HIGH INTENSITY INTERMEDIATE CHARGE STATE HEAVY IONS IN SYNCHROTRONS

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Introduction

In order to reach the desired intensities of heavy ion beams for the experiments at FAIR [1, 2], the existing heavy ions synchrotron SIS18 and the planned FAIR synchrotron SIS100 have to be operated with intermediate charge states [3, 4]. Operation with intermediate charge state heavy ions at the intensity level of more than 10^{11} ions per cycle has never been demonstrated elsewhere and requires a dedicated upgrade program for SIS18 and a dedicated machine design for SIS100. The specific problems arising from the intermediate charge state operation in terms of charge exchange processes at collisions with residual gas atoms, pressure bumps by ion induced desorption and corresponding beam loss appears far below the typical space charge limits. Thus, new design concepts and new technical equipment addressing these issues have been developed and realized with highest priority.

The upgrade program of SIS18 addressing the goal of minimum ionization beam loss and stable residual gas pressure conditions has been defined in 2005 [5]. A major part of this upgrade program has been successfully realized, with the result of a world record in accelerated number of intermediate charge state heavy ions with more than $2x10^{10}$ U-ions per cycle.

INITIAL SYSTEMATIC BEAM LOSS, PRESSURE BUMPS AND IONIZATION BEAM LOSS

The reduction of the initial beam loss has an outstanding importance for the dynamic vacuum and ionization beam loss in the FAIR synchrotrons. Initial beam losses originate initial pressure bumps, which determine the whole dynamic vacuum situation and ionization beam loss in the overall machine cycle. Therefore, the reduction and control of beam loss in the injection channel, during multi turn injection and during the Rf capture process is a major issue of the SIS18 machine development program. Various experiments, e.g. using the collimator system in the transfer channel to minimize such beam losses have been performed successfully.

NEG PANELS IN THE ELECTROSTATIC INJECTION SEPTUM

A major progress in the process of preparing the future FAIR booster mode of SIS18 has been achieved by successfully increasing the static beam life time of intermediate charge state heavy ions. From previous measurements it was know, that the biggest amount of ionization beam loss appears in the injection straight (section 12). This has been expected from the relatively high measured residual gas pressure and has been proven by means of fast current measurements on the charge catcher system one section downstream (in section 1). In order to increase the pumping power, two sets of NEG panels have been installed in the injection septum just below the electrodes of the electrostatic deflection unit (Figure 1).

The static pressure in the injection septum was always enhanced by its link to the transfer beam line. By means of the significantly increased pumping power, the static pressure could be reduced significantly.

The dynamic pressure in the septum tank is driven by three major processes:

a) Surface sputtering by high voltage break downs during high current operation
b) Gas desorption from the cathode and anode by scraping-off the beam halo
c) Gas desorption by beam loss during multi turn injection on the backside of the cathode

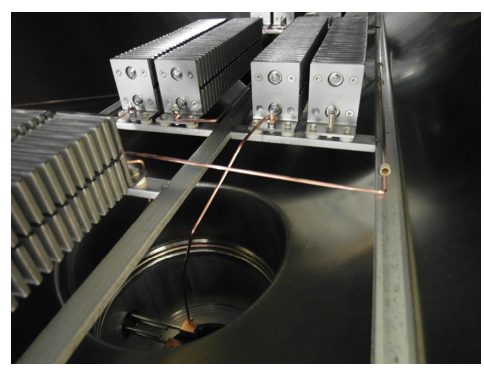

Figure 1: Major ionization beam loss has been caused by pressure bumps in the electrostatic injection septum. To enhance the pumping power and to speed up the recovery process, two sets of NEG panels have been installed in the electrostatic injection septum.

By the installation of the NEG panels, the decay time after pressure bumps generated by the above mentioned mechanisms, could be drastically reduced. The recovery time of the pressure after a high voltage break down affects the total ionization beam loss over multiple machine cycles. Thus a fast removal of the generated pressure bump is of major importance especially at the high repetition rate of 2.7 Hz as foreseen for the FAIR booster operation.

After insertion of the NEG panels in the electrostatic injection septum, a perfect agreement of the single

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particle beam lifetime as predicted by STRAHLSIM [6], with the measured life time as a function of energy has been achieved. Before the pumping power has been increased, the local static pressure in the injection septum has defined the overall average pressure of the machine. Thus, the beam lifetime was always restricted by this (short) enhanced pressure region.

At high intensity operation, beam loss on the septum electrodes (halo), is potentially causing high voltage break downs. High voltage break downs generate strong pressure bumps in the injection septum tank. The removal of the desorbed and sputtered atoms and molecules by the conventional pumps attached to the septum tank takes an unacceptable long time. Even with the support of the new NEG panels, the complete recovery of the beam lifetime after a high voltage break down takes up to 6 minutes. Therefore, a second set of NEG panels has been added in the last shut down.

Figure 2 shows one of eleven charge scrapers installed in SIS18 downstream each dipole pair [7]. At the position of the charge scrapers, stripped beam ions are well separated from the reference ion and can be scraped off without affecting the machine acceptance. The electrical current on the scrapers can be measured and indicates the amount of ionized particles in the section upstream the scraper.

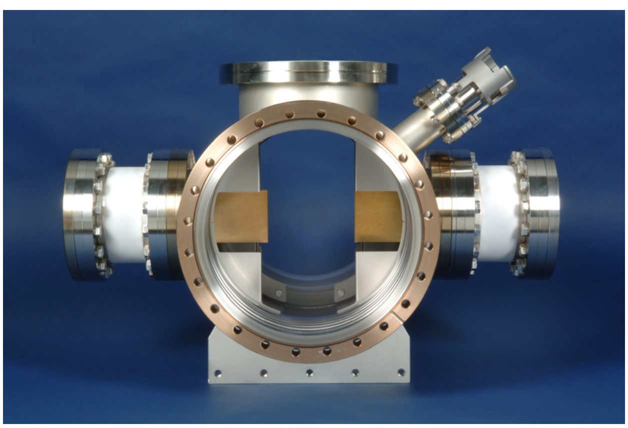

Figure 2: Low desorption charge scraper installed in the SIS18. Charge scrapers have been installed in all sections of SIS18, downstream each dipole pair. At these positions, stripped beam ions are well separated from the reference ions and can be scraped off without affecting the machine acceptance.

Figure 3 shows the electrical current measured on the charge scraper in section one. The current measured on this scraper is generated by incident beam particles which have been further ionized in the upstream injection section. As can be seen, the charge scraper current decays significantly faster after installation of the NEG panels. This shows that the major ionization beam loss which was generated before installing the NEG panels, by the various described mechanisms in the injection region, could be removed to a large extend.

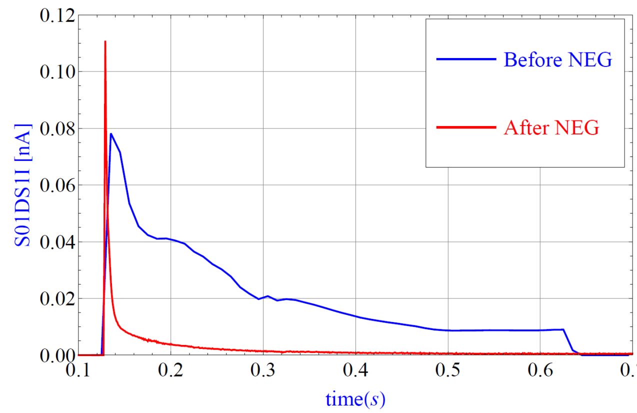

Figure 3: The electrical current measured on the charge scraper in section one has been significantly reduced by means of the NEG panels in the injection septum. This indicates that the pressure bump at injection and consequently the ionization beam loss in the injection section have been effectively removed.

BEAM COLLIMATION IN THE TANSFER CHANNEL

Major efforts have been taken to reduce the amount of beam loss in the injection channel and during multiturn injection and thereby to minimize initial pressure bumps [8]. A set of collimators in the beam line between UNILAC and SIS have been used to generate a sharp edge beam profile for injection into the synchrotron.

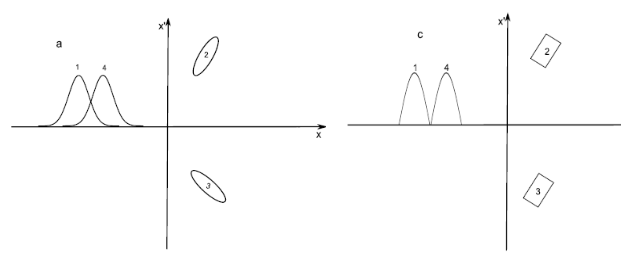

Figure 4: Collimators in the transfer channel are used to generate a sharp edge beam profile for multi turn injection into SIS18. The beam halo which otherwise would be lost in the injection channel or after injection during the multi turn injection process, is removed by the collimator system upstream the injection system. Thereby, the initial pressure bump at injection is reduced and beam loss by ionization minimized. The figure shows a sketch of the transverse phase space during multi turn injection, without (left) and with (right) collimation.

A proper setting of the quadrupole magnets between the collimators itself and between the collimators and the injection system is required to provide the phase advance needed for collimation of the phase space and to generate an imaging optics for injection. Figure 4 shows a sketch of the transverse phase space at multi turn injection with a fractional tune of about 1/3 with and without a collimated, sharp edge beam. By means of collimating the halo, a beam with smaller emittance and more pronounced intensive core is being produced. It has been shown, that by injecting such a trimmed beam, the same intensity can be achieved on extraction level as with a non collimated beam starting from much higher intensity (followed by significant losses).

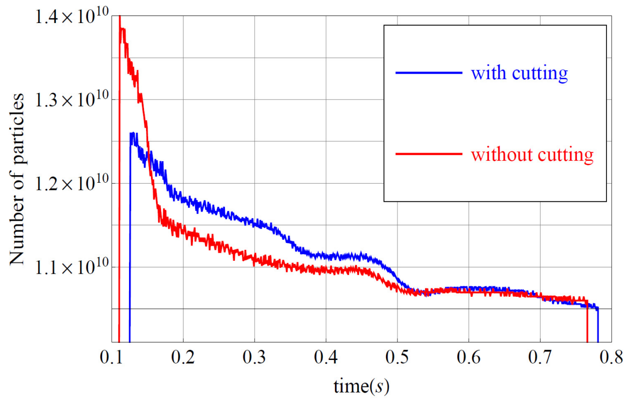

Figure 5: Comparison of the number of ions over a SIS18 cycle with and without injection of a collimated, sharp edge ion beam. With injection of a trimmed beam, the same number of ions can be achieved at extraction with a significantly lower number of ions injected.

OPTIMIZATION OF MULTITURN INJECTION

Injection over multiple turns is needed to achieve the desired high beam intensity for FAIR. After completion of the UNILAC upgrade program, a current of 15 emA will be provided for U^{28+}- ion beams. Depending on the emittance of the injected beam, multi turn injection over more than 10 turns typically generates quite high beam loss. However, at the expected emittance of 10 mm mrad, a stacking factor of 15 is required to achieve an initial intensity of $2.7\text{x}10^{11}$ ions in a SIS18 booster cycle. Therefore, strategies to minimize and control beam losses during the multiturn injection process have been studied.

The efficiency of multiturn injection depends on the horizontal tune and the beam emittance. At high intensity operation, space charge may shifts the tune with highest efficiency. The dependence of the multi turn efficiency on the tune and the beam intensity has been studied experimentally and theoretically [9,10]. Figure 6 shows the multi turn efficiency as a function of the horizontal tune and the beam current. As can be noticed, the maximum multi turn efficiency suffers significantly from high current operation. At high current operation, space charge and beam loading in the UNILAC increases the beam emittance. Thereby, the multi turn efficiency is reduced and the maximum efficiency is shifted to higher tune values.

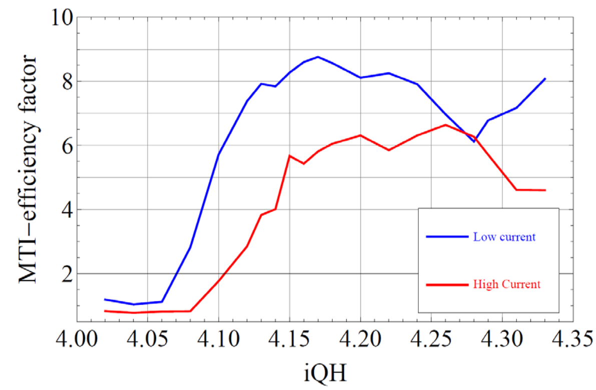

Figure 6: Dependence of the multi turn efficiency factor on the horizontal tune and beam current. Space charge shifts the optimum tune and emittance blow-up reduces the maximum reachable efficiency. Increasing the transverse emittances, sifts the maximum of the MTI efficiency to higher values.

CONCLUSION

By means of STRAHLSIM calculations, it has been shown that the maximum intensity reached (after careful machine setting), always represents the actual machine performance defined by its technical status and the partial completion of the upgrade program. Or in other words, the maximum number of accelerated ions can not be increased above a certain threshold by increasing the injected number of ions. Saturation by dynamic vacuum effects limited the maximum number of extracted ions in the year 2007 to $7\text{x}10^9$ ions, while for the present situation the limit is expected at $5\text{x}10^{10}$ ions. A recent attempt to experimentally prove the expected intensity limit failed because of lacking beam current from the UNILAC. The role of initial beam loss and initial pressure bumps is of increasing importance with further rising intensity. Therefore, the development campaign aiming for a reduction and control of the initial beam loss will be continued in the frame of machine experiments in the next years.

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