SUPERCONDUCTING MAGNETS AT FAIR *

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Abstract

For the FAIR (Facility of Antiproton and Ion Research) accelerators, various technologies of superconducting magnets have been developed. In total, 613 superconducting magnets are required for the FAIR modularized start version. For the heavy ion synchrotron SIS100, which is the central accelerator under construction, fast ramped, iron dominated superconducting magnets of the Nuclotron type will be used. Due to the high beam intensity operation desired for SIS100, highest precision and reproducibility is requested for the iron yoke of these magnets. For the dipole magnets of SIS100 the series production has already been released. In parallel, the Super-FRS will be built for the generation of radioactive beams and for isotope separation. Huge aperture superconducting dipole magnets and multiplet modules are required for the main separator of the Super-FRS. For testing of the various types of sc magnets, three test facilities at GSI, JINR and CERN have been set-up. We give an overview on the modern design aspects for the different magnet types and their first test results and the preparation of the appropriate test facilities.

INTRODUCTION

The FAIR research programme includes 14 initial experiments, which form the four scientific pillars of FAIR:

APPA: Atomic and plasma physics, and applied sciences in the bio, medical, and material sciences;

CBM: Physics of hadrons and quarks in compressed nuclear matter, hypernuclear matter;

NuSTAR: Structure of nuclei, physics of nuclear reactions, nuclear astrophysics and radioactive ion beams (RIB);

PANDA: Hadron structure and spectroscopy, strange and charm physics, hypernuclear physics with anti-proton beams.

For this purpose the modularized start version (MSV) of the project is structured in the following four modules:

Module 0: Heavy-Ion Synchrotron SIS100 – the basis facility – required for all science programmes;

Module 1: CBM/HADES cave, experimental hall for APPA and detector calibrations

Module 2: Super-Fragment-Separator for NuSTAR;

Module 3: Antiproton facility for PANDA, providing further options also for NuSTAR ring physics.

Superconducting magnets are the core elements for the SIS100 as well as for the Super-FRS machines. In addition four wide aperture high gradient quadrupole magnets are required for the final focusing system (FFS) of the HEDgeHOB experiment (High Energy Density Matter generated by Heavy Ion Beams) of APPA.

For CBM a heavy superconducting dipole with a magnet gap of 140 cm (height) and 250 cm (width) will be a central part of the detector system.

SIS100: RAPIDLY CYCLING MAGNETS

The heavy ion synchrotron (rigidity 100 Tm), utilises superconducting dipoles providing a maximum field of 1.9 T, ramped with a cycle frequency of 1 Hz (4 T/s). The magnets have to be operated at 4.5 K and use Nuclotron type cables. The characteristics of the main quadrupole and corrector magnets are given in Table 1.

Table 1: Magnet Parameters

Characteristic	Main Quadrupole	Corrector Magnets		
		Multipole (Q/S/O)	Steerer	Chrom. Sextopole
Number	166	12	84	42
Max. field strength, T/m^{n-1}	27.77	0.75/25/333	0.37	232
Effective magnetic length, m	1.264	0.75	0.403 /0.41	0.383
Aperture diameter, mm	100	150	135	120
Operation current	10512	250/246/240	245/ 241	252
mass, kg	850	200	120	145

In principle the maximum dipole field of 1.9 T could be provided also by a normal conducting accelerator magnets. However, besides other arguments in favour of the superconducting magnet design (e.g. operation costs), the planned high current Uranium beam modes with intermediate charge states, require ultra-low vacuum pressures. For long term operation this can be achieved only by cold beam pipes acting as a cryopump with stable temperatures well below 15 K for all operating cycles. So the final layout of the SIS100 magnets is the result of an optimized trade-off between efficient cooling conditions for the superconducting magnet coils and the beam pipe, minimized AC loss generation, high field quality and stable mechanical properties.

SIS100 Dipoles –series Production

The First of Series (FoS) main dipole was delivered in 2014. Intensive tests have shown excellent results with respect to e.g. quench behaviour, electric properties, powering, and AC losses. The nominal field was reached without any issues. However, the geometrical properties of the yoke aperture were found to be beyond the specified values caused by an inappropriate production technique chosen by the contractor. It was based on a standard welding technique of the yoke followed by the milling of the aperture. As a result the magnetic-field homogeneity showed characteristics which are insufficient for beam operation and the series production could not be released [1, 2]. After a broad survey for alternative production techniques a second yoke was produced with lamination directly cut to the final cross section geometry in cooperation between GSI and the contractor using a novel laser welding technique (among other changes). Tests of the magnet with the new yoke were finalized in Q1/2016 with positive results. The aperture geometry was well improved with respect to the specified values. Consequently, the magnetic field provides properties suitable for beam operation proven by a sophisticated measurement system developed at GSI [3]. In parallel, about 140 issues between the FoS and the series dipoles concerning design details, fabrication, and quality assurance were identified in a basic technological optimization process. With such adjustments and changes of the production technique the supplier's manufacturing concept of the series dipoles was successfully reviewed (FDR) and the series production was released in 07/2016. In Q3 and Q4 of 2016 the manufacturer started to acquire the required material and tools, and the first components of the series dipoles were manufactured. The delivery of the first genuine series dipole is expected in 08/2017.

SIS100 Quadrupole Units

The SIS100 lattice is based on a doublet focusing concept, where two quadrupoles are arranged in close proximity. A steerer dipole, a chromaticity correcting sextupole or the beam position monitor are mounted on a quadrupole. The different combinations are called units. All SIS100 main quadrupoles and corrector magnets will be produced at JINR, Dubna in the framework of a Russian inkind contribution to FAIR. The multipole corrector and the steerer were designed as longitudinal-space-saving nested magnets, i.e. a quadrupole, a sextupole and an octupole in the multipole corrector and horizontal and vertical dipole coils in the steerer. These magnets are of the Cosine-theta type, the chromaticity sextupole is a superferric magnet. All the corrector coils are wound from a Nuclotron type cable with electrically insulated sc strands as these magnets are powered individually. The wires of the coil are connected in series that reduces the current by the number of wires below 260 A. The design of the remaining components – terminal boxes (connecting in series the insulated strands) and the cold terminals of the 250 A current leads – is already finished by GSI and the engineering drawings were transferred to JINR. A prototype of the terminal box for the corrector magnets was tested at GSI and has shown reliable operation. The production of the first two units, i.e. one quadrupole (Fig.1) with a steerer (Fig. 2) and the second quadrupole with a sextupole will be completed by the end of May 2017. After intensive cold tests of the magnets and of the assembled units it is planned to start the series production for all quadrupole units of the SIS100 in Q4/2017.

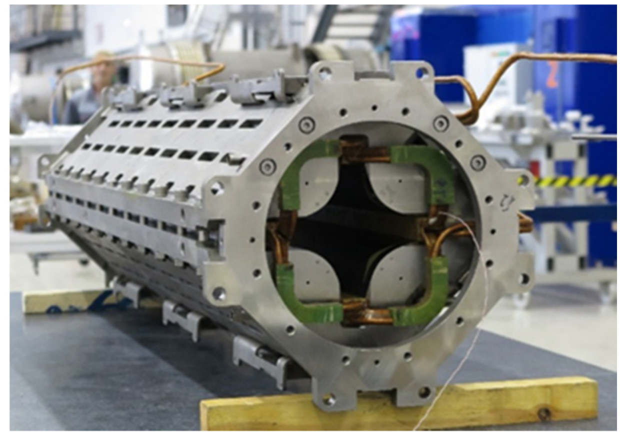

Figure 1: Photo of the first SIS100 main quadrupole.

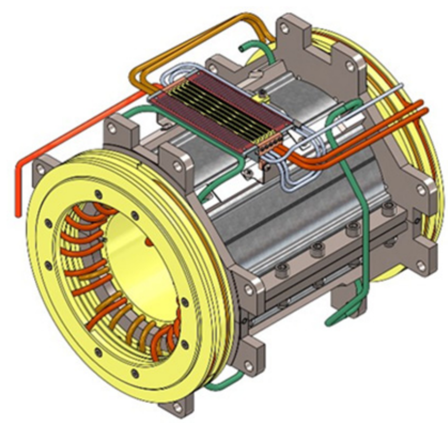

Figure 2: Drawing of the SIS100 steerer magnet.

Quadrupole Doublet Integration

The cold mass of two quadrupole units are installed on a common girder and placed in a single cryostat. Various combinations with a cryo-catcher module, beam position monitor and additional corrector magnets are required. The first version of a SIS100 quadrupole doublet module (QDM) in its final configuration was finished in engineering design in 2016. This QDM located in the SIS100 arc section. It is equipped with two different superconducting quadrupole units. In between these two units, a cryo-collimator is located within the integrated cold mass. The second unit is equipped with a beam position monitor. The full module also provides LHe supply for magnet cooling, high current supply for main quadrupole magnet operation, and local current supply for corrector magnet operation as well as the beam vacuum chambers. The engineering design for the complete series of all configurations of the SIS100 QDMs was derived from the design of the first QDM type. The series consists of four differ-

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ent module classes with, in total, eleven configurations including two special modules for injection and extraction of the beam with very special engineering design and configuration. The first QDM type QDM will be manufactured in 2018 in a series of 83 modules for SIS100. The procurement of the full series of SIS100 QDMs is planned in a process including multiple contractors for the various subsystems. All critical ultra-high vacuum components are planned to be procured separately by specialised manufacturers. For manufacturing of cryostat components and mechanical integration of the SIS100-QDMs a dedicated contractor shall be commissioned. The preparation work for tendering of the module integration was completed in 2016. An according contract for module integration is planned to be signed in 2017.

MAGNETS FOR THE SUPER-FRS

The superconducting magnets of the Super-FRS comprise 33 multiplets (assemblies of quadrupole, sextupole and other corrector magnets) and 24 dipoles. The multiplets are being built by ASG, Genoa, Italy. The final design of the first of series multiplets has been approved in December 2016 and the production is about to start. The first multiplet will be available in spring 2018. The design of 21 standard superconducting dipoles by CEA Saclay is finished and the tender has started. The contract signature with a manufacturer is planned for the end of 2017. The design of three special branching dipoles (i.e. dipoles with an additional straight exit) will also be carried by CEA, Saclay.

MAGNET TESTING

Prototype Test Facilities

The prototype test facility (PTF) at GSI was upgraded to be able to power the high current superconducting dipoles. The new DC power converter is able to provide 20 kA at an output voltage up to 66 V with a current stability of 10□4. Since the cooling power of the cryoplant is limited to 300W the conventional vapour cooled copper current leads used before were replaced by 14 kA DC HTS-current leads in order to reduce the heat load and guarantee a reliable cooling of the magnet. One of the main tasks running at the prototype test facility is the development of new and the adjustment of existing measurement systems for testing the SIS100 series dipole magnets. The new system for magnetic-field measurements was developed in collaboration with CERN. It consists of a shaft of five rotating coil probes, a motor drive with an angular encoder and the data acquisition electronics. Next to this a system to measure the geometry of the magnet´s aperture was developed and successfully tested during the measurements on the first of series dipole magnet for SIS100.

Series Test Facilities

The GSI test facility for SIS100 series dipoles (STF) was built from 2014 to 2015 and is under commissioning. The main use of the STF is to execute the series tests of the SIS100 dipoles and the SIS100 string test, a short part of SIS100 consisting of one dipole and one quadrupole module together with local cryogenic components. Besides this the STF allows for testing of every type of superconducting magnet for SIS100, Super-FRS and later on of Heavy Ion Synchrotron SIS300. Moreover, it provides cooling capacity for operating a superconducting continuous-wave linear accelerator (cw-linac) later on. The main supply systems such as a cryoplant with a cooling power of 1500Wand two power converters with 20 kA (at 66 V output voltage) were successfully commissioned during 2015 and 2016. The STF is expected to be ready for operating in May 2017.

SIS100 Quadrupole Unit Testing

A facility for testing of superconducting magnets for FAIR and NICA projects has been commissioned and put in operation at Joint Institute for Nuclear Research in Dubna in November 2016. JINR and GSI shared the costs of building the facility. Three of six cryogenic test benches are foreseen for testing of quadrupole units for the SIS100 synchrotron. The testing program will include the power tests of the magnets at helium temperatures, measurements of the magnetic-field quality as well as the adjustment of the hydraulic resistance for each type of the quadrupole unit. Tested units will be shipped to the company responsible for the integration of the units to the Quadrupole Doublet Module. Cold testing of two pre-series quadrupole units is scheduled for the middle of 2017.

Testing of Super-FRS Magnets

The Super-FRS dipoles and multiplets will be tested under cold condition (4 K) at a novel cryogenic test facility in CERN. In accordance with a collaboration agreement between CERN and GSI, refurbishment of the facility and installation of the new infrastructures have been done. The commissioning of the facility is partly started. The handover of the facility from CERN to GSI is planned in the middle of 2017. The pre-series multiplet testing starts from 2018.

CONCLUSION

The release of the series production of the superconducting dipole for SIS100 was passed. The start of the pre-series production at JINR Dubna complements this process on the quadrupole unit side. The first magnets and the releated components are on the track. The engineering design of the first quadrupole doublet module was finalized, the other modules are derived from this concept. Regarding the production of the Super-FRS magnet, the manufacturer's concept of the pre-series multiplet was reviewed and confirmed. The engineering design of the Super-FRS dipole was finished, the tendering for manufacturing will be started soon. The magnet production is started for the successful realisation of the FAIR project.

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