

# Status of the superconducting magnets for FAIR\*

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## Introduction

Within this paper we report shortly on all the many different activities of the group which now is mainly focused on procuring the magnets and associated systems for the FAIR project. While many activities were pursued the successful tests of the SIS100 dipole magnet stick clearly out.

## Superconducting magnets

### *Rapidly cycling magnets for SIS100*

**Dipoles – production status and first tests** The First of Series SIS100 main dipole was delivered last year and its testing campaign has been conducted since December 2013 with a successful cool down, measurement of the virgin field curve, required for field optimisation calculations, and finished with a successful training.

The coil structure was found to provide an insulation of 3 kV already at the factory test. During the first run the magnet quenched slightly below the nominal current with the second quench already above nominal field and reached up to now a maximum current of 15.7 kA and thus shows sufficient operation margin.

The AC losses produced by the SIS100 main dipole magnet are one of the main loads on the cryoplant. are well below the expected value of 70 W for a triangular cycle of 1 Hz. This is considered explainable by the choice of iron (M600-100A silicon steel), the superconducting low loss wire with a CuMn matrix and extra inserts at the magnet ends, foreseen for optimising the end field quality.

The magnetic field was measured using: a hall probe mounted on a mapper, a single stretched wire system, and rotating coil probes at different locations [1, 2]. The field measured with these different systems gave results which were matching each other with sufficient accuracy and second the soundness of the measurement system design.

So the overall tests of the magnets were successful: quench behaviour, magnetic field strength, AC losses. The magnetic field was however a bit deteriorated. The mechanical accuracy of the yoke assembly was investigated with appropriate gauges, which showed that the yoke mechanics was slightly out of specifications. Based on these measurements mitigation actions were discussed with the

manufacturer and will be tested and incorporated in the production beginning next year.

**Quadrupole modules** Aside of the dipoles the main quadrupoles together with all corrector and steerer magnets are assembled into so called units consisting of a main quadrupole and up to two correctors. These quadrupole units will be produced and tested at cold temperature at Joint Institute for Nuclear Research (JINR). The collaboration contract for production of quadrupole-, corrector- and steering magnets as well as the integration into units at JINR are finalised and will be signed in January 2015. The units are located within 83 quadrupole doublet modules split in 11 configurations and four basic classes with modules located in the arc, the end of the straight section of the SIS100 machine. All these modules are currently designed in interaction with Babcock Noell GmbH Würzburg / Germany. The integration of the modules has to fulfill demanding stability criteria of  $\pm 125 \mu\text{m}$  for the main quadrupoles, which makes the design challenging. The tendering process for the involved components and the integration of modules is in preparation and will be established also in 2015.

### *Rapidly cycling magnets for SIS300*

After manufacturing of a first dipole magnet in collaboration with INFN, Italy, a second collared coil was built together with INFN and CERN in frame of the EU-CRISP project. Ongoing is also the design work on wide aperture quadrupoles for FAIRs HEDgeHOB experiment by IHEP in Protvino, who had already successfully built SIS300 quadrupole and corrector prototypes.

### *Magnets of the Super-FRS*

The specifications of the SuperFRS magnets were released and the tender launched. The dipoles design has been finalised by CEA/Saclay. The multiplets have been thoroughly negotiated and the contract will be awarded soon.

## Testing

### *Prototype test facility activities*

While the magnet was produced in parallel the test facility was upgraded so that all parameters of the magnet could be derived including an upgrade of the power converter and procurement of HTS current leads.

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The measurements of the field quality were made with the mole, i.e. a rotating coil probe system with a motor operating inside the magnetic field. For series measurements a measurement shaft will be used with cold coil probes as their cores. Together with CERN a system was adapted for measuring the magnetic field in cold conditions in vacuum and successfully tested. A shaft based on this principle will be tested beginning next year.

### *Series test facility activities*

The series test facility is being built up which is currently mainly dedicated for testing the SIS100 dipoles. The cryo-infrastructure including also the feed boxes have been procured supervised by our colleagues of the cryo group and are currently being tested. It will provide 4 test benches organised in 2 clusters and allow testing the SIS100 string.

At the beginning of the SIS100 series dipole testing all four benches will be used for the tests of the dipole magnets. When the first of series quadrupole doublet will be delivered to GSI one of the test benches will be used to operate the string test [3].

### *SIS100 quadrupole tests*

The test facility at JINR for these magnets is currently being built up. The first power converter is being assembled and will be commissioned soon. Each test bench is equipped with a satellite refrigerator for cooling down and operating of the magnets. This concept simplifies the parallel operation of the test benches. Two satellite refrigerators have already been produced.

### *Testing Super-FRS magnets at CERN*

The cold tests of Super-FRS will be done at CERN under a collaboration agreement between CERN and GSI. Three test benches, suitable for dipole magnets and multiplets respectively, will be available. This allows a continuous operation with one bench being cooled down, one cold and the measurements running, and the third being warmed up. Given that these choices have been made now the hardware can be procured. CERN is already refurbished the necessary cryogenic infrastructure and setting up the other necessary test equipment as, for example, power converters, quench detection systems, and systems for magnetic measurements.

### *Current leads*

The successful test of the first pair of HTS current of last year gave the green light to produce the second pair which was delivered this year and successfully tested. So the series production of the current leads for the series test station and the SIS100 machine was launched. Along with this high current current low current leads have been designed. A prototype has been procured that will be tested beginning next year. For the  $\gamma_t$ -Jump-Quadrupole, a cold normal conducting magnet within a quadrupole doublet module, the

design of current leads has been started. For the Hedgehog collaboration 4 pairs of 6 kA HTS current leads shall be procured. A specification is in preparation.

### *Electrical systems and magnet protection*

The quench detection systems for the series test facility have been procured. While these systems could detect a quench reliably in the SIS100 machine, the required cables would create too large parasitic capacitance. Therefore an alternative based on transducers is currently under development.

## **Conclusion**

After the procurement of the different superconducting magnets has been started in 2013, the first SIS100 dipole was tested thoroughly in 2014 and a new built chromaticity sextupole is ready now for testing as a first corrector type magnet. The dipole tests results proved that the magnet design is sound and the requested operation parameters are achievable. In-depth technologic investigations of the yoke production process, supporting the manufacturer, have shown that the remaining problems can be solved by improving the welding technology so that the specified tolerances of the yoke geometry can be achieved. Thus a second yoke will be produced and the corrected first dipole is expected to provide the required magnetic field accuracy. This will allow us launching the series production still in 2015. The production of the other magnets was also prepared in 2014. The telegraphic style of this paper reflects the many activities that are undertaken to realise the FAIR project within the given scope and schedule.

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