INITIAL BEAM LOSS AND CONTROL OF DYNAMIC VACUUM EFFECTS IN SIS18

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Abstract

To stabilize the dynamic pressure in the SIS18, the systematic initial beam loss must be minimized. Beam Particles which are lost on the vacuum chamber cause a local pressure increase. Thereby the collision rate between beam ions and residual gas particles and consequently beam loss by ionization is enhanced. The reduction and control of beam loss in the injection channel, during multi turn injection and during the RF capture process, has an outstanding importance for the vacuum dynamics. One way to minimize the initial losses in the synchrotron is to displace the beam loss into the transfer channel (TK) between the injector LINAC and SIS18. In the transfer channel, the beam edges are trimmed by means of a collimator system and a sharply defined phase space area can be injected into SIS18. The effect of reduced initial beam loss on the vacuum dynamics is presented.

INTRODUCTION

For the FAIR project, the beam intensity in the heavy ion synchrotron SIS18 must be increased by a factor of 100 compared to the situation in 2001 [1]. To reach the desired intensities of 5×10^{11} particles in the new synchrotron SIS100, ion bunches of four cycles of SIS18 with 1.25×10^{11} particles each must be injected into the SIS100. The increase in intensity is essentially achieved by increasing the space charge limit due to a reduction of the charge of the ions. Intensity and brilliance losses can be avoided by dropping the charge exchange foil between the UNILAC and the SIS18 [2]. Instead of U^{73+} ions, U^{28+} ions are used.

Intermediate charge state ions show high cross sections for charge exchange processes due to interaction with residual gas particles. Collision of a beam particle with residual gas atoms can easily change its charge by electron capture or electron loss. This changes its magnetic rigidity with respect to the reference ion and it hits, after a dispersive element, the vacuum chamber walls, driving ion induced desorption of adsorbed gas. The desorbed gases generate a local pressure rise in the machine and increase the yield uncontrolled of charge exchange reactions [3]. If these losses are, this may lead to a complete loss of the beam during a few turns in the synchrotron.

Various measures to reduce/control these losses were made. A low desorption catcher system has been successfully installed in the SIS18. To increase the pumping rate all dipole and quadrupole chambers were coated with NEG (Non Evaporable Getter). Furthermore, ten NEG Panels were installed in the injection tank.

Particles that are lost during the multi turn injection (MTI), increase the dynamic pressure in the SIS18 by desorption. For stability of the vacuum pressure, the systematic losses at the beginning of the cycle must be below 2%.

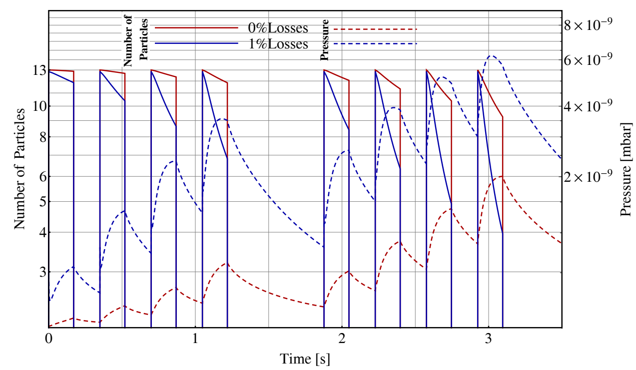

Figure 1: Simulated intensity and pressure profiles for the SIS18 booster mode for different injection losses. Four SIS18 cycles are performed with a 3 Hz repetition frequency.

Figure 1 shows a simulation with the STRAHLSIM code with eight injections of the SIS18 (i.e. for two SIS100 cycles). The dependence of the extracted particles and the pressure on different percentages of injection loss is evident. It can be seen that the pressure even at small injection loss increases rapidly and in subsequent cycles more particles are lost.

The injection losses can be shifted from SIS18 to the transfer channel to avoid an additional pressure increase. They do not interfere with the circulating beam in the SIS18 and the dynamic pressure in the SIS18 does not increase. In the transfer channel, the beam edges are trimmed with the help of slits, resulting in a sharply defined phase space area. Furthermore, the injection duration can be extended without increasing the injection losses. This results in an increase of the accelerated particles by minimizing the charge exchange of ions. Furthermore, a non-linear decline of the bumper flank contributes to the optimization of the multi turn injection.

After the multi turn injection the beam is bunched. The particles, which are not captured in the RF buckets, get lost in dispersive elements at the inner side of the ring at the start of acceleration. These losses can be captured with the movable collimator in the third sector of SIS18.

BEAM COLLIMATION IN THE TRANSFER CHANNEL

The minimization of beam losses in SIS18 at injection has a special influence on the dynamic vacuum and the beam loss due to ionisation in the synchrotron. Initial losses increase and cause a pressure rise in the whole machine. Such losses can overcharge the throughput of the vacuum system and, in the worst case, lead to a complete loss of the beam. The reduction and control of the beam loss during the MTI is an important theme of the SIS18 machine development. One possibility to reduce the losses in SIS18 is to shift these losses in the transfer channel. To this end, a set of collimators in the transfer channel have been used to generate a sharp edged beam profile in horizontal phase space for injection into the synchrotron. 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 [4].

After collimation the bam has a smaller emittance with a defined core and high brilliance.

$$B = \frac{I}{\pi\epsilon_x \pi\epsilon_y \delta} \quad (1)$$

Here, I is the beam current, $\epsilon_{x,y}$ is the horizontal and vertical emittance and δ the standard deviation of the momentum distribution. This allows better filling of the SIS18 acceptance. To eliminate the complete beam edge two collimators are used, one after the other and the phase advance between the both collimators is 90°. 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.

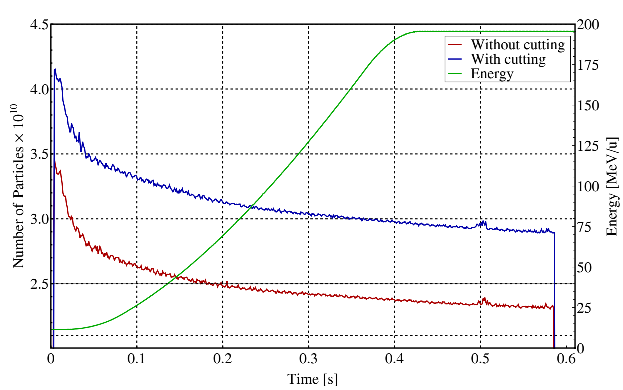

Figure 2: Comparison of the number of ions over a SIS18 cycle with and without injection of collimated, sharp edge ion beam. An increased number of ions can be accelerated with the injection of a trimmed beam.

NON LINEAR BUMP FLANK

During normal operation, the bumper magnets fall off linearly with time. One possibility to increase the accumulation length, and thus the intensity in SIS18, is to set a non linear decline of the bumper magnets flank. The nonlinear bumper flank should be flatter towards the end of the injection time to gain more time for injection. The Figure 3 shows the difference of the injection process between a linear and a nonlinear bumper flank. The non linear bump flank allows more injection time.

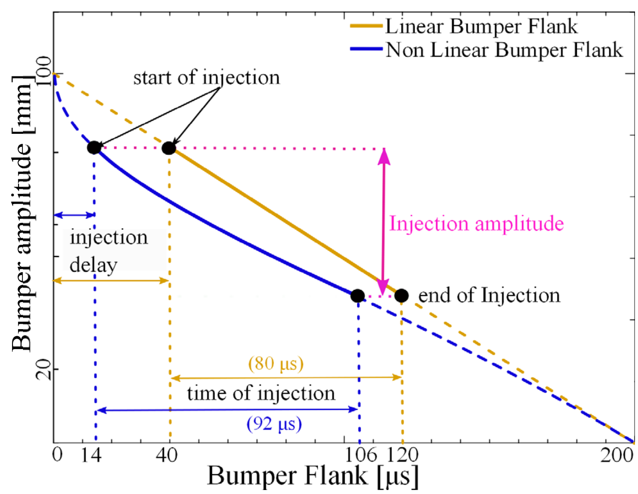

Figure 3: Comparison of the linear and non linear bumper flank decline.

The nonlinear bumper flank falls at the beginning of the ramp faster with time. Therefore, the injection delay is shortened so that the injection starts at the same amplitude level as the linear bumper flank. The injection time is extended, until the injection ends at the same amplitude of the linear bumper flank. Whereby the free phase space beam produced by the beam collimation can be filled.

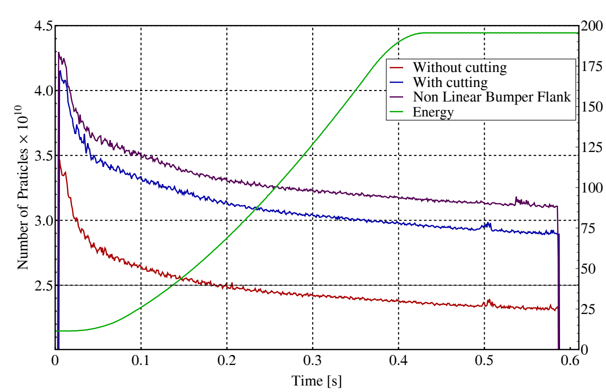

Figure 4: Comparison of the number of ions over a SIS18 cycle with linear and non linear bumper flank decline with collimation of the beam in the transfer channel.

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PRESSURE IN INJECTION CHAMBER

The local pressure is highest in the SIS18 injection septum chamber. This is the Place where most losses take place resulting in many charge exchange states. The generated pressure increase and the free electrons may cause high voltage breakdowns. The high voltage breakdowns are typically delayed by a few milliseconds with respect to the beam injection [5]. A breakdown generates an immense pressure increase in the overall septum chamber.

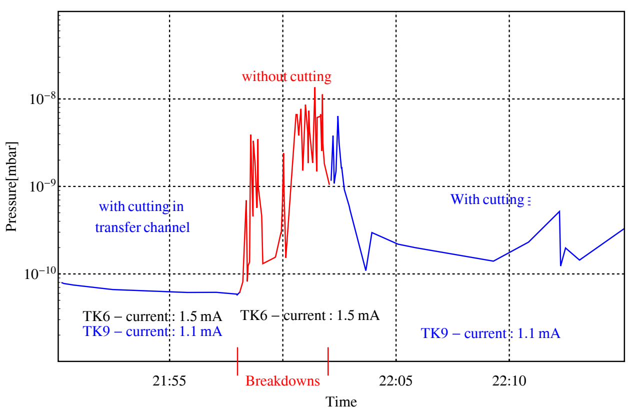

Figure 5: Pressure in the injection septum chamber with and without cutting the beam edge in the transfer channel. High voltage breakdowns in the electrostatic injection septum create strong local pressure bumps which ionize the revolving intermediate charge state beam and lead to significant beam loss within the cycle.

Figure 5 shows the pressure in the injection spetum chamber during breakdowns and during the cutting of the beam edge in the transfer channel. Here, 1.4×10^{10} particles were injected and approximately 1×10^{10} particles were extracted. After collimation of the beam edge in the transfer channel and optimization of the multi turn injection parameters the machine ran stable and the pressure was about 9×10^{9} mbar in the septum chamber.

RF CAPTURE LOSSES

The particles which are not captured in the RF buckets are lost on the vacuum chamber on the inside of SIS18 at the start of the magnetic ramp. During the machine experiments, it has been observed that the RF losses mainly hit the reinjection septum in the sector S11. There they caused a local pressure bump. The resulting charge exchanged ions hit the catcher in sector S12. This was observed during the machine experiments with U^{28+} ions in April 2012. The pressure in sector S11 was increased about one order of Magnitude. Since the RF losses take place on the inner ring side, there is the possibility that these losses could be collected using the movable collimator in the sector S03. This collimator normally has the task to protect the electrostatic extraction septum. For this reason, the collimator can be moved closer to a position in which it does not obstruct the resonant particles in the slow extraction and therefore does not constitute a limitation of the machine acceptance. During the experiments, the collimator was moved closer to the beam such that it collects particles that are lost during RF capture. This could be verified on the number of extracted particles, which remains constant while the current of the catcher in sector S12 decreased.

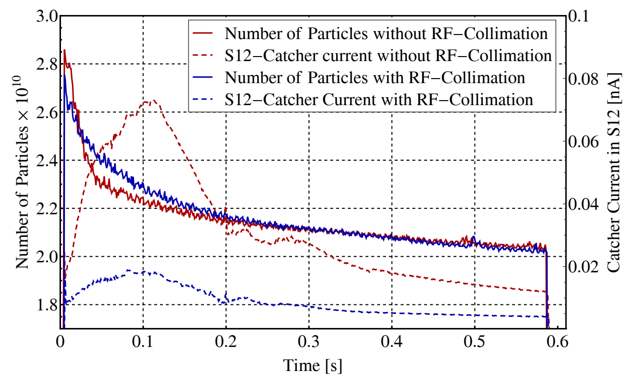

Figure 6: Comparison of the number of ions over a SIS18 cycle with and without RF-collimation, and the current of the collimator in S12.

Figure 6 shows two cycles of U^{28+} in SIS18 with and without the use of the collimator in sector S03. Without collimation there are 2.9×10^{10} particles at the beginning of the cycle and with collimation only 2.7×10^{10} particles yet, the number of extracted particles for the two cycles was 2.1×10^{10} particles. The current on the catcher in the sector S12 has declined for the cycle with collimation, which is a sign of the postulated improvement in the situation in the vacuum sector S11.

CONCLUSION

After collimation of the beam edges in the transfer channel and setting the non linear bumper flank it was possible to accelerate and extract 3.2×10^{10} particles of intermediate charge state Uranium ions [6]. This is at present world wide unique.

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