NORMAL CONDUCTING QN QUADRUPOLE FOR THE HERA LUMINOSITY UPGRADE

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Abstract

The magnet QN is a septum quadrupole with a narrow septum coil for focusing the protons with a gradient of 30T/m, needed for the HERA Luminosity upgrade [1]. It is 1.93m long and has a pole radius of 35mm. The field error must be limited to $3*10^{-4}$ at 25mm reference radius over the whole excitation range of $G_{max}=20\times G_{min}$. The required current density in the septum coil is $21A/mm^2$ which results in a high power consumption of 124kW and a complicated water cooling system. Additional magnetic shielding between the septum coil and the nearby electron beam reduces the stray field below the limit of 20Gauss. The optimization of the field quality and the detailed design are described here.

1 INTRODUCTION

QN is a septum coil quadrupole with a large current density in each of the coils. QN is placed at a distance of 18m from the IP where the proton and electron beam orbit are separated by 130mm [2-4]. The profile of this magnet is extra wide to provide space for the electron beam and synchrotron radiation fun which pass between the coil and return yoke of the magnet respectively. In order to decrease the value of the field in the region of electron beam (B<10gauss) a magnetic shield is put between the septum coil and the electron beam. The required high field quality, requires a perfect quadrupole symmetry of the magnet [5]. Therefore, the magnet laminations have a full symmetry and the coil geometry is identical for all four quadrants. High mechanical precision during production and assembly is also necessary.

2 FIELD CALCULATION AND DESIGN FOR QN MAGNET

The 1.93 meter long magnet has a strong gradient of 30T/m at a relatively large pole radius of 35mm. The field errors must be less than $10{\cdot}10^{-4}$ for low excitation case and $3{\cdot}10^{-4}$ for high excitation on a reference radius r = 25mm. The computations for the optimization of the pole profile were performed by OPERA 2D code [6]. The results of the profile optimization are presented in Fig. 1.

In order to achieve a gradient of 30T/m a current density of $J=21A/mm^2$ is required (counting only the copper part of the conductor). The coil consist of two parts with slightly different conductor dimensions, a two-layer coil which runs parallel to the side-face of the pole and a one-layer coil (septum coil) which extends along the magnet midplanes. The magnetic field seen by the electron beam must be less than 20Gauss with a nonlinear content of less than 5Gauss. In order to reduce calculated field value to the required level, a plate of magnetic shielding material is inserted between the coil and the e-beam. In order to suppress the forbidden harmonics due to the distortion of symmetry (odd harmonics, mainly: $a_3/a_2\approx 2\times 10^{-4}$) the shielding needs to be inserted in the other quadrants as well. The shape of these insertions, however, is slightly different from the screen shape to make facilitate the assembling of the magnet. The results of optimization coil and shielding are presented in Fig. 2.

The results of numerical simulation for a QN magnet of perfect symmetry are summarized in table 1.

Table 1: Results of quadrupole QN computations.
$S=1-f(Aw)/f((Aw)_{max})/2$, $f(Aw)=G/Aw$

Aw	G	a_6/a_2	a_{10}/a_2	a_{14}/a_2	S
KA	T/m	10^{-4}	10^{-4}	10^{-4}	10^{-2}
0.7	1.392	1.74	0.29	-0.80	2.3
1.5	3.014	1.78	0.29	-0.80	1.33
3.5	7.095	1.69	0.29	-0.81	0.44
6.0	12.204	1.65	0.30	-0.81	0.10
8.5	17.306	1.60	0.30	-0.81	0
11.0	22.324	1.50	0.30	-0.81	0.35
13.5	26.477	1.24	0.29	-0.80	3.68
15.0	28.549	0.72	0.24	-0.80	6.53
16.0	29.681	0.26	0.21	-0.80	8.89
16.5	30.155	0.03	0.19	-0.79	10.22

The magnet yoke will be produced from laminated magnet steel of 0.75mm thickness and 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 mechanical construction is such that the magnet can be separated into two halves inside the HERA tunnel to allow for easy installation of the beam pipes. The magnet also has removable pole tips for optimization of the fringe field. The magnet coils are made from rectangular copper conductors with a specific resistance of not more than $17.2m\bullet /mm^2$. The coil insulation will be made with vacuum impregnation. Turn-to-ground insulation is designed for voltage V=1000V. The coils are water cooled. Despite of the large gradient of 30T/m, the width available for the coils between two beams is only about 50mm. As a result of the high current density in the coil a big number of the parallel cooling circuits (2 for each coil) is necessary. 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.

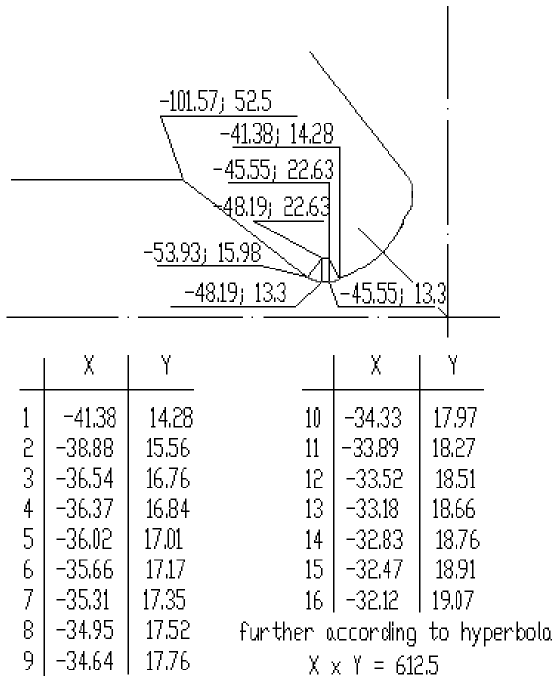

Fig. 1. Results of the profile optimization.

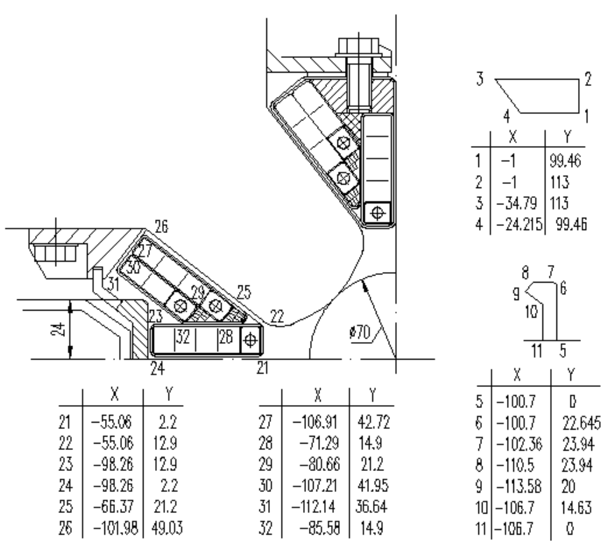

Fig.2. The results of the coil and shielding optimization

The high field quality requires high precision in stamping of the well optimized pole contours and also high precision in magnet assembly. Required stamping and assembly precision are at level 10-20µm (see section 3). In addition, the magnets have small correction windings which 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).

Fig. 3 gives a detailed view of the cross section of QN Questions concerning quality control of the magnet are described in the report "Normal conducting QI and QJ quadrupoles for the HERA luminosity upgrade" [7].

The main parameters of the magnet are summarized in table 2.

Table 2: Main parameters of the QN magnet

Parameters	Value
Field gradient, [T/m]	30
Aperture radius, [mm]	35
Magnetic field homogeneity	$3x10^{-4}$
Rated current, [A]	1460
Voltage drop, [V]	84.6
Ohmic resistance of the winding, [m•]	51.7
Inductance of the winding, [mH]	8.68
Power consumption, [kW]	123.6
Number of the coils per winding	4;4
Number of turns per coil	5;7
Conductor dimensions, [mm]	8x10; 8.2x10.5
Conductor cross-section area, [mm^2]	70.5;68
Hole cross-section, [mm^2]	14.2;18.1
Pressure drop per cooling circuit, [bar]	7
Cooling circuit per coil	2;2
Water speed per cooling circuit, [m/s]	3.61
Water volume in the cooling system, [l]	3.4
Water flow per winding, [l/s]	0.88
Water overheating, [K]	35
Cooling system is designed for	
max water pressure, [bar]	21
Magnet length [m]	2.095
Iron length [m]	1.93
Yoke steel weight, [t]	3.4
Winding copper weight, [t]	0.13
Magnet weight, [t]	3.6

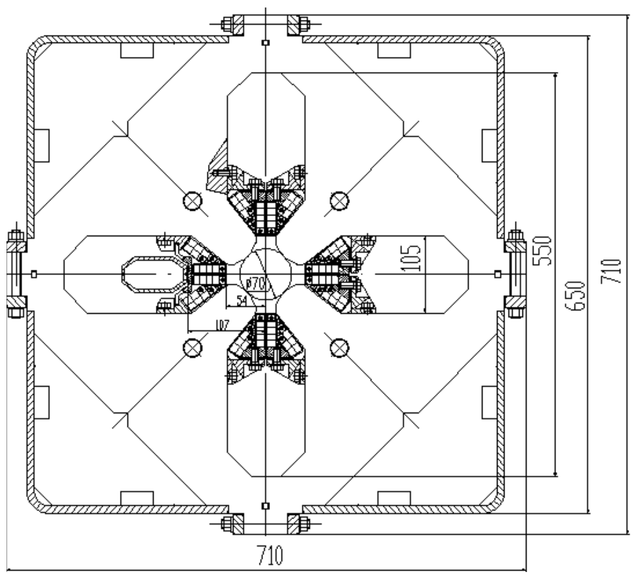

Fig. 3 Cross section of the magnet QN

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