NORMAL CONDUCTING QM QUADRUPOLE FOR THE HERA LUMINOSITY UPGRADE

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Abstract

Design and properties for the septum half-quadrupole QM for the HERA luminosity upgrade [1] are discussed. The magnet is 3.4m long; it has a gradient of 25T/m with a pole radius of 37mm. The field error must be limited to $3*10^{-4}$ at 25mm reference radius over the whole excitation range of $G_{max}=20*G_{min}$. The septum is the vertical mirror plate of the half quadrupole. The thickness of the plate (85mm) is reduced near the origin by a cut-out providing a septum of only 5mm thickness. By this way a field free space with B<20Gauss for a second beam is provided very close to the high gradient region. The optimization of the field quality and the detail design featuring pole shaping and shim coils of this challenging magnet are described here.

1 INTRODUCTION

Four types of normal conducting iron quadrupole magnets are needed for strong and effective low-β-focusing of the proton and the lepton beams in the new interaction region of HERA[2-4].

The QM magnet is a novel type of quadrupole septum magnet. It is a half quadrupole with a cut-out mirror plate. The field quality requirements of QM is quite large. Nonlinearities at radius of 25mm must not exceed a limit of a few units of 10^{-4} in • B/B.

Just in front of the QM magnet, the two beams of HERA are separated in different beam pipes.

2 FIELD CALCULATION AND DESIGN FOR QM MAGNET

The 3.4 meter long magnet has a gradient of 25T/m at a relatively large pole radius of 37mm. The field errors must be less than $3\cdot10^{-4}$ for low excitation case and $3\cdot10^{-4}$ for high excitation on a reference radius r = 25mm. The QM quadrupole magnet is a septum quadrupole which provides strong focusing to the proton beam which passes through its aperture and provides a quasi field free region for the electron beam which is as close as 56mm to the center of the protons. QM is a half-quadrupole. Its mirror plate represents the septum. An ideal mirror plate would provide perfect quadrupole symmetry. The main feature of the QM magnet affecting field quality is its steel mirror plate with cut out. This arrangement causes a serious distortion of the quadrupole symmetry for the two quadrupole quadrants.

The optimum of the opening angle of the triangular cut out has been found at 90^0. The edge of the cut out at the origin of the half quadrupole is removed, leaving a small septum of 5mm thickness (first estimation). The mirror plate has a thickness of 85mm. However, even after optimization, which also has to take into account the field seen by the lepton beam in the cut out, the field quality is not satisfactory. Without special measures, the non-symmetric geometry leads to strong field imperfections, in particular near the origin. A perfect "knife edge" mirror plate with zero width at the origin would provide a more favorable situation, however, this must be excluded for the reasons of mechanical stability.

The minimum width of the mirror plate as the result of optimization has been chosen as 5mm[5]. This helps to provide a field of less than 10Gauss seen by the electron beam in the cut out. Furthermore, the steel quality of the mirror plate is an important factor in the field quality consideration. However, high quality, soft magnetic steel with sufficiently large permeability over the whole ration range is available only in form of thin sheet metal, but not in form of large blocks as it would be required for the plate. For this reason, it has been chosen to add correction winding around the mirror plate to reestablish a symmetric field configuration. Two pairs of coils are necessary to obtain satisfactory results.

The optimization of QM is performed in two steps. First, the magnet profile is optimized for a perfectly symmetric geometry [6]. In a second step, effect of the correction windings is added to take into account the effect of the mirror plate. The computations for the optimization were performed by OPERA 2D-code [7]. The results of optimization of the QM magnet are summarized in table1.

The mirror plate must be manufactured from soft magnetic steel with large permeability (μ > 3000 over the whole range). In order to achieve high field quality a high precision of the current in the correction windings (I_{co}~0.1%) is required.

The high field quality requires high precision in manufacturing of the magnet and also high precision in magnet assembly. In addition, the magnet has small correction windings, which are wound around the pole and help to assure that the field quality can be achieved over the whole excitation range and which help to compensate field errors from manufacturing tolerances (harmonics k=3).

The results of dependence field errors from the manufacturing and assembly tolerances for QM magnet are summarized in table 2 [8].

Table 1: The results of the QM computation as full quadrupole magnet. S=1-f(Aw)/(f(Aw)$_{max}$/2).

Aw	I_{co}	G	G/Aw	S
KA	A	T/m	T/(m*kA)	-
0.7	8.25	1.25	1.786	0.021
1.5	12.3	2.705	1.803	0.012
4.0	19.0	7.277	1.819	0.003
8.0	31.0	14.593	1.824	0
12.0	45.0	21.57	1.798	0.014
14.0	52.0	24.319	1.737	0.048
16.0	59.86	25.905	1.619	0.112

Table 2: Dependence field errors from the manufacturing and assembly tolerances for QM quadrupole.

Type of production or assembly errors	Number of Harmo-nics	Expected (ΔB/B) R_{ref}=25mm	Require-ment (ΔB/B) R_{ref}=25mm
Identical errors in the two poles profile Δ=10μ (production errors)	6,10,14	3*10^{-5}	3*10^{-4}
Errors in the only one pole Δ=10μ (production errors)	3	2.4*10^{-4}	
Displacement of one pole Δ=10μ (assembling errors)	3	1*10^{-4}	
Displacement of two poles Δ=10μ (assembling errors)	3	2*10^{-4}	

The magnet yoke will be produced from laminated magnet steel 0.75mm thick. The magnet yoke is re-enforced by a rectangular magnet frame made from 10mm strong magnetic steel. This frame is welded to the laminations of the yoke. The magnet also has removable pole tips for optimization of the fringe field. The mirror plate is subject to strong magnetic forces. The horizontal force F_x on the mirror plate is about 25kN/m at full excitation. Since the plate can not be allowed to move by more than 10μm under the influence of these forces to assure the field quality, the plate is supported from the magnet poles by bronze support bars. With the help of these supports, the deformation of the mirror plate under load of the magnetic forces is within the limits of 10μm. The length of the plate exceeds the length of the iron yoke of the magnet by 35mm to decrease the stray field on the e-beam trajectory. In addition, the mechanical stability of the mirror plate is improved by a stainless steel reinforcement structure, consisting of an array of massive handles, which are bolted to the plate.

The mirror plate can be removed and the two quadrupole quadrants are then separable. However, for reassemble high precision tooling is required.

The magnet coils are made from rectangular copper conductors with a specific resistance of not more than 17.2m• /mm^2. The coil insulation will be made with vacuum impregnation. Turn-to-ground insulation is designed for voltage V=1000V. The coils are water cooled. A pressure gradient of up to 7bar is allowed in each of the parallel cooling circuits. Thermo switches on the conductor detect the temperature of the coil.

The main parameters of the magnet are summarized in table 3. Fig. 1 gives a detailed view of the cross section of QM magnet.

Table 3: Main parameters of the QM magnet

Parameters	Value
Field gradient, [T/m]	25
Aperture radius, [mm]	37
Magnetic field homogeneity	3x10^{-4}
Rated current, [A]	471
Voltage drop, [V]	49
Ohmic resistance of the winding, [m•]	91
Inductance of the winding, [H]	0.175
Power consumption, [kW]	23
Number of the coils per the winding	2
Number of turns per coil	34
Conductor dimensions, [mm]	10x12
Conductor cross-section area, [mm^2]	97.2
Hole cross-section, [mm^2]	19.6
Pressure drop per cooling circuit, [bar]	7
Cooling circuit per coil	3
Water speed per cooling circuit, [m/s]	1.35
Water volume in the cooling system, [l]	10
Water flow per winding, [l/s]	0.18
Water overheating, [K]	40
Cooling system is designed for	
max water pressure, [bar]	21
Magnet length [m]	3.585
Iron length [m]	3.4
Yoke steel weight, [t]	3
Winding copper weight, [t]	0.44
Magnet weight, [t]	3.75

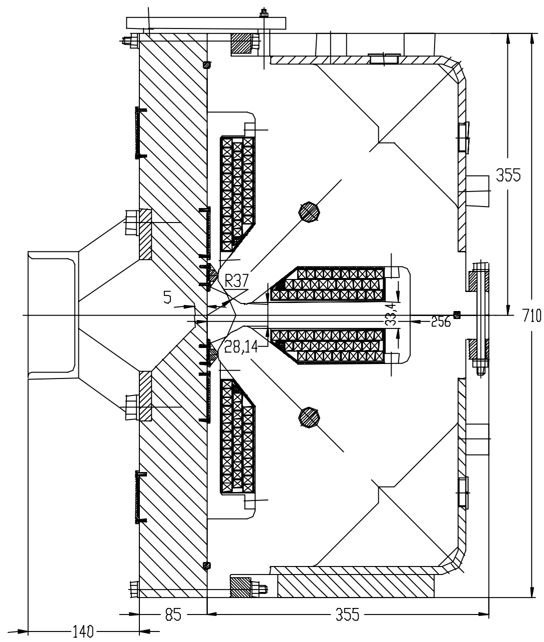

Figure 1: Cross section of magnet QM

Questions concerning quality control of the magnet are described in the report "Normal conducting QI and QJ quadrupoles for the HERA luminosity upgrade" [9].

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