DYNAMIC VACUUM STABILITY IN SIS100*

P. Puppel, GSI, Darmstadt, Germany and Goethe-Universität Frankfurt, Germany
P. Spiller, GSI, Darmstadt, Germany
U. Ratzinger, Goethe-Universität Frankfurt, Germany

Abstract

SIS100 is the main synchrotron of the FAIR project. It is designed to accelerate high intensity intermediate charge state uranium beams from 200 MeV/u up to 2.7 GeV/u. Intermediate charge state heavy ions are exposed to a high probability of charge exchange due to collisions with residual gas molecules. Since the charge exchange process changes the magnetic rigidity, the involved ions are lost behind dispersive elements, and an energy-dependent gas desorption takes place. The StrahlSim code has been used to predict the stability of the residual gas pressure in SIS100 under beam loss driven dynamic conditions. The results show, that a stable operation at highest U^{28+} intensities is possible, under the constraint that the vacuum chambers of the ion catcher system are cold enough to pump hydrogen. Furthermore, in order to determine the load to the cryogenic system, the average beam energy deposition onto the ion catcher system has been calculated.

INTRODUCTION

The heavy ion synchrotron SIS100 will provide high intensity U^{28+} beams for the experiments of the FAIR project. Intermediate charge state ions show high cross sections for charge exchange processes due to interactions with residual gas particles. Downstream dispersive elements, the charge changed ions, which differ in magnetic rigidity with respect to the reference ion, hit the vacuum chamber walls and drive an ion induced desorption of adsorbed gas. The desorbed gases generate a local pressure rise in the machine, and increase the yield of charge exchange reactions. This effect can be self amplifying and is called dynamic vacuum.

To prevent dynamic vacuum effects in SIS100, an ion catcher system will be installed. Due to the ion optical structure of the SIS100 lattice, the charge changed ions are separated from the main beam and dumped at dedicated positions, where the ion catchers are installed [1]. The ion catchers provide very low desorption yields and suppress the build up of pressure bumps. SIS100 has a sixfold symmetry. Each sector contains 10 ion catchers on the inner side of the ring. A prototype ion catcher for SIS100 has been designed and tested successfully at GSI with beams accelerated by SIS18 [2].

A very low static pressure and a high pumping speed are necessary to avoid the buildup of dynamic vacuum, and to remove desorbed gas particles from the vacuum system, respectively. In order to provide these high pumping speeds, SIS100 is build as a cold machine with superconducting magnets. The magnet chambers, cooled with liquid helium, work as highly efficient surface pumps. The residual gas particles are supposed to freeze out on the cold chamber walls, and the average pressure is expected to be in the range of 10^{-12} mbar.

The StrahlSim code has been developed and used to verify the stability of the dynamic vacuum in SIS100. This code simulates charge exchange driven beam loss and dynamic vacuum effects in heavy ion synchrotrons [3]. The code accounts for the energy-dependent charge exchange cross sections by considering the detailed cycle properties of a heavy ion accelerator. Furthermore, the code implements a time and space resolved vacuum system, considering the vacuum conductance between vacuum elements[1], outgassing from the chamber walls, conventional vacuum pumps, and surface pumps like NEG-coated chambers and cryogenic surfaces. Thereby, the StrahlSim code is able to simulate charge exchange beam loss in a space and time dependent pressure environment, which is described in Ref. [4].

Each sector of SIS100 consists of warm straight sections and a cryogenic arc. Both parts require a completely different modeling of the vacuum system. StrahlSim is a unique code, which is able to handle such a system, calculating a space and time resolved pressure profile.

[1] In case of SIS100 the vacuum is resolved with a resolution of 0.5 m.

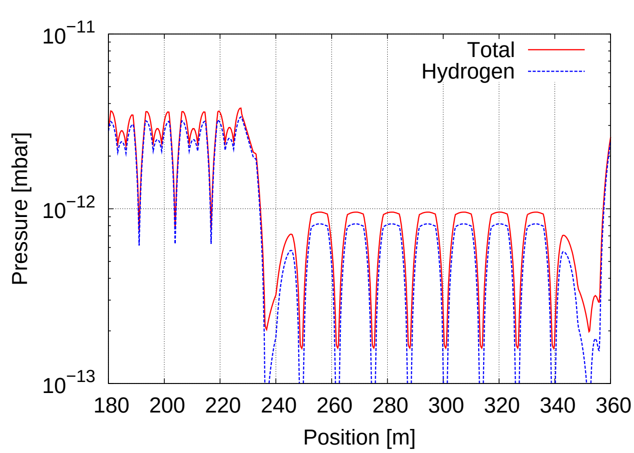

Figure 1: Simulated static pressure distribution within sector 2 of SIS100. In the warm straight sections (180–230 m) the pressure is higher than in the cryogenic arc (230–360 m).

* This work is supported by HIC for FAIR.

SIMULATION OF CRYOGENIC SURFACES

As mentioned before, in SIS100 the residual gas particles are supposed to freeze out on the cryogenic surfaces of the vacuum chambers. Therefore, a proper simulation of this process is crucial for the simulation of the dynamic vacuum in SIS100.

The cryogenic surfaces are simulated by considering the amount of thermally desorbed and adsorbed gas particles within each time step. The number of particles in the gas phase and the number of particles on the cryogenic surfaces are tracked for each gas species separately. The number of gas particles leaving the wall within each time step is directly connected to the mean sojourn time on the surface, while the number of particles sticking onto the surface is determined by the sticking coefficient. Both numbers depend on the surface temperature.

The mean sojourn time of hydrogen is only known at liquid helium temperatures [5], while the sticking coefficient was measured over a broader temperature range [6]. Thus, it is only possible to simulate the behavior of hydrogen at the temperature of liquid helium. At higher temperatures, the StrahlSim code assumes that hydrogen is not pumped at all[2].

SIMULATION OF DYNAMIC VACUUM AND BEAM LOSS

The existing SIS18 accelerator at GSI will act as a booster synchrotron for SIS100. Four consecutive cycles of SIS18, which are supposed to deliver 1.25×10^{11} U^{28+} ions, will be accumulated in SIS100 over 1 s. SIS100 will ramp with 4 T/s to a maximal magnetic rigidity of 100 Tm, which corresponds to an energy of 2.7 GeV/u. After acceleration, the beam will be either fast or slow extracted from SIS100.

[2]It is known that hydrogen can be cryosorbed up to 18 K.

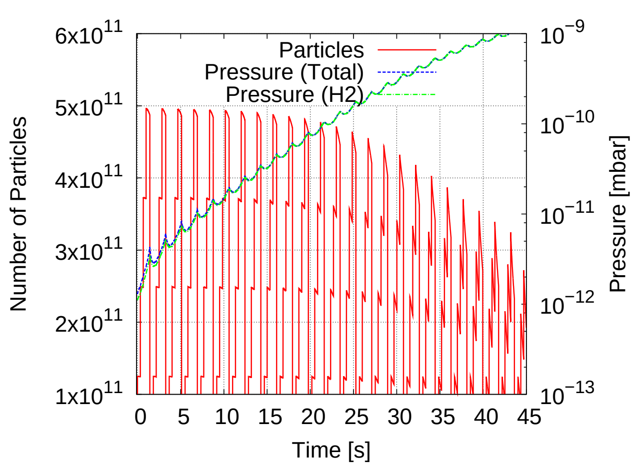

Figure 2: Number of particles and pressure in SIS100 over 25 cycles. The scenario considers a situation, where the desorbed hydrogen is removed by cryoadsorption pumps only.

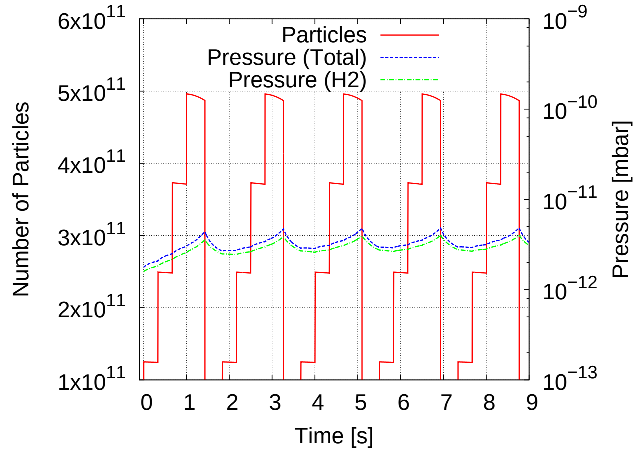

Figure 3: Number of particles and pressure in SIS100 over five cycles. The scenario considers a situation, where the desorbed hydrogen is pumped by the cryogenic surfaces of the ion catcher chambers.

The first simulated scenario considers a vacuum system, where the hydrogen in the cold arcs of SIS100 is only pumped by cryoadsorption pumps. These pumps are situated between each dipole pair and are foreseen to work as auxiliary pumps only. The heavier gas species are pumped by the cold surfaces according to the saturated vapor pressure curves. In Fig. 1 the static pressure profile calculated with the StrahlSim code is shown. In order to obtain this profile, the pressure in the system was set to a uniform value of 10^{-12} mbar and was then evolved until a relative pressure change between two consecutive time steps of less than 10^{-3} was achieved. The obtained pressure distribution was used as the initial pressure profile for the dynamic vacuum and beam loss calculations.

Figure 2 shows that the beam performance of SIS100 is not stable in the first scenario. After approximately 10 cycles with fast extraction, the mean pressure, which is dominated by hydrogen, reaches 10^{-10} mbar. At this point the amount of charge exchange beam loss exceeds a critical value and the transmission breaks down.

In the next step it was assumed, that the vacuum chambers around the ion catchers are cold enough to pump the desorbed hydrogen. The ion catcher chamber is designed to reach a surface temperature close to 4.2 K. The simulation result is shown in Fig. 3. The mean pressure in SIS100 is stabilized, and the beam performance stays stable over time.

As mentioned before, SIS100 will also provide slow extracted beams. The extraction will take place in the second warm straight in sector 5. By means of a third order resonance the beam ions will be driven into the electrostatic septum. Approximately 10 % of the beam ions will hit the septum wires and will be fully stripped to U^{92+}. The next quadrupole doublet deflects the U^{92+} ions directly onto the

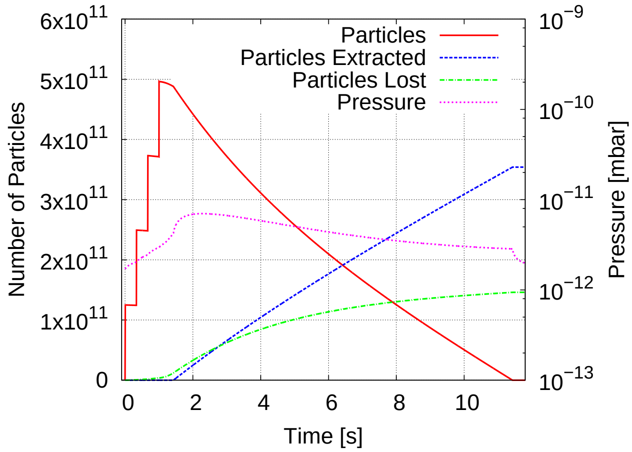

Figure 4: Number of particles and pressure over a cycle with slow extraction.

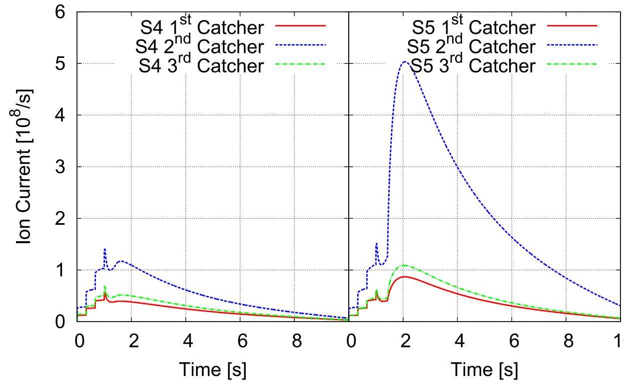

Figure 5: Predicted currents on the first three ion catchers in sectors 4 and 5 during a cycle with slow extraction. The catchers in sector 4 are located in front of the extraction septum, while the catchers in secotor 5 are behind the extraction.

wall, where a pressure rise is generated [7]. The higher pressure at this position will cause an increased amount of charge exchanged beam ions, hitting the second ion catcher in the following cold arc in sector 5.

The number of particles in a cycle with slow extraction over 10 s and the mean pressure are shown in Fig. 4. The operation with slow extraction is stable, assuming the latter described pumping behavior for hydrogen.

Figure 5 shows the simulated ion current on the ion catchers in sector 4 and sector 5 for a cycle with slow extraction. The ion catchers are located in front of and behind the extraction, respectively. Because of the pressure bump created behind the extraction septum, the loads on the catchers in sector 5 are considerably higher. The loads within the sectors 1 to 4 and 6 are equal.

The average beam power on the individual ion catchers during slow and fast extraction are listed in Table 1. For fast extraction, the listed loads correspond to the beam losses shown in Fig. 3, and are equal in all sectors.

The design of the ion catcher module foresees a direct helium cooling of the vacuum chamber. The ion catcher itself is thermally decoupled from the chamber to avoid the transfer of beam power into the cryogenic system. The catcher is connected to the thermal shield of the cryostat [2]. Since the heat transfer to the shield is defined by the thermal conductivity of the ion catcher support, it is sufficient to consider the average beam power on the ion catchers.

Table 1: Predicted average beam energy deposition on the ion catchers within each sector of SIS100 for a cycle with fast (FX) and slow extraction (SX). The differing numbers for sector 5 during slow extraction are given in brackets.

Ion Catcher	Load (FX) [W]	Load (SX) [W]
1	0.5	1.5 (3.1)
2	1.4	3.8 (16.7)
3	1.1	1.9 (3.7)
4	0.6	1.2 (1.4)
5 – 10	0.6	1.2

SUMMARY

In order to verify the dynamic vacuum stability of SIS100, simulations with the StrahlSim code have been conducted. It could be shown that the pumping speed of the cryoadsorption pumps, which are situated between every dipole pair, do not provide enough pumping speed to stabilize the dynamic vacuum in SIS100. The threshold hydrogen pressure, where a stable operation of SIS100 with highest intensities is not possible any more, was determined to be about 10^{-10} mbar.

It was shown, that it is essential to assure sufficiently low temperatures of the vacuum chambers of the ion catchers, to pump the desorbed hydrogen molecules. This is achieved, as the design of the ion catcher module foresees a direct helium cooling of the chamber wall and a connection of the ion catcher to the thermal shield.

Furthermore, the beam power onto the individual ion catchers has been evaluated, considering cycles with slow and fast extraction. The total average load in the case of slow extraction onto the ion catcher system is about 110 W and in case of fast extraction about 43 W. For the overall cryogenic system design appropriate safety margins are applied to these values.

REFERENCES

[1] P. Spiller et al., Proceedings of ICFA 2004.
[2] L. Bozyk et al., these Proceedings.
[3] C. Omet et al., New Jounal of Physics 8, 2006.
[4] P. Puppel et al., Proceedings of IPAC 2010.
[5] E. Wallén, J. Vac. Sci. Technol. A 14(5), 1996.
[6] V. Baglin et al., Vacuum 67 (421–428), 2002.
[7] FAIR Technical Design Report SIS100, 2008.