Design of Superconducting Quadrupole Magnets for CEBAF's Hall A Spectrometer

R. Kreutz, E. Brütsch, K. Dreher, H. Grüneberg, H. Lütkehaus,
W. Nick, H. Peschel, B. Rzezonka, F. Sommer, P. Schäfer
Siemens AG, KWU, Accelerator and Magnet Technology
W-51425 Bergisch Gladbach 1 and Mülheim, Germany

Abstract

The detailed design for the construction of the Q2/Q3 quadrupole magnets for CEBAF's Hall A High Resolution Spectrometers is presented. The quadrupoles have a warm bore diameter of 600 mm and a cryostat length of 3 m. The quadrupole coil will be wound from a cable conductor carrying a current of 1850 A, the field gradient is 3.5 T/m. A set of eight superconducting multipole coils is positioned in the helium vessel within the bore of the main coil. Each multipole coil is supplied by a separate current lead. The cold mass is suspended by eight support rods of Titanium, sized for a static load of 3 g omnidirectionally, which are fixed at the iron yoke tube sourrounding the magnet cryostat. Cold alignment of the quadrupole coil relative to the iron yoke is possible via these supports. The detailed design of the quadrupole coil, the multipole coils, the current leads, the cryostat and of the iron yoke is described.

1. Introduction

The Continuous Electron Beam Accelerator Facility (CEBAF) at Newport News, Va. will perform the experiments within three experimental halls. In Hall A two High Resolution Spectrometers are to be installed. Each spectrometer consists of one small quadrupole (Q1) magnet and two bigger quadrupole magnets of identical design, one before (Q2) and one behind (Q3) a 45° dipole magnet.

In November 1991 Siemens got the order from CEBAF for designing, building and testing the four Q2/Q3 quadrupole magnets.

After a period of 10 months for the detailed engineering the design was finished. In chapter 3 and 4 the design of the quadrupole coil and the multipole coils, respectively is described. The current leads are described in chapter 4. In chapter 5 the main features of the iron yoke surrounding the cryostat are given. The design of the cryostat and its components are described in chapter 6.

2. Main Parameters and Specifications

The coils and the cryostat of quadrupole magnets were designed according to the specifications given by CEBAF [1]. The main parameters are given in Table. 1:

Table 1: Main Parameters and Characteristics

Magnet:	
• Length of quadrupole coil	232 cm
• Magnetic length	180 cm
• Quadrupole field gradient	3.5 T/m
• Quadrupole gradient unformity	1 x 10-3
• Operating current	1.85 kA
• Stored energy	592 kJ
• Peak field of main coil	2.5 T
• Superconducting correction (2) and multipole (6) coils max. operating current	100 A
• Weight of cold mass	2.7 t
Cryostat:	
• Diameter of warm bore	60 cm
• Length	295 cm
• Outer diameter	115 cm
• Height	284 cm
Iron Yoke:	
• Outer diameter	150 cm
• Wall thickness	17.5 cm
• Weight approx.	10 t

3. Design of the Quadrupole Coil

One eights of the cross section of the quadrupole coil is shown in Figure 1 which is composed of two layers without a splice. Figure 2 shows a top view of the coil ends of a single coil.

The coils are wound from a cable conductor with 30 strands and a cross section of 1.64 mm x 14.7 mm wrapped with Kapton of a total thickness of 0.1 mm and a 0.1 mm thick layer of glass fabric. The conductor is would around a center post of stainless steel. The three sections of each layer are separated by copper keys in the straight part and 3D shaped copper spacers in the end regions where additional spacer of G10 material will be provided. The head blocks are of copper.

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After assembling the four single coils on a mandrel the quadrupole coil will be wrapped with a bandage of epoxy with annular channels left for better helium transparency to the coil. The coil assembly will be surrounded by a tube of aluminium shrinked onto it. It is designed for a 50 MPa prestress in the coil at liquid helium temperature. The thickness of 63 mm of the aluminium tube guarantees an uncircularity resulting from the Lorentz forces of not bigger than ± 0.15 mm. The circularity for the manufacture and assembly of the quadrupole coil is tolerated with ± 0.25 mm.

At both ends of the quadrupole coils flanges of Aluminium bound to the Al tube provide for an axial boundary.

4. Correction and Multipole Coils

A set of eight superconducting correction and multipole coils will be installed on the inner tube of the helium vessel. They all are wound on G10 plates with a winding core from a 0.9 mm thick wire capable of carrying a current of 125 A. The inner correction coils (sextupole, octupole) are composed of two layers, the six multipole coils consist only of one layer. In order to save space in radial direction the splices are positioned in the end regions, therefore, the coils are designed for different lenghts. The radial thickness of the total set of coils is 25 mm.

5. Current Leads

The current lead for the quadrupole coil are gas cooled and designed for a current of 2 kA. The poles are connected to the leads of the quadrupole coil via flexible copper tapes in order to compensate an axial motion of 4 mm of the coil relative to the current lead which are chosen to be fixed at the head of cryostat tower for reasons of helium tightness at the feedthrough.

The 16 leads of the correction and multipole coils are each coupled to an bundle of insulated brass wires. They are altogether thigtly bundled and guided through a tube and cooled by gaseous Helium. At the top of this tube the leads are separated and connected with the feedthroughs.

The arrangement of the current leads can be seen from the cross section of the cryostat tower in Figure 3.

6. Iron Yoke

The iron yoke is made from AISI 1006 steel according to the magnetic material requirement of [1]. It is composed of two halve shells and bears the vacuum vessel of the cryostat. It supports the cold mass via eight cold-to-warm supports with titanium rods which are fastened to the iron yoke via a support structure, see Figure 4 and 5. It is the geometrical reference system for the alignment of the quadrupole coil.

7. Cryostat

A general requirement from [1] for the design of the cryostat was to design for a 3 g omnidrectionally mechanical load.

In order to avoid unacceptable mechanical deformations or high costs for the vacuum vessel the concept of suspending the cold mass at the iron yoke was chosen.

The width of the vacuum vessel tower is nearly of the same size as the diameter of the vacuum vessel in order to have enough space for the current leads, for four cold valves with actuators, a liquid nitrogen vessel for the shield cooling, and the corresponding piping for the cryogenic helium and nitrogen supplies, see Figures 3 through 5.

The cryostat was designed for the required heat load limit [1] of 20 W at 4 K.

The radiation shield is made of copper and cooled by liquid nitrogen. Liquid level sensors for helium and nitrogen are provided.

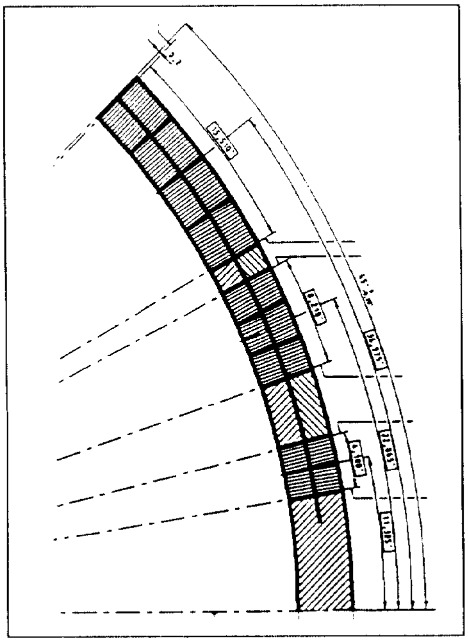
At both ends of the vacuum vessel flanges for the vacuum beam line are integrated.

8. Conclusion

The design of the Q2/Q3 quadrupole magnets was performed according to the global requirements of [1]. These implied a high challange for the manufacturing design of the quadrupole coils and for the mechanical design of the cryostat under cost saving aspects and with respect to the complexity of the electrical and cryogenic supply, especially under restricted geometrical boundaries in the axial direction.

References:

[1] J. Alcorn et. al.; Technical Specification, TS6521-0001, "Four Superconducting Quadrupoles in the Cosine 2Θ Q2/Q3 Geometry for the 4 GeV/c High Resolution Spectrometers to be Installed within Experimental Hall A at the Continuous Electron Beam Accelerator Facility (1992)



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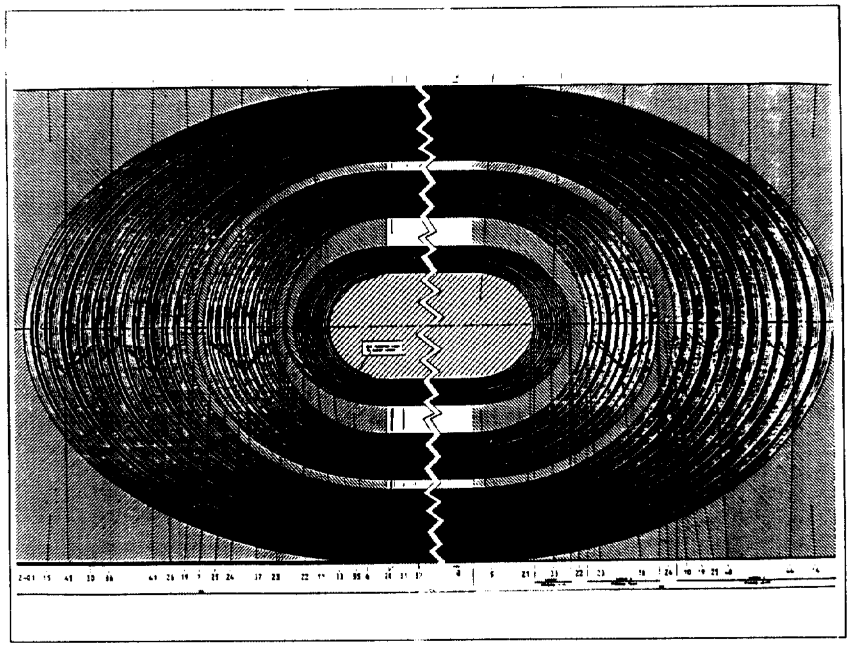

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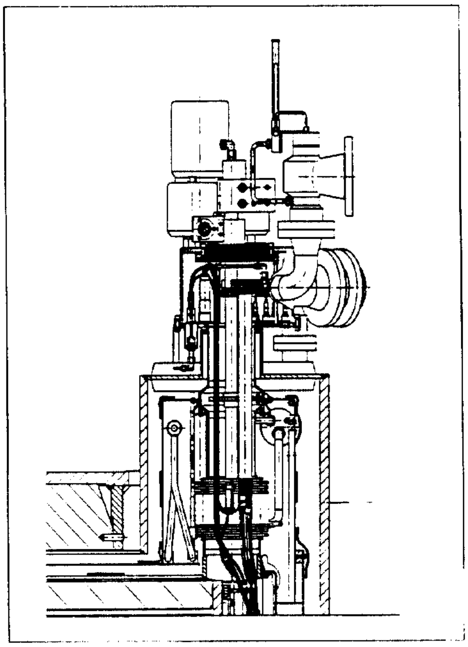

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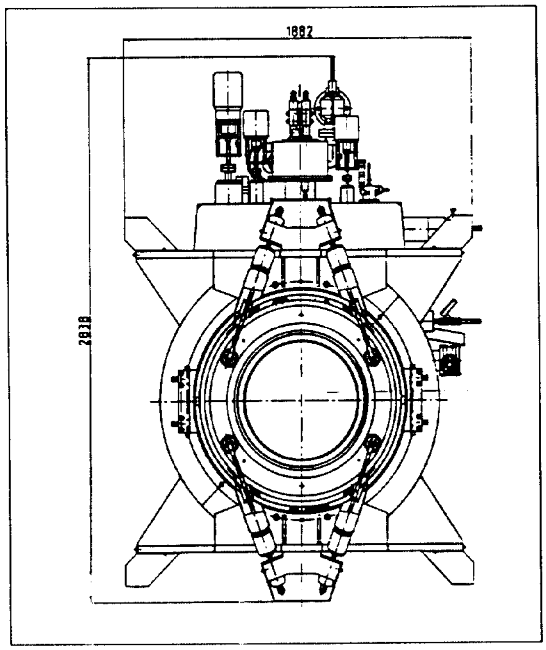

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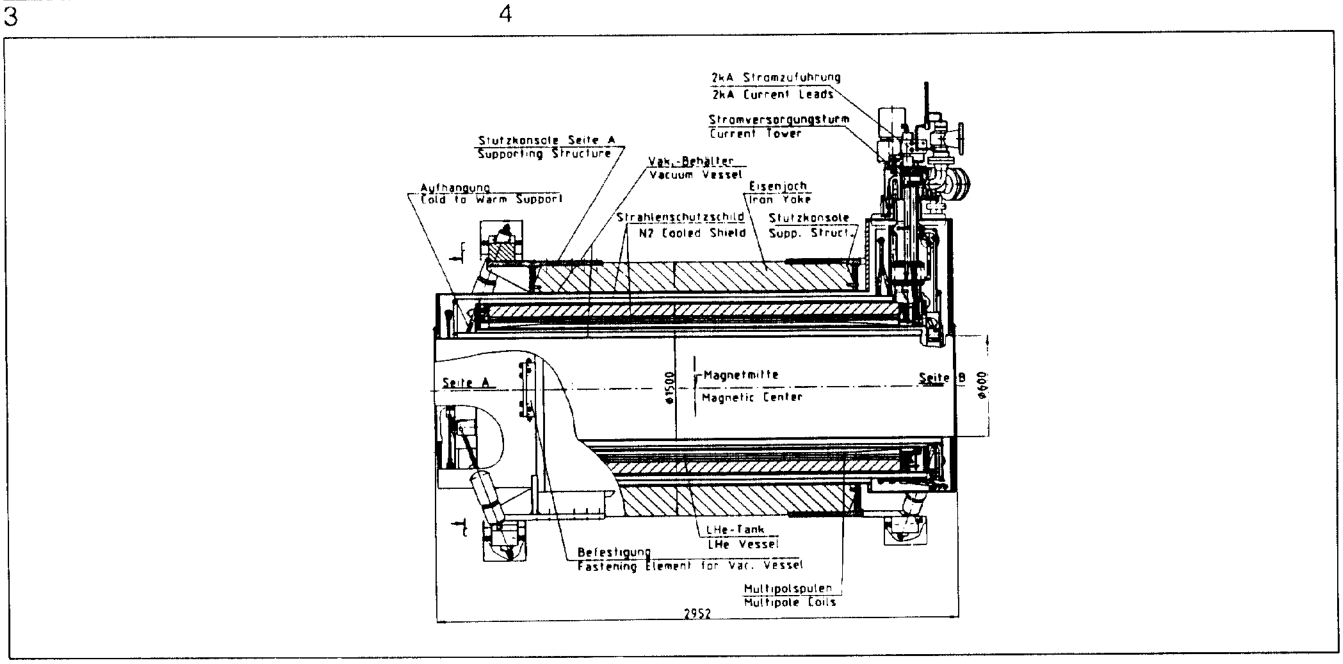
Figure 1:
Cross section
of quadrupole coil
(eights part)

Figure 2:
Top view of quadrupole
coil ends

Figure 3:
Cross section of
cryostat tower

Figure 4:
Front view of Q2/Q3
quadrupole magnet

Figure 5:
Longitudinal section
of Q2/Q3 quadrupole
magnet



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