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FIRST TESTS OF THE MAIN QUADRUPOLE AND CORRECTOR MAGNETS FOR THE SIS100 SYNCHROTRON OF FAIR

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Abstract

The heavy ion synchrotron SIS100 is the main accelerator of the FAIR complex (Facility for Antiproton and Ion Research) in Darmstadt, Germany. Currently the construction site and facility are advancing fast. The series production of the main dipoles was already started in 2017. In parallel, the first two quadrupoles, a chromaticity sextupole and a steerer were built and tested in cooperation between GSI and JINR at the cryogenic test facility in Dubna. We present the operation performance of these two first of series quadrupole units (consisting both of a corrector magnet mechanically and hydraulically combined with a quadrupole). Besides the thermal stability of the fast ramped superconducting magnets special attention is directed to their magnetic field properties. The obtained results provide the basis for starting the series production of all SIS100 quadrupole and corrector magnets in 2018.

INTRODUCTION

SIS100 is built of 6 sectors (Fig. 1), each of them being sub-divided in 14 ion-optical cells.

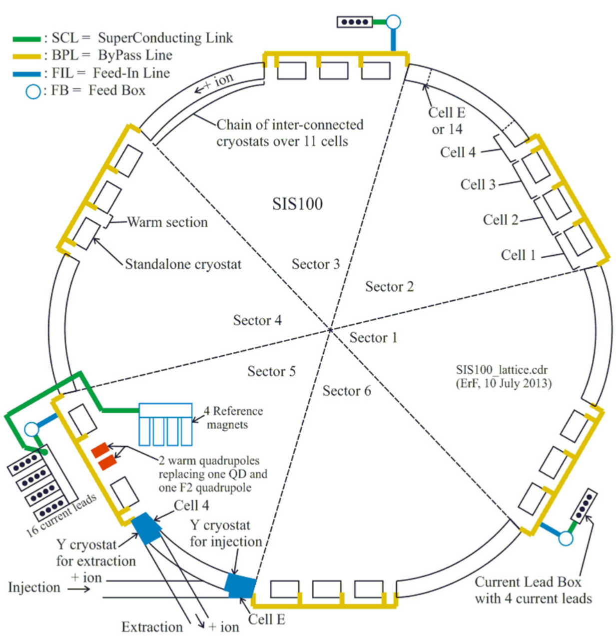

Figure 1: Schematic representation of the SIS100 accelerator showing the six sections of the synchrotron ring with its Bypass Lines and cryogenic and electrical supply systems.

From cells 4 to 14, cryostats are connected to each other without interruption of cryogenic and electrical supply. Cells 1, 2, 3 of each sector and 4 start with a warm section which forces the 3 first cells to have a standalone module. In each sector (from cell 1 to cell 4), a Bypass Line (BPL) is used to provide the helium flow and the electrical current to each standalone module. In sector 5 (Fig. 2), cell 2 has 2 warm quadrupoles instead of a standalone cryostat (with 2 superconducting quadrupoles). The beam is injected in cell E of sector 5 using a special injection module. The beam is extracted in cell 4 of sector 5 using a dedicated extraction module. The SIS100 shows

- one dipole (DP) circuit made of 108 dipoles + 1 reference magnet connected in series,
- one quadrupole defocusing (QD) circuit made of 83 + 1 magnets connected in series,
- a first quadrupole focusing (F1) circuit made of 36 + 1 magnets connected in series,
- a second quadrupole focusing (F2) circuit made of 47 + 1 magnets connected in series.

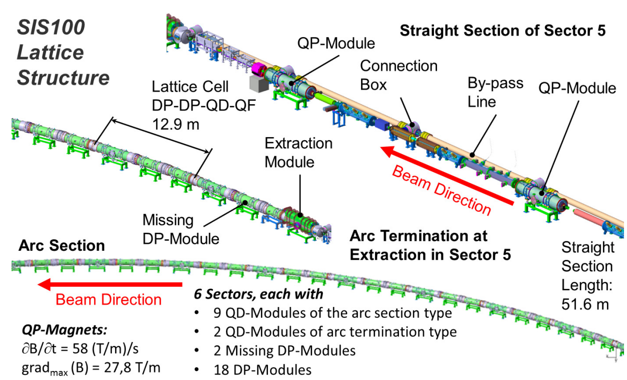

Figure 2: Cryomagnetic components in sector 5 of SIS100.

MAGNET UNITS

The doublet focusing concept of the SIS100 lattice arrange two quadrupoles in close proximity. Combined horizontal and vertical steering dipoles, chromaticity correction sextupoles or the beam position monitors are mounted on a quadrupole magnet. The different combinations are called Quadrupole Units. All SIS100 main quadrupoles and the corrector magnets will be produced and tested at JINR in Dubna. The multipole corrector and the steering magnet 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

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[1]. The first two units, i.e. one quadrupole QD with a steering magnet (SF2B-unit) and the second quadrupole F2 with a sextupole (VQD-unit) were manufactured and tested at JINR Dubna in 2017. After successful testing all the Quadrupole Units will be later on combined by GSI into Quadrupole Doublet Modules (QDM). 83 QDM in 11 different configurations have to be fabricated. A cryogenic QDM is an assembly of 2 quadrupole units within a common cryostat. Between 2 quadrupole units, one cry-collimator may be installed. A quadrupole doublet has 2 quadrupole vacuum chambers and one middle vacuum chamber (if there is no collimator). 4 quadrupole vacuum chambers have a star shape, all the others are elleptical. The vacuum chamber is the UHV beam pipe. There is also a version with a collimator between 2 units.

MAGNET TESTING

The basic design of the fast cycling magnets for both NICA and FAIR projectss was developed and optimized in close collaboration between GSI and JINR. The same concerns also construction and commissioning of the testing facility at JINR [2, 3].

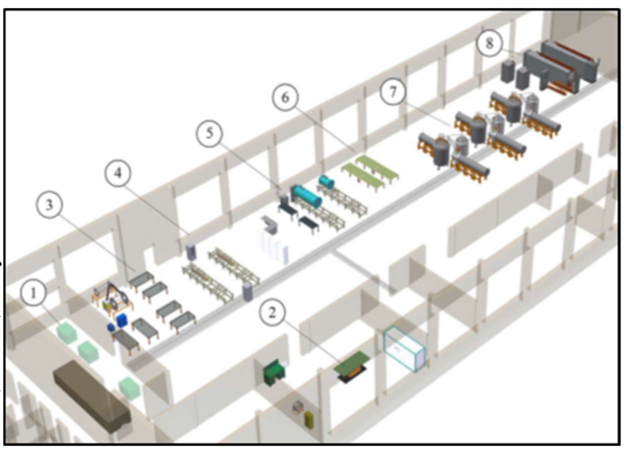

Figure 3: Schematic 3D-view of the facility halls and main equipment placement: 1 – superconducting cable; production hall; 2 – coil production hall; 3 – magnet assembling area; 4 – warm magnetic measurements; 5 –vacuum tightness check 6 – magnets assembly in cryostats; 7 – cryogenic tests at 6 benches; 8 – power converters area.

Cryogenic Operation

The SIS100 first of series units were tested in Q4/2017 (Fig. 3). After cool down from room temperature to 4.5 K within 2-3 days the magnet training was started. Both quadrupoles had shown excellent training behaviour, i.e. even the first quench was about 10 % (DQ) and 20 % (F2) above the nominal operation current of 10,5 kA. After the following two quenches up to 13,7 kA the training was stoped at a maximum current of 14,5 kA without further quench. The training of the corrector magnets revealed also good results: The chromaticity sextupole had reached its operation current (252 A) up to the maximum current of the power supply (260 A) without any quench. For the steering magnet only in the horizontal coil a first quench was obtained at 95 % of its operation current.

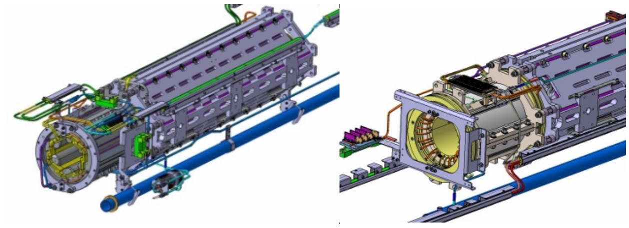

Figure 4: 3D-drawing of the first tested units VDQ (left) and FS2B (right).

All the tubular coils (Nuclotron-type cable) of the superconducting dipoles and quadrupole units are cooled by a forced two phase helium flow in parallel channels. They must be correctly adjusted concerning their hydraulic resistance for stable operation of the SIS100. For this purposes the DC heat load and AC losses of 10 different arrangement types of the units must be carefully measured before the full series can be manufactured. This was done for the first unit types VQD and SF2B in Fig. 4. The results confirmed our preliminary estimation of 25 W of dynamic heat load for the maximum operation mode, the details will be presented in a following publication.

Magnetic Measurements

The magnetic field measurements (in AC, i.e. ramped and DC modes) are required to provide the integral field of the magnets, their field quality and the real position of the magnetic axis. A rotating coil probe was used. The measurement scheme is scetched in Fig. 5. It compensates the dipole component by a factor of $3 \cdot 10^{-3}$ and the quadrupole component bny a factor of $1 \cdot 10^{-2}$. For the correctors only integral field was measured.

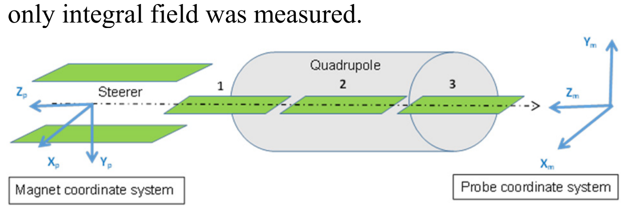

Figure 5: Layout of the sections of the harmonic coils.

The measured transfer function of the quadrupoles is given in Fig. 6 for different ramp rates. The effective magnet length is about 5 % shorter than the specified one (1264 mm). This could be compensated by a higher operation current (using the high margin as shown during the magnet training) and slightly enlarging the iron yoke. Nevertheless for the planned SIS100 operation modes the effect will be insignificant and the decision was made not to change the quadrupole design or operation conditions. The obtained harmonics of the QD quadrupole are presented in Fig. 7, showing some enhancement for the higher components b_4 (octupole) and b_6 (dodekapole). In preparation for series production we have started detailed calculations of the effects due the possible manufacturing tolerances.

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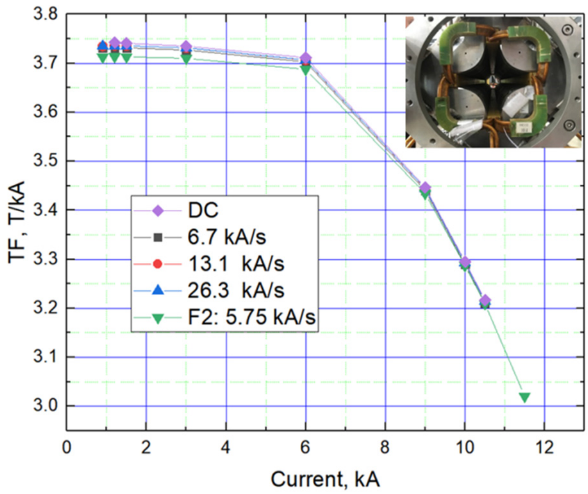

Figure 6: Tansfer function of the quadrupoles QD and F2 measures at various ramp rates. The insert shows a picture of the coil end part and the yoke poles of the quadrupole.

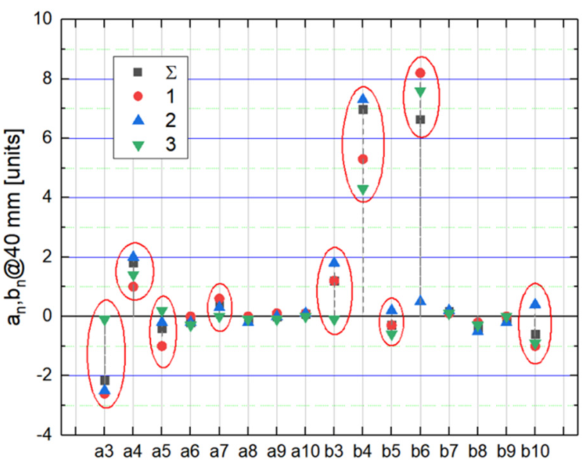

Figure 7: Circular harmonics of the QD Quadrupole for 10.5 kA, 6.7 kA/s (∑ - integrated harmonics, 1, 2, 3 – harmonics at the different sections).

The magnetic field data for the chromaticity sextupole are shown in Fig. 8, including a picture of magnets end part. The results for the vertical and horizontal steerer components as well as a picture of the characteristic cosine-theta design is presented in Fig. 9. Both corrector magnets fulfill the specified operation parameters. In addition the crosstalk between the magnets was investigated. No effect was seen beween the sextupole and the quadrupole within the VQD unit, whereas it must be taken into account for the operation of SF2B unit beween the quadrupole and the steering magnets. For series testing an optimized magnetic measurement will be built. Based on the given results the remaining 6 units of the SF2B-type and 18 units of the VQD-type can be produced. The eight other unit assembly types still have to be tested in detail. Nevertheless it is already established now, that the properties of the tested SIS100 main quadrupoles, the chromaticity sextupole and the steering magnets satisfy thes requested operation parameters. This still have to be proven for the multipole corrector magnets as well as for the low current quadrupoles of the injection and extraction modules. Both magnets types will be manufactured and tested until 2019.

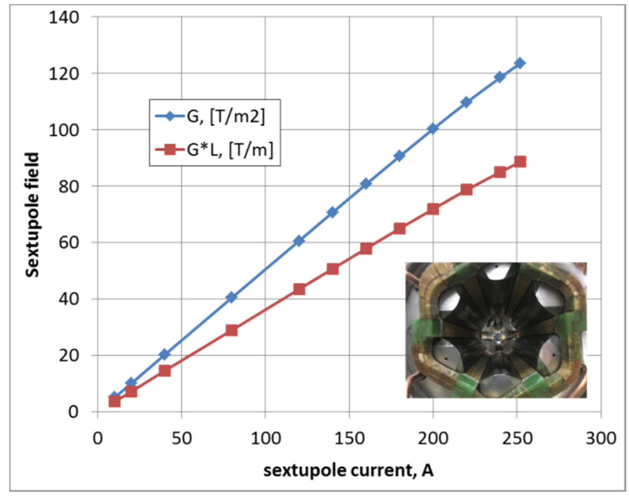

Figure 8: Effective and integral magnetic field data of the chromaticity sextupole.

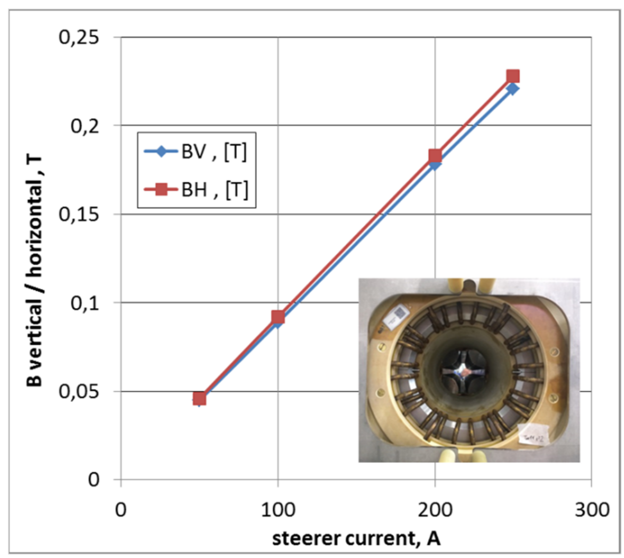

Figure 9: Magnetic field of the vertical and horizontal steerer components.

CONCLUSIONS

Two main quadrupoles, a steering and a sextupole magnets were produced and successfully tested for the superconducting SIS100 synchrotron of the FAIR project. Their cryogenic operation parameters as well as the magnetic properties achieve the requested performance. The series production of these magnets will be started in Q2/2018. Using these magnets the complete series of the first two unit types VQD (18 units) and SF2B (6 units) can be assembled, tested and provided for further integration into cryogmagnetic quadrupole doublet modules. The integration work is planned to start in Q1/2019.

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