CRYOGENIC SURFACES IN A ROOM TEMPERATURE SIS18 IONCATCHER

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Abstract

For FAIR operation, the existing heavy ion synchrotron SIS18 at GSI will be used as booster for the future SIS100. In order to reach the intensity goals, medium charge state heavy ions will be used. Unfortunately, such ions have very high ionization cross sections in collisions with residual gas particles, yielding in beam loss and a subsequent pressure rise via ion impact stimulated gas desorption. To reduce the desorption yield, room temperature ioncatcher have been installed, which provide low desorption surfaces. Simulations including cryogenic surfaces show, that their high sticking probability prevents the vacuum system from pressure built-ups during operation. Such, the operation with heavy ion beams can be stabilized at higher heavy ion intensities, than solely with room temperature surfaces. A prototype ioncatcher containing cryogenic surfaces has been developed and built. The surfaces are cooled by a commercial coldhead, which easily allows this system being integrated into the room temperature synchrotron. The development and first laboratory tests including fast pressure measurements of this system will be presented.

MOTIVATION

The FAIR accelerator complex will provide heavy ion beams of highest intensities. The goal is to reach $5 \cdot 10^{11}$ particles per pulse [1]. In order to reach this intensity goal, medium charge state heavy ions have to be used to avoid stripping losses and to shift the space charge limit to higher number of particles. Unfortunately the probability for further charge exchange of medium charge state heavy ions in collisions with residual gas particles is much higher than for higher charge states. Ions which underwent a charge exchange process will be separated from the circulating beam in ion optical elements, as their magnetic rigidity differs from the reference ion. These ions will get lost at the vacuum chamber wall and release a huge amount of gas via ion impact induced gas desorption. This increases the rest gas density locally, which in turn increases the probability for further charge exchange. Such, a self-amplification up to complete beam loss can evolve. The rest gas density is no more constant during operation, wherefore this process is also called “dynamic vacuum". It limits the maximum achievable heavy ion beam intensity. The process is also illustrated in Fig. 1.

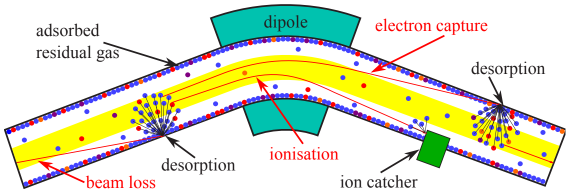

Figure 1: The principle of ionization loss and dynamic vacuum.

To shift this limit to higher intensities, several measures are possible. One is to reduce the residual gas density, another is the installation of low desorbing surfaces, which are called “ioncatcher". Both measures, besides others, have been carried out in SIS18. 65% of its vacuum chamber wall, including the ioncatcher chamber are coated with Non-Evaporable-Getter (NEG) [2]. This did lead to an increase of the maximum achievable intensity [2]. But the intensity goal could still not yet be reached. Even prediction from simulations do not reach the goal [3]. The same sort of simulation however hints, that the installation of cryogenic surfaces would increase the maximum intensity, as the sticking probability of such surfaces is much higher than on NEG surfaces.

In [3] cryogenic magnet chamber were assumed. Different approaches are currently investigated. One approach is the installation of cryogenic pipes cooled by liquids inside the quadrupole magnet chambers [4]. Another approach, which is subject of this proceeding, is the installation of coldhead cooled surfaces around the ioncatcher. This is the location, where most of the gas gets produces during operation by ion impact stimulated desorption and an increased sticking probability shows maximum effect.

MECHANICAL DESIGN

In cryogenic systems, temperatures well below 18 K are desirable. Even Hydrogen, the main part of the desorption gases, will get pumped by such temperatures. Commercially available coldheads can reach 4.2 K while still providing a reasonable cooling power of 1.0 W[1]. The biggest issue of coldheads in combination with UHV-system is, that coldheads can not be baked out because of their delicate mechanics. Even if one removes the sensitive parts, which is already outside of the usual application, only temperatures up to 60°C - 100°C can be used without the risk of damage at the coldhead housing. This is far below the activation temperature of the NEG coatings of 250°C - 300°C, rendering coldheads useless for a baked room temperature vacuum system. On the other hand, a coldhead is more simple in application, than cooling with cryogenic liquids.

A way had to be found for being able to remove a coldhead from the system without breaking the vacuum. To find

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[1] Coldhead RDK-408D2 with compressor F50 by Sumitomo

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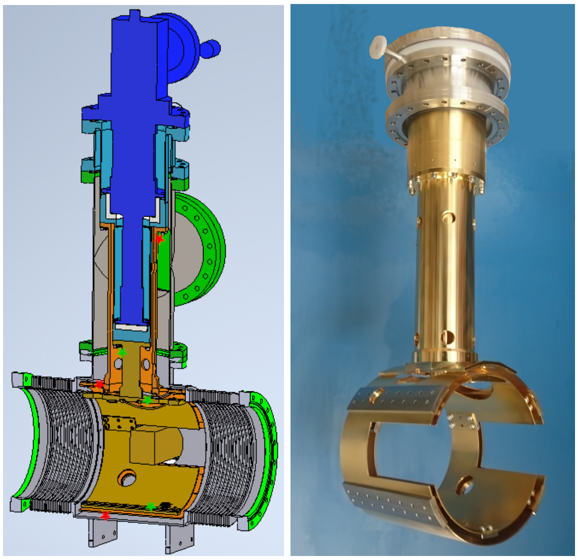
Figure 2: Left: Sectional view of the SIS18 ioncatcher 3D-model with cryogenic surfaces. Details: see text. Right: Photography of the surfaces mounted to the UHV-onset with cryogenic surfaces. (G.Schroeder, ILK)

a solution for this issue and get a prototype, an order consisting of development, construction and manufacturing has been placed to ILK, Dresden. A devices which connects the removable coldhead to the UHV-system with including cryogenic surfaces, was the outcome. Figure 2 shows details. On the left, a sectional view illustrating the principle is shown. The coldhead (blue) is housed by the so-called “UHV-onset", which is shown in turquoise. On the top, both are bolted together. Inside, the first and second stage of the coldhead are contacted by flexible heat transfer parts (white) to the UHV-onset. These parts do not only provide the thermal contact, but also have to cope with the thermal contraction during cooldown. As the coldhead shrinks first, the contact has to be maintained over 1.2 mm varying distance. During bakeout, the coldhead is replaced by a blind flange, without venting the UHV-system. The volume inside the UHV-onset can be evacuated by the small pipe, visible on the top flange in photography on the right of Fig. 2.

The UHV-onset “transfers" the two stages of the coldhead into the UHV-system. A thermal shield (orange) connected to the first stage surrounds the actual cryogenic surfaces (gold) which is connected to the second stage. Everything is mounted inside the existing ioncatcher vacuum chamber (gray with green flanges). The thermal shield could not be designed opaque from room temperature. On the one side, it would have increased the complexity for manufacturing and mounting, on the other side an opening for the circulating is required. Charge exchanged ions shall hit the ioncatcher and sufficient vacuum conductance to the cold surfaces is necessary, too. To reduce the radiation heat transfer despite the non-opaque thermal shield, all surfaces have been coated with a reflecting gold surface. The design of the cold surfaces copes for a good vacuum conductance on the one hand, and as much heat transfer via bulky material on the other hand.

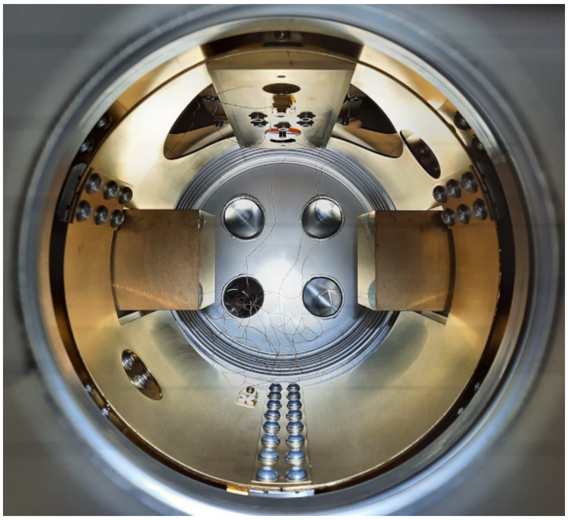
Figure 3: Photography inside the ioncatcher chamber with mounted cryogenic surfaces. The view is against beam direction. The flange at the backside houses vacuum diagnostics and feedthroughs.

Figure 3 shows a photography inside the vacuum chamber, contrary to beam direction. The gold-coated room temperature ion-catcher blocks stick from left and right into the cryogenic surfaces. The backside is covered by cluster-flange housing several diagnostics devices. The flange where the picture was taken is closed by a pump.

TEST SETUP

The ioncatcher-chamber with cryogenic surfaces is part of a test stand. Several properties will be measured, to learn about the performance of the cryogenic surfaces. The test setup is equipped with the following items:

- A turbomolecular-pump, which can bee sealed-off by an all-metal gate valve. This allows outgassing-measurements.
- An extractor gauge and a widerange vacuum gauge to measure the total vacuum pressure.
- A residual gas analyzer for partial pressure measurements.
- A dosing valve for controlled gas inlet, used for saturation measurements.
- A piezo dosing valve for short gas inlets, used for dynamic vacuum measurements.
- Six temperature sensors inside the vacuum system on the cold surfaces, three on each stage.
- Eight temperature sensors on the atmospheric surfaces, used for monitoring during bakeout but also during cooldown.

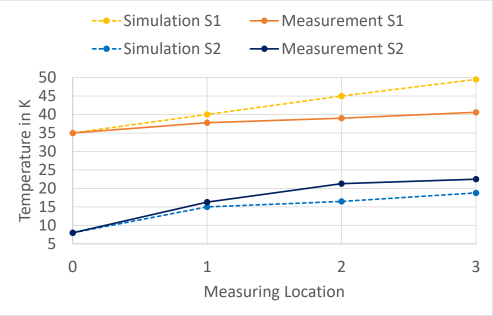

Figure 4: Measured and simulated temperatures at the respective measuring locations. The numbers increase with distance to the coldhead.

The inner temperature sensors have been placed at the following positions, for both stages respectively:

1. As close as possible to the UHV-onset, to measure the heat transfer from coldhead through the UHV-onset.
2. On the upper side of the cryogenic surface, but as close as possible to the thermal connection: These points measure the heat transfer through the support structures.
3. On the lower side of the cryogenic surface, as far away as possible from the UHV-onset, here one gets a feeling about the surface's thermal homogeneity.

In Fig. 2 (left) the locations are marked by red starts for stage 1 and green stars for stage 2.

All measurement devices are connected to a readout software. This software also allows turning on and off the coldhead compressor, to control the dosing valve by a stepping motor, and to control the piezo-dosing valve. Moreover, sequences can be programmed, which allow for semi-automatic measurement sequences without human interference. The sequences can only be operated by given time intervals, but also by e.g. falling below certain temperatures or pressures. Such, time-consuming measurement series become automated and reproducible.

MEASUREMENTS AND RESULTS

Temperature Measurements

As a thermal connection between UHV-onset and coldhead, an aluminum fleece has been pressed into form and been used for the first measurements. As the cooling was not sufficient to reach hydrogen pumping, the UHV-onset was filled with gaseous helium instead of vacuum, to increase the thermal contact. By monitoring the decreasing pressure inside the UHV-onset it could be verified, that the coldhead reaches temperatures to liquefy helium. The simulated (simulation by ILK using Ansys) and measured temperatures are shown in Fig. 4. The expected temperatures of the two coldhead stages are shown for reference. On the first stage, the simulation was to pessimistic. The measured temperatures and their differences are lower than expected. On the second stage, in contrast, the thermal contacts have been overestimated in the simulations.

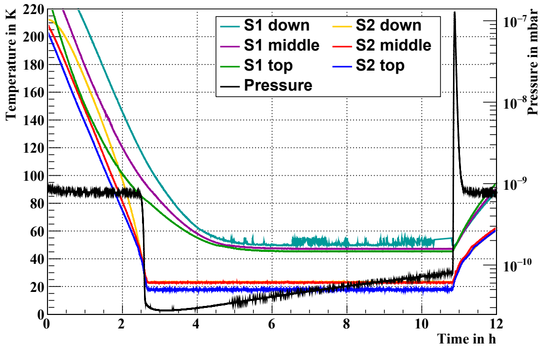

Figure 5: Temperature and pressure evolution during cooldown (0 h - 2.5 h), saturation measurement with hydrogen via dosing valve (2.5 h - 11 h), and the beginning of warmup (later than 11 h) with the fast pressure increase by the release of all adsorbed hydrogen. During saturation measurements, the lowest temperature sensor at stage one "S1 down" was subjected to distortions.

The temperatures of the atmospheric surfaces remain unchanged during cooldown. This hints to a very low emission coefficient of the gold plated cryosurfaces, as it was desired. Only the temperature at the uppermost flange of the UHV-onset drops by up to 9 °C during cooldown. This is due to thermal conductance between the coldhead's first stage and this flange. During warmup, the temperature drops by further 4 °C, before it starts to rise. The interpretation is, that the liquefied helium inside the UHV-onset evaporates and increases the thermal exchange between room temperature and cold surfaces.

By repeated partial warming to temperatures around 60 K at the second stage and subsequent cooling, the minimum temperature could be decreased slightly by 750 mK to even 1.25 K. The effect is not fully understood. A possible explanation is some rearrangement of helium inside the thermal connection between the second stage and the UHV-onset. A new version of the thermal connection is under development. A higher mass density shall increase the thermal conductivity.

A complete cooldown takes roughly 4.5 hours. Warming up requires 25 hours.

Pressure Measurements

Preceding to pressure measurements, the UHV-system has been baked to temperatures of 150 °C for about 50 hours. At room temperature, pressures in the range of $2 \cdot 10^{-10}$ mbar are reached. Via pressure rise measurements an outgasing rate of $8.2 \cdot 10^{-9}$ mbar l/s or $4 \cdot 10^{-13}$ mbar l/(s cm^2) were determined.

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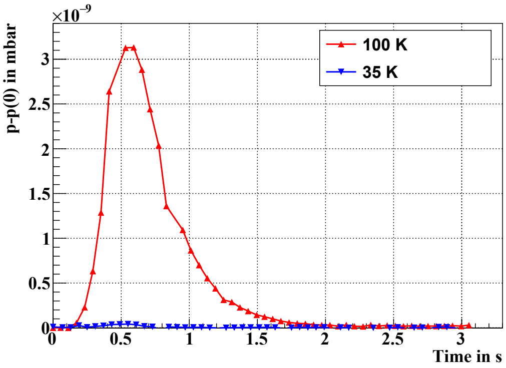

Figure 6: First fast pressure measurements using a piezo dosing valve and ambient air. The pressure difference with respect to the first value is shown.

At the end of cooldowns, a sudden pressure drop down to $2 \cdot 10^{-11}$ mbar can be observed, see Fig. 5. Here, the dosing valve was open during the whole measurement time, yielding in a higher pressure at the start and the end of the measurements than $2 \cdot 10^{-10}$ mbar. The sudden pressure drop is the start of hydrogen adsorption which means, at least parts of the cold surfaces have temperatures sufficiently low for hydrogen pumping. A capacity of $2 \cdot 10^{-3}$ mbar l for hydrogen at minimum temperatures was determined by the help of the dosing valve. The inner surface's NEG coating was not activated at this time.

In order to measure the dynamic vacuum behavior, a piezo dosing valve and a fast pressure measurement have been set up. The piezo dosing valve allows for short and repeatable gas inlet pulses. To establish a fast pressure measurement, the ion current of the extractor gauge is read out by a triggerable current measurement device[2]. Such, a reproducible gas pulse will be analyzed in terms of peak height and decay time for different temperatures and surface saturations. Figure 6 shows first measurements with ambient air for two different temperatures.

SUMMARY AND OUTLOOK

A prototype test setup with cryogenic surfaces inside a SIS18 ioncatcher chamber has been developed and built. The cold surfaces are cooled by a coldhead, which can be removed without venting the UHV-system. Such, the system can be baked out and NEG-surfaces can be activated. The inner surfaces reach temperatures sufficiently low to pump hydrogen via cryosorption. Nevertheless, the capacity for hydrogen pumping could be higher. Therefore improved thermal connections are under development to reach lower temperatures and increase the hydrogen capacity.

The dynamic vacuum properties of the cryogenic surfaces will be analyzed. A fast pressure measurement will allow to analyze the the response to a short pressure pulse coming from a piezo dosing valve. The pressure decay time and such the sticking probability will be examined as an input for dynamic vacuum simulations.

In a later step, the vacuum chamber with its cryogenic surfaces will be installed into SIS18. Effects onto the operation with medium charge state heavy ions will be investigated.

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[2] 65 ms interval length have been reached so far