# DESIGN STATUS OF THE FAIR SYNCHROTRONS SIS100 AND SIS300 AND THE HIGH ENERGY BEAM TRANSPORT SYSTEM*

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### *Introduction*

The heavy ion synchrotrons SIS100 and SIS300 are the central part of the FAIR accelerator facilities. The two stage acceleration concept enables the optimisation of both synchrotrons for specific tasks, allowing a real parallel experiment supply with beams of different properties. The 1083 m long lattice of SIS100 consists of superferric magnets similar to the magnets developed for the NUCLOTRON synchrotron at JINR, Dubna [1]. This magnet technology has been chosen to minimize the cycle time by means of fast ramping with ramp rates of up to 4 T/s. At cycle times of typically 1.5 s, Uranium beams with an average intensity of $3x10^{11}$ ions/s can be generated. Due to the small aperture of superferric magnets, the total pulse power does not exceed 18 MW even at maximum ramp rate. SIS100 is designed for acceleration of high intensity, low charge state heavy ion and proton beams. A powerful magnetic alloy loaded RF compression system enables the generation of short single ion bunches before extraction.

SIS300 is equipped with low-loss, cos(Θ)-magnets providing ramp rates up to 1 T/s. SIS300 may be used as a stretcher ring to deliver linac-like, uninterrupted heavy ion beams of intermediate charge states for fixed target experiments or for acceleration of highly charged ions to high energies (34 GeV/u). By distributing the acceleration and extraction process over the two machines (SIS100 and SIS300) the average intensity can be considerably increased. The FAIR beam transport system contains two parallel beam lines from the synchrotrons to the production targets for radioactive secondary beams. A large number of achromatic beam transport sections, connect the three synchrotrons SIS18, SIS100 and SIS300 with the Super-Fragment Separator (Super-FRS), various areas for plasma physics, atomic physics and biophysics experiments and the antiproton production target. The primary beam production chain allows an optimal beam matching to the targets and the FAIR secondary beam facility.

## SIS100/300 STATUS

### *General System Layout*

After a major change in 2006 when the lattice of SIS300 had to be changed from a doublet to a FODO structure, accommodating the space requirements for the cos(Θ)-main magnets, the system design of both synchrotrons SIS100 and SIS300 [2] has been further detailed. The changes and revisions since the FAIR Baseline Technical Report (FBTR) [3] are summarized in new Technical Design Reports (TDR). The proposed layout of the specific subsystems has been reconsidered e.g. the slow extraction system of SIS100 has been approved by an independent design verification and new settings with larger dynamic aperture have been determined. According to these design verifications, no reason to change the overall or any specific system layout has been identified.
However, especially those open issues have been addressed where a technical solution was not obvious and a confirmation of the principle layout was still outstanding, e.g. the strength and cooling of the extraction septum magnets, the deposition of high beam power in a cryogenic quadrupole module of the extraction system and the switching cryostat modules at injection, extraction and transfer. For these technical systems suitable solution have been developed: The high power normal conducting extraction septa of SIS100 and SIS300 are supposed to be technically feasible if the pressure drop and the heat exchange in the water cooling system is enhanced. The beam loss induced energy, deposited in the quadrupole cryomodule of the extraction system can be removed by means of a local temperature increase and nitrogen cooling. For the switching cryostats a support system structure for the two interleaving doublets has been developed. The planning for all other technical system has been continued and summarized in the new Technical Design Report TDR.

### *Beam Dynamics*

For a better and precise prediction of beam loss during the acceleration cycle the development of high current beam dynamics models have been enforced. New beam dynamics simulations have been performed including non-linear longitudinal and transverse beam dynamics under the influence of space charge and collective effects. Especially during the long accumulation and extraction plateaus, beam loss processes must be studied carefully in order to localize machine activation or prevent residual gas pressure bumps by a suitable halo scraper concept. The following items have been addressed:

- Space charge and cavity beam loading effects during the various parts of the RF cycle.
- Long-term beam loss during accumulation due to the combined effect of magnet errors, synchrotron motion and ‘frozen’ space charge at selected working points.

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- The SIS100 resistive wall and SIS18 kicker impedances.
- The transverse impedance budget with space charge for coasting beams (Octupoles are proposed in order to stabilize the beam) [4].

Tracking, ripple and synchronisation tolerances of the synchrotrons have been studied for:

- Synchronization requirements for the quadrupoles with the dipoles
- Power supply ripple requirements for the quadrupoles
- Synchronization and ripple requirements for the dipoles with the Rf

Based on the predicted beam losses, life time and activation have been estimated for those technical devices which face unavoidably heavy beam load, e.g. due to the slow extraction process. Special protection measures have been derived for radiation sensitive devices and components which have to be installed in the synchrotron tunnel.

*Ionization Beam Loss*

The world wide unique operation with high intensity, intermediate charge state heavy ions (e.g. $U^{28+}$) is one of the most demanding features of SIS100. Due to the high cross sections for ionisation, in combination with ion induced gas desorption, significant beam loss may result from pressure bumps during a cycle.

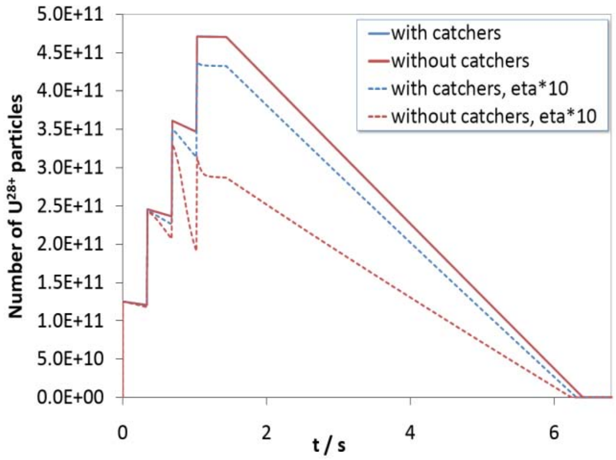

Figure 1: Beam intensity profile in a SIS100 cycle including stacking, acceleration and slow extraction for the expected and a ten times increased desorption yield.

As described in [5], the SIS100 lattice has been optimised for the control of ionisation beam loss with the goal to achieve a stabilization of the residual gas pressure dynamics. New cross sections for ionisation developed by [6] show a faster decrease with beam energy. The new cross sections were obtained from improved atomic physics models for the relativistic energy range of SIS100 and have been implemented in the STRAHLSIM dynamic vacuum code [7]. Furthermore, a new energy loss scaling for the gas desorption yield according to $(dE/dx)^2$ as observed by [8] has been considered. However, this scaling has only been proven experimentally in a low energy regime. In order to determine the desorption yield in the energy range of SIS100, fast pressure measurements have been carried out in AGS (BNL, Brookhaven) [9]. The ionization beam loss in SIS100 has been re-calculated based on the new cross sections and energy loss scaling. The tolerance with respect to increased desorption yields with and without charge scraper system has been evaluated (figure 1).

*Main Magnets*

Based on the results achieved in the R&D project phase, manufacturing of a number of SIS100 full length model magnets has been launched [10].

- Straight, full length dipole magnets are manufactured at BNG (Würzburg) (figure 2) and at JINR (Dubna)
- A curved dipole magnet is under production at BINP in Novosibirsk.
- A prototype quadrupole magnet is under production at JINR (Dubna).

The production of both full length magnets at JINR is supported by the EU FP6 DIRAC program.

Figure 2: Straight SIS100 full length model dipole magnet manufactured at BNG (Würzburg).

For SIS300, the design and R&D of a fast ramped curved 4.5 T dipole magnet has been continued at INFN, Italy. In parallel, the tooling production for a straight s.c. 6 T dipole magnet has been completed at IHEP, Protvino. The manufacturing of the 1 m long, two layer coil magnet and the cold testing shall be finished until summer 2008. Both magnets are optimised for low AC loss and make use of a cable with the bare cable geometry of the LHC dipole outer layer conductor, but with a stainless steel core inside.

Since the ramp rate of SIS300 is much higher than of any other s.c. cos(Θ)-synchrotron and in addition SIS300 is expected to deliver slow extracted beams with very long spills, studies on the influence of persistent currents and transient field errors in the superconducting magnets on the beam dynamics have been started Although the specific coil and cable design and the methods applied for reducing the AC loss during fast ramping help to restrict the persistent current flow, a fast feed back system, similar to the one developed for HERA, is assumed to be required. Based on the transient field harmonics measured in the reference string, the feed back system shall generate set-values for the correction system. Especially under the assumption of a very flexible operation with independent and arbitrary machine cycles, in connection with the stability requirements for slow extraction, the linear and non-linear machine properties must be controlled.

*RF Systems*

The design study performed by BINP, Novosibirsk for the SIS100 acceleration cavity has been completed (figure 3) [11]. The cavity design is close to the existing SIS18 system and the BINP cavity for HIRFL-CSR, Lanzhou, China. Each cavity provides an acceleration voltage of 20 kV in the frequency range of 1.1-2.7 MHz. Twenty cavities are needed to generate an acceleration voltage of 400 kV for ramping with 4 T/s.

To accommodate for the official FAIR start version as agreed by the International Steering Committee (ISC) an initial, reduced equipment with RF acceleration and compression systems has been defined. The reduction in RF voltage in both systems leads to a slightly reduced ramp rate and increased bunch length after compression.

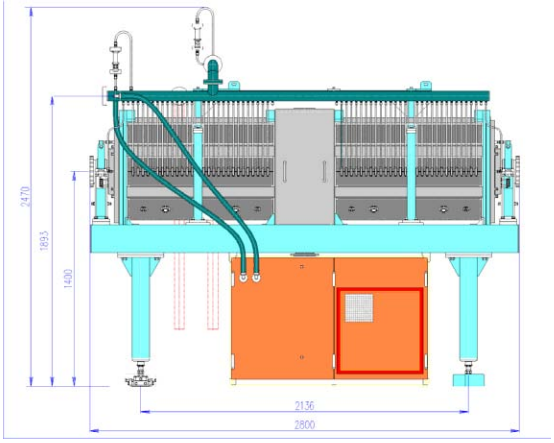

Figure 3: Design study for the ferrite loaded SIS100 acceleration cavity.

The bunch compression cavities of SIS100 will be based on the technical design of the MA bunch compression cavity built for SIS18 [12].

## HEBT STATUS

The layout of the beam transport system has been revised for normal- instead of superconducting SIS100 beam line magnets [13]. The new overall topology is to a large extent consistent with the original layout for superconducting beam transport magnets as described in the FAIR Baseline Technical Report – no significant change in the overall topology size has resulted from the change in magnet technology. The design of the main warm beam line magnets has been optimized with respect to energy efficiency and operation modes. The layout for the beam diagnostics and correction system has been fixed and integrated into the beam transport structure. The charge stripper system between SIS18 and SIS100 has been integrated into the existing layout of the 90 degree bend behind SIS18 without major modifications. By means of a fast linear induction motor the stripper foil required to generate the high charge state beams (e.g. $U^{92+}$) for SIS300, will be moved into the beam path in a shot-by-shot mode. The supply buildings, so far matched for the supply of a superconducting HEBT system have been modified for the supply systems of the normal conducting beam lines.

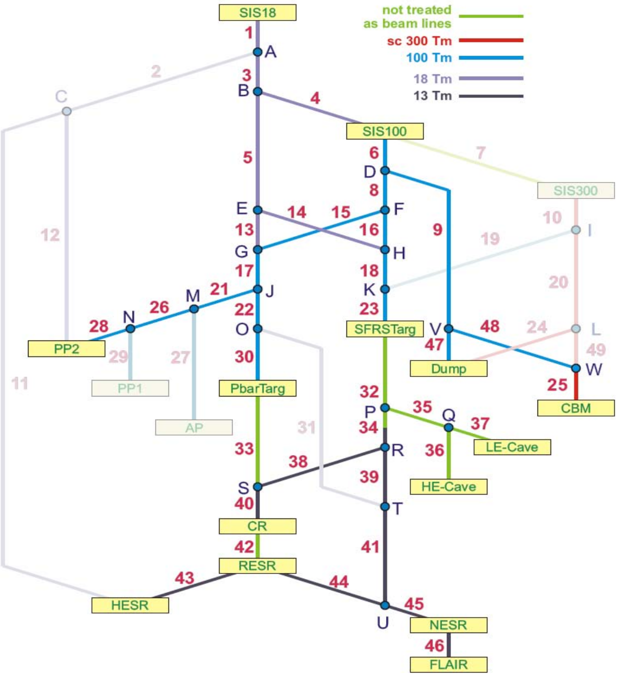

Figure 4: The FAIR beam transport topology. The faint beam line sections are not subject of the official start version.

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