FAIR SYNCHROTRON OPERATION WITH LOW CHARGE STATE HEAVY IONS*

C. Omet†, D.H.H. Hoffmann, P. Spiller, GSI, Darmstadt, Germany

Abstract

Beam loss caused by charge changing processes in connection with dynamic vacuum effects may limit the maximum number of accelerated heavy ions with low charge states in the existing synchrotron SIS18 and the planned SIS100/SIS300 of the FAIR project. With the aim to stabilize the vacuum dynamics and to control ionization beam loss, a substantial upgrade program has been defined for SIS18 and is presently realized. For SIS100, a new lattice design concept has been developed, where each lattice cell acts as a charge seperator and thereby enables the local control of beam loss. Simulation, conducted with the code STRAHLSIM, of the time dependent evolution of beam loss, dynamic residual gas pressure and the effect of the proposed dedicated ion catcher systems will be presented.

INTRODUCTION

The new accelerator facility FAIR [1] at GSI relies on the existing synchrotron SIS18 as injector. Currently most experiments are performed with highly charged U^{73+}-beams. However, higher intensities can be achieved by using low charged U^{28+}, which is one of the reference ions of the FAIR project.

Machine experiments with low charge state heavy ions have been conducted in SIS18. During these experiments, extremely fast and intensity dependent beam loss in connection with a strongly dynamic behavior of the residual gas pressure have been observed. The intensities were far below the space charge limit of the machine. The reason of the observed beam loss is a charge change of the beam particles. The impact of these particles generates a local pressure bump by ion stimulated desorption.

To simulate the dynamic vacuum effects, the program STRAHLSIM has been developed [2]. It includes lattice and vacuum properties, machine cycles and allows calculation of coulomb scattering, charge change or radioactive decay of ions and couples them via ion stimulated desorption to the dynamic vacuum process. Furthermore, efficiency studies of ion catcher systems and the related benefit for the beam life time are possible. The simulation results have been benchmarked with data obtained in machine experiments [3].

For a precise calculation of charge change induced beam loss, energy-dependent charge change cross sections are needed. Recently, new data have been calculated by Shevelko et.al. [4]. As can be seen in Figure 1, the new data show a fast drop from $\sigma_{pi} \approx 10^{-21}$ m^2/atom at 10 MeV/u to $\sigma_{pi} \approx 10^{-22}$ m^2/atom at 200 MeV/u. The data obtained by a n-CTMC approach are plotted for comparison. In the following, simulation results for the upgrade of the existing synchrotron SIS18 and the planned synchrotron SIS100 are presented.

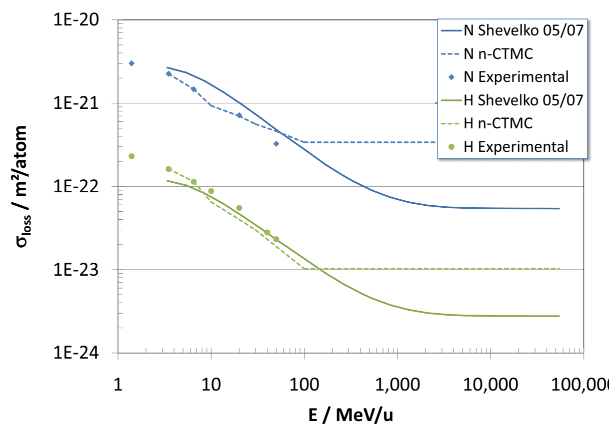

Figure 1: Single and multiple electron loss cross sections, calculated with n-CTMC [5] and the relativistic LOSS code [4]. Experimental data from [6].

DYNAMIC VACUUM IN SIS18

To overcome the current beam intensity limitation for U^{28+}, which is caused by charge change (mainly ionization) and ion induced desorption, a general upgrade program for the SIS18 has been defined [7, 8] and is currently realized. One of the upgrade measures is the design and installation of a dedicated ion catcher system to control ionization beam loss and suppress the desorption gas production. The optimal positions for the ion catchers were found to be directly after each group of two dipoles, as denoted in Figure 2.

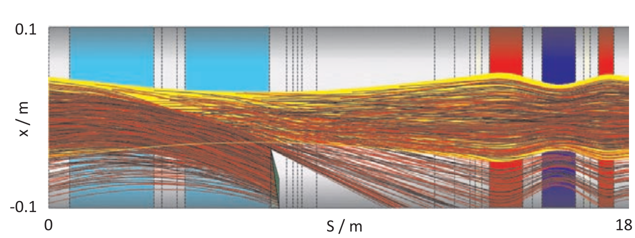

Figure 2: Tracks of ions after a charge change from $U^{28+} \rightarrow U^{29+}$ in the horizontal plane of one cell of SIS18. Ion catchers are green, dipoles cyan, quadrupoles red and blue.

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† c.omet@gsi.de

The design of an ion catcher prototype has been completed recently (see Figure 3). It consists of a transversally movable beam absorber (wedge and block shape, in red), which is placed in a NEG (Non Evaporable Getter) coated secondary chamber. The absorber is confined by a NEG coated primary chamber, which is equipped with vacuum diagnostics. To minimize the production of desorption gases, the beam absorber is coated with a low desorption rate material (Au). Au has been selected according to desorption measurements at GSI using the ERDA technique [9]. The NEG coated surfaces as well as the additional Ti-sublimation and ion-getter pumps (not shown in figure) are used to enhance the local pumping speed. Two prototypes are currently built and will be installed in the sections S02 and S03 of SIS18 during the winter shutdown 2007/2008.

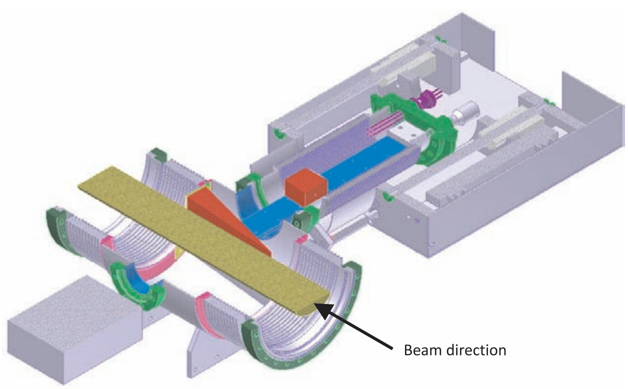

Figure 3: Design of the ion catcher system dedicated for beam loss by charge change in SIS18. A special wedge shaped collimator (red) design will be tested.

After the prototype function has been proven experimentally, a series of 10 ion catchers will be built and installed in SIS18. The calculated efficiency of the full ion catcher system (ratio of the number of particles hitting the collimators divided by the total number of lost particles) as a function of the transversal distance from the beam axis is shown in Figure 4. The efficiency is nearly independent of the distance to the beam axis, but does not reach 100% for several reasons. At first, the SIS18 lattice was never designed to work as a charge state seperator, secondly it is not possible to install an ion catcher system in each section of SIS18. This is due to already installed and not removable insertions, e.g. the magnetic extraction septum in S06 and the electron cooler in S10.

Other measures to stabilize the dynamic vacuum pressure in the SIS18 upgrade program are:

- Enhancement of pumping speed by a factor of 40 by NEG coating of all dipole and quadrupole chambers.
- Enhancement of the ramp rate from currently $\dot{B} = 1.3$ T/s to 10 T/s.
- Minimization of beam loss at injection.

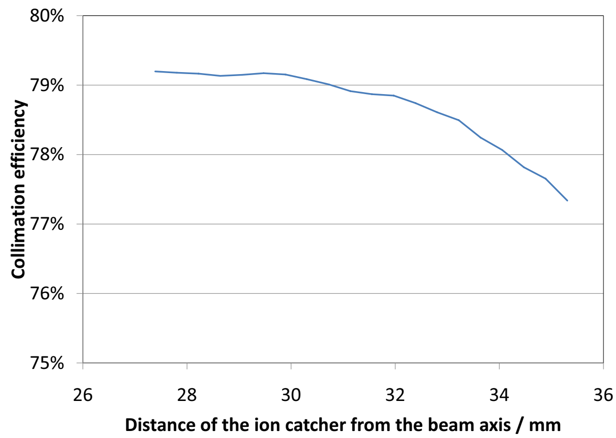

Figure 4: Catching efficiency for the process $U^{28+} \rightarrow U^{29+}$ of the proposed SIS18 ion catcher system.

The difference in beam lifetime between the present and upgraded SIS18 has been simulated using STRAHLSIM and is shown in Figure 5 and Figure 6. Only all upgrade measures together will reduce the amount of beam loss neccessary to reach the desired $1.25 \cdot 10^{11}$ U^{28+}-ions at extraction.

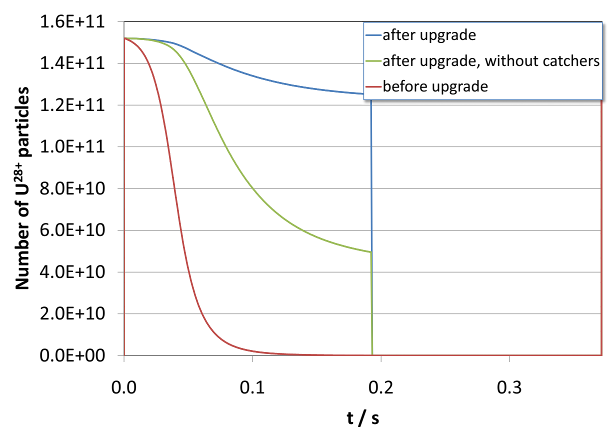

Figure 5: Evolution of U^{28+}beam intensity before and after the SIS18 upgrade program.

DYNAMIC VACUUM IN SIS100

For the planned synchrotron SIS100, specific attention has been taken on the optimziation of the lattice structure [10]. The lattice has been designed such, that each lattice cell of the arcs works as a charge state seperator for the reference ion U^{28+} and the produced U^{29+}, see Figure 7. The ion catchers are positioned between the D and F quadrupoles in the arcs leading to a catching efficiency of nearly 100%.

Since SIS100 makes use of s.c. magnets, its cold vacuum chambers serve as a large and distributed cryopump, resulting in a very high pumping power, which is estimated

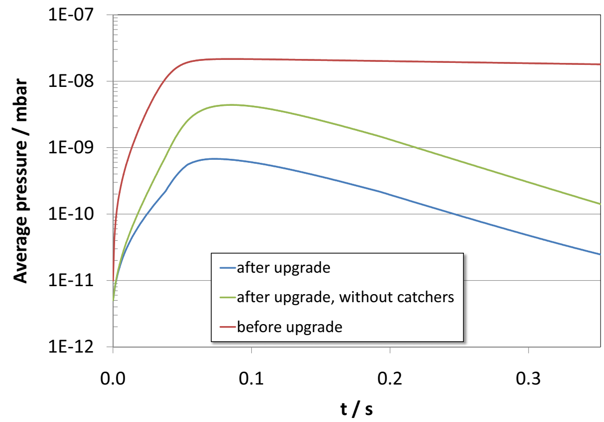

Figure 6: Evolution of the average pressure before and after the SIS18 upgrade.

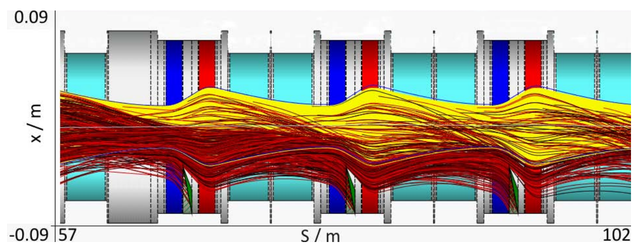

Figure 7: Tracks of ions after a charge change from $U^{28+} \rightarrow U^{29+}$ in the horizontal plane of 4 cells of SIS100.

to be $S_{eff} \approx 335$ m^3/s. This helps to reduce the pressure peaks, produced by ion stimulated desorption. Nevertheless, cross sections for the charge change process decrease with increasing energies and therefore, beam loss by charge change is reduced. The simulation of a SIS100 cylce with 4 injections of $1.25 \cdot 10^{10}$ U^{28+}-ions from the SIS18 is shown in Figure 8. The residual gas pressure remains stable within 10% under these conditions, see Figure 9.

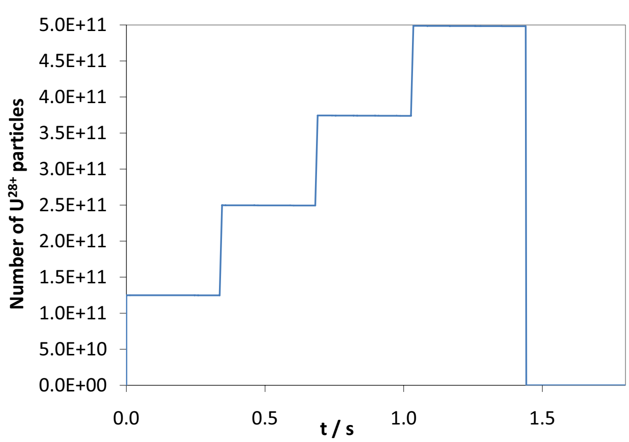

Figure 8: Evolution of U^{28+} beam intensity in SIS100 during stacking and acceleration.

Similar to the SIS18, a dedicated ion catcher system is foreseen in SIS100. However, instead of a NEG-coated secondary chamber, the cryogenic chamber itself acts as a local pump.

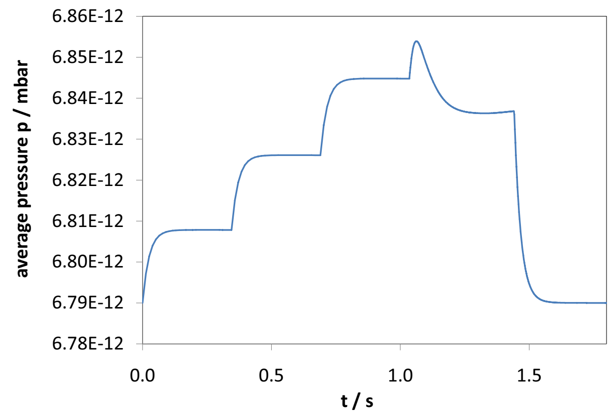

Figure 9: Evolution of the average pressure in SIS100.

SIS300

SIS300 will be operated in a "stretcher" mode for SIS100. Hereby the beam is transferred from SIS100 after acceleration to 400 MeV/u or 1.5 GeV/u. After injection, the beam is slowly extracted in exactly the cycle time of SIS100. In this way, a DC like continous high energy beam is provided for experiments. As the cross sections for charge change has reached rather low values in the energy range of SIS300, no ion catcher system is foreseen.

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