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CONSTRUCTION AND TEST OF SUPERCONDUCTING QUADRUPOLE PROTOTYPES FOR HERA

R. Auzolle, A. Patoux, J. Perot and J.M. Rifflet

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Résumé – Quatre quadrupoles prototypes pour la machine HERA à DESY (Hambourg) sont actuellement construits et testés à Saclay. A ce jour, deux quadrupoles ont été testés avec succès (pas de training et bonne qualité de champ).

Abstract – Four quadrupole prototypes for the HERA machine at DESY (Hamburg) are being constructed and tested at Saclay. So far two quadrupoles have been constructed and successfully tested (no training, good field homogeneity).

GENERAL MAGNET DESCRIPTION

Figure 1 is a cross-sectional view of the quadrupole in its cryostat. The coils (1) consist of two layers of conductors precisely held in position by a system of collars (2) made of stacks of non-magnetic stainless steel sheets. These collars confine the electromagnetic forces acting on the coils. The coils and their frame are mounted in a tube (3) by means of keys (4). This ensures longitudinal rigidity while preventing any twisting of the magnet about its central axis. The annular space between the tube (3) and the particle beam chamber (5) is filled with circulating helium pressurized at 2 to 4 bar. Tubes (6) contain flowing helium boiling at 1 bar (4.2 K). The heat of vaporization of the boiling helium provides cooling for the pressurized helium. A thermal screen (7) at 50 K limits radiated heat input from the vacuum enclosure (9), which is made of soft iron and constitutes the ferromagnetic circuit. The components at the temperature of liquid helium and the screens are held rigidly with respect to the room temperature part by titanium tie-rods (10).

Fig. 1 – Magnet cross section.
Table I - Main magnet parameters

- Central nominal gradient .............. 88.86 T/m
- Central gradient due to the iron yoke ... 0.94 T/m
- Nominal current ...................... 5582 A
- Focusing power ...................... 171 T
- Magnetic length ...................... 1.924 m
- Coil inner diameter .................. 75 mm
- Stored energy ...................... 76 kJ

THE CONDUCTOR

The conductor is a "Keystoned" flat cable of the Rutherford type containing 23 strands. It is insulated first by two layers of Kapton tape 10 mm wide and 25 μ thick with 80% overlap and second by a 10 mm wide and 135 μ thick fiber glass ribbon with a 4 mm gap between adjacent turns. This last ribbon contains a B stage epoxy resin. Each strand is 0.83 mm in diameter and contains about 2000 filaments of 13 μ. The copper to superconducting ratio is 1.8 to 1 and the twist pitch 25 mm. The cable has a dimension of (1.33 - 1.67) x 9.5 mm² without insulation. Its critical current is 6800 A at 5.5 T and 4.2 K.

COIL CONSTRUCTION

The first coil layer is wound on a cylindrical mandrel with key provided for coil angles.

The completed half coil is then put under hydraulic pressure in a first mold and cured at 160°C for 2 H, the maximum force applied is 500 t.

After curing, the layer is removed from the mold, and fiber glass spacers are put on top of it to provide helium channels between the two layers. The second layer is then wound on the first one and cured the same way in a second mold.

All the tooling such as winding mandrel, coil keys, curing mold, are made of punched laminations stacked together up to the needed length (2 m). Using punched lamination gives a very good accuracy and allows to duplicate this tooling for mass production with small extra cost.

Once molded, four coils are mounted around another cylindrical mandrel. This last mandrel is not laminated because it must slide on the coil surface in order to be removed after assembly. Ground insulation made of four layers of 0.125 mm thick Kapton sheet is provided at the outer diameter of the coils and the stainless steel laminated collars are stacked over the coils (Fig. 2).

Fig. 2 - Coils collaring
This stacking is made in such a way that two adjacent pairs of laminations are mounted perpendicular to each other so that two opposite coils are alternatively held by the central keys of the laminations. The collared magnet is then put in a quadrupolar press which applies correct prestress on the coils by pushing the collars in four perpendicular radial directions.

With the pressure still applied, the laminations are fastened together by means of keys so that the applied prestress remains in the coils after the press is removed. After all the collars have been pressed and fastened the central mandrel is removed with an hydraulic jack.

MAGNET TESTS

a) Critical current:
So far two magnets have been made and tested. The working temperature of the quadrupole is 4.6 K in pressurized helium, but the tests took place in a vertical cryostat in boiling helium at 4.2 K.

The current was raised to the nominal current (5582 A) without quench, then raised up to 6335 A which is the critical current at 4.6 K. This last current represents 90% of the critical current at 4.2 K. No quench has been recorded.

The equivalent of the critical current at 4.6 K being reached, no try was made to quench the magnet above this value. The second magnet behaved the same as the first.

b) Field measurements:
The multipole coefficients have been measured using rotating pick-up coils. One correction coil is used to cancel the quadrupole term and another one to cancel the dipole term coming from an off-centering of the rotating system. All these coils extend axially from the middle of the quadrupole to far beyond the end so that the half field-integral is measured.

The multipole field coefficients have the following definition:

$$\frac{\Delta B}{B} = \sum_{n=2}^{n=\infty} C_n \left(\frac{Z}{a}\right)^{n-2}$$

a is the inner coil radius,
Z is any complex coordinate within the useful aperture.

On Table II, the $\Delta B/B$ due to each term is given up to $n = 10$ for $a = 25$ mm corresponding to $Z/a = 0.67$.

CONCLUSION

The two quadrupoles which have been constructed reached their critical current without any training.

Field homogeneity is within a few $10^{-4}$ for most of the multipoles inside the useful aperture.

Therefore the design and the construction techniques used for the quadrupoles can be considered adequate for mass production. Complete tests in their forced flow cryostat remain to be made and cryogenic systems to be checked, such as the suspension scheme.
Table II
\( \Delta B/B \) at 25 mm (67% of coil aperture) for nominal current (in \( 10^{-4} \) units)

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<th>Designed value</th>
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ACKNOWLEDGEMENTS

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