MAGNET DESIGNS OF THE IN-FLIGHT FRAGMENT SEPARATOR FOR THE RISP*

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Abstract

Magnets to be used for the in-flight fragment separator of the rare isotope science project have been designed. The dipole magnet has a gap width of 150 mm and a magnetic rigidity of 10 Tm. The superferric quadrupole magnet, which is main focusing element, has a pole tip radius of 170 mm and a maximum field gradient of 15 T/m. In the high radiation region near the production target, warm iron dipole and quadrupole magnets employing high-temperature superconductor coils have been considered in order to reduce cold mass and to remove large radiation heat loads efficiently at the temperature of 20-50 K. The designs of dipole and quadrupole magnets have been optimized, and prototyping of a superferric quadrupole magnet is in progress. Simulation results using OPERA-3D and a plan of prototyping are discussed.

INTRODUCTION

Rare isotope science project (RISP) was established at the Institute for Basic Science (IBS), Korea to construct a heavy ion acceleration facility for rare isotope beam production. Both the in-flight fragment (IF) separation and isotope separation on-line (ISOL) methods will be utilized [1]. A superconducting linear accelerator, which can accelerate a uranium beam to 200 MeV/u, is the driver for the IF system.

The beam optical design of the separator has been performed in search of its configuration to achieve large acceptance on the isotope beam of interest. Figure 1 shows an array of magnetic elements, in which superconducting magnets with large aperture are needed for focusing. The separator is divided into two stages of pre- and main separator. A main purpose of the pre-separator is to remove the primary and unwanted isotope beams, while the main separator aims to identify the isotope beam of interest. A thin target and a beam dump are located in the pre-separator region, where radiation heating and shielding are the major design considerations.

In the front end of the pre-separator, one dipole and two quadrupole triplet magnets will use high-Tc superconducting (HTS) coils to remove radiation heat more efficiently at the temperature of 20-50 K. The goals of momentum acceptance and angular acceptance of the IF separator are ±5 % and ±50 mrad, respectively.

The IF separator employs 8 dipole magnets and 17 superconducting quadrupole magnet triplets. Beside one dipole next to the target, other dipole magnets could be either room temperature or superferric magnet. Maximum magnetic rigidity of the dipole magnet is chosen to be 10 Tm considering the upgrade plan of beam energy of the driver linac to 400 MeV/u for uranium beam.

All of the quadrupole magnets are of superferric type. Except for two quadrupole triplet using HTS coils with warm iron, other superferric quadrupole magnets will use NbTi conductor at 4.5 K with cold iron. A set of multipole coils will be placed on the cold bore tube for aberration correction. The maximum field gradient for the quadrupole magnets is set to be about 15 T/m.

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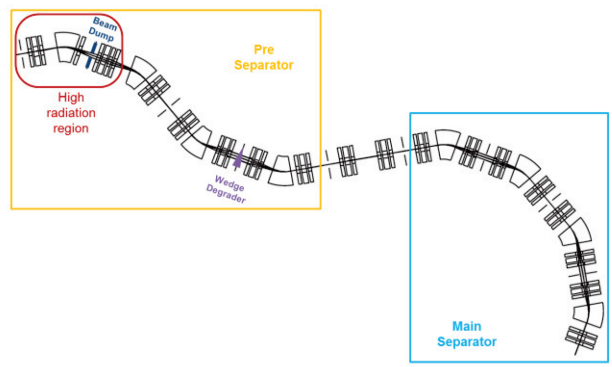

Figure 1: Schematic layout of the fragment separator.

DIPOLE MAGNETS

Dipole magnets have a bending angle of 30 degree, bending radius of 6 m, and a maximum field of 1.7 T. The pole gap and width are designed to be 150 mm and 600 mm, respectively.

A warm iron HTS dipole magnet will be used in the front region of the pre-separator, and its construction will be technically challenging. Figure 2 shows cross-sectional view of the HTS dipole magnet. In the current design each coil is composed of two layers of the same pancake windings. The total current inside the coil is about 120 kA at the maximum magnetic field of 1.7 T. The maximum stored energy is about 0.6 MJ. The HTS dipole coil has a D-shape to avoid negative curvature in winding. The HTS coil package will be cooled using forced flow of cold helium gas through He gas channel inside the package.

The other seven dipole magnets will be of superferric type using NbTi wire or conventional. Some design parameters of superconducting dipole magnet are similar to those of the HTS dipole magnet. The maximum total current is about 125 kA, and the maximum stored energy is 0.6 MJ. The maximum total current of conventional dipole is about 115 kA with the power consumption of 220 kW when the coil packing fraction is assumed to be 0.5.

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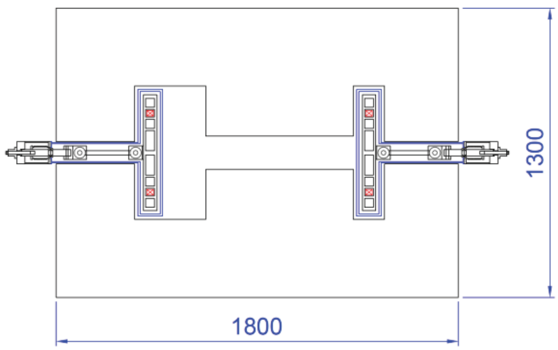

Figure 2: Cross section of the HTS dipole magnet.

QUADRUPOLE MAGNETS

Some parameters of the quadrupole magnets are listed in Table 1. Five different types are considered, in which three kinds use HTS coils. The pole tip radius of the first HTS quadrupole magnet is 120 mm, which is smaller than that of the following HTS quadrupole magnets. These aperture sizes were determined according to beam optics, and will be further optimized along with the results of prototyping and magnetic field mapping. Superferric quadrupole magnets operating at 4.5 K share the same design besides the magnet length.

Table 1: Some Parameters of the Quadrupole Magnets

Q-magnet	HQs	HQ1	HQ2	LQ1	LQ2
Type	HTS	HTS	HTS	LTS*	LTS
Number of magnet	1	3	2	30	15
Warm bore radius (mm)	120	170	170	120	120
Yoke length (mm)	480	450	800	450	800
Field gradient (T/m)	20	14	16	15	15

*LTS means low temperature superconductor.

HTS Quadrupole Magnet

In case of the HTS quadrupole magnet, only the HTS coil and coil support structure are cooled to reduce the amount of cold mass, which is cooled conductively by cold He gas. Figure 3 shows a 3D model of the HTS quadrupole magnet by OPERA-3D [2]. Currently its design is similar to that developed at BNL for FRIB [3]. Three sections of pancake winding of HTS coil with each section area of 40*12 mm^2 are included in the cryostat. The magnet pole was shaped to accommodate the cryostat.

In the HTS coil winding, we plan to co-wind a metal tape made of such as stainless steel for insulation because organic insulation is not acceptable in the high-radiation area of the pre-separator. For the prototype of HTS coil, 2G HTS wire manufactured by SuNam, a domestic company, will be used. The superconductor is made of GdBCO ($GdBa_2Cu_3O_{7-x}$). Width of the HTS tape is 12 mm and its thickness is 0.1 mm. The critical current is about 400 A at 77K.

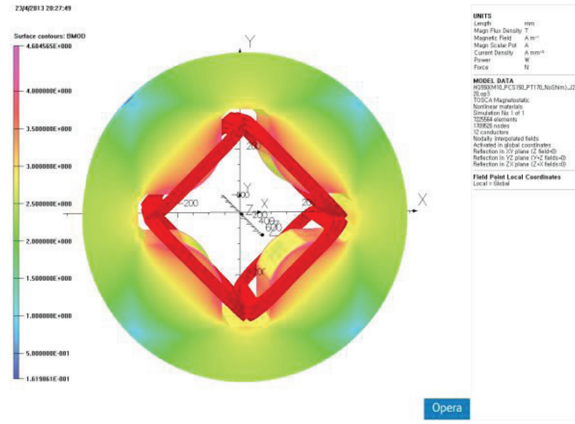

Figure 3: A 3D model of the HTS quadrupole magnet.

Superferric Quadrupole Magnet

A superferric quadrupole magnet triplet is placed in one cryostat, and it is cooled by liquid helium. We consider two types of cryostat for actual installation: 1) pool boiling with liquid helium supply, 2) cryocooler to re-condense evaporated helium gas. For the test of the prototype magnets, a cryostat with two units of GM cryocooler having heat capacity of 3.0 W at 4K in total will be constructed for stand-alone operation as shown in Fig. 4. Total heat load of a prototype cryostat at 4K is estimated to be lower than 3 W.

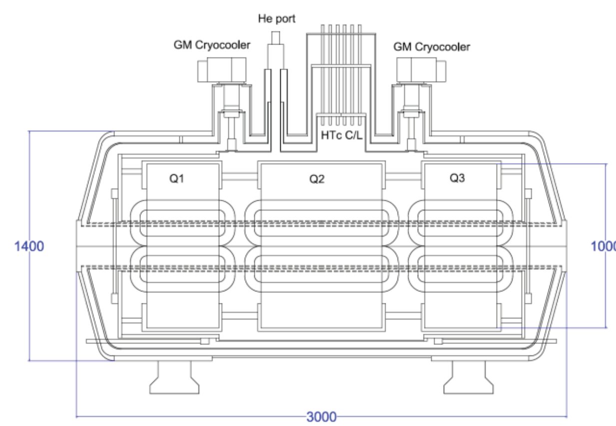

Figure 4: Schematic sectional view of the cryostat with a prototype of superferric quadrupole magnet triplet inside.

Design Study of Quadrupole Magnet

For the prototype of superferric quadrupole magnet, three types of designs having different pole and coil shapes were studied to minimize multi-pole components. First, type A has a hyperbola pole shape and a simple rectangular racetrack coil. Type B has a modified pole shape and the same coil shape with type A. Type C has the same pole shape as type A and a racetrack coil with modified cross section, which is similar to the design of the magnet used at MSU and RIKEN [4, 5]. Figure 5 shows one quadrant of cross sections for the three types of quadrupole magnet and the pole geometry of type B.

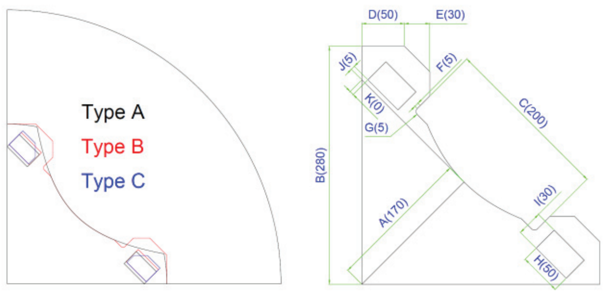

Figure 5: Quadrant cross section of three types of quadrupole magnet (left) and the pole geometry of type B (right).

The ratio of integrated dodecapole field to the integrated quadrupole field at the radius of 120 mm was compared. The pole shape together with coil position was adjusted to reduce the dodecapole component in the operation range up to 15 T/m. Figure 6 shows the resulting ratios of the integrated dodecapole and 20-pole fields to the integrated quadrupole field as a function of field gradient for three different types of the design.

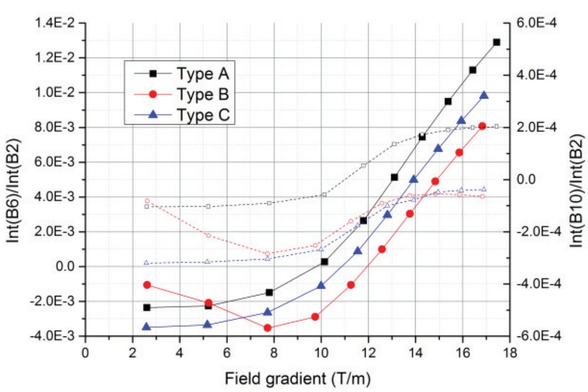

Figure 6: The ratios of integrated dodecapole field (solid line) and 20-pole field (dashed line) to integrated quadrupole field.

The ratio of integrated field strength of dodecapole compared to quadrupole increases at higher excitations. Over the entire operation range, it changes from -0.2% to 0.9% for type A, from -0.4% to 0.5% for type B, and from -0.4% to 0.7% for type C. The shape of type B shows a smaller overall variation in the ratio as shown in Fig. 6.

SEXTUPOLE MAGENTS

Multipole magnets such as sextupole magnet will be installed for the correction of chromatic aberration. In the target area, two resistive sextupole magnets using mineral insulated radiation-resistant cable are considered. The maximum field gradient of resistive sextupole magnets is 25 T/m^2.

In the cryostat of superferric quadrupole magnet triplet, one sextupole coil will be placed on the cold bore tube of each triplet. The maximum field strengths of sextupole coils in the pre- and main separators are 50 and 20 T/m^2 respectively.

CONCULSIONS

The designs of superconducting magnets in the IF separator for the RISP have been studied. One or two HTS coils for quadrupole magnet to be used in high radiation area will be prototyped to ensure the technique of coil winding and to study quench properties and quench protection. A superferric quadrupole magnet operating 4.5 K will be prototyped soon. The NbTi superconductor has been purchased and magnet steel will be acquired soon. Optimization of the pole and coil shape to reduce the integrated multi-pole components in the operation field range has been carried out. After testing of a fully assembled quadrupole magnet in the LHe dewar, cryostat containing a quadrupole magnet triplet will be constructed for magnetic field mapping.

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