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The MQXA quadrupoles for the LHC low-beta insertions

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Abstract

High-performance superconducting quadrupole magnets, MQXA, for the LHC low-beta insertions have been designed, manufactured in series and tested. The design field gradient of the quadrupole, which has a coil aperture of diameter 70 mm, was 240 T/m at 1.9 K; its effective length is 6.37 m, and it is required to operate reliably at up to 215 T/m when subjected to radiation heat deposit in the coils of up to 5 W/m. The series of 20 magnets has been produced in industry, and tested at KEK. The magnet design is explained, and the construction and performance of the series units, in terms of training, field quality and geometry, are presented.

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Keywords: Accelerator magnet; Superconducting magnet; LHC insertion magnet; Magnet test; Magnet field quality

1. Introduction

The magnet system for the inner triplets of the four LHC low-beta insertions features 32 high-performance superconducting quadrupoles [1]. Sixteen of these magnets are supplied by KEK. The large aperture 6.37 m long magnets are designed to work safely at 240 T/m, with the coils sufficiently permeable to superfluid helium at 1.9 K to ensure continuous reliable operation at up to 215 T/m when up to 5 W/m of heat is deposited in the coil windings due to radiation emanating from the interaction of the colliding particle beams.

A development program was initiated in 1996, and to confirm the ongoing design five 1 m long model magnets were built and tested at KEK from 1998 to 2000. This was followed by the fabrication of two full-scale prototypes, which served to transfer the technology to industry prior to the main production run. The 20 series magnets,

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including four spare units, were produced in industry between 2001 and 2004, and have been tested and measured in superfluid helium at KEK. The report presents the salient features of their design, construction and performance.

2. Magnet design

2.1. Overview

The cross-section and main parameters of the magnet are presented in Fig. 1 and Table 1. The field in the MQXA quadrupole is produced by an assembly of four, series-connected, superconducting coils. Each coil quadrant is composed of two two-layer coils, called the inner coil and the outer coil, with the current density in each of the four shells approximating a $\cos 2\theta$ distribution. The coils are made of keystoned Rutherford cable of two types: inner and outer. The cables have the same width but different thicknesses, with the thinner outer cable running at a higher current density; they are insulated with multilayer polyimide tape. The inner coil incorporates two wedge spacers, one in each layer, which allow a fine adjustment of the field quality in the magnet straight section; the outer coil has no such wedges. The complex form of the ends calls for a number of spacers designed to optimize field quality and to minimize peak field in the winding.

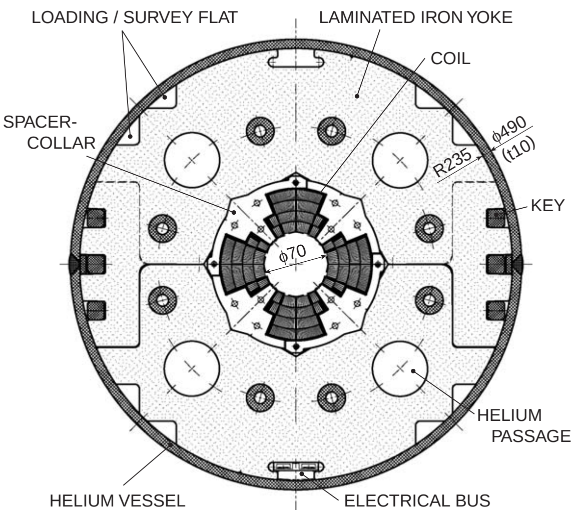

Fig. 1. Cross-section of the MQXA insertion quadrupole.

Table 1
Main parameters of the MQXA superconducting quadrupole

Field gradient (T/m)	215
Coil inner radius (mm)	35
Yoke outer radius (mm)	235
Magnetic length (m)	6.37
Peak field in coil (T)	8.63
Excitation current (A)	7149
Superconductor load line ratio	0.80
Inductance (mH)	87.9
Stored energy (MJ)	2.24
Magnetic force/octant (MN/m)	1.19 (radial)
	1.37 (azimuthal)

The quadrupole coils are accurately positioned by thin, non-magnetic steel spacer-collars, and pre-stressed and mechanically supported by means of collaring laminations that form the thick iron flux-return yoke. The outer shape of the spacer-collars includes a ridge to locate the quadrupole coil assembly via corresponding grooves in the iron yoke. The yoke laminations have four round holes for superfluid helium penetration, two rectangular grooves for housing the electrical connection buses, and specific cutouts for fabrication and alignment purposes.

The horizontally split iron yoke is assembled under sufficient compression to provide correct pre-stress of the coil and tight contact between the upper and lower yoke blocks, and this position is maintained by inserting keys into designated slots on either side of the magnet. Further support is provided by the cylindrical wall of the helium vessel, which fits tightly around the yoke. To restrict the elongation of the coil due to the Lorentz forces on the coil ends, the external end spacers are supported via stainless steel end plates that are fixed to the helium shell. The electrical splice assembly is mounted, via an insulation layer, on the outer surface of the lead end plate.

The choice of a graded four-layer as opposed to a two-layer coil geometry was based on (i) the relative ease of winding a coil with a smaller cable, (ii) the possibility of having a full keystone angle,