HIGH INTENSITY URANIUM OPERATION IN SIS18

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Abstract

In order to follow the requirements of the ongoing experimental program at GSI and later on of the planned operation as a booster for the Facility for Antiproton and Ion Research FAIR, the intensity of uranium beams in SIS18 must be enhanced significantly. The goals are to increase the number of particles per cycle up to the space charge limit and to enhance the average intensity by an increased repetition rate.

SIS18 UPGRADE PROGRAM

An upgrade program has been launched with the goal to reach the space charge limit of SIS18 for high charge state (U^{73+}: $2x10^{10}$) and intermediate charge state (U^{28+}: $2.7x10^{11}$) ions within the next four years. So far, only for lighter ion species, e.g. argon, the intensity of the injected UNILAC beam was sufficiently high to reach the space charge limit. Nevertheless, for uranium beams a level of intensities was achieved where significant beam losses caused by interactions with the rest gas started to occur. Therefore, the development of appropriate measures for the conservation of the injected number of ions, rather than increasing the number of ions is at present the main issue. Three major medium term project goals were summarized in the SIS18 upgrade program:

1. Measures to increase the number of uranium ions per cycle up to the space charge limit and to minimize beam losses and emittance growth.
2. Measures for the operation with enhanced field rate of 4 T/s up to 18 Tm and a repetition rate of 1Hz.
3. Measures to prepare the booster mode with a field rate of 10 T/s up to 12 Tm and a repetition rate of 4Hz for FAIR [1,2].

In order to reach these milestones a large number of individual improvements and upgrade projects have been proposed.

1. Injection System

- Increase of the field strength of the electrostatic septum for injection of U^{28+}-beams at the standard energy of 11.4MeV/u (today 7.1MeV/u).
- Increase of the septum acceptance, installation of a profile grid and a collimator in the injection channel.
- Improvement of the transverse matching to SIS18.

2. RF Systems

- Development and installation of a new acceleration cavity operated at h=2, including a feed back system around the final amplifier.
- Development and installation of a broad band longitudinal feed back system for the damping of coupled bunch modes and coasting beam instabilities.
- Improvement of the longitudinal matching.
- Installation and operation of a prototype MA-loaded bunch compression cavity.
- Development of low level, digital electronics for synchronization and bunch phase controle.

3. TFS

- Comissioning of the new transverse feed back system.

4. UHV

- Replacement of all dipole- and quadrupole chambers.
- Increase of the local and distributed pumping power by NEG coating and cryopumps.
- Research program on desorption physics [7].

5. Magnets

- Comissioning of the new air coil correction magnets and compensation of important systematic resonances.

6. Beam Diagnostics

- Comissioning of the new residual gas profile monitor.
- Development of a new, dc high current transformer.

7. Protection Systems

- Set-up of a hardware transmission interlock system for beam losses at injection.
- Comissioning of the new septum collimators.

8. Collimator System

- Development and integration of a collimation system for ions lost by charge exchange processes.

9. Extraction System

- Increase of the acceptance of the extraction channel for fast extraction of low energetic, high emittance beams.

10. Pulse Power Supply

- Upgrade of the GSI pulse power supply by a new, independent connection to a local power station.

BEAM INTENSITY

The uranium beam intensity reached in SIS18 during the last year has benefited from the significant progress in UNILAC and MEVVA source developments. While U^{73+} is a common ion generated for the ongoing experimental programs, U^{28+} acceleration was only performed in dedicated machine development shifts. Beam currents of 1mA for U^{73+} and 2.7mA of U^{28+} could be provided for SIS18 injection. Thereby, the maximum number of injected ions could be increased up to $6.5x10^{9}$ for U^{73+} and more than 10^{10} for U^{28+}-ions. However, in both cases only $3\text{-}4x10^{9}$ ions could be accelerated to the final energy. Significant losses are generated by charge exchange processes in collisions with the residual gas atoms. While at the typical injection energy of 11.4 MeV/u electron capture processes are dominating at U^{73+}-operation, at U^{28+}-operation ionization is the dominating mechanism.

The reason for the dramatic losses during U^{28+}-operation is the significantly larger ionization cross section, which leads to a factor of 5 shorter beam life time (τ_{U28+}=5s instead of τ_{U73+}=25s). In December 2003, high U^{73+}-beam intensities were accelerated in SIS18. For the first time the beam current profile measured with a DC transformer showed that beyond a certain threshold, even at high charge state operation beam losses are driven by charge exchange processes. (figure 1).

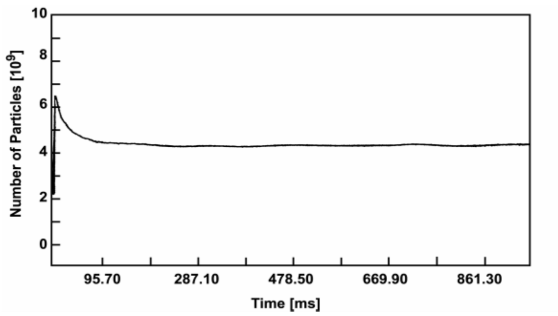

Figure 1 : Number of highly charged uranium ions (U^{73+}) during acceleration in SIS18. The losses observed at the beginning of the cycle are generated by a significant life time reduction due to strong gas desorption processes.

The combination of charge exchange processes and ion impact induced gas desorption leads to a dynamic vacuum, which is determined by the pumping power of the UHV system, the ionization cross section and the gas desorption rate. Since the interaction of the beam ions with the rest gas presently limits the intensity, new measures for the stabilization of the dynamic vacuum and the control of beam losses must be developed.

DYNAMIC VACUUM

Figure 2 shows the evolution of the residual gas pressure with and without beam load. The different lines indicate the pressure in each of the twelve SIS18 sections. The graph shows that the base pressure (left), is significantly affected by desorbed gases during beam acceleration [3].

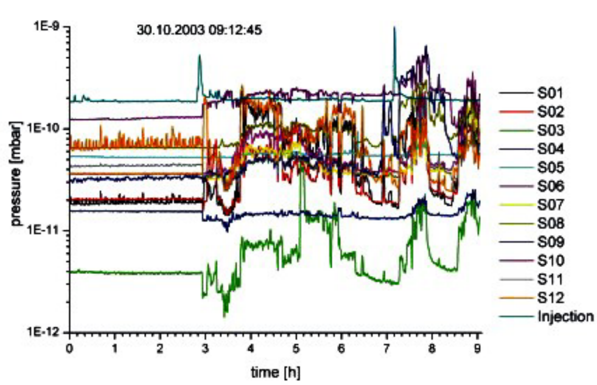

Figure 2 : Residual gas pressure profile in each of the twelve SIS18 sections. The initial situation (left) indicates the base pressure without beam load. The strong pressure variations (mid and right) during the beam operation phase is generated by desorbed gases from the beam pipe.

The strong variations of the pressure lines are related to initial beam losses and indicate the quality of the machine setting. Up to 10^{10} U^{28+}-ions were injected leading up to an order of magnitude pressure rise.

In order to avoid such pressure variations in SIS18 and to minimize the additional load to the UHV system, a new concept was suggested. The concept is based on the fact that the loss positions of stripped U^{28+}-ions (U^{29+}) can be well determined by ion optical calculations. The calculated loss profile along the circumference, shows well pronounced peaks behind each dipole group. Unfortunately, the SIS18 lattice was never optimized for an operation with intermediate charge state ions. Therefore, it can not be avoided that beam losses appear already in the dipole magnets. However, it could be shown that most of the stripped ions can be caught by dedicated collimators placed at the loss positions (80 %) [4]. The proposed collimator system shall furthermore be able to control the desorption gases. A prototype of such a collimator has been built and installed in front of the injection septum where losses during multi-turn injection generate local pressure bumps (figure 3) [5].

Figure 3 : Prototype wedge-shape desorption collimator installed in front of the electrostatic injection septum. The collimator shall protect the septum from beam losses during multi-turn injection and prevent gas desorption from the anode backside.

The concept described is feasible if the probability of multiple ionizations is very low. Multiple ionizations would lead to a wide distribution of the losses behind the dipole magnets and would not allow an efficient collimation. However, recent atomic physics collision studies and extrapolations from measurements have shown that multiple ionization of U^{28+} is a probable stripping mechanism at rest gas collisions at typical SIS18 energies [6]. However, the probability of multiple ionization depends mainly on the amount of heavy components. Therefore, a UHV upgrade program is planned with the goal to supply the desired rest gas mass spectrum with a low fraction of heavy components and a low average pressure in the order of $5x10^{-12}$ mbar [7].

SEPTUM PROTECTION

After major damage of more than 400 wires of the electrostatic extraction septum during a high current uranium operation, protection collimators were installed in front of both septa. Although the process of destruction was not observed directly, most probably a malfunction of the RF system caused the damage. The increasing dipole field moves the beam inwards towards the wires of the electrostatic extraction septum. Since the range of the uranium ions is smaller than the thickness of the wires (0.1mm) the whole kinetic energy of the beam was subsequently dumped in the wires. The new collimator in front of the electrostatic extraction septum is used to protect the wires against processes as described above, another new collimator in front of the injection septum is used to protect the septum during multi turn injection to localize beam losses as described in the chapter before and to keep secondary atoms and molecules away from the circulating ion beam [5].

ACCELERATION AND COMPRESSION

Conservation of the longitudinal phase space area is essential for limiting the RF voltage requirements at fast acceleration and compression in SIS18 and later in SIS100. However, the desired fast repetition rate in the booster mode and the need for fast capture processes, are not in consistence with the required adiabaticity. Therefore, machine experiments were performed with the goal of optimizing the RF capture process and to determine the minimum capture time. RF capture losses, longitudinal emittance blow up and weak damped coherent oscillations at high current operation, are often generated by a mismatch of the cavity frequency with the revolution frequency. The longitudinal beam dynamics in the RF bucket was studied at different mismatch parameters. It was shown that a frequency mismatch of only 1 kHz of a reference frequency of 850 kHz creates a significant emittance blow-up. Furthermore, experiments were performed to demonstrate that the radial beam position can be used for the optimization and fine tuning of the RF capture process.

In order to provide a sufficient bucket area for the planned fast acceleration with enhanced field rate of intermediate charge state heavy ion beams a new RF acceleration system is required. Furthermore, in order to reach the intensities proposed for the booster operation the space charge limit must be enhanced by means of a reduced RF bunching factor. For the enhancement of the bunching factor and the bucket area a new cavity will be installed and operated in parallel to one of the two existing cavities. The existing RF system consists of two ferrite loaded cavities operated at h=4, i.e. 0.86 to 5.8 MHz with a maximum amplitude of 2x12 kV. One of the two existing cavities will be removed for the installation of the new cavity. The new cavity will be loaded with magnetic alloy (MA) cores, operated at h=2, i.e. 0.43 to 2.8 MHz with a maximum amplitude of 40 kV and has a total length of 2 m. The remaining ferrite cavity shall serve as the second harmonic cavity operated at h=4. In addition, new fast feedback and control systems for high beam intensity operation in the combined system of the new MA cavity and the existing ferrite cavity will be designed and installed. For a proper matching of the high intensity uranium beam to the targets, plasma physics experiments and experiments using the Fragment Separator (FRS) request for strong compression after acceleration. In the framework of plasma physics experiments conducted in December 2003, a slightly nonlinear compression scheme with a low pre-bunching amplitude followed by a fast voltage jump was applied. A beam pulse with a length of only 124 ns (FWHM) and 5×10^9 uranium ions could be generated for the experiments (figure 4). The pre-bunching voltage was only 1 kV while the final voltage of 24 kV was given by the maximum voltage of the two SIS18 cavities. Earlier tests with pure linear compression had led to bunches of a length of 350 ns.

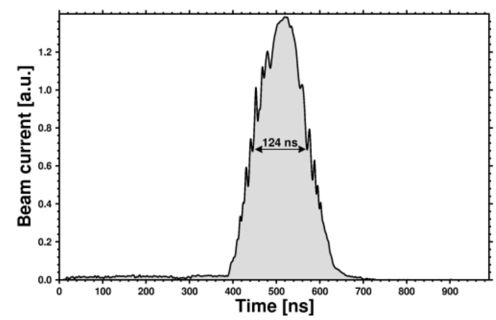

Figure 4 : Non-linear compressed uranium bunch with 5×10^9 ions and a FWHM length of 124 ns measured in the GSI plasma physics cave.

With growing beam intensities, the bunch length must be further compressed and matched to the expansion velocity of the generated target plasma. Therefore, a dedicated bunch compression cavity is being developed and will be installed in autumn 2005. The system under construction serves also as a prototype for the compression system of SIS100 and as a test bed for MA-core material studies [8].

POWER NET CONNECTION

In order to increase the average beam intensity for the ongoing experimental program and for the planned FAIR facility, SIS18 shall be operated in a fast mode with four cycles per second (4Hz) and 10 T/s up to 12 Tm (SIS12 mode). Since at present the ramp rate is limited by the power connection of GSI (max. 5 MW), negotiations with the main network operating companies were conducted through out the last year. Meanwhile, a two stage concept for an upgrade of the GSI pulse power connection to the power grid was developed and contracts could be prepared to build up a separate 110 kV line between GSI and a 220 kV transformer station in Urberach next year.

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