THE GSI SYNCHROTRON FACILITY PROPOSAL FOR ACCELERATION OF HIGH INTENSITY ION AND PROTON BEAMS

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Abstract

The two-stage synchrotron complex SIS100/SIS300 is the central part of the proposed “International Accelerator Facility for Ions and Antiprotons” at GSI [1]. The design concept of the synchrotrons will be described with emphasis on the status of R&D work, especially on the novel rapid cycling super-conducting magnets and on the required powerful, low-frequency RF-systems [2]. Furthermore studies are discussed, which refer to the life time of intermediate charged heavy ions and the dynamic vacuum pressure instability induced by ion beam desorption.

DESIGN CONCEPT

For the first synchrotron stage superconducting magnets of superferric type were proposed to provide a moderate pulse power at a rather large aperture of 130 x 65 mm and an operation with one cycle per second. A cold beam tube is foreseen to obtain a sufficiently high pumping speed for a stable operation with intermediate charge-state heavy ion beams.

The bending magnets are arranged in six arcs. The six long straight sections in between provide space for injection and extraction, the transfer line from SIS100 to SIS300 and also for the RF-systems required for acceleration (300 kV) and fast bunch compression (1000 kV). As in the SIS18 triplet focusing will be used to achieve a large acceptance at injection with dynamic change-over to doublet focusing during acceleration.

Four SIS18 booster cycles will be used to fill the SIS100 with up to 2.5×10^{13} protons or 1×10^{12} U^{28+} ions.

For the production of radioactive ion- and antiproton beams, the accelerated beam will be transformed into one single, short bunch (about 50ns for heavy ions). Thereby the produced secondary beams will have an appropriate time structure for injection, fast debunching and cooling in the planned array of storage rings. The SIS100 will be also used to accelerate antiproton beams from 500 MeV to 15 GeV for experiments in the high energy storage ring HESR.

The second synchrotron stage SIS300 was planned with superconducting cosθ-magnets for operation up to a flux density of 4 T. Meanwhile it is discussed to raise the flux density to 6 T by making use of double layer coils. The SIS300 ring will be mainly used for acceleration of U^{92+}-beams to high energies up to 34 GeV/u. In addition the SIS300 can be used as a stretcher ring to obtain a 100 % duty cycle, linac-like beam in operation with slow extraction

SUPERCONDUCTING MAGNETS

SIS100

Superconducting window-frame magnets shall be used in the SIS100 [3]. One major design goal was to achieve a low amount of stored energy, i.e. 45 kJ in a 2.62 m long dipole magnet with a beam tube aperture of 130 x 65 mm compared to 112 kJ in a conventional magnet as the one used in the SPS (CERN) or the SIS18 (GSI). Such a design reduces the total peak power of 120 magnets in fast pulse operation with a ramp rate of 4 T/s, a repetition rate of 1 Hz and a peak field of B=2 T to the moderate value of +22/-22 MVA compared to +62/-50 MVA in a conventional design.

In addition, the magnet weight will be strongly reduced to about 2 t per magnet compared to 20 t for a conventional magnet. The magnet design is based on the superferric cold iron magnet, which has been used in the Nuclotron at the JINR Dubna since 1993. In close cooperation with the JINR the dynamic losses of the existing magnets could be reduced to a value of 18 W/m. This translates into total power losses of 5.4 kW at 4 K for 120 dipole magnets using a standard triangular cycle (2 T, 1 Hz). In parallel an improvement of the field quality and the mechanical long-term stability was achieved. Figure 1 shows that the original losses of about 40 W/m have been reduced to 18 W/m.

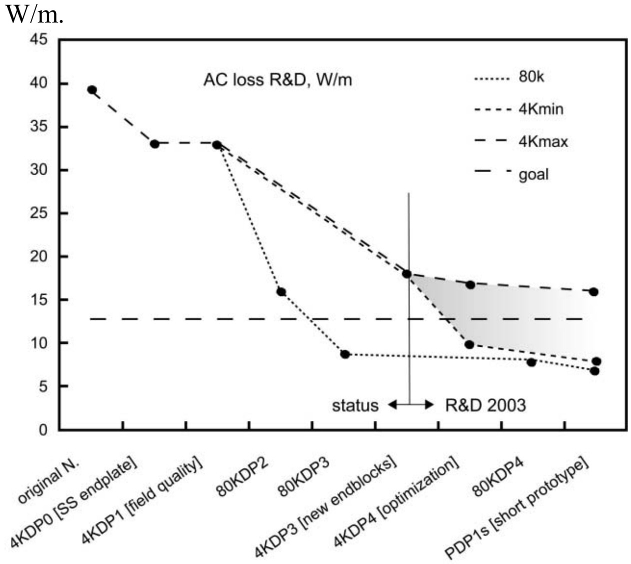

Figure 1 : A significant reduction of the dynamic losses of the Nuclotron magnet has been achieved.

To determine the sources of the losses, a detailed test program was launched. The 3D field configuration at the magnet ends was found to be one of the most important

sources for eddy current losses in the iron yoke. 3D calculations confirmed the measured data [4].
In parallel, an alternative magnet design with an iron yoke at 80 K was developed and tested. The remaining AC loss in the coil amounts to 9 W/m (Figure 1) [5]. As an additional design option, the replacement of the Nuclotron cable by a CICC cable was studied [6].
The model magnet development for SIS100 shall be completed by the end of 2004.

SIS300

The SIS300 will be equipped with superconducting magnets similar to the RHIC arc dipole (BNL) with a one-layer cosθ-coil or the UNK dipole (IHEP), with a two-layer coil. In cooperation with BNL, a RHIC dipole was modified to reduce the dynamic losses for a standard triangular cycle (4 T, 1/8 Hz). Tests of a first model dipole started at the end of 2002. With the main emphasis on the development of a cored Rutherford cable dynamic losses of 9 W/m were achieved [7]. This translates into a total power loss of 2.8 kW at 4 K for 120 dipole magnets.
There is a strong user interest in raising the maximum beam energy of the second synchrotron stage by using 6 T dipole magnets for an operation of up to Bρ=300 Tm. In cooperation with IHEP the design of the 6T UNK dipole magnet, constructed with a two-layer cosθ-coil has been modified for operation at a fast ramp rate of 1 T/s [8]. Planned R&D to achieve this goal will include a large coil inner radius of 100 mm, an increase of the temperature margin and tests of model magnets.

RF SYSTEMS

The planned SIS100 operation requires powerful, low-frequency RF systems for stacking, acceleration and bunch compression. A low bunching factor is required in order to restrict the space charge tune shift during the long injection time of 1s to $\Delta Q<0.2$. Bunching factors of 0.45 and 0.85 can be achieved in a multi-harmonic and a barrier bucket potential. Both options are presently under investigation. An injection into a barrier bucket in SIS100 requires a time consuming preparation of the bunch before extraction in SIS18. Therefore the barrier bucket injection is not an appropriate scheme for the generation of maximum number of particles per second (gen. of secondary beams), but is considered for the generation of maximum number of particles per pulse (plasma physics exp.). For the generation of high average beam intensities a transfer into a two-harmonic potential in SIS100 is being considered as a sufficiently fast standard scheme.

Acceleration in SIS100 at h=10 requires a total RF voltage of 290 kV in a frequency range of 1.1-2.8 MHz. Furthermore 1 MW of compression voltage at the extremely low frequency of 465 kHz needs to be provided for the planned generation of short, single bunches after acceleration.

We investigate two alternative concepts for the technical layout of the RF systems. The first option is to install two separate RF systems for acceleration and compression, while the second option is to combine both functions in the same RF system [9]. Detailed design studies and optimisations with respect to costs, peak power requirements, shunt impedance and maintainability are in progress.

Table 1 : Comparison between separated and combined RF systems for acceleration and compression. $V_{0,a}$ and $V_{0,c}$ are the gap voltages of the acceleration and compression systems, $N_{a,c}$ the total number of cavities, $L_{a,c}$ the total RF system length and P_c the peak power of the compression system.

	$V_{0,a}$	$V_{0,c}$	$N_{a,c}$	$L_{a,c}$	P_c
Separate RF Systems	16 kV	40 kV	18+25	57 m +21 m	20 MW
Combined RF System	3 kV	10 kV	100	90 m	10 MW

The SIS300 RF system consists only of acceleration cavities which provide a total voltage of 80 kV.

DYNAMIC VACUUM AND LIFE TIME

Measurements in the SIS showed that the stripping cross section σ for U^{28+} at 8.6 MeV/u is of the order of 10^{-16} cm^{-2}. With increasing energy the observed beam lifetime does not improve, from this we conclude that the product σI (current I) remains constant under the present SIS UHV conditions [10]. In order to limit the beam losses due to stripping in the residual gas to values below a few percent a pressure in the 10^{-12} mbar region must be ensured in all (warm and cold) section of SIS 100/300. Recent experiments at CERN, BNL and GSI showed that lost heavy ions in the energy range between 1 and 10 MeV/u lead to large outgassing rates of heavy gas components from stainless steel chambers.
The measured desorption coefficients η varys between 10^3 and 10^5 molecules per incident beam ion. Assuming homogenously distributed stripping losses and pumping, the equilibrium dynamic pressure is

$$P = \frac{P_0}{1 - \frac{L}{S}\eta\sigma\frac{I}{q}}$$

with the pumping speed S, the base pressure $P_0 = Q/S$ (thermal outgassing rate Q), the circumference L and the beam current divided by the charge I/q. Using the existing pumping speeds in SIS ($S/L \approx 70\ l\ m^{-1}s^{-1}$) together with the measured parameters we obtain a negative denominator, meaning a pressure instability, for the SIS 100 design current at injection energy. The pressure instability was observed in the SIS at relatively low ($N \approx 10^9$) uranium intensity confirming the desorption coefficients which were found at CERN. In order to maintain the required pressure of 10^{-12} mbar in the warm sections of SIS 100/300 ongoing efforts focus on low-η materials for collimators, on combined collimator/ pumping posts and on increased linear pumping in NEG coated chambers. All these measures should reduce the overall factor η/S by a factor 1/1000 compared with the existing SIS. In the cold sections the cold wall pumping ($S/L \approx 10000\ l\ m^{-1}s^{-1}$) needs to be confirmed for the SIS 100/300 environment [11]. Such efficient pumping is hoped to limit the dynamic pressure increase in the cold sections.

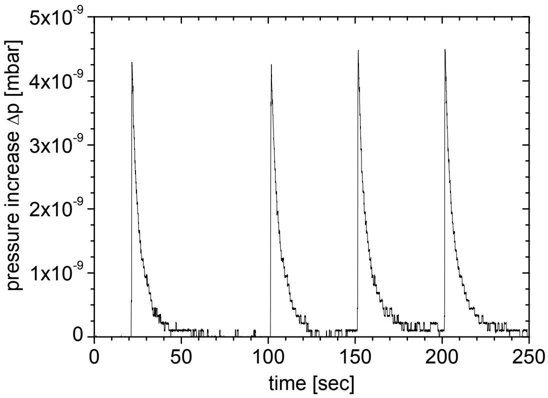

Figure 2 : Measured beam desorption induced total pressure increase in the test-stand. Shown is the pressure rise by the irradiation of a Cu sample with a 1.4 MeV/u C^{2+} -beam.

In order to measure the scaling of the desorption coefficient with projectile energy, mass and charge a desorption test-stand was recently set up at GSI. These experiments should also lead to low-η materials suitable for collimators or for vacuum chambers. First results with low energy (1.4 MeV/u) C^{2+}-ions irradiating a Cu target are shown in Figure 2.

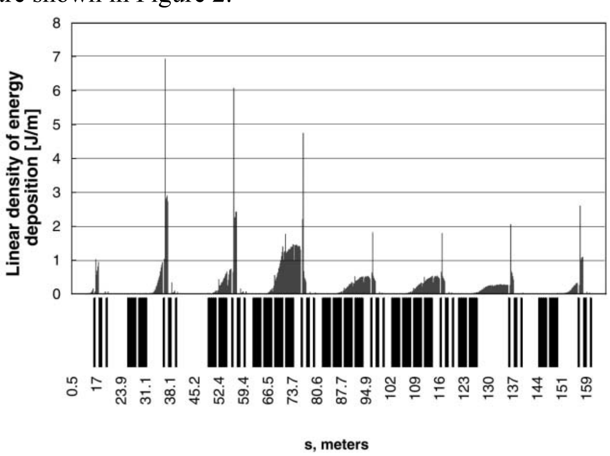

Figure 3 : Calculated distribution of beam loss induced energy deposition in one arc of SIS100, assuming 5% losses of the initially 10^{12} U^{28+} -ions.

The distribution of losses due to ionisation of U^{28+} to U^{29+} and the thereby deposited energy per meter have been determined for the SIS100 lattice. The losses occur mainly after charge separation in the arc dipoles. Figure 3 shows the calculated energy distribution assuming a fraction of 5 % lost ions. The plot shows the strongly peaked energy deposition along the beam pipe with a maximum after the first pair of dipoles following the straight sections.

One option to act against the vacuum instability is to control as many as possible of the lost ions by installing new types of collimators in the hot spots. Basis for this counter measure is the assumption that the threshold for vacuum instability can be enhanced if the loss-created desorption gases are to a large fraction prevented from reaching the optical axis. Therefore, a prototype of desorption collimator was developed for the U^{28+}-operation and will be tested in SIS18[12]. The concept of the proposed collimator is to localize beam losses and to capture the created desorption gases in a secondary vacuum chamber (Figure 4). A wedge shaped block acts as a collimator and is installed such that the surfaces points to contrary direction of the optical axis. In order to eliminate the desorption gases produced on the wedge surface, the secondary chamber was equipped with two high conductivity pumping ports and with a powerful cryo pumping system. First tests of the prototype desorption collimator are planned for August 2003.

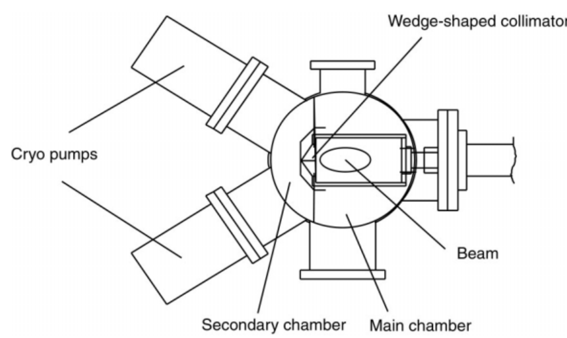

Figure 4 : Layout of a dedicated collimator for the control of ionisation beam losses and desorption gases.

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