SUPERFERRIC MAGNETS FOR SUPER-FRS AND STORAGE RINGS OF FAIR*

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Abstract

The Super Fragment Separator (Super-FRS) of the FAIR-project (Facility for Antiproton and Ion Research) [1] is conceived as a large acceptance fragment separator, with three branches serving different experimental areas, including a new storage ring complex. Rare isotopes of all elements up to uranium can be spatially separated by the Super-FRS. Unique studies with these isotopes and antiprotons will be performed in the Ring Branch, consisting mainly of a Collector Ring (CR), the New Experimental Storage Ring (NESR), and the Recycled Experimental Storage Ring (RESR). A common requirement for the magnets of these systems is a large acceptance at moderate fields, which can be fulfilled by superferric magnets with wide apertures. Similar requirements for the Super-FRS and CR magnets allow using the same magnet designs for both systems, yielding a reduction of costs and development time. Rare ions and antiprotons will be decelerated in the NESR and RESR, thus requiring pulsed magnets. This requires a coil design different from CR and Super-FRS. The cryostat design has to prevent large eddy current losses. This paper describes the status and development of the aforementioned superferric magnets. Differences and common features will be clarified.

INTRODUCTION

Iron dominated superconducting magnets, so called superferric magnets, are often used if wide apertures for large acceptance are required and the maximum field density doesn't exceed 2 Tesla. In most cases resistive magnets could also be used, but a resistive coil design needs mostly a larger cross section so the cross section of the iron yoke must be increased, too. Due to this the overall investment costs of normal conducting magnets could be similar or even higher then the investment costs for a superferric solution. In all cases, the operating costs of normal conducting magnets are much higher than the operating costs of superconducting magnets. This difference could be serious during a lifetime of a facility like FAIR. These cost estimations are most significant for the decision using either superconducting or normal conducting magnets.

SUPERCONDUCTING MAGNETS FOR THE CR AND THE SUPER-FRS

Superferric Dipoles for the CR

The Collector Ring is designed for Stochastic precooling of secondary rare isotope beams from the fragment separator or antiprotons from the pbar target. 24 dipoles, 44 quadrupoles, 28 sextupoles, some corrector and septum magnets are intended for the CR, but only the dipoles will be superferric magnets. A large aperture of 140 mm $\times$ 380 mm and a maximum flux density of 1.6 Tesla argue against a normal conducting solution. A superferric H-type design was selected to achieve the required field quality of $\pm 1 \times 10^{-4}$. The dipole design have a warm bore and a warm iron yoke. Only the both racetrack coils are embedded in one common cryostat. Several options were investigated for the iron design: a curved magnet, a D-shaped magnet and a straight magnet [2]. The straight version is by far the version simplest to calculate and fabricate. Due to the short length of 2.1 m the sagitta is only 70 mm. This leads only to a small increase of iron of 11 % compared to the curved version. Therefore we decided for the stacked straight version. The sector shape (zero entrance

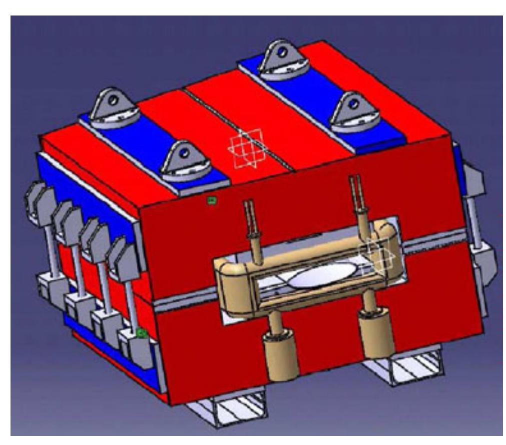

Figure 1: Preliminary sketch drawing of a CR/Super-FRS dipole.

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Table 1: Dipole specifications of the common design

Location	Super-FRS	CR
Number of magnets	21	24
Maximum field	1.6 T	
Minimum field	0.15 T	1.2 T
Deflection angle	9.33°	15°
Edge angle (entrance / exit)	−2.83°	0°
Bending radius	12.5 m	8.125 m
Effective length	2.1 m	
Usable horizontal aperture	±190 mm	
Sagitta	40 mm	70 mm
Horizontal good field area	±225 mm	
Vertical aperture	±70 mm	
Pole gap height	±85 mm	
Integral Field quality (relative) in 10^{-4} units	± 3 ($B < 1.2$ T) ± 1 ($B \geq 1.6$ T)	

/ exit angle) will be machined after stacking. An air slot guarantees the required field quality of 100 ppm over the field range between 1.2 T and 1.6 T. The particles in the CR are neither accelerated nor decelerated so the magnets will run in DC mode. This allows magnets with a large inductance. Quench calculations showed that the magnet is self-protecting with a copper-to-NbTi ratio of 10:1. The operating current is less than 25% of short sample limit. In the CR dump resistors and bypasses will be used to protect the individual quenched magnet within the string of 24 dipoles. The number of turns is high, and consequently the current in the monolith conductor is low, avoiding large cryogenic losses in the normal conducting leads. Dipoles of this type were already installed in the A1900 Fragment-Separator at MSU [3].

Superferric Dipoles for the Super-FRS

The Super-FRS is a large-acceptance superconducting fragment separator and therefore requires magnets with wide apertures. The 3 first quadrupoles and the first 3 dipoles after the target will be resistive, using a special radiation resistant conductor with metal oxide insulation. All other magnets in the Super-FRS will be superconducting magnets. It emerged in the first concept of the Super-FRS that the requirements of the dipoles for the Main Separator and of the dipoles for the CR are very similar. Just the effective lengths, the minimum fields and the requirement of the field quality are different. A little change of the Super-FRS design gave the possibility to create a common dipole design for both sections (table 1), leading to a cost reduction for design and spare magnets. Therefore all said about the CR-dipole is also valid for the dipoles of the main separator. Three dipoles are connected in series in the Super-FRS. So, no special protection scheme in necessary.

A superconducting dipole prototype is presently being developed and will be fabricated in collaboration with the FAIR China Group (FCG), consisting of the Institute of Modern Physics (IMP) in Lanzhou, Institute of Plasma Physics (ASIPP) in Hefei, and Institute of Electric Engineering (IEE) in Beijing. All institutes are members of the Chinese Academy of Science (CAS). Figure 1 shows a skech drawing of the magnet. All other superferric dipoles of the Super-FRS will be scaled versions of this common design.

Superferric Quadrupoles and Sextupoles for the Super-FRS

Because of the required large acceptance of the Super-FRS the quadrupoles and sextupoles will have wide apertures, too. The warm circular bore of these magnets has a diameter of 380 mm. The maxima gradients are 10 T/m and 40 T/m^2, respectively. The high pole tip field, due to high gradient and large aperture, requires the use of a superferric quadrupoles in the Super-FRS. Two short quadrupoles together with one long quadrupole and two sextupoles will be installed together in one cryostat forming the multiplets of the lattice. Unlike the dipole magnets the yoke and the pole of these magnets are also cooled down in the cryostat. Figure 2 shows the design of a typical multiplet. The two

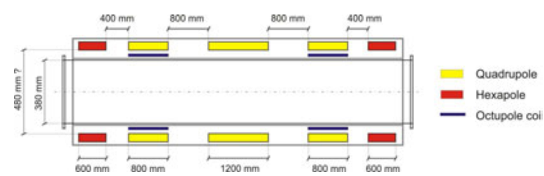

Figure 2: Schematic layout for Super-FRS multiplet .

quadrupole types differ in length (0.8 m and 1.2 m) and the short version has additional embedded octupole coils, winded on the surface of the inner wall of the Helium containment. Both quadrupoles and the sextupole magnets are self protecting with copper-to-NbTi ratio of 3.5:1 and 6.5:1, respectively. The maximum current in the racetrack coils is in all cases less then 300 A, so standard wires and standard (no HTSC) current leads could be used. All magnets will be powered individually.

Similar multiplets for the BigRIPS at RIKEN [4] have already been fabricated on an industrial scale in Japan by Toshiba Corporation [5]. The quadrupoles in the multiplets will be scaled versions of these magnets. A conceptual design of the Super-FRS multiplet, based on the experience with the quadrupoles triplets for the BigRIPS, was developed by the Toshiba Corporation, too.

SUPERFERRIC DIPOLES FOR THE NESR AND RESR

The baseline is to have a normal conducting design for the NESR/RESR main dipoles, but the use of superferric magnets is still in discussion. A study [6] will compare the costs between a superconducting and a conventional solution for the dipole, including prototype and series manufacture. Similar to the Super-FRS/CR dipole the NESR/RESR dipoles will have a warm iron and a warm bore, only the coil will be cooled down. Also due to the high field quality requirement a H-type design was chosen. The important differences to the dipoles of the CR and Super-FRS are:

- Particles will be decelerated in the NESR and RESR. So pulsed magnets are required with a maximum ramp rate of 1 T/s.
- The usable gap volume is smaller, 250mm x 70 mm compared to the 380mm x 140 mm of the Super-FRS/CR dipole. In order to keep the inductance low one has to choose a high-current-option.

The main parameters of the dipole including coil size, number of turns and inductance are given in Table 2. Nuclotron-conductor, designed for large steady-state-AC losses, will be used for these magnets. In this case one does not need a helium containment. The small number of turns (10 only, 2 layers) makes a curved magnet with negative coil curvature possible. As the saturation happens mostly near the corner of the pole, it has been necessary to add a saturation control hole in the center of the pole to equilibrate the saturation at high excitation. The shape and position of the shim, flank and hole have been found after several hundred optimization loops (figure 3). The cryostat is based on an austenitic stainless steel structure, made of 7 mm thick plate. Using a common structure for both coils allows to react the Lorentz vertical forces (8.2 kN/m) inside of the cryostat. The eddy current circulation is not acceptable in case the currents are allowed to circulate around the cryostat, but introducing an insulating insert in the cryostat brings the eddy current to an acceptable value (2.5 J/cycle), that doesn't effect the field quality. Both coils will be immersed in a G11 in-situ fabricated structure, capable of compensating the vertical forces between the coils. For the horizontal Lorentz forces (11 kN/m) radial support links are required. The gravity support is based on a Cardan joint to allow for the thermal

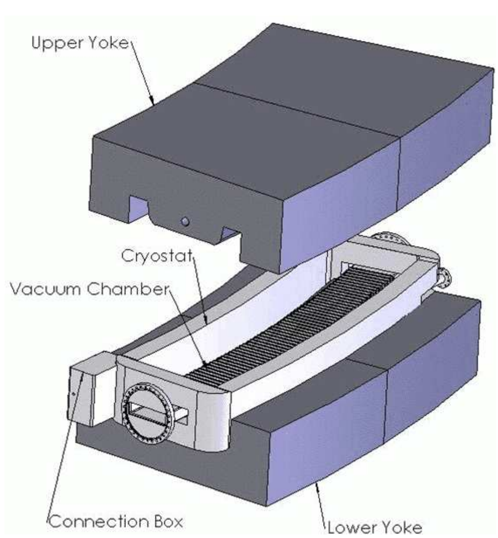

Figure 3: Preliminary design of a superferric NESR/RESR dipole.

Table 2: Requirements of the NESR/RESR dipoles

Numbers	24
Maximum field	1.6 T
Minimum field	0.06 T
Ramp rate	1 T/s
Maximum ΔB	1.5 T
Bending radius	8.125 m
Deflection angle	$15°$
Effective length	2.128 m
Usable gap width	250 mm
Usable gap height	70 mm
Pol gap hight	90 mm
Field quality	$\pm 1 \times 10^{-4}$
Overall weight	21100 kg
max Current	6000 A
Inductance	6.9 mH
Conductor size	6.3×6.3 mm^2
Coil cross section	13×32 mm^2
Number of turns	2×5

deformations of the coil. The thermal design requires 2 W at 4.2 K and 30 W at 77 K of cooling power.

SUMMARY

Superferric magnets are foreseen for the storage rings and the Super-FRS of FAIR. Conceptional designs of these magnets were done together with our collaborations and industrial partners. First prototypes will be built and tested by the end of 2007.

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