DOUBLE SYNCHROTRON COMPLEX SIS100/200 FOR A NEW RESEARCH FACILITY AT GSI

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Abstract

In November 2001 a new research facility has been proposed by GSI [1]. The proposed facility consists of two superconducting synchrotrons SIS100/200 and three cooler storage rings for radioactive ion and antiproton beams. The new accelerators will use the existing accelerators UNILAC and SIS18 as drivers. SIS100/200 is characterized by a number of demanding technical features. These are especially fast ramped superconducting magnets and powerful rf systems for accumulation, compression and acceleration.

1 THE TWO STAGE SYNCHROTRON CONCEPT

In order to achieve optimum performance by separating different functions, a two stage concept has been proposed for the heavy ion synchrotrons SIS100/200. The functions of the two synchrotron stages are :

SIS100

- Accumulation of high intensity heavy ion and proton beams in barrier buckets at moderate tune shifts dQ < 0.25 e.g.
  U^{28+} ion beams :
  1x 10^{12} at an injection energy of 92 MeV/u
  2x 10^{12} at an injection energy of 196 MeV/u
  p beams :
  1x 10^{13} at an injection energy of 1 GeV/u
- Fast acceleration of heavy ions with 4 T/s to energies between 0.4 and 2.7 GeV/u (U^{28+}) and 29 GeV (p).
- Generation of strongly compressed single bunches e.g.
  U^{28+} : 25 – 90 ns pulse duration
  p : 20 ns pulse duration

SIS200

- Stretcher operation with 100% duty cycle of slow extracted heavy ion beams e.g. U^{28+} of an average intensity of 1x 10^{12}/s at an energy of 1 GeV/u.
- Acceleration of highly charged heavy ions (e.g. U^{92+}) with 1 T/s to 23 GeV/u

Both synchrotrons will be installed in the same tunnel with a circumference of 1083 m, which is five times the circumference of SIS18. Injection, extraction and rf devices are distributed over the straight sections of the six superperiods (Figure 1).

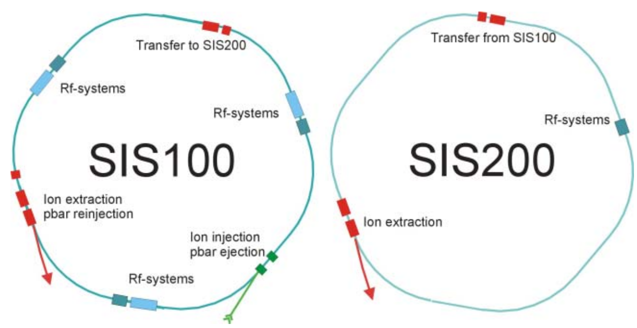

Fig. 1 : Schematic of SIS100 and SIS200 with the distribution of injection, ejection and rf devices.

2 SIS100 - ACCELERATOR TECHNOLOGIES

2.1 Superferric Dipole Magnets

In order to maximize the number of particles per unit time, SIS100 shall be operated with a maximum ramp rate. Under the premise of a most economic operation and installation, a superconducting magnet technology will be used. Conventional cos θ magnets are limited in ramp rate by the power loss (at e.g. 4 K) induced temperature increase in the superconductors. Superferric magnets, as developed for the Nuclotron ring are limited in maximum flux density to 2 T, but can be ramped fast with a high margin of safety against quenching. Therefore, we have decided to use this kind of magnet technology as basis for SIS100. However, in order to achieve the design goals of SIS100 with respect to the total power requirements, a development program has been originated in collaboration with JINR. The main development issue is the further reduction of power losses from 38 W/m to 13 W/m at a ramp rate of 4 T/s and a triangular cycle with 1 Hz. About two-third of the losses occur in the iron yoke. A first step of reducing the power losses by 7 W has been achieved by equipping the iron yoke with stainless steel end plates. Furthermore, by a new design of the iron laminations, with the insertion of air slots, the field quality of a model magnet could be improved. A further reduction of the AC power losses by about 25 W (at a model magnet length of 1.4 m) is planned by operating the iron yoke at higher temperatures (80 K instead of 4

K). The radiation and ion induced heat load in the superconducting coils, can be avoided by using alternative yoke configurations. Since the loss budget at the operation with intermediate charge state heavy ions is essential and crucial, H-type yokes are still under consideration. Further studies are in preparation concerning

- the application of radiation resistive materials (life time of organic materials under high neutron flux)
- the coil temperature with energy deposition in the magnet due to lost beam ions
- the destruction of the superconductor by heavy ion track formation

2.2 Barrier Bucket Cavities

After acceleration with the booster synchrotron SIS12/18, the beam will be prepared for the injection in the SIS100. Before transferring the beam from SIS18 to SIS100, the four accelerated ion bunches will be adiabaticely debunched in a barrier bucket. The required voltage of a single barrier for a beam of dp/p =$\pm$ 10^{-3} is 15 kV. The operation frequency of the barrier bucket rf system is planned to be 2.4 MHz. On one side this frequency is still sufficiently low for the application of MA(magnetic alloy)-cores as inductive loads, while on the other side the generated gap of 200 ns is still suitable for the SIS18 extraction kicker system. In parallel, in SIS100 four (at 92 MeV/u transfer energy) or eight (at 196 MeV/u transfer energy) barrier buckets will be prepared for accumulation. The barrier bucket frequency used in SIS100 will be the same as in SIS18. Therefore the same cavity type may be used in both machines. The gap width at the transfer energy of 92 MeV/u will be adjustable by using two separate barrier bucket rf systems. In order to provide a sufficiently high barrier voltage for the accumulation of eight SIS18 batches at 196 MeV/u, both rf systems will be operated in parallel with equal phases (Figure 2).

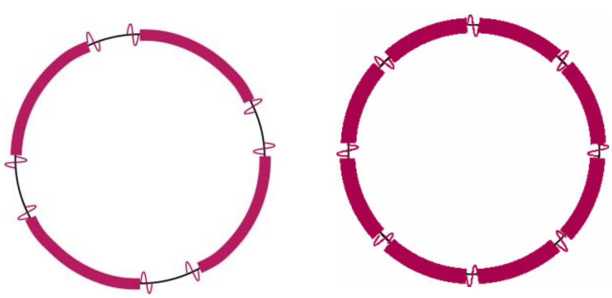

Figure 2 : Two different barrier bucket systems will provide four buckets at 92 MeV/u transfer energy (left) and in a phase coupled operation, eight buckets at 196 MeV/u (right).

The generation of a single sine wave as barrier, without any overshooting at the beginning or the end, demands for a careful technical design. It is necessary to superimpose a rectangular dc pulse to the sine wave. However, in this case a precise coupling of both pulses in phase and the ratio between sine voltage and offset voltage is required.

2.3 Rf Acceleration Cavities

For acceleration, 18 ferrite loaded rf cavities will be installed in the straight, warm sections of SIS100. A total rf voltage of 300 kV needs to be provided for fast acceleration. At harmonic number h = 20 the cavities must be tuned over a frequency range of 2.28 – 5.34 MHz. In order to achieve a most economic operation by reducing the total required bias current, we plan to study the properties of various ferrite materials at alternative harmonic numbers.

Alternatively options to combine the acceleration cavities and the bunch compression cavities are studied.

2.4 Bunch Compression Cavities

After acceleration, plasma physics and fragment beam experiments, as well as the optimised production of antiproton beams require a strongly compressed single bunch. For heavy ions as U^{28+} a rf voltage of 1.3 MV at the very low frequency of 465 ±70 kHz must be generated in SIS100. An appropriate cavity type is already under development for compression in SIS18 [2,3]. Only by the application of properly chosen, high quality MA cores the envisaged voltage of 40 kV per gap is achievable with the foreseen driver peak power of 600 kW. For the SIS18 compression project we have examined a large variety of MA materials of different manufacturers around the world. One of the main criteria is the quality product µQf which defines the shunt impedance and thereby the achievable voltage at a given driver power. For the bunch compressor cavity, the shunt impedance must be in the order of 134 Ω and the quality product µQf = 7 GHz. Meanwhile promising materials have been developed and offered by a number of manufacturers. Small test cores have been delivered to GSI and are currently under quality verification. Before setting up the full scale prototype compressor cavity, it is planned to test smaller MA cores at a comparable power density in a factor 1:5 scaled test cavity.

In SIS100, 32 bunch compressor cavities of the type presently under development for SIS18 will be required. Set-up as double cavity systems, sixteen modules will be installed in three of the six straight sections of the ring.

3 SIS200 - ACCELERATOR TECHNOLOGIES

3.1 Superconducting Magnet Technology

The SIS200 will be equipped with superconducting RHIC type cosθ dipole magnets. In order to operate SIS200 with the foreseen ramp rate of 1 T/s, the cooling of the coils must be improved and the power loss of the standard Rutherford cable must be significantly reduced. Together with BNL and the university of Jena, we have launched a development program for an advanced Rutherford cable for fast ramped synchrotrons. One already realised development issue was to enhance the wire twist pitch from 13 mm to finally 4 mm. As next it is planned to use filaments of minimum diameters e.g. 3.5 μm. Further reductions of the power loss will be achieved by inserting a 25 μm stainless steel core in the new cable. In order to improve the access of the He coolant to the superconductor, the cable has been perforated by means of a laser. This laser cutting of one side of the cable insulator was successfully demonstrated by the university of Jena. A test coil of the improved cable has been finished at BNL.

A vertical bath test of a model magnet equipped with the improved coil is planned for 2002.

In parallel, we are studying options to increase the maximum rigidity from 200 to 300 Tm. A contract for a design study for a 6 T, two layer cosθ magnet has been signed by GSI and the IHEP in Protvino (Russia).

3.2. Rf Acceleration Cavities

At the present state of technical design, for acceleration in SIS200, 6 ferrite loaded rf cavities of the same type as in SIS100 are foreseen , providing a total voltage of 80 kV. At harmonic h = 20 the cavities must be tuned over a frequency range of 4.84 – 5.48 MHz.

4 SIS12/18 - BOOSTER OPERATION

A number of R&D projects have been launched in order to prepare SIS18 for the foreseen booster operation. The development of barrier bucket and bunch compression cavities have been mentioned before. Furthermore the operation with high incoherent tune shift dQ ≈ 0.5 is being prepared by the installation of air coil correction magnets and by the choice a new high current working point. A feed back system for the damping of transverse coherent oscillations is currently under commissioning. In addition, the following technical improvements are prepared :

4.1 Power Grid Connection

Key issue for the booster operation is the increase of ramp rate from today 1.3 T/s to 10 T/s, leading to a repetition rate of 4 Hz. The four existing main power units of SIS18 were specified for an operation with 10 T/s up to 12 Tm (I_{max} = 2300 A) or 4 T/s up to 18 Tm (I_{max} = 3500 A). In machine experiments, beam acceleration has been demonstrated up to 5.5 T/s. The main restriction is given by the current GSI connection to the external power grid, which is in parallel used for the supply of the town Darmstadt. From the envisaged maximum total pulse power of about 55 MW for the new facility, the largest fraction, namely 26/-17 MW (10 T/s) is determined by the SIS12/18 booster operation. Only ± 17 MW and ± 7 MW are required for the ramping of SIS100 and SIS200. A sufficient power supply for the planned accelerator operations requires a separate connection via a 110 kV to the 380 kV power grid. Negotiations with the local energy supplier HEAG and RWE are currently in progress.

4.2 Skew Quadrupoles

Due to the multi-turn injection scheme applied in SIS18 the horizontal beam emittance is typically a factor of 5 larger than the vertical emittance. In order to limit the vertical incoherent tune shift to dQ < 0.25 over the rather long storage time in SIS100 (1 sec. at 96 MeV/u and 3 sec. at 196 MeV/u) an equilibration of the transverse emittances is planned before extraction [5]. A periodic exchange of emittances shall be excited by means of skew quadrupoles. The most appropriate final condition will be frozen in by an appropriate extraction timing. Eight air coil correction magnets have been manufactured and delivered to GSI. All of correction magnets are equipped with skew quadrupoles. It is planned to complete the installation by the end of 2002.

4.3 Static and Dynamic Vacuum

One of the most crucial problems connected with the operation with intermediate charge state heavy ions, compared to highly charged ions, is the significantly reduced life time. We have measured the life time in SIS18 of U^{73+} and U^{28+} ions at comparable conditions, at an average residual gas pressure of about 5 x 10^{-11} mbar.. At 11.4 MeV/u the life time of U^{73+} ions was measured to be about 20s while the life time of U^{28+} ions at 8.6 MeV/u was only 0.8s. The difference in life time is growing for increasing energy e.g. up to a factor of 100 at 200 MeV/u.

Furthermore the life time of intermediate charge state ion beams is strongly effected by local pressure bumps caused by gas desorption from the beam pipe wall or any inserts. These local pressure bumps could be measured in SIS18 by fast pressure gauges. At present these pressure bumps are dominantly originated by the beam losses at multi turn injection. Therefore it is of highest priority to avoid any initial beam losses. Those beam losses which can not be avoided shall be dumped locally and controlled in collimator-pump stands [4].

In order to find materials with less desorption rates, a research program has been started with the GSI material science group. A test stand for systematic studies of various materials and different angles of beam incidence has been set-up.

5 ACKNOWLEDGMENTS

The author list contains only representatives of the different technical and research fields. Special thanks are addresses to the working groups and collaborators who are contributing to the technical developments and research relevant for SIS100/200.

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