STATUS OF THE SUPER-FRS MAGNET DEVLOPMENT FOR FAIR

H. Müller, H. Leibrock, M. Winkler, P. Schnizer, E. Fischer, GSI, Darmstadt, Germany
L. Quettier, J.-E. Munoz-Garcia, Irfu, CEA, Saclay, France
L. Serio, CERN, Geneva, Switzerland

Abstract

The Super-FRS is a two-stage in-flight separator to be built next to the site of GSI, Darmstadt, Germany, as part of FAIR (Facility for Anti-proton and Ion Research). Its purpose is to create and separate rare isotope beams and to enable the mass measurement also for very short lived nuclei. Due to its three branches a wide variety of experiments can be carried out in the frame of the NUSTAR collaboration. Due to the large acceptance needed, the magnets of the Super-FRS have to have a large aperture and therefore only a superconducting solution is feasible. A superferric design with superconducting coils was chosen in which the magnetic field is shaped by an iron yoke. This paper presents the actual design status of the dipole and multipole magnets as well as the status of the development of the dedicated test facility at CERN.

INTRODUCTION

The Super-FRS is a new two-stage in-flight separator. It will be built as part of the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany [1]. Due to its three branches (high-energy branch, low-energy branch, and ring branch) a wide variety of experiments will be possible [2,3]. The large acceptance required and the DC operation of the magnets led to a superconducting solution. Only the very first magnets after the target have to be built as normal conducting magnets with special radiation resistant conductor, due to the high radiation levels.

From protons to uranium all sorts of ions can be accelerated in the Super-FRS up to energies of about 1.5 GeV/u and with beam intensities of 10^{12}/s.

The general layout of the Super-FRS magnets is shown in Fig.1. Overall the Super-FRS consists out of 24 dipole magnets and 31 multiplets (containing 80 quadrupoles, 41 sextupoles, 14 steerers, and 46 octupoles).

Additional superconducting magnets are needed for the Energy Buncher in the low energy branch. These magnets are an Indian in-kind contribution to FAIR and are not treated within this paper.

MAGNET DESIGN

The magnets of Super-FRS have several common design features. Firstly, they are of so called superferric type (with the exception of the small correction magnets steerer and octupole which are made as surface coils). The magnetic field is shaped by the magnetic iron as for normal conducting magnets, but the coils of the magnet are wound with superconductors.

Secondly, the magnets have to be self-protected, i.e. they have to survive a quench without any damage even in case the quench protection system fails. Nevertheless dump resistors are foreseen for machine operation to extract as much energy as possible. The requirement of self-protected magnets leads to the use of superconductors with a high Cu/SC ratio (>9 in case of the dipoles, ~3.5 for quadrupoles and sextupoles).

Each of the magnets is powered individually and has its own pair of leads. To limit the size of the current leads and warm power cables the maximum current of the magnets have to stay below 300 A. This leads to coils wound of insulated wires rather than a cable.

The cooling of the magnets will be done by a pool boiling Helium bath. The design pressure of the Helium containers is set to 20 bars to avoid helium losses in case of quench and to be able to operate the cryogenic facility of FAIR with one common pressure.

An additional requirement is a warm beam pipe.

Despite of being operated in DC mode three consecutive triangular cycles up to maximum current with a ramp up time of 120 sec have to be possible in between the different operation cycles. This cycling is necessary to always have reproducible field conditions independent from the previous setting.

The beam height in Super-FRS is at 2 m the height of the cryogenic supply was fixed to 3.3 m over ground.

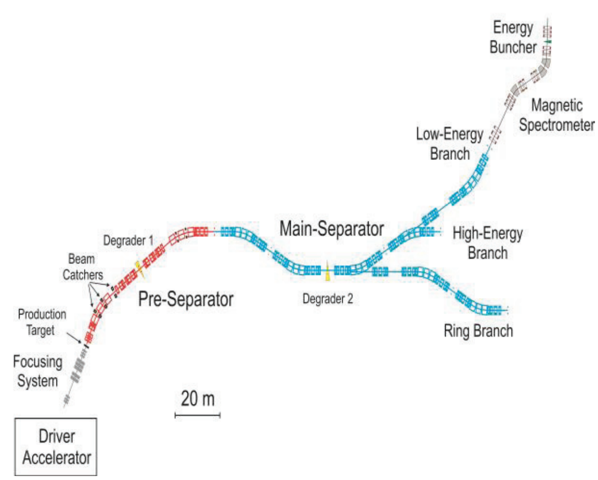

Figure 1: Magnetic Layout of Super-FRS.

DIPOLES

Two types of dipoles, differing in their magnetic lengths, are required in the Super-FRS. From the 21 dipoles of type 3, three magnets must provide holes for a straight beam tube at the splits of the different branches. The main parameters of the dipoles are given in table 1. The dipoles are H-type magnets with racetrack coils, and only the coil is cooled; the iron yoke is at room temperature as for a normal conducting magnet. A prototype of a Super-FRS dipole has been built in China in a collaboration of the Institute of Electrical Engineering, Beijing, responsible for the conceptual design, the Institute of Plasma Physics, Hefei, which produced the coil and the cryostat, and the Institute of Modern Physics, Lanzhou, which produced the yoke and carried out the tests [4].

Table 1: Main Parameters of Super-FRS Dipoles. Three of the Magnets of type 3 Have an Additional Straight Exit

	Type 2	Type 3
Number of magnets	3	21
Dipole field [T]	0.15-1.6	0.15-1.6
Bending angle [°]	12,5	9,75
Curvature radius [m]	12,5	12,5
Effective straight length [m]	2,4	2,13
Good field region [mm]	±190	±190
Pole gap height [mm]	170	170
Integral field quality (relative)	±3*10-4	±3*10-4

Despite successful tests concerning field quality, quench behaviour, and ramping, several modifications of the design showed to be necessary for the series magnets. These modifications include:

- Adaptation of the bending angle which was 15° for the prototype (common design for Super-FRS and CR, another storage ring of FAIR)
- Strengthening of cryostat mechanics (the prototype was not designed for 20 bar pressure) and to reduce deformation due to magnetic forces
- Modification of the coil support system due to space requirements in the machine
- Branching dipoles (with straight exit)

The redesign was assigned to CEA, Saclay, as French in-kind contribution to FAIR and is nearly finished. Fig. 2 shows a preliminary 3D model of the current design. The weight of the magnet is about 50 t.

MULTIPLETS

Quadrupole, sextupole and steerer magnets, as well as octupole coils embedded in the short type of quadrupoles, are arranged in so-called multiplets. The magnets of a multiplet are grouped together in one common cryostat. Depending on the position of the multiplet within the Super-FRS it contains from 2 up to 9 magnets. Table 2 gives an overview of the main parameters of these multiplet magnets. A sketch of the biggest multiplet is given in Figure 3. Altogether 33 multiplets are needed for Super-FRS (including two spare multiplets).

For the multiplets also the iron is at 4.2 K. The Helium inventory needed for the largest multiplet is about 1300 l (in contrast to the dipole where the He volume is about 30 l). At the moment only preliminary designs exist. According to these studies the stored energy of the type 4 quadrupole is about 1.2 MJ and the inductance of this magnet is about 27 H. Studies of the quench behaviour of the magnets show that for the quench of a single magnet the pressure rise in the vessel is below the design pressure of 20 bar even in the case of failure of activation of the dump resistor, so all the helium can be kept inside the vessel. This is also the case if all the magnets of the largest multiplets quenches and the dump resistors are activated as foreseen.

Figure 2: Outer shape of the dipole (design status 12-2014). One clearly sees the warm iron and the embedded cryostat. The big turret is due to the DN400 flange for the cryogenic and electrical interfaces standardized for ease of connection with the cryogenic jumper lines.

MAGNET TEST FACILITY

The cold testing of the dipoles and multiplets will take place at CERN in the frame of a collaboration contract between CERN and GSI. For this, refurbishing of an existing cryogenic test facility has started. It is planned to install three parallel test benches to allow testing of a magnet assembly every two weeks. In the total duration

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Table 2: Main Parameters of Super-FRS Multiplet Magnets

	Quadrupole Type 3	**Quadrupole Type4**	**Sextupole**	**Steerer**	**Octupole (embedded in Quadrupole 3)**
Number of magnets	46	34	41	14 (13v/1h)	
Field/Gradient range	1-10 T/m	1-10 T/m	4-40 T/m²	0-0,2 T	105 T/m³
Effective length [m]	2,4	2,13	0,5	0,5	
Radius of usable aperture [mm]	±190	±190	±190	±190	
Field quality	$\pm 8\cdot 10^{-4}$	$\pm 8\cdot 10^{-4}$	$\pm 5\cdot 10^{-3}$		

of the test of 6 weeks there would be included 2 weeks of mounting and cool down, 2 weeks of testing, and 2 weeks of warm up and dismounting.

Tests performed at CERN include:

- Vacuum and HV insulation tests;
- Instrumentation checks
- Cool-down and warm-up
- Magnetic measurements
- Ramping tests (120 seconds ramp time; 3 cycles)
- Static heat loads

An overview sketch of the planned arrangement of test benches is given in Fig. 4.

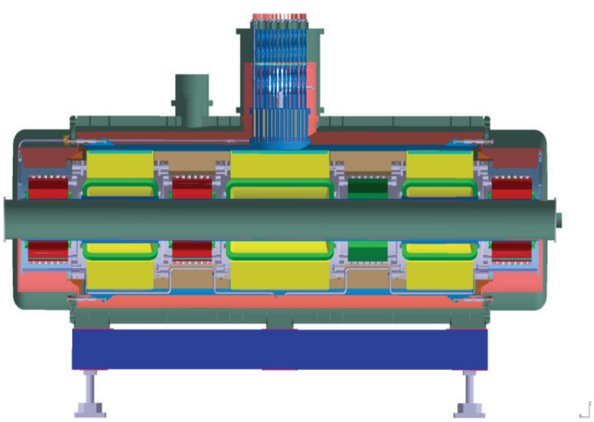

Figure 3: Cross section of biggest multiplet. Yellow and Green are the three quadrupoles (the bigger type 4 in the centre), red are the sextupole magnet and green is a steerer magnet. Together with the two octupole coils embedded in the shorter quadrupoles and not shown here, the multiplet contains 9 magnets, which are all powered individually.

STATUS AND OUTLOOK

The Super-FRS dipoles will be tendered by FAIR; the tendering process is going to start as soon as the design is finalised. The technical follow-up of the dipole production will also be managed by Irfu, CEA, Saclay, as French in-kind contribution.

The multiplets are a German in-kind contribution and therefore will be purchased by GSI. The tendering procedure for the multiplets is nearly finished. The contract signing shall take place by June of this year.

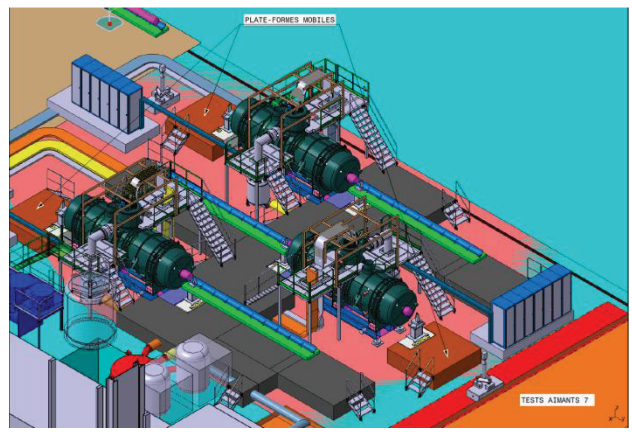

Figure 4: Sketch of the test station at CERN (with a long multiplet installed at all three benches).

Meanwhile the preparation of the test facility at CERN has started; the facility will be ready by the end of 2016. The first magnets are planned to arrive beginning of 2017. These will be so-called First of Series (FoS) magnets that will undergo longer and more complete testing before releasing the series production itself. The tested magnets will be then shipped to GSI and ready for installation in the Super-FRS.

REFERENCES

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