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ROOM TEMPERATURE VACUUM CHAMBER WITH CRYOGENIC INSTALLATIONS

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Abstract

The FAIR complex at the GSI Helmholtzzentrum will generate heavy ion beams of ultimate intensities. To achieve this goal, low charge states have to be used. However, the probability for charge exchange in collisions with residual gas particles of such ions is much higher than for higher charge states. In order to lower the residual gas density to extreme high vacuum conditions, 65% of the circumference of SIS18 have already been coated with NEG, which provides a high and distributed pumping speed. Nevertheless, nobel and nobel-like components, which have very high ionization cross sections, do not get pumped by this coating. A cryogenic environment at moderate temperatures, i.e. at 50-80 K, provides a high pumping speed for all heavy residual gas particles. The only typical residual gas particle that cannot be pumped at this temperature is hydrogen. With an additional NEG coating the pumping will thus be optimized for all residual gas particles. The installation of cryogenic surfaces in the existing room temperature synchrotron SIS18 at GSI has been investigated. Measurements on a prototype chamber and simulations of SIS18 with cryogenic surfaces based on these measurements are presented.

INTRODUCTION AND MOTIVATION

The FAIR accelerator complex will provide high intensity heavy ion beams of up to $5 \cdot 10^{11}$ [1] particles per pulse. To avoid stripping losses and to shift the space charge to higher numbers of particles, medium charge states have to be used. However, the probability for charge exchanges of these ions with the residual gas particles is much higher than for higher charge states. These charge exchanged ions will be deflected differently, hit the vacuum chamber wall at some point, see Fig. 1, and will release gas particles into the vacuum chamber via ion impact induced desorption processes. This desorption leads to a localized higher density of residual gas particles, resulting in increased charge exchanges in this area and more desorption from hitting vacuum chamber walls again. This process is called dynamic vacuum, it is self-reinforcing and can evolve up to complete beam loss [2].

Several upgrade measures have been realized in the existing heavy ion synchrotron SIS18 at GSI [3] to minimize the dynamic vacuums effects. Surfaces with low desorption surfaces, so called ion-catchers, have been installed to reduce the gas production by ionization beam losses. Besides that 65% of SIS18 vacuum chamber walls have been coated with NEG. This provides a high pumping speed for light residual gas particles like hydrogen, to lower the residual gas density.

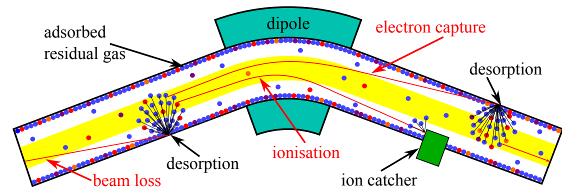

Figure 1: Principle of dynamic vacuum [2].

Although an improvement of the beam intensity was achieved [4], different simulations of SIS18 [2] have shown that this current setup cannot reach the intensity goal for FAIR. The issue of the NEG coating for use in heavy ion accelerator is that it only provides a high pumping speed for light particles like for hydrogen, but not for nobel and nobel-like gases [5]. Unfortunately those components have high cross sections for charge exchanges with U^{28+} [6], see Fig. 2. Therefore the reduction of such components requires a different solution, such as cryogenic installations. The combination of the already existing pumps and NEG-coating with cryogenic installations can pump every residual gas component in SIS18 efficiently.

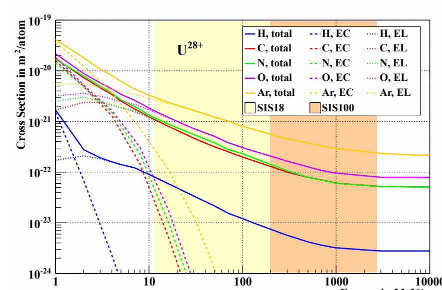

Figure 2: Cross sections for charge exchange of U^{28+} for different targets, distinguished for electron capture (EC), electron loss (EL) and total cross section. The energy regimes of SIS18 and SIS100 are marked [7].

PROTOTYPE TEST SETUP

A prototype quadrupole chamber is used to test the performance of cryogenic installations in a room temperature environment. The prototype features a similar structure to the geometry of SIS18's quadrupole chambers.

It is a thin-walled elliptical chamber with a turbo molecular pump (TM) on one side and an ion getter (IG) pump on the other side, see Fig. 3. There are a few differences to the existing quadrupole chambers. The prototype chamber has a length of 3 m, which is over 1 m shorter than the SIS18

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quadrupole chambers. The thin walled vacuum chamber is interrupted by two thick-walled vacuum chambers (measuring chambers). These allow for the installation of vacuum gauges to measure a pressure profile along the length of the chamber. To identify the residual gas species one residual gas analyser (RGA) is mounted at the prototype.

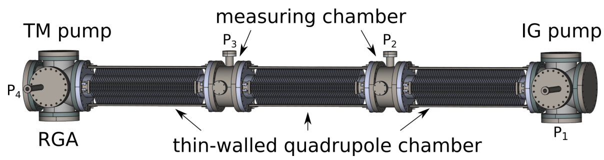

Figure 3: Sketch of the prototype quadrupole chamber with the positions of the pressure sensors p_i.

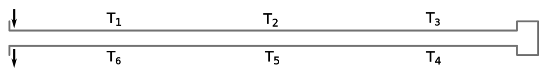

Figure 4: Sketch of the installed pipes with the positions of the temperature sensors T_i. The direction of the coolant flow is marked.

The cryogenic installations contain two pipes with an outer diameter of 8 mm integrated into the chamber. They can be cooled with liquid nitrogen or helium and can be used either in series as shown in Fig. 4 or independently of each other. Furthermore three temperature sensors are installed on each pipe. Their location is shown in Fig. 4.

Figure 5 shows the reduction of residual gas partial pressure, while both pipes were cooled with liquid nitrogen to 84 K and with helium to 26 K. The major masses of all common residual gas particles of SIS18 are plotted.

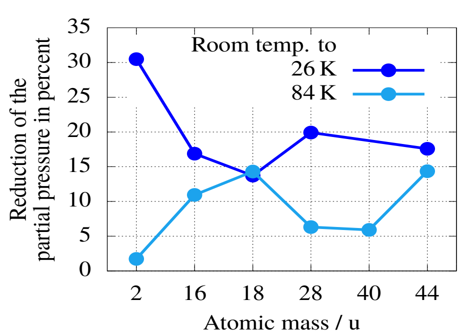

Figure 5: Reduction of the residual gas components with both pipes cooled with liquid nitrogen (84 K) and helium (26 K), with respect to room temperature

All residual gas components are pumped more at lower temperatures than at higher ones, except for water (atomic mass 18 u). Water has the highest saturation vapour pressure in this pressure range and is the only component which should already be pumped by cryogenic condensation at 84 K and not sorption. Hydrogen can be pumped significantly at 26 K, which contradicts previous findings that hydrogen on steel surfaces can only be pumped below 18 K. In [8] hydrogen pumping on a gold-plated surface under 40 K was observed which would correspond to that measurement. Unfortunately no argon (Atomic Mass 40 u) was measured at the measurement with liquid helium this is expected to change with a follow up measurement.

The pumping speed of the different rest gas species can be calculated out of the measurements using liquid nitrogen at 84 K [9]:

$$S_{\text{(eff)}} = \frac{\text{Outgassing rate}}{\text{Pressure}}. \quad (1)$$

The results of this calculation are shown in Table 1. Unexpectedly the calculated pumping speed of water is second lowest to hydrogen, which will only get pumped at much lower temperatures. One explanation could be that the outgassing of water in the prototype was very low in the range of 10^{-16} mbar · l/cm^2. The outgassing for argon was in the same range but the argon partial pressure is much lower than that of water. The highest pumping speed can be observed in residual gas particles with an atomic mass of 16 u which are methane and oxygen.

Table 1: Pumping Speed Calculated via Outgassing and Simulated with Molflow

Atomic mass in u	$S_{\text{(eff)}}$ in l/s	S simulated with Molflow in l/s
02	0.015 ± 0.003	–
16	13.619 ± 2.841	24.52
18	0.022 ± 0.004	–
28	4.660 ± 0.978	12.36
40	0.293 ± 0.104	0.74
44	1.780 ± 0.363	3.45

For the measurement with liquid helium no matching outgas measurement exists, therefore no pumping speed could be calculated as of this time. Nevertheless, there is a greater reduction in the various residual gas components. Only at atomic mass 18 u (Water) is it almost identical.

With these calculation and the measurements of the pressure gauges along the chamber a Molflow simulation was conducted, to evaluate the measurement and look at the influence of geometry on the effective pumping speed. Molflow is a simulation program of CERN designed to calculate the pressure in the range of UHV with in an arbitrarily complex geometry [10]. The results of these simulations are also shown in Table 1 and are about 2.2 times higher than the calculated effective pumping speed. Simulated were four of the six atomic masses of residual gas components.

First, the measured pressure in the chamber was reproduced by adjusting the pumping speeds of the two regular pumps. The pressure measured during cooling is then reproduced by changing the pumping speed of the pipes, see Fig. 6. Each set pressure was in the range of ±5% of the measured one, except the pressure at the IG pump, which due to the other settings could only be made to a precision of ±10%.

The average pressure profiles in the area of the thin walled quadrupole chambers were also simulated with Molflow. Figure 7 shows exemplary the profiles for the atomic mass of

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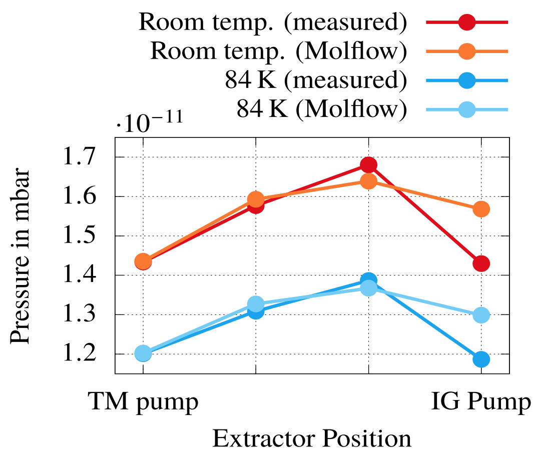


Figure 6: Comparison of the measured pressure profiles (atomic mass 28 u) to those simulated with Molflow.

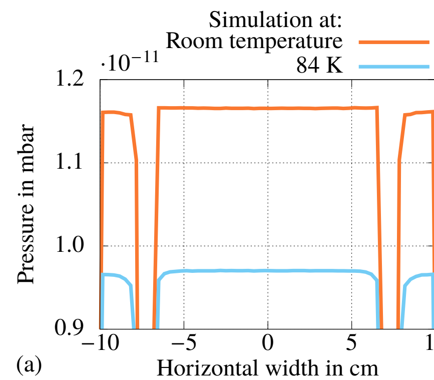
28 u (nitrogen and carbon monoxide). Figure 7 (a) shows the horizontal and (b) vertical plane profiles. This simulation shows that although the cryogenic installations are not uniformly distributed the transversal pressure profile in the area of the accelerated ions is almost homogeneous. Therefore it is possible to assume a single pressure in simulations and other calculations where the ion beam would pass evenly. The pressure variance for atomic mass 28 u between the edge of the chamber and the centre amounts to 0.36% at room temperature in the horizontal plane. It increases to 0.5% with cooled pipes. In the vertical plane the variance increases by cooling from 0.001% to 1.43%

SIMULATIONS

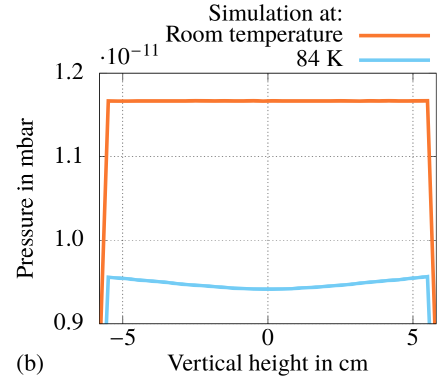
For different cryogenic installations such as the pipes presented above or surfaces as shown in [11] the influence of these structures on the extracted particle counts from SIS18 were simulated with StrahlSim. The description of this simulation is beyond the scope of this publication and can be found in [11].

SUMMARY AND OUTLOOK

The prototype quadrupole chamber could be used successfully to show that every common residual gas in SIS18 can be pumped with cryogenic installations at 84 K except for hydrogen. At a temperature of 26 K hydrogen can be pumped as well. The results of Molflow simulations show pumping speed by a factor of 2.2 higher. These simulations show that although the installations are not uniformly distributed the average pressure profile in the quadrupole chamber nonetheless is almost homogeneous. In the near future the pumping speed will be calculated for installations cooled with helium, which show a higher reduction of the residual gas particles than those cooled with liquid nitrogen.



(a)



(b)

Figure 7: Average pressure profiles in the area of the thin walled quadrupole chambers for the atomic mass of 28 u (nitrogen and carbon monoxide) simulated with Molflow. Profiles are shown in the horizontal (a) and in the vertical plane (b).

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