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SIS100 – A NEW AND UNIQUE HEAVY ION SYNCHROTRON UNDER CONSTRUCTION

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Abstract

SIS100 is a fast-ramped superconducting heavy-ion synchrotron under construction at GSI, Darmstadt, and will serve as the main accelerator of Facility for Antiproton and Ion Research (FAIR). It is designed to deliver intense beams from protons to uranium, including medium charge state ions such as U^{28+}. A central design goal is stabilization of the dynamic vacuum to minimize charge-exchange-driven beam loss. Key features include a charge-separator lattice, cryogenic ion catchers, cryo-adsorption pumps, a liquid-helium-cooled ultra-high-vacuum system, and rapid acceleration. The concept has been validated in SIS18 and the SIS100 string test. Despite its superconducting technology, SIS100 will provide cycling flexibility comparable to room-temperature machines. Installation in the tunnel began in early 2024, with beam commissioning foreseen for the end of 2028.

INTRODUCTION



Figure 1: Prototype SIS100 quadrupole unit.

SIS100 is the central synchrotron of the FAIR complex [1]. The machine design and principal parameters have been described in detail in Ref. [2]. A major design objective is the stabilization of the dynamic vacuum during operation with medium charge state heavy ions, where charge-exchange processes can lead to significant beam loss. The overall mitigation strategy—including the charge-separator lattice, cryogenic ion catchers, cryo-adsorption pumping, the liquid-helium-cooled ultra-high-vacuum system, and the fast acceleration scheme—has been developed and documented in Refs. [3–5]. Experimental verification of the underlying concepts has been carried out at the existing SIS18 synchrotron and in the SIS100 string test, confirming the effectiveness of the adopted measures in reducing charge-exchange-driven beam loss.

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GENERAL PROJECT STATUS

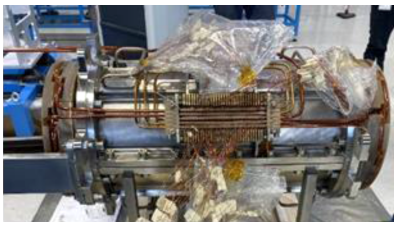


Figure 2: Multipole corrector magnet manufactured in industry.

The procurement of components for the FAIR subproject SIS100 progresses largely according to plan. The production and testing of superconducting quadrupole units, comprising the main s.c. quadrupole magnets, the steerer- and sextupole magnets, including their shipment, continued closely to scheduled. So far, 82 quadrupole units of 166 have been accepted and approved for pairwise integration into quadrupole modules. Following a careful risk assessment and in order to minimize risk for project execution and schedule completion, further 36 quadrupole units have been contracted to industry. In order to prepare the series production in industry, four prototype s.c. quadrupole units and one multipole corrector, comprising three different multipole coils (Figs. 1 and 2) have been manufactured and are presently cold tested.

For qualification of the industry units, dedicated equipment for power tests and magnetic field measurements at cold has to be build-up at GSI. The procurement of the corresponding components, such as testing cryostats, preparation benches and anti-cryostats has been launched. For the development of the required magnetic field measurement equipment consisting of stretched wire systems and rotating coil probes a collaboration with mutual benefit with CERN has been established.

At the beginning of the Ukraine crisis the integration of quadrupole units into quadrupole modules at company BNET had to be interrupted. After catching up the unit production, the module integration process could be fully re-established, and the desired integration rate of two modules per month has almost been achieved. For cold testing, the integrated modules are shipped from company BNET in Germany to the Thor test facility in Salerno, Italy [6]. An updated integration schedule and slightly extended scope

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has been accounted in a new contract amendment which has been signed by INFN and GSI.

In spite of the progress achieved in manufacturing and procurement of components technical challenges are still showing up especially during final acceptance tests. During the acceptance tests of the injection kicker systems problems occurred with the low inductance HV pulse cables used for energy storage and transmission. Several cables have shown insufficient insulation strength with HV breakdown and corresponding damages at operation with a voltage of up to 80 kV.



Figure 3: Wire eroded model thin-wall quadrupole chamber (star-shaped) with LHe cooling pipes.

For mitigation a strategy has been developed providing a second injection kicker module and an extended testing program for alternative HV cables. The second injection kicker module has already been contracted and by lowering the required maximum voltage shall provide higher reliability in operation. Technical challenges, such as surface damages of the anodized cathode have also significantly extended the acceptance process of the two electrostatic extraction septa.

Most components of the cryogenic UHV system, such as the thin-wall elliptical LHe-cooled dipole- and quadrupole chambers, have been delivered. Presently, star-shaped thin-wall chambers and cold-warm transitions are in procurement. After successful Final Design Review (FDR) a short model has been manufactured for technology demonstration. The highly demanding model of the thin-wall, star-shaped quadrupole chamber with LHe-cooling pipes has successfully been manufactured by means of wire erosion (Fig. 3).

Due to the unavoidable charge of the medium charge state beam ions during interaction with the wires of the electrostatic extraction septum quite concentrated beam loss in the next magnet downstream occurs. Therefore, the two lattice quadrupoles following the extraction septum are not realized as superferric magnets but as normal conducting radiation hard magnets. These two radiation-hard quadrupole magnets have been manufactured in New Zealand and arrived at GSI after an extended sea transport.

The LHe supply of SIS100 is managed via three niches attached to the accelerator tunnel. In these niches, a feed-box, a feedinline box and the current lead boxes are situated. While the production of the feed boxes for niche 30 has been well advanced, progress has also been achieved in terms of the procurement strategy and the procurement itself for the feed boxes 50 and 10. The Wroclaw University for Science and Technology (WUST) is in charge of the design and accompanies the manufacturing process of all local cryogenic components. Meanwhile the first feedinline box for niche 30 has been accepted and shipped to GSI (Fig. 4). Furthermore, a FOS current lead box has been delivered and successfully cold tested at the GSI series test facility. Further current lead boxes are presently on sea transport from India.



Figure 4: Feed-in line box for niche 30 during the Factory Acceptance Test (FAT) at the company Kriosystem.

FINAL STRING TEST OPERATION

SIS100 is a fast ramped s.c. synchrotrons. The main dipole magnet circuit is operated at maximum with 28 kA/s up to 13 kA and the main quadrupole magnets with 22 kA/s up to 11 kA. The cycle time of the most extreme pure triangular cycle is less than one second. Such an operation generates high electromagnet forces between the busbar systems. In order to test the reliability of the design, clamping and fixation concept a long-term maximum load operation is presently conducted of the SIS100 string test. So far, 2 million of such cycles have been conducted successfully (Fig. 5).

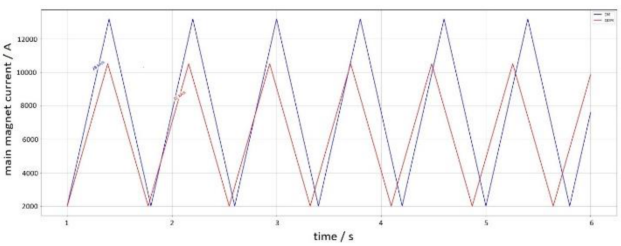


Figure 5: Maximum load operation of the SIS100 string with a peak current of 13 kA and a peak ramp rate of 28 kA/s in the s.c. dipole magnets (blue line) and 11 kA and 22 kA/s in the quadrupole magnets (red line). The cycle time is 0.8 s.

INSTALLATION AND INTEGRATION HIGHLIGHTS

In terms of the installation process major progress has been achieved in the integration of the dipole-dipole interconnections. The first steps comprise the assembly and

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testing of the UHV system and the busbar soldering. The second step comprises the process line welding and integration of the process line bellows and hoses. The welding process for the process lines and hoses (pressure equipment) in the interconnection regions between the s.c. magnet modules was successfully developed and conducted by a GSI in-house welding team (Fig. 6). The present status in the six arc sections is shown in Table 1.

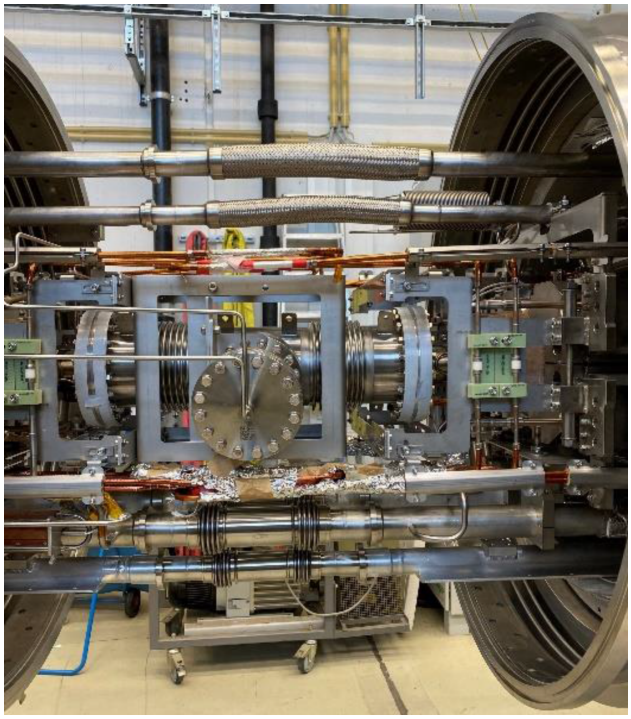


Figure 6: Dipole-dipole interconnection with the cryo-adsorption pump in the middle, the connected UHV- and busbar systems and the welded process lines bellows and hoses.

Table 1: Installation and Integration Status of Dipole-Dipole Interconnections

Section/arc	Transport + Positioning	Integration Step 1	Integration Step 2
3	100 %	95 %	90 %
4	60 %	10 %	0 %
5	0 %	0 %	0 %
6	90 %	90 %	20 %
1	100 %	95 %	90 %
2	100 %	100 %	90 %

Following completion of integration step 2 for all dipole modules, a comprehensive survey and alignment are planned in preparation for the installation of the quadrupole modules. This measure is necessary to minimize subsequent lateral movements after the stiff process lines have been connected.

In parallel, company General Electrics has almost completed the set-up of the SIS100 main power converters for the dipole- and the two quadrupole circuits. The first of two acceptance runs is presently under preparation with scheduled start in August 2026. While the first test will be conducted in short circuit mode the second step will be conducted with the completed cryomagnetic system.

The set-up of the world-wide first laser cooler [7] in a user synchrotron has been continued. Mirror boxes for guiding the laser beam from the laser room situated in the parallel supply tunnel into the accelerator tunnel were manufactured and installed in the straight of sector 3. All chambers needed for overlapping the laser beam with the heavy ion beam and for analyzing the fluorescence light have been manufactured and installed.

The installation of the room-temperature devices in the straight section of sector 4 — including the RF acceleration and bunch-compression cavities, first-turn chambers, and resonance sextupole magnets — has progressed to a stage that permits commissioning of the beam-line vacuum system.

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