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START OF THE SERIES PRODUCTION FOR THE CRYOGENIC MAGNET CORRECTOR MODULES OF FAIR

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Abstract

The fast cycling superconducting synchrotron SIS100 has to deliver high intensity beams for the FAIR project at GSI, Darmstadt. The main dipoles will ramp with 4 T/s up to a maximum magnetic field of 1.9 T where the field gradient of the main quadrupole will reach 27.77 T/m. The integral magnetic field length of the horizontal/vertical steerer and of the chromaticity sextupole will provide 0.403/0.41 m and 0.383 m respectively. We present the status of the first magnets test results as well as the overall procedure of production and testing of the complete series of the cryomagnetic corrector modules.

INTRODUCTION

The Facility of Antiproton and Ion Research (FAIR) under construction at GSI [1] will provide high intensity beams of ions and antiprotons for experiments in nuclear, atomic and plasma physics as shown in Fig. 1.

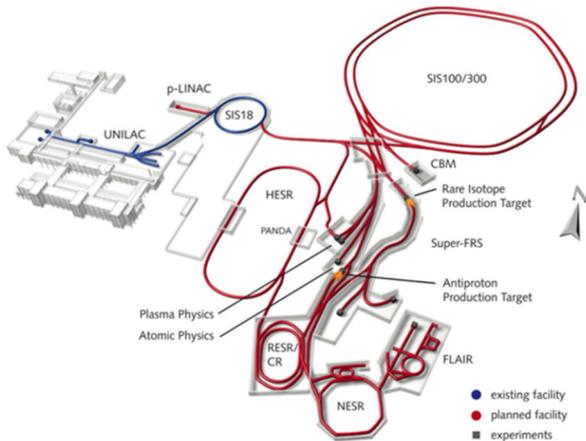


Figure 1: Scheme of the existing accelerator facility at GSI (left) and the planned FAIR complex (right).

The operation modes of the FAIR facility will facilitate four experiments simultaneously. Besides the reference Uranium and proton beams, acceleration of all other ion species is foreseen. The SIS100 synchrotron with magnetic rigidity of 100 T·m is the key component of FAIR. The high repetition rate of SIS100 acceleration cycles up to 1 Hz requires fast-ramped superconducting magnets with high dynamic heat load. The SIS100 dipole and quadrupole magnets as well as the magnets for the NICA project [2] were designed on the basis of the fast-cycling superferric magnets for the Nuclotron synchrotron at JINR in Dubna [3]. During an intensive R&D phase the dynamic heat generation caused by fast cycling was considerably

reduced in comparison to the original Nuclotron magnets [4]. The losses were experimentally measured on short models and on full size prototypes. Finally, the first-of-series dipole, quadrupole and corrector magnets for SIS100 were built and tested at the cryogenic test facilities at GSI and at JINR. The dynamic heat loads and helium mass flow rates were measured for different operation modes of SIS100. Like for the Nuclotron accelerator the cryogenic cooling scheme of SIS100 and NICA is based on using of the two-phase forced flow helium. All dipole and quadrupole magnets in one sector of the accelerator are connected to one supply and one return header and are cooled in parallel. Due to very different hydraulic resistances of the parallel cooling channels the hydraulic adjustment of each channel is important.

THE SIS100 SC MAGNETS

The Nuclotron type design was chosen for the SIS100 lattice dipole and quadrupole magnets [5], [6]. A single-layer dipole magnet (see Fig. 2) has a radius of curvature of about 52 m. A quadrupole magnet with hyperbolic poles is shown in Fig. 3. The iron yokes of the magnets are fabricated of laminated isotropic 1.0 mm thick M600-100A silicon steel. The multipole corrector and the steerer were designed as nested magnets, namely, a quadrupole, a sextupole and an octupole in the multipole corrector and horizontal and vertical dipoles in the steerer (see Fig. 4). These magnets are of the Cosine-theta type. The chromaticity sextupole designed as a superferric magnet (see Fig. 5).

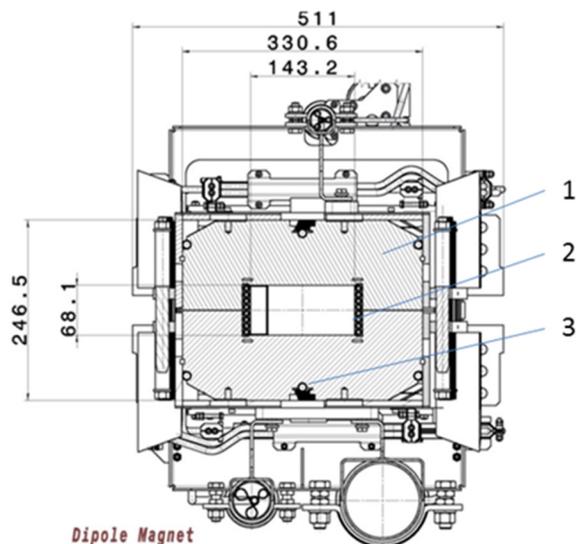


Figure 2: Cross-section of the SIS100 dipole. 1 – lamination, 2 – SC coil, 3 – tube for cooling the yoke.

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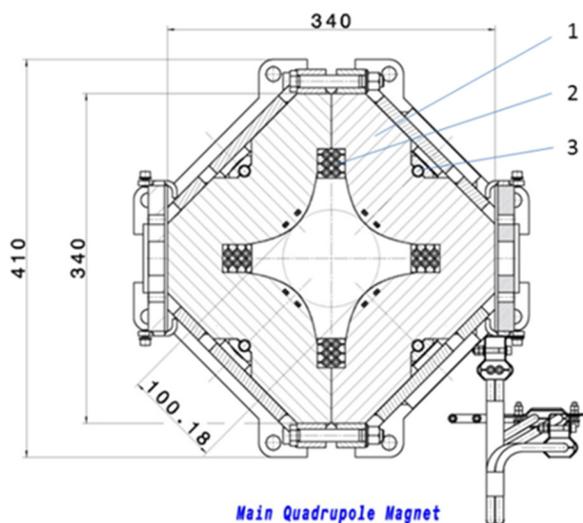


Figure 3: Cross-section of the SIS100 quadrupole magnet.

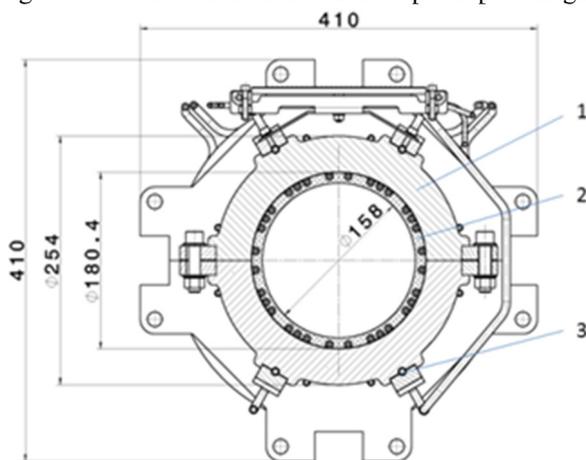


Figure 4: Cross-section of the steerer magnet.

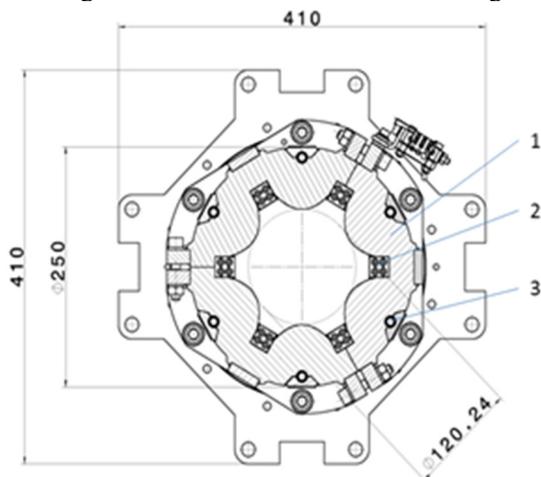


Figure 5: Cross-section of the chromaticity sextupole.

The corrector coils are wound with the Nuclotron type cable of electrically insulated wires.

PRODUCTION AND TESTING

The production of 110 SIS100 Dipoles was contracted with the Bilfinger Noell GmbH in Würzburg, Germany. The series production had been released on 22.07.2016

and the first dipole module was received at the GSI series test facility on 29.09.2017. There are four feed boxes in the cold testing area that provides a maximum throughput of one complete tested magnet per week. The details of this test facility and the present operation experience are given in [7], [8].

All SIS100 main quadrupoles and corrector magnets will be produced at JINR Dubna in the framework of a Russian in-kind contribution to FAIR. A common production and testing facility for these magnets as well as for the superconducting magnets of the NICA project is shown in Fig. 6 It was constructed and commissioned in Dubna in close collaboration between GSI and JINR [9], [10].



Figure 6: View of the NICA-FAIR test facility.

The first two units, i.e. one defocusing quadrupole QD with a steering magnet (SF2B-unit) and the second focusing quadrupole F2 with a sextupole (VQD-unit) were manufactured and tested in 2017. The cryogenic tests include: training of the magnet, measuring the static heat input and dynamic heat dissipation, measuring the hydraulic resistance of the cooling channel during operation in a reference cycle, measuring the quality of the magnetic field in the aperture and the effective magnetic length of the magnet, checking the tightness of the helium cooling channels and the electrical insulation strength in the operating conditions, etc. [11]. Analogous to the dipoles, 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. 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. Both corrector magnets fulfil the specified operation parameters. In addition the crosstalk between the magnets was investigated. No cross-talk effect was seen between the sextupole and the quadrupole within the VQD unit, whereas it must be taken into account for the operation of SF2B unit between the quadrupole and the steering magnets. For series testing an optimized magnetic measurement system was designed. Based on the given results the remaining 6 units of the SF2B-type and 18 units of the VQD-type can be pro-

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duced. The series production of the magnets was started in Q4/2018. For example of the test results Fig. 7 shows the quench training of the QD quadrupole as well as the measured effective and integral magnetic field parameters of the chromaticity sextupole.

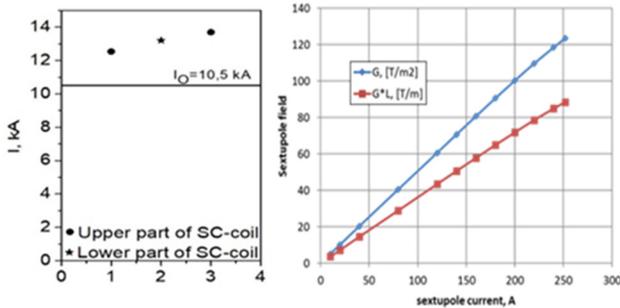


Figure 7: Quench training of the first SIS100 Quadrupole (left) and the magnetic field characteristics of the chromaticity sextupole (right).

DYNAMICAL LOSSES IN THE FAST RAMPED MAGNETS

The operation modes of the SIS100 synchrotron depend on the kind of the ions to be accelerated, the required energy and the extraction type, slow or fast. Some samples of the operation cycles are presented in Fig. 8.

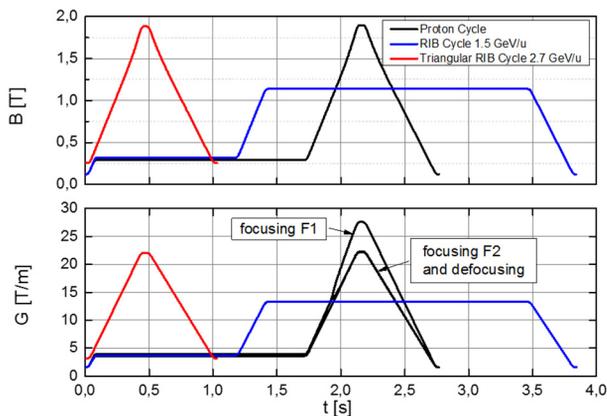


Figure 8: Some examples of the SIS100 operation cycles. The plots show the main dipole field (upper plot) and the field gradients in three families of quadrupole magnets (lower plot) as a function of time. The highest dynamic heat release in the superconducting magnets will be generated in the triangular RIB cycle with 1 Hz repetition rate.

The upper plot shows some typical time charts for the main dipole field. Each acceleration cycle starts with a beam injection plateau at 0.2 – 0.3 T. The time required for the beam injection and the beam manipulations might vary between 0.01 s for the single-turn injection and 1 – 2 s in case of the multi-turn injection. After the beam injection the dipole field is ramped up to the extraction plateau with the rate of 4 T/s. The level of the extraction plateau depends on the required beam energy and varies between

0.5 T and 1.9 T. The operating current of the dipole magnet at 1.9 T is 13.2 kA. The extraction can take up to several seconds in case of the slow extraction. Then the field is ramped down with the ramp rate of 3.5 T/s and a new acceleration cycle starts. Generally, the SIS100 will serve several experiments concurrently. In this case the sequence of different acceleration cycles will be combined into one super-cycle.

The most demanding operation mode with respect to the dynamic heat generation in the superconducting magnets is the acceleration of U28+ ions to 2.7 GeV/u with one-turn injection and fast beam extraction (Triangular RIB Cycle in Fig. 8). Due to the extraction field of 1.9 T and the high repetition rate of about 1 Hz this cycle will generate the highest dynamic heat load in dipole magnets. The measured AC losses of the quadrupole magnets are shown in Fig. 9. These values are well confirm our previous R&D results for design optimisation and loss minimisation. Also our special design of the low current corrector magnets based on Nuclotron-type cable with electrical insulated strands was successfully tested.

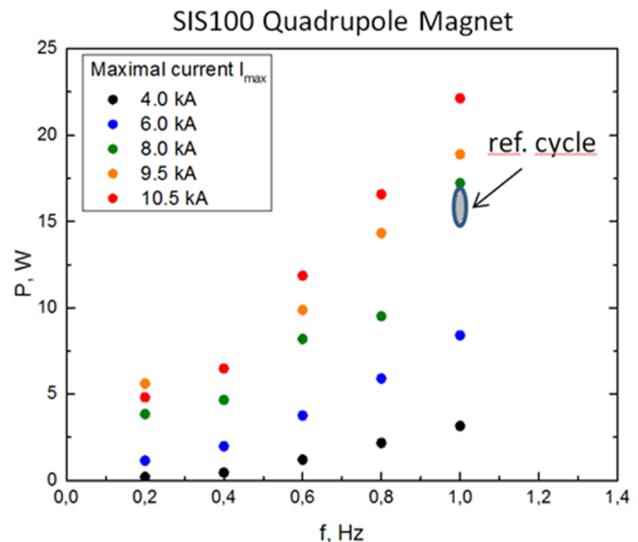


Figure 9: Dynamic heat release (loss matrix) measured on the first-of-series quadrupole magnets. The dashed areas show the dynamic heat release in the reference cycle.

CONCLUSION

The basic Nuclotron type design for fast ramped superconducting magnets was successfully optimized and adapted to the operation requirements of the SIS100 accelerator of the FAIR project. Following intensive tests on the first of series magnets the continuous production and testing of the superconducting magnets for the SIS100 were started. The various magnets stable fulfil the required operation parameters. For the main dipole and quadrupole magnets as well as for the corrector magnets the series production and testing proceeds. Completion of all the magnets manufacture and testing is planned until March 2023.

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