Design of air cooled quadrupole magnets for high current injector at IUAC

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Introduction

The high current injector facility (HCI) at IUAC consists of a high temperature superconducting electron cyclotron resonance ion source (HTS-ECRIS) to produce higher currents of multiply charge states. The ions are first extracted at 30kV potential from the source and then mass analysed using a combination of a quadrupole doublet and a large acceptance combined function dipole magnet [1]. Ions are further accelerated to 8keV/u using an electrostatic accelerating column. Ions are further bunched using a multi harmonic RF buncher and transported using a set of magnetic quadrupoles to the entrance of radio frequency quadrupole (RFQ) for subsequent acceleration. The beam transport section from source to RFQ is known as low energy beam transport section (LEBT). Here, we are presenting the ion optical and hardware design of magnetic quadrupoles involved in this section.

Design parameters

The quadrupole doublets after HTS-ECRIS are required to increase the acceptance of analyzing magnet. The magnetic quadrupole are preferred since they lie outside the beam pipe without increasing the vacuum load in LEBT section.

Table 1: Design parameters of quadrupoles

Parameters	After HTS-ECRIS (Doublet)	Before RFQ (Quartet)
Effective length (mm)	78	156
Aperture Radius a (mm)	39	39
Max. Field Gradient (T/m)	2.56	3.85

The beam dynamics studies [2] of LEBT using codes like TRANSPORT, GIOS, TRACE3D shows that maximum field gradient of quadrupoles is around 3.85T/m. This can be achieved using air cooled coils in the quadrupoles without significant heating effects for a smooth operation over time. The designing parameters of magnetic quadrupole are shown in table-1.

Field computation studies and hardware design of magnets

The magnet has been simulated using the 2D/3D codes such as Poisson [3] and Opera3d [4] for field computation and analyzing harmonic contents. Constant field profile as calculated within circular aperture using Opera3d is shown in fig. 1. Pole profile is designed to minimize higher order harmonics. The shape of the pole is circular up to 90 deg. with radius 1.13a and the rest is chamfered to accommodate the coils. The angle of chamfered is optimized to obtain minimum higher order harmonics as shown in fig. 2. The coils have been designed to obtain maximum field gradient and to suite normal air cooling for heat dissipation. The details specifications of the coil and the magnet are summarized in table-2.

Test Results

Two quadrupoles of field gradient 2.56T/m have been fabricated and tested using a Group 3 hall probe and the field mapping is done in both transverse and longitudinal directions. The comparison of simulation and experimental results is shown in fig. 3. Fabrication of other quadrupoles is in progress. The results are compared in table-3.

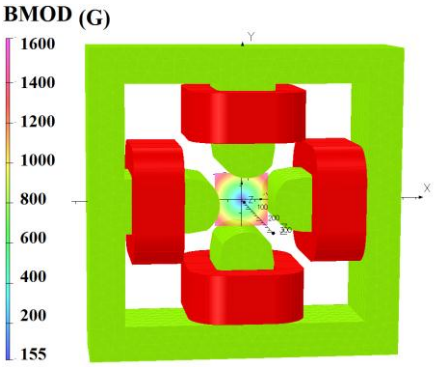

Fig. 1 Constant field contour of the magnet

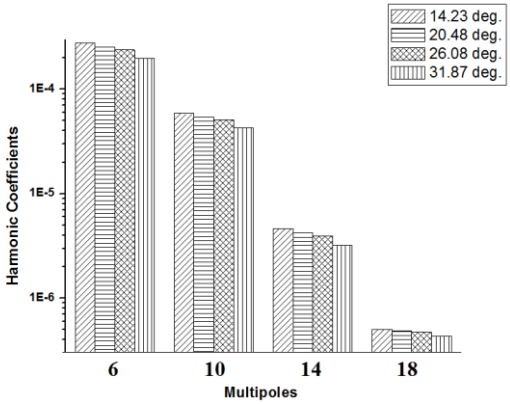

Fig. 2 Harmonic coefficients of multipoles

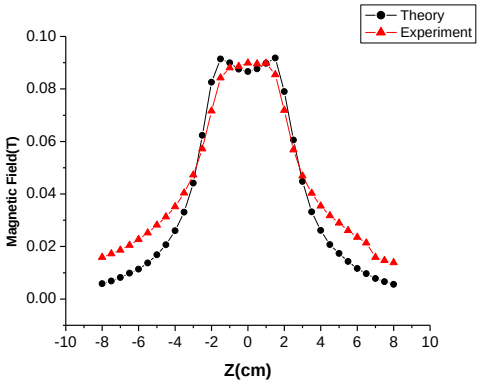

Fig. 3 Measured longitudinal field at 4A along longitudinal direction along with simulated values

Tabel-2 Summarized parameters of magnets

Parameters	After HTS-ECRIS (Doublet)	Before RFQ (Quartet)
Maximum Field (G)	1000	1500
Ampere Turns (NI)	1550	2331
Length of iron yoke(mm)	40	121
Pole Tip radius (mm)	43	44
SWG No. and dia. of coil (mm)	12, 2.64	12, 2.64
Voltage ,current , Power required	9V, 5A, 45W	16V, 6A, 96W

Table-3 Comparison of magnetic parameters

Parameters	Simulated (Opera3d)	Experimental
Effective length (m)	0.075	0.081
Field Gradient (T/m)	2.081	2.256

Conclusion:

The test results agree with the specification and the temperature rise over a long period of operation is suitable for normal air cooling.

References

1. A.Mandal et al, NIM A, Volume 583, Issues 2–3, 21 December 2007, Pages 219–227
2. Sarvesh Kumar et al, Proceedings of InPAC-2009
3. Reference Manual for the POISSON/SUPERFISH Group of Codes, LANL
4. Opera-3d Reference Manual version 15R1, Cobham Technical Services Vector Fields Software