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STATUS OF CONSTRUCTION OF THE NEW HEAVY ION SYNCHROTRON SIS100 AT FAIR

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Abstract

The construction of the new Facility for Antiproton and Ion Research (FAIR) heavy ion accelerator facility at GSI is progressing well. With the start of installation of SIS100 an important new milestone in project execution has been reached. SIS100 is the first superconducting, fast ramped synchrotron with special design features dedicated to the acceleration of high intensity, low charge state heavy ions. The full performance of the specific functional systems, stabilizing the dynamic vacuum at operation with high Uranium intensities in combination with high repetition rates, was recently demonstrated at the SIS100 string test. Even under the influence of eddy current heating of the chamber walls at high ramp rates, its separately cooled cryogenic vacuum system assures a stabilization of the residual gas pressure at extremely low values.

INTRODUCTION

The general goal of the Facility for Antiproton and Ion Research (FAIR) [1] injector chain is to reach the space charge limit in SIS18 for all ions. Since many years, the intensity of Proton and light ion beams provided by the linear heavy ion accelerator UNILAC for injection in SIS18 is sufficient for reaching the space charge limit; actually exceeds the maximum intensity, which can be stored without major loss. However, for the FAIR reference ion Uranium, GSI has never succeeded to reach the goal of 10^{10} ions in user operation of SIS18 over the last decades. The so far provided intensities and qualities of the Uranium beams provided for injection into SIS18 enables stacking of intensities far below the space charge limit. In order to overcome this deficit of heavy ion intensities for FAIR, or in other words to significantly increase the number of particles in Uranium beams, the charge state for acceleration in the synchrotrons will be lowered. Lowering the charge state has two positive effects, a) the transfer channel stripper generates a charge distribution that creates a major loss in particle current for injection into SIS18 – not stripping the heavy ions enhances the particle current for injection by a factor of 7 and b) the space charge limit in SIS18 is increased by the lower charge state. While the typical intensities of U^{73+} ions in SIS18 is still on the level of 2 U/cycle to 3×10^9 U/cycle, the intensities reached for U^{28+} ions is already 4×10^{10} U/cycle. However, lowering the charge state of heavy ions does also generate a major challenge for acceleration in SIS18 and SIS100. The cross sections for charge exchange processes at collisions with residual gas particles of low charge state heavy ions, is about a factor of Hundred higher than for highly charged ions. In combination with ion induced desorption processes, operation with low charge state heavy ions creates major intensity limitations driven by a self-amplification of the dynamic pressure in the accelerator vacuum system. The intensity limitations show up at much lower levels than any space charge driven limits and depend on the technical set-up of the machine and the machine cycle. In the course of preparing FAIR, GSI has developed a world leading expertise and understanding of the phenomena of charge exchange driven beam loss and dynamic vacuum. This understanding has motivated the meanwhile completed SIS18 upgrade program [2] with an investment of about 15 M€ in new hardware and the special design of SIS100, being the first synchrotron world-wide optimized for the acceleration of low charge state heavy ions. The completed upgrade program comprising all major technical systems of SIS18 and has led to a stable acceleration of 4.5×10^{10} U/cycle at high repetition rate. Nevertheless, the goal of serving SIS100 for reaching the desired intensity of 5×10^{11} U/cycle is to extract 1.5×10^{11} U/cycle from SIS18 with a repetition rate of 2.7 Hz. In order to minimize beam loss by ionization and to stabilize the dynamic vacuum, SIS100 is the first synchrotron which has explicitly been optimized for this purpose. Several publications have been issued describing the design features of SIS100 [3–6]. In this paper we present the present status of realization.

STATUS OF DEVICE PROCUREMENT

While all 110 s.c. dipole modules have been manufactured and tested [7], the production and cold testing of s.c. quadrupole units is still continued at the Joint Institute for Nuclear Research, JINR in Dubna, Russia. The collaboration between FAIR and JINR had been terminated at the beginning of the Ukraine crisis and was relaunched after about two years based on the international status of these

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organizations. At the restart of production and testing, a new schedule has been agreed. So far, all agreed schedule milestones for the delivery of units were met and the integration of quadrupole modules at BNET, Wurzburg was successfully served. Nevertheless, due to various reasons, relying and depending on the continuation of the deliveries from Russia is a high risk for the FAIR project. Therefore, it was decided to build up an alternative supply chain for the s.c. quadrupole units. In order to be prepared for a series production in industry four prototype units have been contracted to company BNET. With contracting these units, the availability of the required tooling for the manufacturing of further series units will be assured. The manufacturing of the four prototype units is almost completed and the delivery will start in May 2025.

With the units from JINR, the integration of quadrupole modules at BNET has been re-established and ramped up to higher rates [8]. An integration rate of two modules per month has been agreed. In parallel, several quadrupole modules were tested at the GSI series test facility (STF). A number of less important technical issues are still to be resolved during the execution of series integration. The module test facility at INFN, Salerno [9] is presently upgraded for operation and parallel testing with two feed-boxes. However, due to the delay created by the Corona and Ukraine crisis, the collaboration contract between GSI and INFN had to be amended by a new addendum covering the extended testing period. Consisting of two dipole and one quadrupole modules, representing one lattice cell of SIS100, a string-test has been build up at the GSI STF. The testing program has been continued with special focus on the mechanical stability of the assembly in different load situations, cross talk between bus bar systems, re-enforcement of process lines and especially the string-test has been used to develop the overall installation procedures and work instructions for the tunnel. No major technical issues have been observed during the cold- and power tests of the modules in the string.

For the SIS100 quench detection system, all quench detection boards have been delivered and tested. Last procurements for racks and trigger units are being continued.

Major progress has been achieved in the area of room-temperature magnets. At slow extraction of intermediate charge state heavy ions, charge exchange processes in the wires of the electrostatic septum unavoidably generate beam loss in subsequent quadrupole system. Thus two of the s.c. lattice quadrupoles are replaced by radiation hard quadrupole magnets. These two large radiation hard quadrupole magnets using a Cyan-Ester coil insulation have recently been accepted after FAT at Buckley, New Zeeland and shipped to GSI (Fig. 1).

In addition, the design and manufacturing of the powerful extraction septa at Elytt, Spain is progressing.

A major achievement for the SIS100 project is the completion of the production of all components of the main dipole- and quadrupole power converter at GE, Berlin. The installation of the main power converter system was launched in May 25 with the quench protection system above Niche 3.

Figure 1: Radiation hard quadrupole magnets for the SIS100 extraction straight at FAT at Buckley, New Zeeland.

The overall installation process will take almost one year, followed by a first commissioning test using the internal energy dumping system. Further power converter series, such as the power converters for the γ-t jump quadrupoles and the chromaticity sextupole magnets have been contracted to industrial suppliers. As next, the procurement of the power converters for the extraction septa will be addressed.

While all sixteen acceleration cavities are produced and accepted, the final acceptance process of the nine bunch compression cavities is still ongoing. Six of the nine cavities have been accepted so far after successful Rf power tests. A re-arrangement of the acceleration cavities positions from sector 6 to sector 3 enables an early continuation of the installation process. The relocation of cavities enables their installation while the Southern arc of the SIS100 tunnel has still not reached the end of the settlement process.

The manufacturing of the star-shaped quadrupole chambers needed for the enhanced aperture requirements in the extraction straight has been awarded to company RI. RI has already successfully managed the demanding manufacturing of the elliptical quadrupole chambers made of the special, low permeability Boehler steel.

The injection- and extraction kicker systems are challenging devices. During the acceptance tests of the injection kicker modules, major issues emerged from the HV Pulse cables. After several HV brake troughs it became clear that the required HV strength of 80 kV of the low impedance cables does not meet the requirements for both, the injections- and extraction kicker systems. Consequently, a worldwide search for an alternative cable has been conducted and in parallel technical meetings have been organized with Prysmian (former Draka) on the development of a new cable with optimized design. The development and testing of the new HV cable will further postpone the completion of the kicker systems.

Beside the kicker systems, also the acceptance tests of the electrostatic extractions septum is significantly delayed by an erosion of the cathode surface observed after the UHV bake-out procedure (Fig. 2). A second acceptance test is in preparation using a newly anodized cathode.

The manufacturing of the current lead boxes at Inox, India is running smoothly. A FOS current lead box has been delivered to GSI and was cold tested with maximum current ramp rates of 29 kA/s, up to 16 kA at the STF (Fig. 3). WUST has

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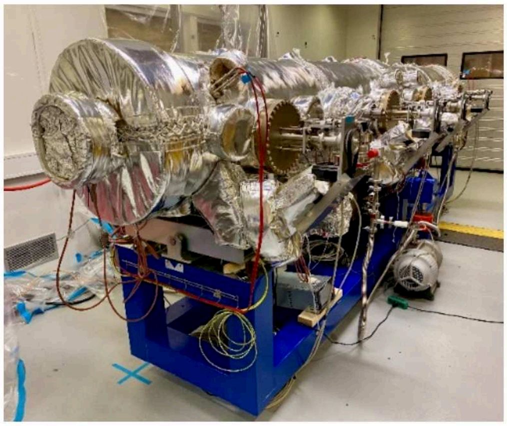

Figure 2: Electrostatic extraction septum during FAT at Danfysik, Denmark.

awarded a first feed box to company Inox. In order to enable an efficient operation of the cryogenic system, the SIS100 feed-boxes comprise a LHe pump and a phase separator. The procurement via tendering by the FAIR GmbH of the two remaining feed-boxes is presently in preparation.

Figure 3: The FOS current lead box at cold testing at the GSI series test facility (STF).

STATUS OF INSTALLATION

Installation of SIS100 components has started in January 2024 and shall be completed in January 2028. From the point of procurement, the quadrupole modules are on the critical path and may be the last components fed into the corresponding gap of SIS100. In three arcs, the installation of the s.c. dipole modules has reached a certain degree of integration (Fig. 4). The set-up of the interconnection system starts with the installation of the UHV system components and the soldering of the bus bar system. Welding of the process lines has just been started.

Figure 4: S.c. dipole pairs after installation one of the arcs.

In two other arcs, the dipole modules are temporarily transported to a parking position. The installation of the straight sections has started in sector 4 and will be continued clockwise. In this way the fact that the tunnel is still in motion in the Southern area is accounted. The installation of the straight section starts with the positioning of the bypass lines behind the room temperature components. The straight in sector 4 is dominated by the RF bunch compression and acceleration systems. All other room temperature components are placed in the gaps between the s.c. quadrupole modules and the UHV system has been closed. The s.c. quadrupole modules are not yet available. Thus, this space will be kept free for later installation. The installation of the straight in sector 3 is presently in preparation and will be launched on short term. In the straight 3 major components of the SIS100 laser cooling system [**?**] will be installed. All vacuum chambers for feeding in the laser beam into the accelerator vacuum system are produced and accepted. The installation of supply systems, power converter and LLRF systems in the parallel tunnel is running in parallel and decoupled from the accelerator systems. In March 2025 the installation of the main power converters in level 20 (second underground level) and the quench protection systems above the three cryogenic niches was started.

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