

TECHNOLOGICAL FEATURES AND STATUS OF THE NEW HEAVY IONS SYNCHROTRON SIS100 AT FAIR

P. J. Spiller, P. Bartolome, J. Blaurock, L. Bozyk, M. Draisbach, T. Eisel, U. Gambardella (*), A. Illuk (**), M. Janke, F. Kaether, M. Kauschke, G. J. Ketter, S. Klammes, S. Klammes, P. Kowina, H. Klingbeil, H. Kollmus, D. Lens, J. P. Meier, D. Ondreka, M. Osendorf, I. Petzenhauser, V. Plyusnin, I. Pongrac, N. Pyka, P. Rottlaender, C. Roux, J. Schmidt, K. Sugita, A. Szwangruber, P. Szwangruber, S. Wilfert, T. Winkler, D. Winters, GSI GmbH, Darmstadt, Germany, (*) INFN, Salerno, Italy, (**) WUST, Wroclaw, Poland

Abstract

SIS100 [1] is a new superconducting heavy ion synchrotron optimized for the acceleration of low charge state, high intensity heavy ion beams. Most crucial intensity limitation for heavy ion beams in SIS100 is the dynamic vacuum and corresponding beam loss by projectile ionization [2]. Ionization loss and ion induced desorption drive the residual gas pressure into an instability, generating an intensity barrier at much lower intensity levels than any space charge limit. Technologies for stabilizing the dynamic vacuum, such as extensive charge separator lattice, pumping by cryogenic magnet chambers, cryo-adsorption pumps and cryo-ion catchers were the design drivers for SIS100 [3]. SIS100 will also be the first user synchrotron comprising a laser cooling system for beam cooling at relativistic beam energies. Combined with a strong bunch compression system, laser cooling will support the generation of short ion bunches. Meanwhile, a large amount of the SIS100 components have been delivered and preparations for installation are intensified.

STATUS OF CIVIL CONSTRUCTION



Figure 1: View on the FAIR construction site with the re-filled SIS100 tunnel pit in front.

The SIS100 tunnel, which is part of the construction area North, consists of two parallel 1.1 km long tunnels [4]. One outer ring for the SIS100 accelerator itself and one inner ring for the supply systems. Since the tunnel is situated in public area, only minor on-ground buildings were accepted by the authorities. The shell construction has been completed and the excavation pit has been refilled with soil (figure 2). Presently the installation of the technical infrastructure and the cryogenic distribution system is being

conducted. The start of installation of the first accelerator section is planned for January 2024.

STATUS OF THE ACCELERATOR

The integration process of the 110 cryogenic dipole chambers into the superconducting dipole modules has been completed (figure 2).



Figure 2: Integration of thin-wall, ripped and LHe-cooled dipole chambers into the s.c. dipole modules (behind).

Due to the Ukraine crisis, the collaboration in terms of the manufacturing of quadrupole units with JINR (Russia) has been suspended. However, negotiations have been continued, because JINR was recognized as an international research institute, such that the sanctions imposed after the Russian invasion of Ukraine may not apply in full extend. To date no further units have been completed and shipped to GSI and measures have been initiated to compensate for these shortfalls. The number of units delivered so far, served for completing the integration of 13 quadrupole modules at Bilfinger Noell, Germany. Due to the shortfall of units, the integration process had to be interrupted after assembly of these modules. Correspondingly, the module cold testing at the THOR test facility in Salerno, has to be suspended on short term. The whole reorganization of the assembly chain of quadrupole modules, creates a significant additional effort for the subproject and generates additional budget needs for investments and personnel and potentially delay until completion. The replacement of the quadrupole unit manufacturing conducted at JINR, Russia by European industry is possible. However, the local know-how for manufacturing the Nuklotron-type magnets, especially the corrector magnets using a cable with insulated s.c. strands, has to be further developed. As first step,

the production capacities, including tooling for the production of most units types and few prototype units will be contracted. Depending on the result of negotiations and evaluations with JINR, further series units will be made in industry. In addition, cold testing capacities for the units, including magnetic field measurement equipment need to be build-up, potentially at the GSI STF (series test facility). Due to resource limitations, GSI will not be able to perform both, the cold testing of the quadrupole units and the cold testing of the integrated quadrupole modules, therefore, the continuation of the collaboration with INFN, Italy is of great importance. Cold testing of the integrated quadrupole modules has to be continued and accelerated at the test facility THOR in Salerno for the potentially extended sub-project duration. In order to prepare the production of the series of quadrupole units at an alternative manufacturer, the re-procurement of yoke steel and s.c. wire, required for s.c. cables have already been launched by GSI. At the THOR test facility at the University Salerno, the preparation for the series testing of the quadrupole modules is meanwhile well advanced. The set-up of the test facility, as well as the cold commissioning has been completed successfully. Major decisions have been taken for the process lines in the interconnection regions (figure 3). Especially the expected lateral forces at the pressure test of up to 28 bar, stiffening of the process line bellows and measures to minimized forces on the cold mass has been carefully investigated.

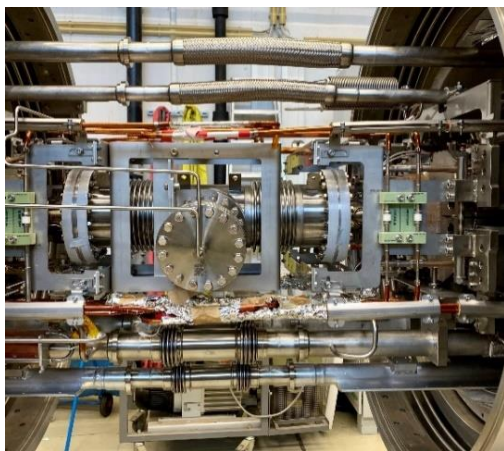


Figure 3: Dipole-dipole interconnection region with a cryo-adsorption pump in the middle, process lines on top and bottom and the main bus bar systems.

The First-of-Series FOS quadrupole module, send to Salerno, has been integrated into the test facility and used for training the agreed testing program at room and cryogenic temperatures. The FOS testing did also serve for training the INFN team on site. The series production of the thin-wall and actively LHe-cooled quadrupole chambers has been completed by the company RI, Germany. The LHe-cooled chambers consist of 0.3 mm thick special steel (Boehler steel) which maintains its low permeability down to the operation temperature at 4.5-10 K. The quadrupole chambers and all other parts to be integrated into the quadrupole modules, such as cryo-ion catchers, cryogenic BPM

system etc. are available and stored until the integration process is being continued. This is also the fact for the large components of the quadrupole modules itself, such as cryostat vessels, girder, supports, telescopic bellows and thermal shields. The design of the main SIS100 dipole and quadrupole power converters has been completed by GE (General Electric) and was approved in the frame of the Conceptual Design Review (CDR) and Final Design Review (FDR) milestones. All 20 kV transformers and the switchyard systems are available and will be installed in SIS100 tunnel in the fall of 2023. Several corrector magnet power converters have been manufactured and delivered. Especially the Indian shareholder and provider have completed manufacturing of the 166 steerer magnet power converter. As last major components of the SIS100 beam line components, the procurement process for the extraction septum magnets 1 and 2 could be successfully completed and the contract for production has been awarded. The tendering process for the last device of the extraction system, the extraction septum 3 is presently in the negotiation phase. With the contracting of these septum magnets, the procurement process for all devices of the extraction system is closed. After a rather long phase of R&D and technical issues, progress has also been achieved in terms of the performance of the injection kicker system. With the FOS kicker a sufficiently short rise time of the system could be demonstrated. The impact of disturbing reflections in the discharge current, after the main pulse, has been minimized by using transmission cables with slightly different length. In this way, superposition of the reflection can be avoided and their impact on the beam minimized. With the demonstrated performance, the Factory Acceptance Test (FAT) could be passed successfully. The delivery of parts and systems for the extraction kicker system is progressing. The bi-directional SIS100 extraction kicker system is used to deflect the beam upwards towards the extraction system or downwards towards the internal machine dump. The kicker system is synchronously ramped with the beam rigidity and able to dump the beam in any moment of the cycle. At company RI, Germany a first Pulse Forming Network (PFN) system used for the energy storage has been assembled and promising measurements have been conducted. All Rf acceleration and bunch compression cavities have been delivered. Acceptance tests with the MA loaded bunch compression cavities showed additional cooling needs of the ring cores. The development of a dedicated forced air cooling system is completed and the integration and preparation for final power tests are presently conducted. Wroclaw University of Technology (WUST) is the main provider for the SIS100 local cryogenics components. The production of bypass lines (figure 4), which do not only contain the liquid Helium process lines but also the main bus bar systems, has been awarded to the company Kriosystem, Poland. The series production is well advanced and will be completed mid of 2023. To verify the quality and functionality of special technical details, such as the s.c. cable feed-through in the vacuum barrier, a number of bypass lines were cold tested at the GSI STF facility. Another invitation to tender for the production of

the current lead boxes has been repeated and is presently published. A concept and strategy to involve more potential bidders has been developed with the aim to enable a successful next procurement process also for the upcoming feed-boxes.



Figure 4: Cryogenic bypass lines containing the LHe process lines and the four main magnet bus bar systems made of Nuklotron type cable.

In parallel to the ongoing procurements, the set-up of a string-test is under preparation. The string test consists of all components of one regular SIS100 lattice cell (figure 5). The string test is not only important for design confirmation and mechanical and electrical measurements, but also to develop the work instructions and QA processes for the final tunnel installation. The mechanical integration is used to develop working teams conducting the assembly process of the overall cryomagnetic- and local cryogenic system of SIS100. The string test assembly is almost completed and the first cool down will be conducted until May 23.

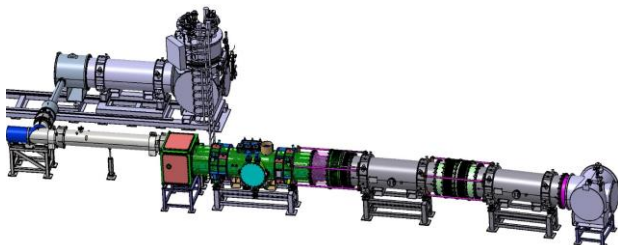


Figure 5: Sketch of the SIS100 string test comprising one lattice cell and the interface to the local cryogenics system.

LASER COOLING

At very high kinetic energies ($\gamma > 5$) and high intensities, respectively, stochastic and electron cooling methods become less attractive. Therefore, as the first high energy, high intensity, heavy-ion synchrotron worldwide, the SIS100 will be equipped with a laser cooling facility [5].

Although laser cooling is typically applied to ions with a low charge state and at low velocities and intensities (e.g. ions in traps). It can also be applied to ions with a very high charge state at relativistic velocities and high intensities. This can be achieved by exploiting the huge Doppler shift ('Lorentz boost') of the cooling transition in the ions (as measured in the lab frame) due to their relativistic velocity. The laser force results from the scattering of many laser photons from an ion via this fast electric dipole transition. The counteracting force required for cooling is provided by the Rf-bucket when the ion beam is bunched. One thus achieves bunched beam laser cooling [6]. Within the wavelength range of the laser systems and within the range of the magnetic rigidity of the SIS100, many ion species in different charge states can be laser-cooled. The laser systems can be operated at either 257 nm (UV light) or 514 nm (green light). The magnetic rigidity can be varied between 9 and 100 Tm. This powerful combination enables laser cooling of bunched ion beams ranging from very light ions, such as carbon to medium-heavy ones like xenon. For laser cooling at the SIS100, three different laser systems will be operated simultaneously. There will be one tuneable continuous wave (cw) laser system and two tuneable pulsed broadband laser systems, which will have a very high repetition rate (\sim MHz). The pulsed laser systems differ in the duration of the laser pulses. The 'short pulse' system will produce pulses between 1 and 100 ps, the 'long pulse' system between 50 and 750 ps. The average UV power of each laser system will be of the order of a few Watts. This should be sufficient to achieve fast and powerful cooling, i.e. a reduction of the longitudinal momentum spread of the ion beam by several orders of magnitude within a few seconds [7]. The laser systems will operate from the laser lab, which will be situated in the maintenance tunnel of the SIS100. From there, the laser beams will be guided through a 25 m long laser beamline, consisting of high-reflectivity mirrors, to the accelerator tunnel. The first part of this beamline was already successfully installed in January 2021. Via a dedicated vacuum chamber, the laser light will enter the vacuum of the SIS100. Since the laser light must enter and exit in a straight section of the accelerator, two aluminium mirrors will be used to guide the light along the ion beam direction. The laser light will travel a distance of about 45 m inside the SIS100 vacuum. However, to prevent the ion beam from hitting these mirrors, a horizontal closed orbit distortion, which tilts the beam axis by only a few mrad, is required. Good spatial overlap between the laser beams and the ion beam will be obtained using two sets of scrapers and by measuring the XY positions of the beams at two different locations, about 20 m apart. The effective overlap range between ion and laser beams will be about 22 m. Since the length of stored ion bunches is directly related to the longitudinal momentum spread of the beam, laser cooling will also help to produce very short ion bunches which could be extracted from the SIS100 towards experiments.

REFERENCES

- [1] P. Spiller *et al.*, “The FAIR heavy ion synchrotron SIS100”, *JINST*, vol. 15, paper T12013, 2020.
- [2] L. H. J. Bozyk *et al.*, “Ionization loss and dynamic vacuum in heavy ion synchrotrons”, in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, paper TUPVA056, pp. 2201-2204.
- [3] P. Spiller *et al.*, “Technologies for stabilizing the dynamic vacuum and charge related beam loss in heavy ion synchrotrons”, in *Proc. IPAC'16*, Busan, Korea, May 2016, paper MOPOY055, pp. 977-980.
- [4] M. Draisbach *et al.*, “Progress and status on civil construction of the SIS100 accelerator buildings”, 12th Int. Particle. Acc. Conf. IPAC'21, 4493 (2021)
- [5] D. Winters *et al.*, *Phys. Scr.* T166 (2015) 014048.
- [6] M. Bussmann, *ICFA Beam Dyn. Newslett.* 65 (2014) 8.
- [7] L. Eidam *et al.*, *Nucl. Instr. Meth. Phys. Res. A* 887 (2018) 102.