

MEASUREMENT OF BEAM IONIZATION LOSS IN SIS18

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Abstract

In the heavy ion synchrotron SIS18 at GSI an ion catcher system has been installed to provide low desorption surfaces for ionization beam loss to reduce dynamic vacuum effects. Medium charge state heavy ions can change their charge state in collision with residual gas molecules. Those ions are caught by the ion catcher system. The ion catcher blocks are mounted electrically insulated, such that it is possible, to directly measure the electrical current, induced by the incident ions. Changes in vacuum density during an acceleration cycle and also the energy dependent decrease of the cross sections for electron loss and electron capture can be measured by this system.

Different ion catcher currents, measured during the operation with U^{28+} , and their interpretation are presented. The measurement of ionization beam loss is a valuable tool to benchmark the dynamic vacuum simulations.

INTRODUCTION

For the FAIR-booster operation with highest intensity heavy ion beams medium charge states, i.e. U^{28+} will be used in SIS18. To suppress dynamic vacuum effects, all magnet chambers have been NEG-coated, and an ion-catcher system has been installed, which provides low desorption surfaces for charge exchanged ions [1]. This system is equipped with a current measurement to directly measure the electrical current, induced by the lost charge exchanged ions. First measurements of ionization loss have been shown in [2] and [3]. In the meantime, the measurement of ionization beam loss is used on a regular basis during operation with medium charge state heavy ions at the SIS18, yielding in several intensity records [4].

ION CATCHER SYSTEM IN SIS18

Figure 1 shows two out of twelve sections of SIS18. The ion catchers are installed behind the dipoles. Although the lattice has not been optimized for the installation of an ion catcher system, a catching efficiency of 68% for $U^{28+} \rightarrow U^{29+}$ can be reached. Figure 2 shows the catching efficiency for different ions, charge states, and degrees of ionization. The underlying variable q/q' is the relative change of charge of the ion before (q) and after (q') the ionization process. The loss distribution and thus also the catching efficiency only depends on the ion optical lattice, not on the beam energy, assuming a negligible energy loss in the collision with the rest gas. The area $q/q' < 1$ represents the catching efficiency for electron loss (EL), whereas $q/q' > 1$ describes the catching efficiency for electron capture (EC).

An ion catcher module is shown in Fig. 3. EC ions are deflected to the outer side of the ring and hit the left ion catcher,

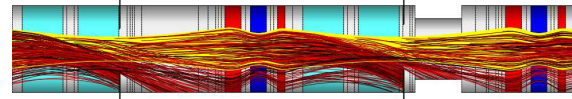


Figure 1: Part of the SIS18-lattice, dipoles are shown in cyan, quadrupoles in red and blue, the circulating U^{28+} beam in yellow. Trajectories of U^{29+} ions are shown in red. Intercepting ion-catchers are shown in green.

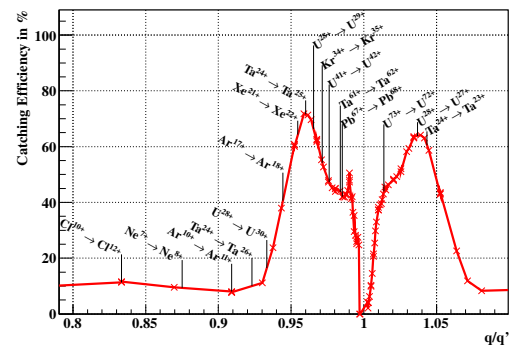


Figure 2: Catching efficiency of the SIS18 ion catcher system for different charge exchange channels.

EL ions experience a higher bending force in dipoles, which makes them getting lost on the inner side, i.e. hit the right ion catcher. The mounting of the catcher-blocks contains an insulating ceramic, which allows the direct measurement of the ion current. The measurement is realized via sensitive current-to-frequency-converter [5], which are connected to the beam loss monitor system ABLASS [6] of the synchrotron's control system.

In total ten ion catcher modules are installed in the twelve sections of SIS18. Two sections are missing, because the space is blocked by extraction devices and electron cooler. Trajectories of ionized ions have an average length of 13.5 m, i.e. they are lost in the section subsequent of the position of ionization. Such, the current on the ion catcher always reflects the vacuum conditions in the previous section. Losses during the multiturn-injection process happen in section 12, the resulting vacuum dynamics can be observed on the catcher currents in section 1.

IONIZATION LOSS OF A STORED HIGH INTENSE URANIUM BEAM

The upper part of Fig. 4 shows two measurements, where an intensive U^{28+} -beam¹ was stored at injection energy in the SIS18. The small spike at the beginning reflects injection losses, resulting in a pressure rise in section 12. It is remarkable, that the measurement with the higher initial

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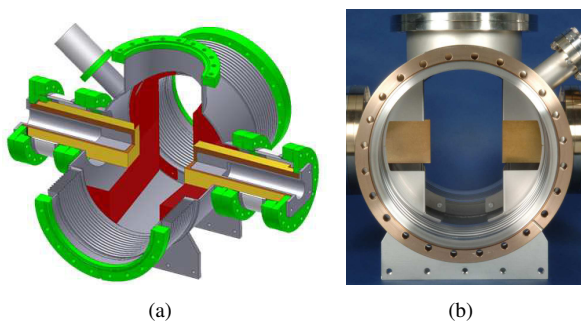


Figure 3: SIS18 ion catcher modules: (a) Cut-model, the ion-catcher are shown in yellow, secondary chamber plates in red, and insulating ceramic in white. (b) Photography of an ion catcher pair, as seen by the beam.

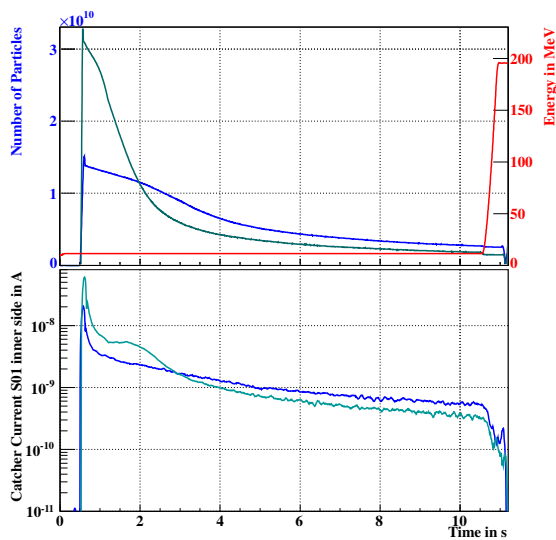


Figure 4: Two U^{28+} beams with different intensity have been stored at 11.4 MeV. The beam with higher initial intensity drives more vacuum instabilities resulting in more intensity loss. The ion catcher currents show the vacuum dynamics of the injection region. The decrease at the end is due to decreasing ionization cross sections with increasing energy.

intensity is subjected to a higher amount of losses, resulting in a lower intensity at the end of the cycle. The lower part of the figure shows the raw signal of the measured current on the EL ion catcher in section 1, right behind the injection section.

Both measurements show a sharp peak at the beginning, driven by the injection losses. The subsequent fast decrease is due to the high pumping speed installed at the injection septum. Around 10.5 s the acceleration starts. Since the ionization cross sections drop with increasing energy [7], also the loss currents drop.

The reason for the decrease of the measured current during the storage time is the reduction of the beam intensity on the one hand, and the adsorption of released gas, induced by beam loss, on the other hand. To distinguish both effects, the catcher currents are normalized to the corresponding

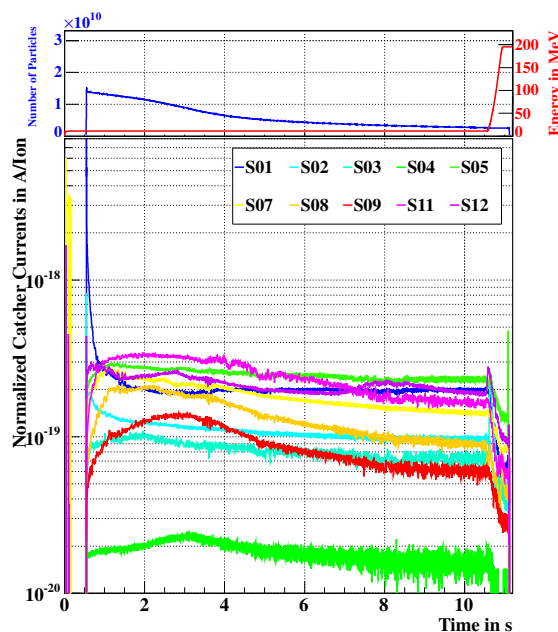


Figure 5: Beam intensity and ion catcher currents for electron loss during a medium intensity cycle with stored beam.

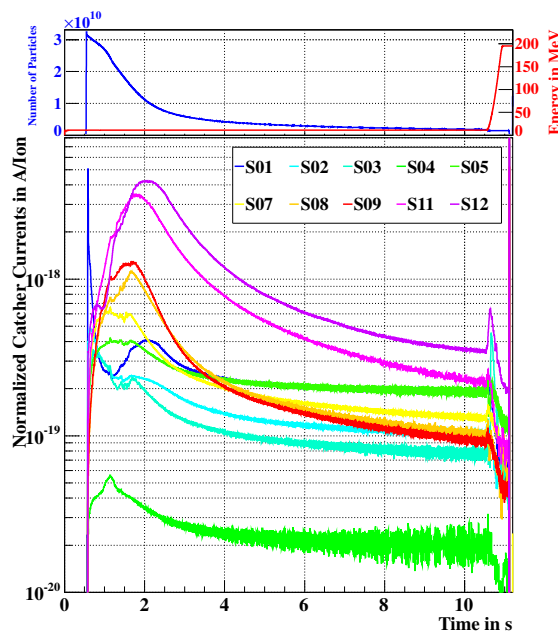


Figure 6: Beam intensity and ion catcher currents for electron loss during a high intensity cycle with stored beam. A much stronger vacuum dynamic than in Fig. 5 appears.

beam intensity. Figures 5 and 6 show all normalized catcher currents for ionization beam loss from the two measurements of Fig. 4.

Prominent in the medium intensity storage cycle in Fig. 5 is the strong peak in S01 and the subsequent constant development. The pressure in the injection region relaxes quite fast due to the huge pumping speed. The following section S02 shows the same trend, but sharply reduced. S03 shows

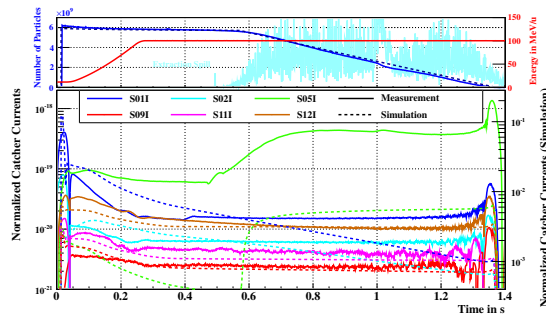


Figure 7: Beam intensity and selected ion catcher currents for EC during a slow extraction cycle, measurement and simulation.

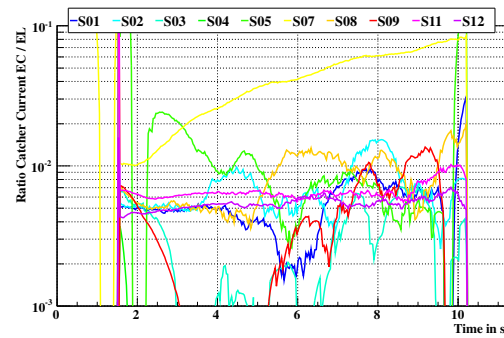


Figure 8: Ratio between EC and EL during the storage time at 11.4 MeV.

only weak dynamics. Here the ultimate pressure of the ring is reached, resulting in the lowest catcher currents for S04. The pressure in S06 underlies a higher dynamic due to missing ion catcher. In the subsequent sections S07 and S08 time delayed pressure rises can be observed. S10 also misses ion catcher, yielding in high pressure and loss currents in S11.

Most eye-catching in Fig. 6 are the high currents in S11 and S12. The missing ion catcher in S10 also results in a huge pressure build-up in the following section S11, indicated in the catcher currents of S11 and S12. Even the high pumping speed in S12 can not prevent a small pressure rise, represented by the bump in the S01-current at 2 s. After most of the beam is lost within 3 s, the pressure along the ring relaxes by one order of magnitude. With the start of the acceleration around 10.5 s a radial motion of the beam induces a fast increase of catcher currents, followed by the decrease due to increasing energy.

The two measured cycles show the emergence of vacuum instabilities. While in the medium intensity cycle in figure 5 the pressure varies only within a factor 2-3, the high intensity cycle in figure 6 drives pressure variations spanning over 1-1.5 orders of magnitude, resulting in huge ionization losses.

IONIZATION LOSS DURING SLOW EXTRACTION

Figure 7 shows a measured slow extraction cycle with U^{28+} together with a simulation of that cycle. During the extraction process, losses at the electrostatic septum in S04 can not be avoid. Again, these losses produce a pressure rise, yielding in an increase of the subsequent catcher current in S05. During the acceleration the currents drops, due to decreasing cross sections. The cycle has been simulated using the StrahlSim code [8]. For the intensity evolution and most of the catcher currents, the simulation reflects the measurements. In S04 the simulation neglects the build-up of a pressure bump during continuous operation, resulting in an underestimated catcher current by the simulation for S05. Nevertheless, both show the pressure increase caused by extraction losses.

The high pumping speed in the injection region is obviously not yet correctly described by the simulation. Here, the

measurement of ionization loss helps to identify inaccuracies of the simulation to improve it.

RATIO BETWEEN EC AND EL

EC loss rates can only be measured at the injection energy of 11.4 MeV in SIS18, since the EC cross sections decrease very fast in this energy regime. At this energy the total effective cross section for EC is predicted to be a factor of 22.7 lower than for EL (assuming a typical UHV rest gas composition). Figure 8 shows the ratio of EC and EL currents during the high intensity storage cycle of figure 6. Since the beam was not perfectly aligned in the middle between the ion catcher pairs, and the rest gas composition is not constant along the ring, the different sections do not perfectly align. Variations of the ratio during the storage time can be explained by changes in the rest gas composition, caused by different pumping speeds and mobilities for different gas species. This technique needs further development, but shows potential to cross check cross sections.

CONCLUSION

The electrical current measurement on the ion catchers allows a direct measurement of ionization loss in SIS18. This is a valuable tool to detect locations with high pressure. Pressure bumps can be caused by losses due to a misaligned beam. The catcher currents are also a useful tool to benchmark simulations and to improve the simulation model. Such, predictions for SIS100 and other planned facilities get more reliable. The potential of the current measurement will be further exploited.

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