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QUADRUPOLE MAGNET DESIGN FOR A HEAVY-ION IH-DTL*

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Abstract

Xi'an 200 MeV proton application facility (XiPAF) is planned to be upgraded to provide heavy-ion beams with a heavy-ion injector. The injector consists of an electron cyclotron resonance (ECR) heavy-ion source, a low energy beam transport line (LEBT), a radio frequency quadrupole (RFQ), an interdigital H-mode drift tube linac (IH-DTL), and a linac to ring beam transport line (LRBT). The IH-DTL can accelerate the ions with mass to charge up to 6.5 from 0.4 MeV/u to 2 MeV/u. To provide transverse focusing, the electro-magnetic quadrupoles are installed inside the drift tubes of IH-DTL, thus the magnet needs to be high-gradient and compact. In this paper, the design of the quadrupole magnet is presented for the heavy-ion IH-DTL. The results show that the quadrupole magnet design can meet the requirements.

INTRODUCTION

Presently Xi'an 200 MeV proton application facility (XiPAF) can provide a proton beam with the energy of 60 ~ 230 MeV and is mainly used for the research of proton single event effect [1–5]. XiPAF is planned to be upgraded to provide additionally a heavy-ion beam with a heavy-ion injector. Based on the existing proton synchrotron, the heavy-ion beamline will be added to provide heavy ions with charge mass ratios in the range of 1/2 ~ 1/6.5. The injector consists of an electron cyclotron resonance (ECR) heavy-ion source, a low energy beam transport line (LEBT), a radio frequency quadrupole (RFQ), an interdigital H-mode drift tube linac (IH-DTL), and a linac to ring beam transport line (LRBT). The IH-DTL can accelerate the ions from 0.4 MeV/u to 2 MeV/u. The injector can provide 2 MeV/u heavy-ions with a repetition rate of 0.5 Hz, a pulse width of 100 μs [6].

The quadrupoles are installed in the drift tubes of the IH-DTL, which leads to a high gradient, a limited outer diameter, and a limited length for the quadrupoles installed in the IH-DTL [7]. The basic goal for the magnet design is to be compact.

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REQUIREMENT OF QUADRUPOLES

The requirement parameters of the quadrupoles for the IH-DTL are listed in Table 1. The length of the quadrupoles with the coils should be shorter than the drift tubes. The gradient should be large enough to focus the heavy ions transversely. In the following, type A quadrupole, which is the most compact quadrupole among the three, is discussed.

Table 1: Requirement Parameters of the Quadrupoles

Quad Type	**A**	**B**	**C**
Bore radius	13 mm	14 mm	15 mm
Outer radius	75 mm	75 mm	75 mm
Length with coil	84 mm	90 mm	110 mm
Integrated gradient	4.8 T	4.4 T	4.0 T
Good field region	80%	80%	80%
Integrated homogeneity	0.05%	0.05%	0.05%
Higher order gradient	0.1%	0.1%	0.1%

MODEL OF THE QUADRUPOLE

To install the magnets in the drift tubes, the magnets need to be compact. The 3D diagram of the quadrupole magnet for type A is shown in Fig. 1. The overall dimensions of the magnet meet the requirements of Table 1.

MAGNETIC CALCULATIONS

Material

To meet the requirement of the integrated gradient, the gradient of the quadrupole should be larger than 60 T/m. The high focusing strength and short focal lengths lead to high gradients and high pole-tip fields. These high pole-tip fields cause large fields at the secant of the pole. Due to the small outer diameter, the yoke fields are high, too. Fe-Co-V soft magnetic alloy (Vacoflux50 or 1J22 in China) can reach high field. The material has high saturation magnetic induction (>2.0 T) so that the size of the yoke can be compact. The

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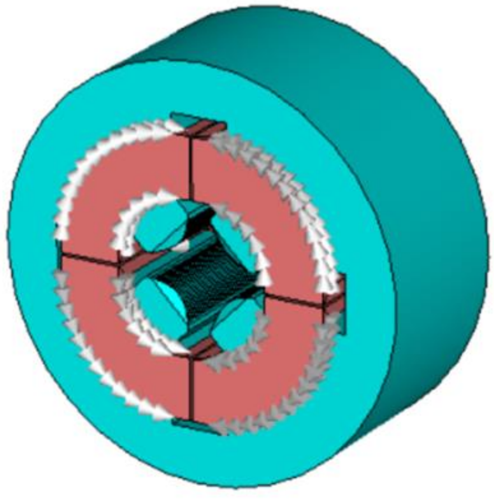

Figure 1: 3D diagram of the quadrupole magnet type A.

comparison of the BH curves for soft magnetic alloy and ordinary silicon steel is indicated in Fig. 2. The BH curve of Vacoflux50 is adopted from CST [8]. The BH curve of 1J22 is the measured result.

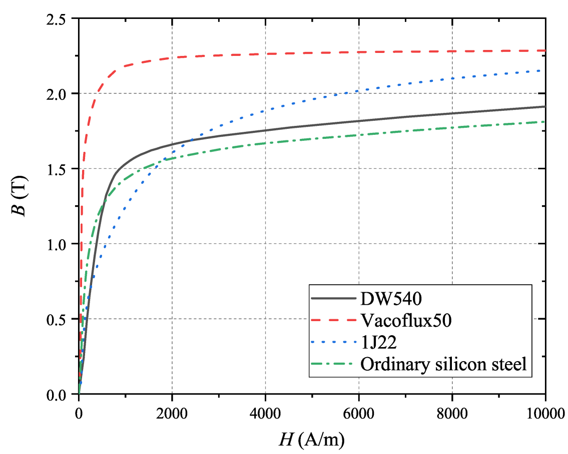

Figure 2: Comparison of the BH curves for soft magnetic alloy and ordinary silicon steel.

Saturation

The quadrupole saturation dependence on the excitation current has been studied for the different yoke materials. To reach the integrated gradient of 4.8 T, Fig. 3 depicts that the linearity of the magnet is 95% for Vacoflux50 while the linearity is only about 90% for the ordinary silicon steel.

DW540 is adopted as the yoke material with good processing performance.

3D Result

With the excitation current of 4450 AT, the integrated gradient can reach 4.8 T. Figure 4 shows the B field in the yoke of type A magnet. The gradient along the beam axis

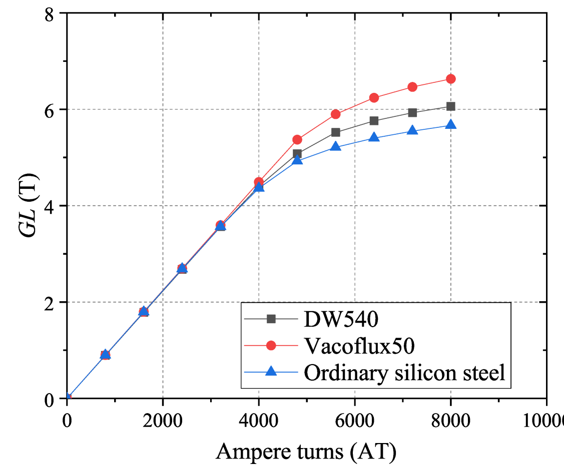

Figure 3: Quadrupole saturation of type A magnet with different yoke materials.

of type A magnet with the excitation current of 4450 AT is shown in Fig. 5. The gradient of the magnet is above 63 T/m.

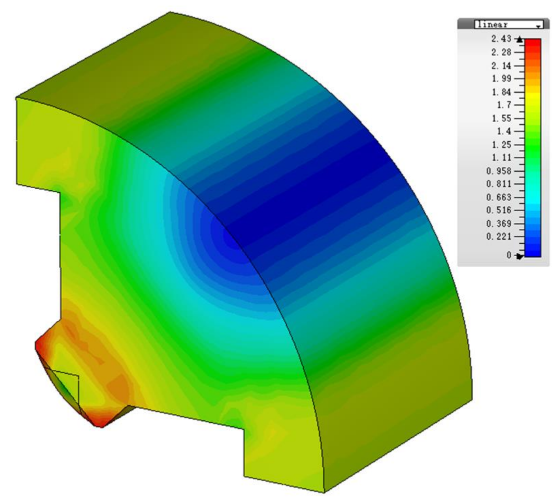

Figure 4: *B* field in the yoke of type A magnet.

Multipole

The values of the various multipole normalized with quadrupole strength are smaller than 0.1%, which is shown in Fig. 6. The values meet the requirement of the higher-order gradient.

COOLING CALCULATION

SAKAE type coil [9] is adopted to obtain a compact magnet. If the excitation current works on the DC mode, the temperature rise of type A magnet can reach 20 °C, which is a little high. Pulsed power supply with a duty factor of 3% is used to provide excitation current, thus the temperature rise of type A magnet is smaller than 0.6 °C. The flat-top time is 10 ms, the ramp-up time is 15 ms, and the ramp-down time is 30 ms. The design results of the quadrupoles are listed in Table 2.

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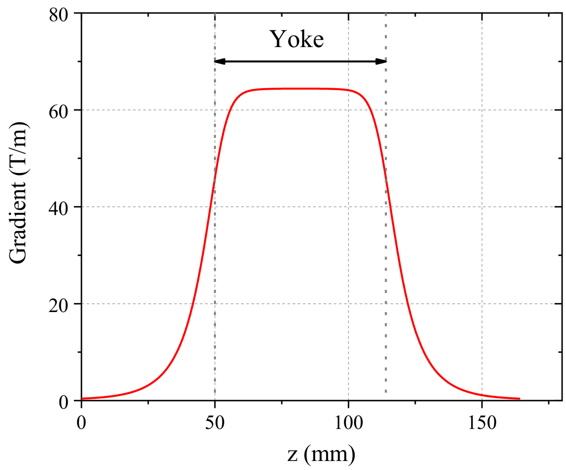

Figure 5: Gradient along the beam axis of type A magnet with the excitation current of 4450 AT.

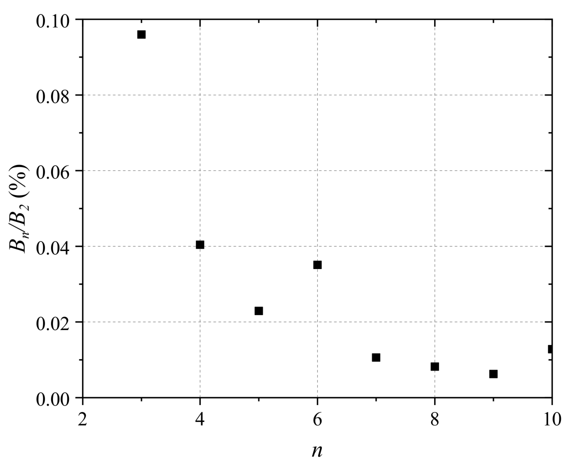

Figure 6: Values of the various multipole normalized with quadrupole strength.

Table 2: Design Result of the Quadrupoles

Quad Type	A	B	C
Excitation current	1300 A	1235 A	1020 A
Turns	3.5	3.5	3.5
Ampere turns	4450 AT	4250 AT	3500 AT
Yoke length	64 mm	70 mm	90 mm
Wire size	6*6D4	6*6D4	6*6D4
Peak power	6.7 kW	6.3 kW	4.8 kW
Duty factor	3%	3%	3%

INSTALLATION

The quadruples will be installed in the drift tubes of the IH-DTL. The diagram of the assembly of the quadrupole inside the first drift tube with quadrupole (DTQ) is shown in Fig. 7.

Figure 7: Diagram of the assembly of the quadrupole inside the first DTQ.

CONCLUSION AND FUTURE WORK

The quadrupole magnet design for the heavy-ion IH-DTL is given. The results show that the quadrupole magnet design can meet the requirements.

The detailed design of the magnet is undergoing. The machining of the prototype of the magnet will be carried out in the future.

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