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PUMPING PROPERTIES OF CRYOGENIC SURFACES IN SIS100*

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Abstract

The synchrotron SIS100 of the planned FAIR facility will provide heavy ion beams of highest intensities. The required low charge states are subject to enhanced charge exchange processes in collisions with residual gas molecules. Therefore, highest vacuum quality is crucial for a reliable operation and minimal beam loss. The generation of the required low gas densities relies on the pumping capabilities of the cryogenic beam pipe walls. Most typical gas components in ultra high vacuum are bound by cryocondensation at LHe temperatures, resulting in ultimate low pressures with almost infinite pumping capacity. Hydrogen can not be cryondensated to acceptable low pressures. But if the surface coverage is sufficiently low, it can get bound by cryoadsorption. The pumping capabilities of cryogenic walls for Hydrogen have been investigated for SIS100-like conditions. The measurement results have been used in dynamic vacuum simulations at heavy ion operation. The simulation results are presented.

EXPERIMENTAL SETUP

An experimental setup to measure the mean sojourn time and the sticking probability has been built at GSI. It consists of two parts: The warm part is made of an upper and a lower recipient, vacuum diagnostics, pumps, a defined vacuum conductance, a gate valve, and a gas inlet. The cold part consists of a cryogenic vacuum chamber inside a cryostat, which is cooled by a cryocooler, type RDK-408E2 by Sumitomo. This chamber is connected to the warm part via a cold-warm-transition (CWT), which minimizes the heat load onto the cryogenic system while providing a maximal vacuum conductance. The cold chamber is coated with copper on the outside, resulting in a homogeneous temperature distribution. The whole vacuum system can be baked at 150 °C to reduce the background by outgasing of the chamber walls.

Design considerations and concepts of the measurements, as well as measurements with the warm part have been described in [1]. Figure 1 shows a sectional view of the whole test setup.

A minimal temperature of 7.2 K was reached on the vacuum chamber. Two calibrated temperature sensors (Lakeshore silicon diodes, type DT-670, typical sensor accuracy: ±12 mK) are mounted on the chamber, one close to the cryocooler, the other close to the cold-warm-transition. A difference of 190 mK is measured, i.e. the temperature of the cryogenic chamber is homogeneous within 200 mK. The reason for not reaching the expected 4.2 K is still under investigation, a non-ideal connection to the cryocooler might be the reason. The thermal shield usually reaches a temperature of 36 K, measured with uncalibrated temperature sensors of the same type.

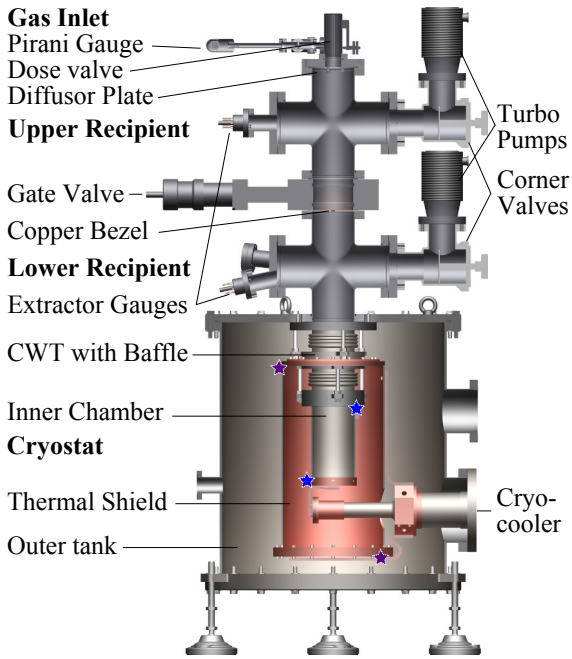

Figure 1: Sectional view of the experimental setup. Position of temperature sensors are marked with stars (blue: cryogenic vacuum chamber, purple: thermal shield).

MEASUREMENTS OF CRYOGENIC PUMPING PROPERTIES

After evacuation of the UHV system, measurements are prepared by the following steps:

- Bakeout of the UHV system at 150 °C for about one week. Special care has to be taken to prevent damages by overheating of delicate components of the cold part. The cryocooler is removed during the bakeout. The cryostat is evacuated, the missing convection yields in a homogeneous temperature distribution.
- Cooldown to room temperature, meanwhile degassing of UHV diagnostics.
- Purging of the gas inlet system with hydrogen. Special care has to be taken to prevent the production of an explosive gas mixture in the exhaust system. The amount of gas in the gas pipes lasts for the whole measurements, the hydrogen bottle remains closed after purging.

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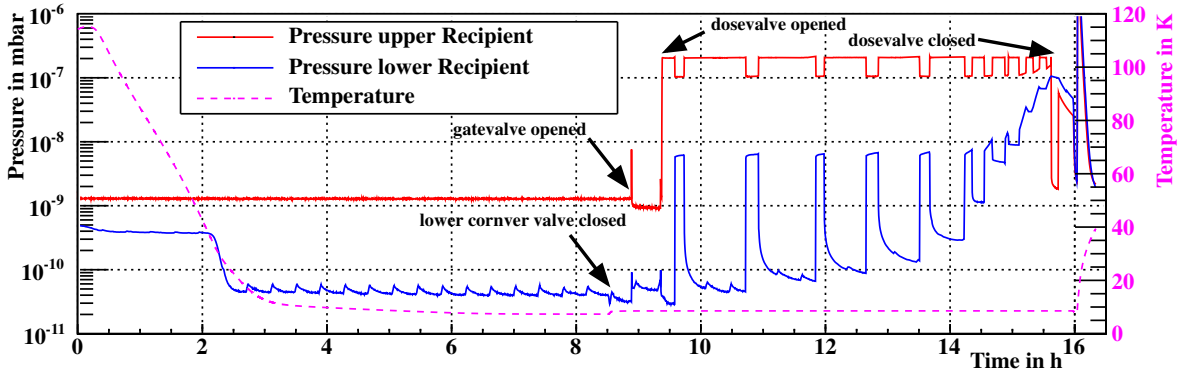

Figure 2: Typical process of an experiment. After 2.5 h the temperature is sufficiently low that cryoadsorption of hydrogen starts. The periodic structure in the pressure is caused by thermal variations in the gauge controller. At 9 h the actual measurement starts with a chamber temperature of 8.5 K. Opening the gate valve lowers the pressure in the upper recipient (additional pumping speed) while it raises the pressure in the lower recipient (additional gas load). The saturation of the cryogenic surfaces can be seen in the increasing relaxation pressure in the lower recipient, while the gate valve is closed. After 16 h the cryocooler is turned off and the adsorbed gas gets released.

- Establish the connection between cryocooler and cryogenic vacuum chamber inside the cryostat, evacuation of the cryostat.
- Close the gate valve and start the cooldown of the cryogenic components (about 10 hours). Ready for measurements.

The measurements shall begin close after reaching the desired temperature. The outgasing of the chamber walls starts to saturate the cryogenic walls. This background has to be taken into account during the analysis. Temperatures above the minimal reachable temperature are achieved by a resistive heater, which is mounted to the inner chamber.

A typical measurement is shown in Fig. 2. Around 9 h the following measurement procedure starts:

1. Close the valve of the lower pump. Open the gate valve for a short time to get a background measurement.
2. Open gas inlet, adjust a pressure of about $2 \cdot 10^{-7}$ mbar in the upper recipient.
3. Open the gate valve, the pressure in the upper recipient decreases due to the additional pumping speed, the pressure in the lower recipient increases due to the gas load.
4. Wait for a time $\Delta t \simeq 10$ min, then close the gate valve. Wait, until the pressure in the lower recipient relaxes (at least about 60 minutes).
5. Go to step 3, chose a shorter Δt if required.

Δt has to become shorter, the more the cryogenic surfaces become saturated. The saturation can be recognized by the increasing relaxation pressure, after closing the gate valve. Close to the end of the measurement, Δt is only in the order of one minute, the relaxation pressure is reached after very short time. After complete saturation of the cryogenic surfaces, the gas inlet is closed, the gate valve is opened, and the heater and cryocooler are turned off (16 h in Fig. 2). The released amount of gas flows upwards through the bezel. This opens the opportunity to cross check the amount of adsorbed gas on the cryogenic surfaces.

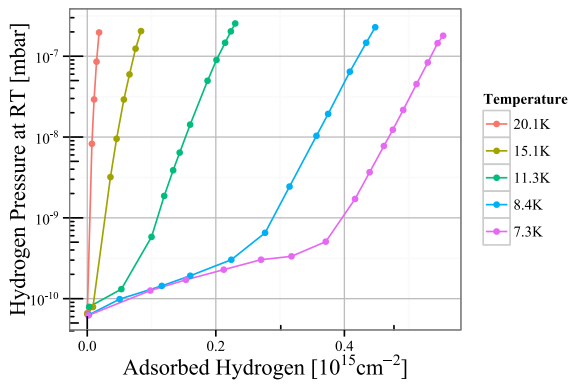

Figure 3: Measured adsorption isotherms for different temperatures. Above 10^{-7} mbar no synchrotron operation is possible, therefore the measurement is limited by this pressure.

RESULTS OF THE MEASUREMENTS

From the pressure ratio and the geometry simulation with Molflow+ [2] the sticking probability (SP) can be estimated. Measured pressure ratios in the order of 15 yield in SP $\simeq$ 1. Curves linking the SP to a pressure ratio for different baffle opacities were presented in [1]. They suggest, that without baffle a better resolution for the determination of the SP is achieved. A measurement without baffle hints to the same SP. A complete error estimation is still pending.

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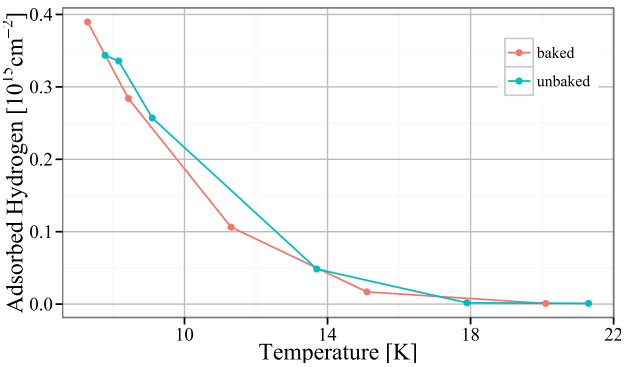

Figure 4: Hydrogen capacity for 10^{-9} mbar depending on the temperature.

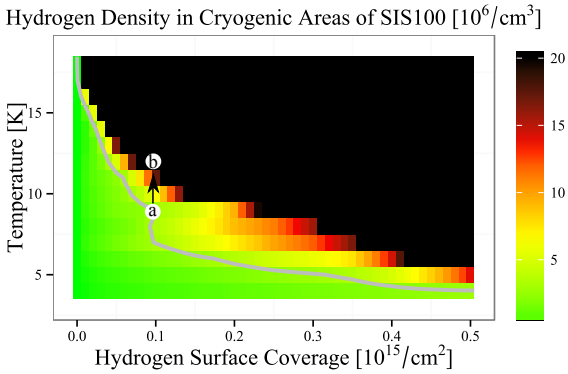

Figure 5: Hydrogen density in cryogenic areas of SIS100 as implemented in StrahlSim. The grey line represents a density of $3 \cdot 10^6$ particles/cm^3. Below, a stable operation with high intensity heavy ion beams is possible. The markers (a) and (b) represent the working points of the simulation shown in Fig. 6.

Adsorption isotherms are gained by plotting the relaxation pressure after closing the gate valve over the integrated amount of adsorbed gas on the cryogenic surfaces. Figure 3 shows measured adsorption isotherms for different temperatures of the cryogenic vacuum chamber. The higher the temperature, the faster the relaxation pressure increases with the adsorbed hydrogen. Therefore, measurements at high temperatures run quite fast into saturation.

Figure 4 shows a cut through the adsorption isotherms at 10^{-9} mbar, depending on the temperature for unbaked and a baked cryogenic walls. As expected, the hydrogen capacity drops with increasing temperature. A difference between baked and unbaked cryogenic surfaces can not be recognized.

DYNAMIC VACUUM SIMULATION IN SIS100

To simulate the dynamic vacuum in SIS100 the measured adsorption isotherms have been implemented into the StrahlSim code [3]. The measured values are interpolated in the code. Including the adsorption isotherms out of [4],

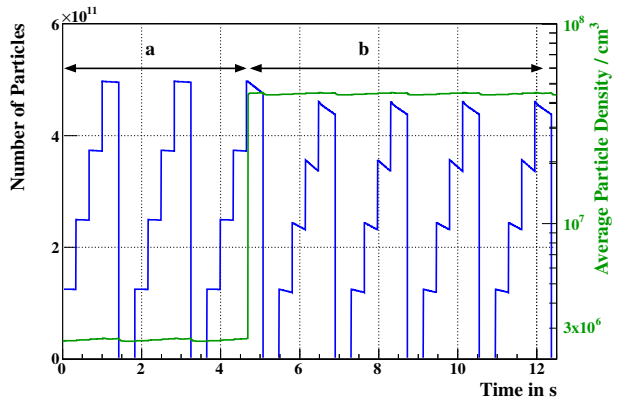

Figure 6: Simulation of SIS100: In the 3rd cycle at 4.8 s, with starting energy ramp, the magnet vacuum chambers are heated up from 9 K to 12 K (a → b in Fig. 5). Adsorbed hydrogen gets released, which increases the average rest gas density, yielding in higher ionization loss.

the parameter space covers a temperature range between 4.2 K and 18 K and a surface occupancy between 0.01 and 0.5. Using these parameters, a mean sojourn time is calculated for each cold surface in the simulation, yielding in a coverage dependent outgasing rate for each surface. In combination with the sticking probability a hydrogen density in the cryogenic areas of SIS100 is calculated. In Fig. 5 the acquired densities are shown. The grey line represents a border underneath which a stable synchrotron operation with low ionization loss is possible.

To demonstrate the capabilities of the newly implemented isotherms, SIS100 operation with U^{28+} has been simulated with an invented temperature rise. According to its design, four injections with each $1.25 \cdot 10^{11}$ particles at an energy of 200 MeV, subsequent acceleration with 4 T/s to 2.7 GeV, and fast extraction were assumed. All cold surfaces were given an initial surface occupancy of 0.1 monolayers of hydrogen and a temperature of 9 K. Figure 6 shows the result. Only 0.1% of ionization loss is expected for this scenario. At the start of the acceleration ramp in the third cycle the temperature of the magnet vacuum chambers is increased suddenly to 12 K. Here the transition between the working points (a) and (b) of Fig. 5 takes place. Now the surface occupancy is higher than its capacity, the excess of gas is released, generating a higher average gas density in the machine. The amount of ionization loss increases to 12.4%.

The introduction of the isotherms into StrahlSim works as expected and now allows simulations with higher reliability.

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