STATUS OF THE FAIR ACCELERATOR FACILITY

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Abstract

The accelerators of the facility for Antiproton and Ion Research – FAIR are designed to deliver stable and rare isotope beams covering a huge range of intensities and beam energies. The ion and antiproton beams for the experiments will have highest beam quality for cutting edge physics to be conducted within the four research pillars CBM, NuSTAR, APPA and PANDA. The challenges of the accelerator facility to be established are related to the systems comprising magnets, cryo technology, rf-technology, vacuum etc. FAIR will employ heavy ion synchrotrons for highest intensities, antiproton and rare isotope production stations, high resolution separators and several storage rings where beam cooling can be applied. Intense work on test infrastructure for the huge number of superconducting magnets of the FAIR machines is ongoing at GSI and several partner labs. In addition, the GSI accelerator facility is being prepared to serve as injector for the FAIR accelerators. As the construction of the FAIR facility and procurement has started, an overview of the designs, procurements status and infrastructure preparation will be provided.

INTRODUCTION

FAIR will provide worldwide unique accelerator and experimental facilities allowing to investigate "cosmic matter" in the laboratory. The main part of FAIR research focuses on the structure and evolution of matter in the universe, on both a microscopic and on a cosmic scale. The FAIR accelerator complex must therefore provide high-energy, precisely-tailored beams of exotic nuclei, of antiprotons as well as stable ions in different energy regimes and time structures. A key feature of the FAIR facility is a highly sophisticated accelerator system that will allow the parallel and versatile production of an unprecedented range of particle beams [1].

The FAIR accelerator facility of the Modularized Start Version (MSV) is shown in Fig. 1 [2]. The central part of the FAIR accelerator facility is a synchrotron accelerator ring with maximum magnetic rigidity of 100 Tm – the SIS100. The synchrotron will have a circumference of about 1100 and will be installed in a 20 m deep tunnel, which is designed for the installation of the SIS300 synchrotron in a later stage of the project. The magnets employed will be new, rapidly cycling superconducting magnets in order to minimize construction and operating costs. For the highest intensities, it is planned to operate the SIS100 at a repetition rate of 1 Hz and therefore with ramp rates of the dipoles up to 4 T/s. The goal is to achieve intense pulsed U^{28+} beams with $4\cdot10^{11}$ ions per pulse at 1.5 GeV/u and intense ($2\cdot10^{13}$) pulsed proton beams at 29 GeV.

This unique combination of a primary beam driver that delivers highest intensities of ion beams and the new superconducting Fragment Separator (Super-FRS) will yield an increase of radioactive beam intensities by almost four orders of magnitude. The Super-FRS will be the most powerful in-flight separator worldwide for exotic nuclei up to relativistic energies. Rare isotopes of all elements up to uranium can be produced and spatially separated within some hundred nanoseconds, thus very short-lived nuclei can be studied efficiently. The Super-FRS is a large-acceptance superconducting fragment separator with three branches serving different experimental areas including the new storage ring complex.

The accelerator facility is complemented by a system of storage rings. The main task of the collector ring (CR) is stochastic cooling of radioactive ions or antiproton beams from the production targets. In addition, this ring offers the possibility for mass measurements of short-lived ions, by operating in isochronous mode. The high-energy storage ring (HESR) is optimized for antiprotons of energy up to 14 GeV. This ring will operate with an internal target and associated detector set-up (PANDA).

PRIMARY BEAM ACCELERATOR

The demand on the primary beam driver of FAIR, the synchrotron SIS100, with respect to beam intensities and time structure, has an according impact on the main systems like the superconducting magnets, the rf-cavities and the vacuum system [3]. A short acceleration cycle is required to obtain a sufficiently high average intensities require a fast ramping with 4 Tesla per second. Fast acceleration, fast bunching of the beams and beam transfer between the synchrotrons require a significant number of sophisticated cavities. The vacuum chambers are used as a huge system of cryogenic pumps and contribute significantly to the required extremely low vacuum pressure. Beam losses by stripping via collisions of the ions with residual gas atoms are sufficiently reduced at a residual gas pressure below 10^{-11} mbar, which is required to control the dynamic vacuum effect [4]. Therefore those systems are in the focus of the procurement of components. Concerning the superconducting magnets, the first of series dipole of SIS100 (Fig. 2) has been delivered in June 2013 and went through a detailed test and measurement programme.

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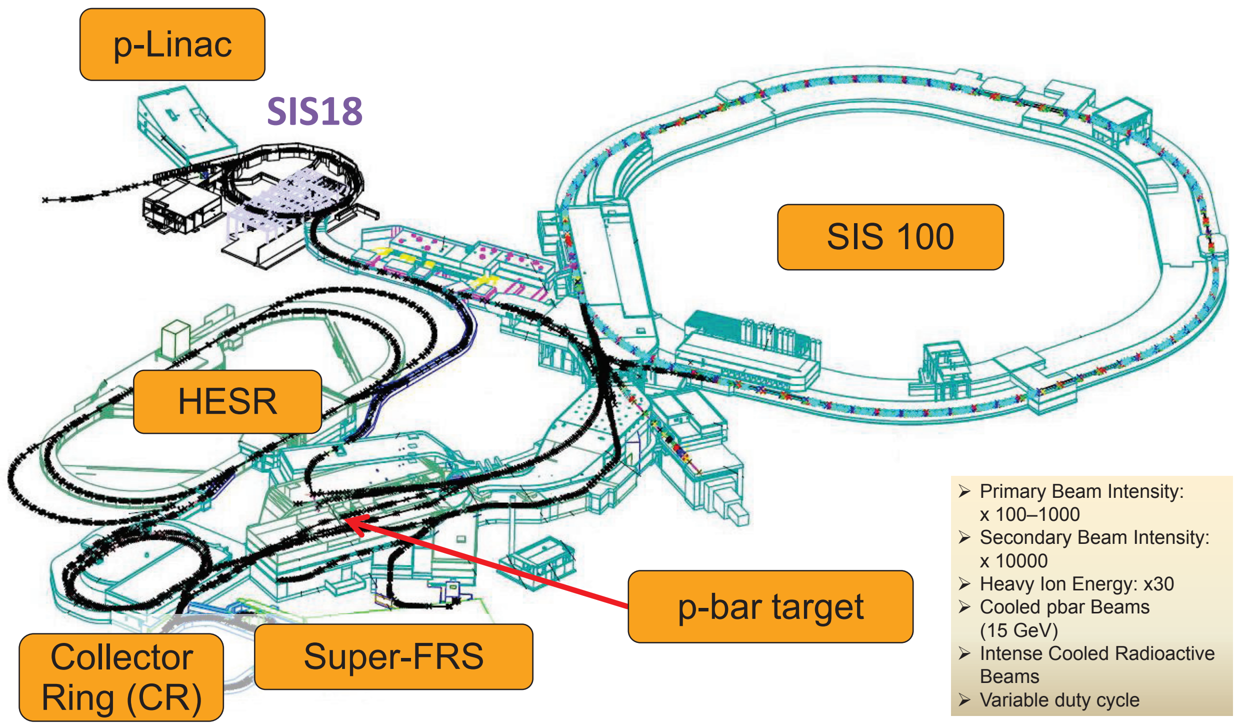

Figure 1: Overview of the FAIR accelerator facility.

Cycle test have been performed and a ramping period of 1.1 s has been achieved. The quench training of the magnet has been completed reaching 15 kA compared to the 13.5 kA required for SIS100 operation.

Figure 2: The first of series SIS100 dipole.

A ramping period of τ = 1.1 s has been achieved. DC magnetic field measurements and quality evaluation are ongoing and summarized in [5]. The quadrupole doublet modules (Fig. 3) of SIS100 will be built in a collaborative effort of GSI and JINR/Dubna. Following the agreement between JINR and GSI JINR will build 175 quadrupole units to the technical specifications, which are available now. A complete set of drawings and 3D-models have been sent to Dubna. The units will be subject to detailed factory cold tests and measurements to be certified in accordance with the Q-plan determined by GSI.

The rf systems of SIS100 comprises (in the start version) 14 acceleration cavities, 9 bunch compressor cavities and one cavity for barrier bucket operation. For all cavity types, procurement has been started and the bunch compressor cavities have been already ordered.

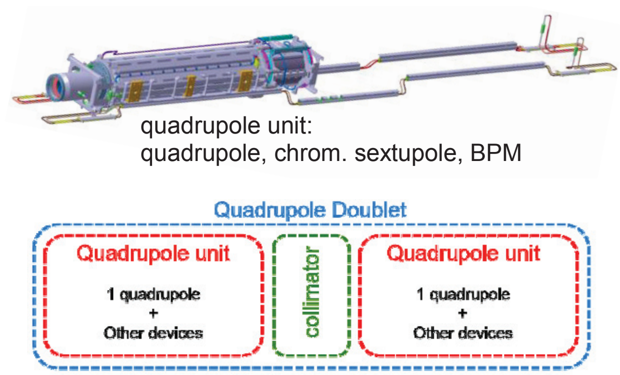

Figure 3: Example of a quadrupole unit and the mount of two units on a common girder as a quadrupole doublet.

THE FAIR SUPER-FRS

The multi-stage superconducting fragment separator (Super-FRS) is the work horse of the NuSTAR collaboration. The produced fragment beams consist of a very wide variety of different isotopes from the entire area of the nuclear chart. The layout of the Super-FRS [6] consists of magnets with $B\rho_{max}$ of 20 Tm. Approximately 10% of the primary beams provided by the SIS100 will be converted in a special target into exotic isotopes. In the production process of such exotic beams the kinetic energy is approximately preserved. The remaining 90% of the primary beam are selectively dumped in special beam catchers made of graphite and iron. The in-flight production provides secondary beams with high kinetic energies. Nevertheless, their large phase space volume requires huge magnets with enormous apertures and high field gradients. Ultimately, this demands the use of

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massive, superferric magnets. Due to the strong exposure to radiation in the vicinity of the production target, radiation-resistant magnets with ceramic insulation must be used (see Fig. 4). Prototype of the dipole magnets exist, the multiplets will be ordered in the next few weeks.

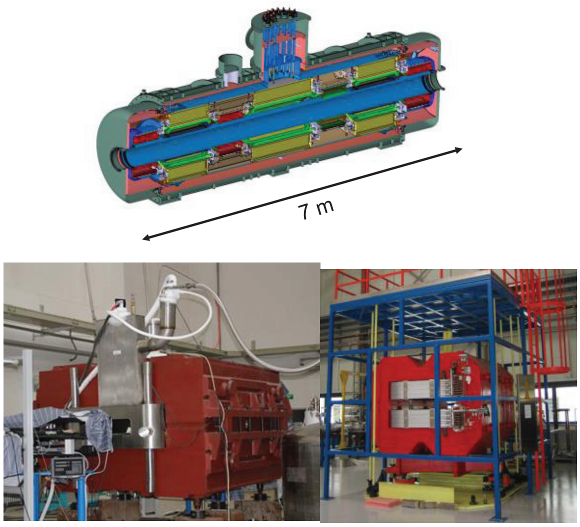

Figure 4: Magnets of the Super-FRS. Large multiplet, SC-dipole and a radiation resistant dipole of the target area.

THE FAIR STORAGE RINGS

The FAIR facility will comprise several storage rings for beam preparation and for experiments [7]. One of the most important rings for the preparation of secondary particle beams is the Collector Ring CR. The CR is a high acceptance ring with full aperture injection and extraction kickers, RF cavities for bunch rotation, adiabatic debunching and rebunching, and a very dedicated stochastic cooling system. The CR will collect and cool secondary particle beams that emerge from the production targets and have a large spread in beam energy and a huge spatial extension In the past half year GSI and Budker Institute in Novosibirsk (BINP) have conducted several workshops under the auspices of FAIR, to prepare the transfer of the technical supervision of the CR to BINP. Meanwhile BINP is working on the design of the CR magnets, vacuum chambers, injection/extraction system and beam dynamics. The CR-Debuncher and the stochastic cooling system remain GSI in-kind contribution to the CR. It is envisaged that the collaboration with GSI follows the successful collaboration of GSI and FZ-Jülich concerning the HESR.

In the HESR [8], antiprotons can be collected and further cooled. Therefore beams with increased intensity will be available for the PANDA experiment. The CR has to perform stochastic precooling of secondary beams at a fixed kinetic energy of 740 MeV/u for radioactive isotopes and 3 GeV for antiprotons which may be transferred in a later stage to the RESR storage ring system.

OUTLOOK

The testing infrastructure for several hundred of superconducting magnets of SIS100 and Super-FRS is under construction. At GSI all prototype of SIS100 magnets and the series of SIS100 dipoles will be tested in a new test facility (see Fig. 5). A 2 kW cryo plant will serve four test stands in the adjacent hall. The SIS100 quadrupole units will be tested in Dubna, where a large hall has been refurbished in the context of magnet testing for NICA and FAIR. 6-7 test benches will be available, as well as the cryogenic infrastructure using satellite refrigerators. All Super-FRS superferric magnets will be tested at CERN, where in hall 180 a test infrastructure is presently set-up, serving for three huge test benches available for those magnets. The SC-magnets, their testing and the cryogenic infrastructure are the long lead items and determine the critical path of SIS100 and Super-FRS. According to the present planning, the SIS100 will be operational in 2019, the Super-FRS in 2020, if civil construction will not cause a significant delay of the accelerators and the common systems.

Figure 5: The new hall SH5 for the cryoplant that serves the SIS100 magnet series test facility. The installation work will be completed in August 2014.

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