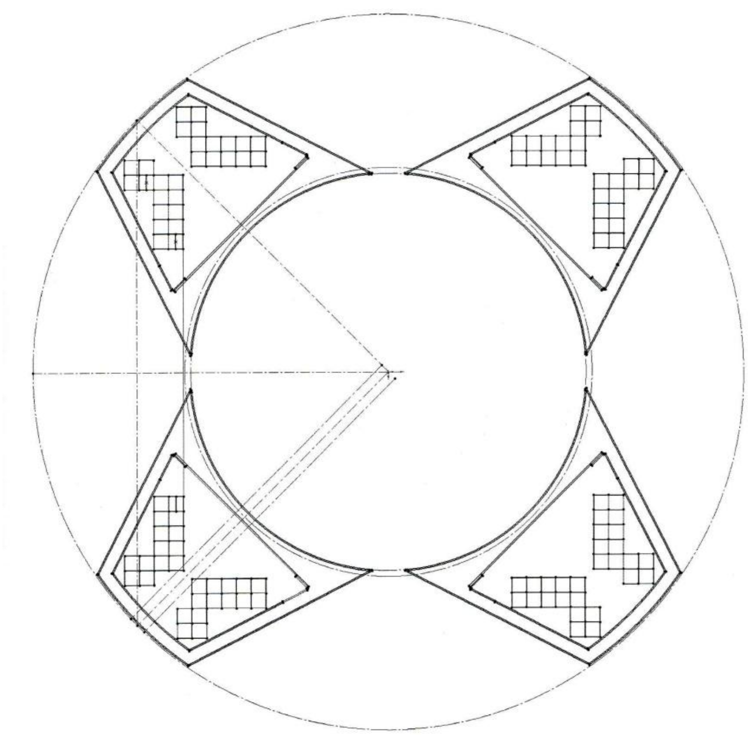

Fig. 2. Cross section of the quad.

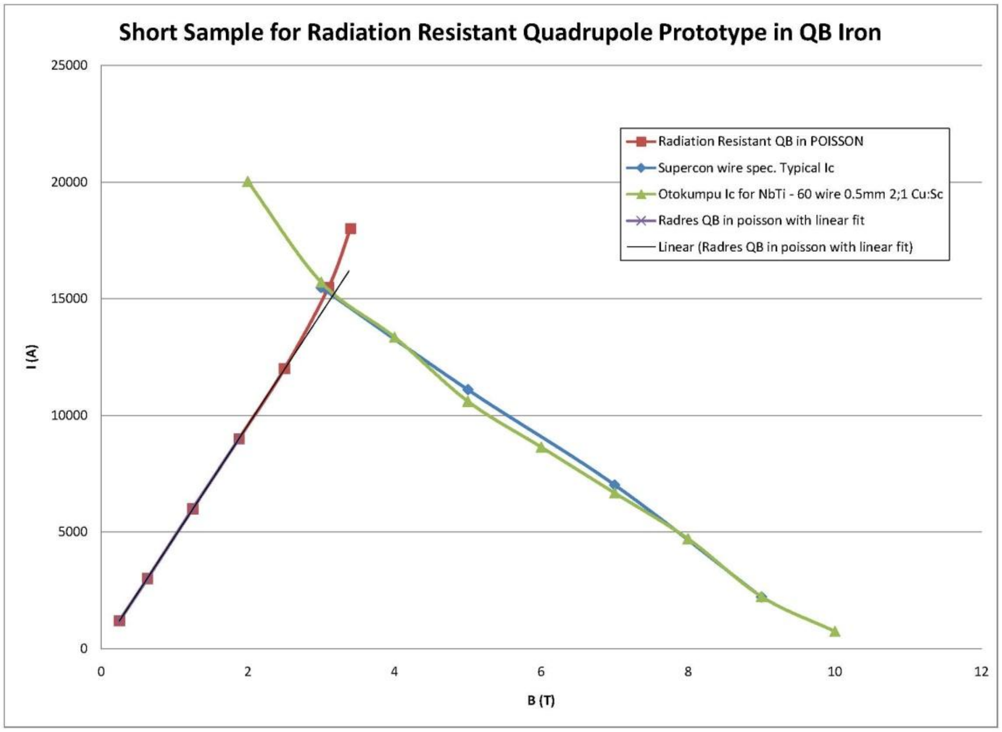

Fig. 3. Load line for the coils in the quadrupole.

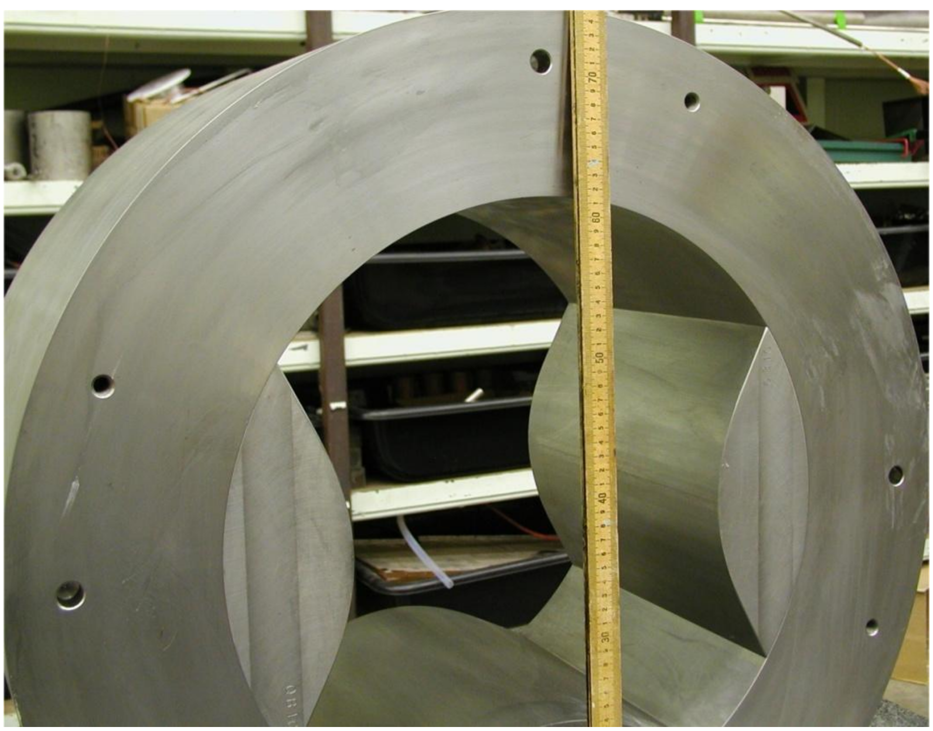

Fig. 4. Magnet iron with one pole tip removed.

The iron yoke, a spare A1900 quad, is shown in Fig. 4, prior to assembling the coils around the pole tips. For simplicity, the quadrupole will have cold iron, instead of the warm iron needed for use in the fragment separator. This simplifies the design and reduces cost. Cryostat construction is something that NSCL has been doing for thirty years, so no R&D is required.

QUARDUPOLE CONSTRUCTION

The construction of the cold iron quad proceeds along the path of:

Conductor insertion into the conduit
Coil winding
Coil placement
Wiring the sub-coils together

The conduit comes to the lab straight, so the conductor can be inserted without having to remove the bends. The conduits are shown in Fig. 5. Typically, inserting the conductor takes about two days.

Fig. 5. Straight sections of the conduit.

After the conductor has been inserted it is prepared for winding. Since the sub-coils are double pancakes, the second layer is supported above the winding fixture while the first layer is wound. This is shown in Fig. 6. The actual coil winding is a labor-intensive operation, as can be seen in Fig. 7. A complete first layer is seen in Fig. 8. The second layer is then wound on top of the first and the braze-joints are ground flat. This can be seen in Fig. 9.

Fig. 6. The conductor for the second layer is supported above the winding fixture.

Fig. 7. Coil winding.

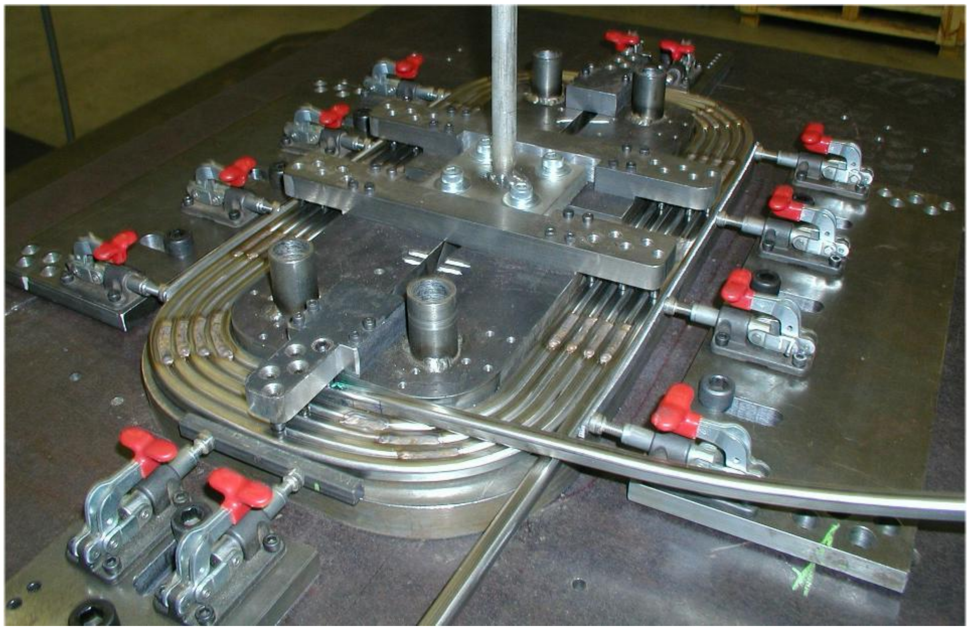

Fig. 8. The complete first layer. Note the conductor for the second layer going off to the right and the braze-joints securing the winding.

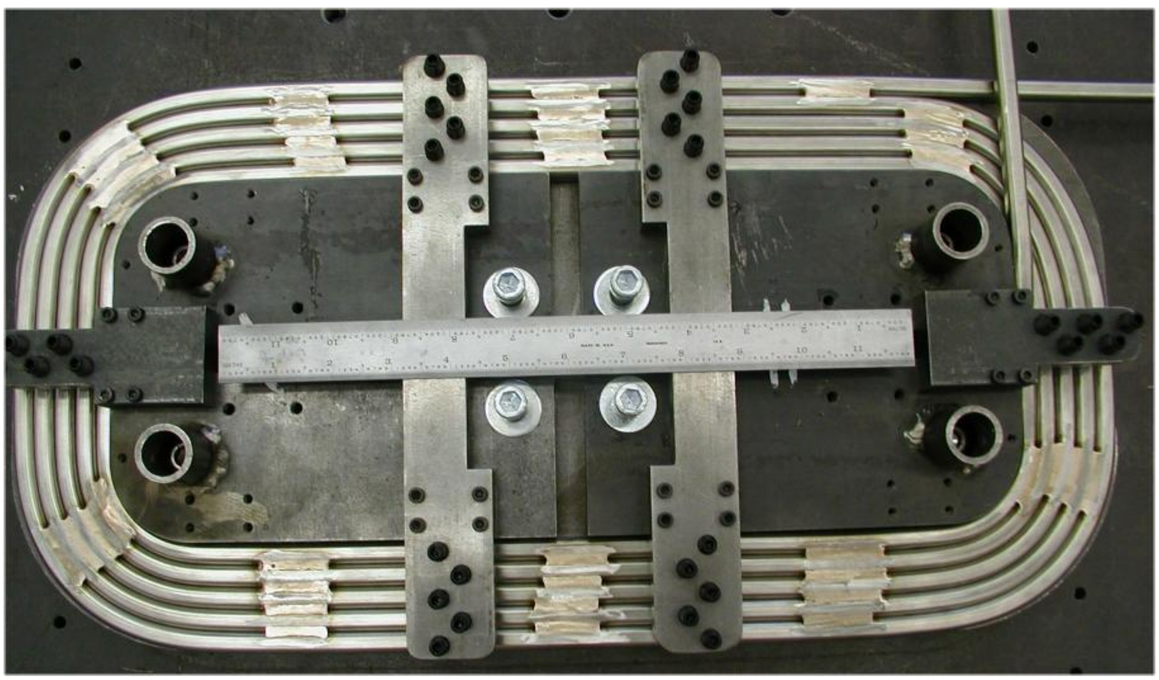

Fig. 9. A complete sub-coil with ten turns. The braze-joints holding the coil together have been ground down.

ASSEMBLY

The sub-coils are then assembled around each pole piece. Each sub-coil needs to be connected in series electrically. The sub-coils are in parallel for liquid helium circulation. The connections between sub-coils require a joint that allows liquid helium circulation. This is shown schematically in Fig. 10. The two conductors (60 individual conductor in each conductor) are placed side-by-side and crimped together. Fig. 11 shown a test splice. The whole splice assembly is placed in a can that will contain the liquid helium. The splice is insulated from the can with a ceramic piece (left side).

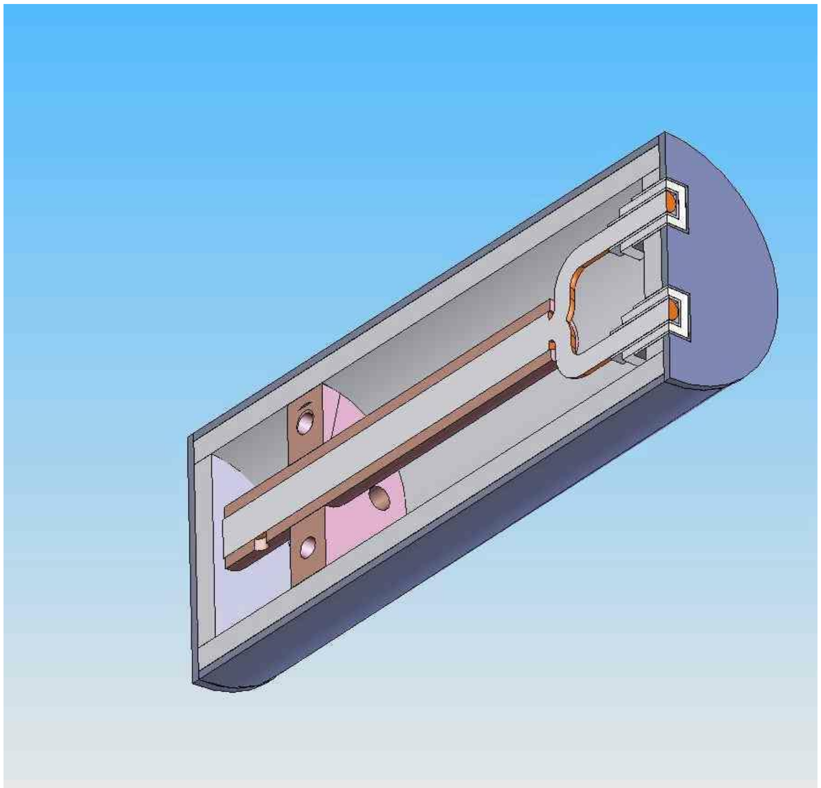

Fig. 10. Splice can design showing the sub-coil conductors placed side-by-side and supported by a ceramic insulator.

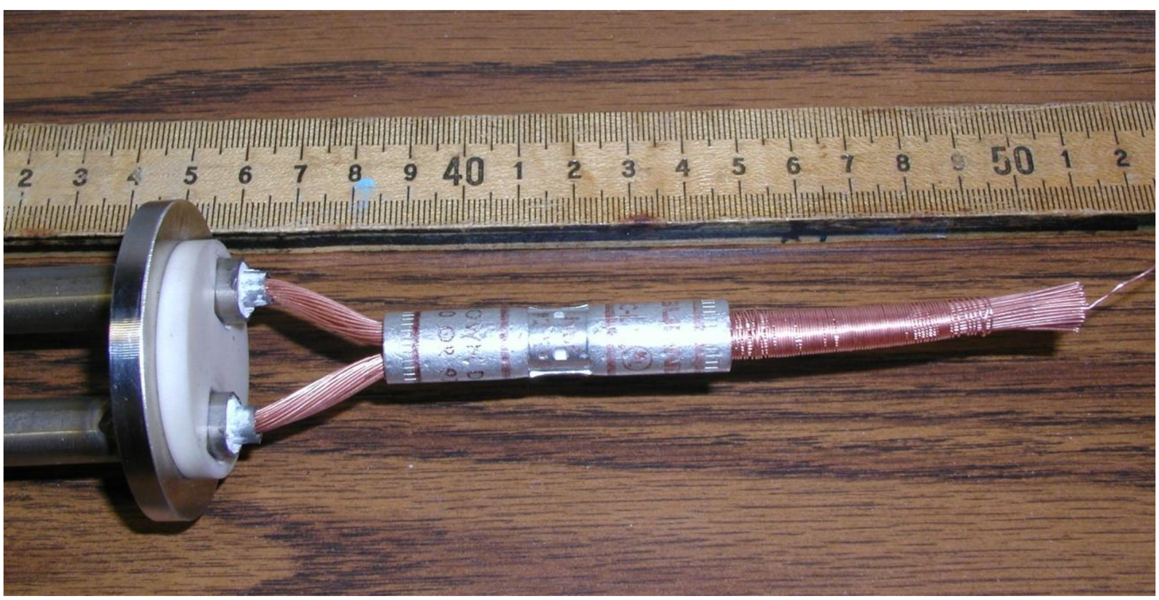

Fig. 11. Test splice.

The complete quadrupole is shown in Fig. 12. The two current leads are to the right. The small coil of wire at the top is the connections to the voltage taps and the co-wound wire that allows measurement of the coil voltage during ramping. The co-wound wires allow cancellation of the inductive voltage generated during ramping.

Fig. 12. Complete quadrupole.

SUMMARY

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A radiation resistant superconducting quadrupole using metal oxide insulated CICC has been designed and built. This version uses cold-iron, in contrast to a quadrupole that would be used in a fragment separator, where the iron would need to be a room temperature.