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CRYOGENIC INSERTS IN THE ROOM TEMPERATURE SYNCHROTRON SIS18 AT GSI

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Abstract

The existing room temperature heavy ion synchrotron SIS18 at GSI will be used as booster for the future SIS100 at FAIR. One of its features is the generation of high intensity heavy ion beams. In order to create such beams, medium charge states are used, which have a lower space charge limit and can be created with less stripping losses. Unfortunately, such heavy ions have very high ionization cross sections in collisions with residual gas particles, yielding in beam loss and subsequent pressure rises via ion impact stimulated gas desorption. Although an extensive upgrade plan, including NEG-coated magnet chambers and an ion catcher system, has been realized, the required intensity goals will not yet be reached. Simulations including cryogenic surfaces around the ion catchers show, that their high sticking probability prevents from pressure built-ups during operation. A prototype ion catcher, including such cryogenic surfaces cooled by a commercial cold-head has been developed, built, and tested. It has recently been installed in SIS18 and will undergo further tests, including measurements with heavy ion beams. Findings for the operation and further cryogenic inserts are presented.

MOTIVATION AND INTRODUCTION

In order to serve as booster synchrotron for FAIR, SIS18 will have to provide $5 \cdot 10^{11}$ particles per pulse. Such intensities can only can be achieved by using medium charge state heavy ions, because stripping losses are avoided and the space charge limit is shifted to a higher number of particles. For such charge states, the probability of charge exchange in collision with residual gas particles is much higher, than for higher charge states. Charge exchanged ions have a different magnetic rigidity than the reference ion and get separated from the circulating beam. They are lost at the vacuum chamber wall, releasing a huge amount of gas via ion impact induced gas desorption. This locally increases the residual gas density, which in turn increases the probability of further charge exchange and gives rise to a self-amplification up to complete beam loss. The residual gas density is no longer constant, which is why this process is also called "dynamic vacuum". It limits the maximum achievable intensity of heavy ion beams. This limit can be shifted by different technical measures. Lowering the static gas density or the installation of low desorbing surfaces, which are called "ion catcher", are examples for such measures [1]. The intensity of SIS18 could be increased significantly [1, 2], but the FAIR-intensities are not yet reached. However, simulations using cryogenic surfaces hint, that they would help to increase the maximum intensity [3]. The sticking probability on cryogenic surfaces is close to one and such much higher than on NEG surfaces.

A test setup with cryogenic surfaces around an ion catcher has been set up, tested and described in [4]. It contains gold-coated copper surfaces, which are cooled by a commercially available cold head. This cold head can be removed without breaking the beam vacuum for the vacuum-bakeout. Figure 1 shows a sketch of the test setup, as it is used in vacuum simulations with MolFlow [5].

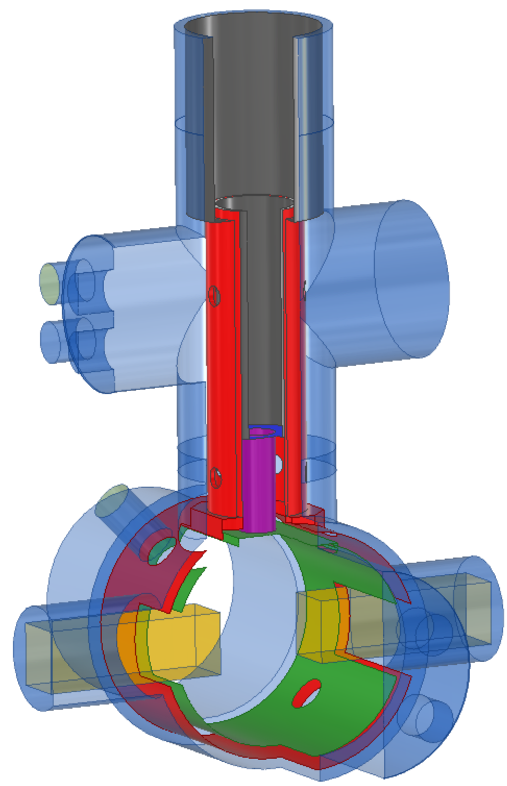

Figure 1: Geometry of the test setup, as it is used in vacuum simulations. Transparent light blue surfaces represent room temperature vacuum chamber sufaces. The "UHV-onset", where the cold head gets installed is shown in black. The thermal shield, which is connected to stage 1, is red. The cryogenic surfaces are shown in green. They are connected via the purple connection rod to the blue contact surface of stage 2. Beam will enter from the bottom right, ionized particles will hit the yellow ion catcher. The PDV-pulses are injected from this direction. The three pressure measurement surfaces are shown in orange. A pump is connected at the rear side (not shown).

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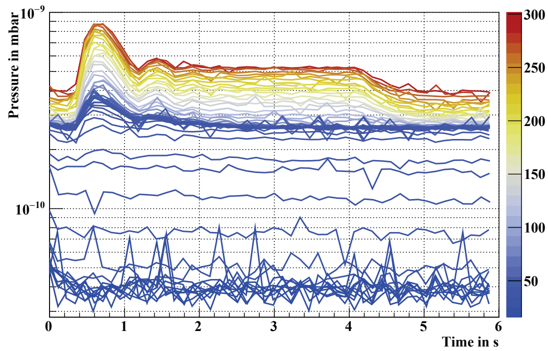

Figure 2: Measured pressure evolution of PDV pulses at different temperatures (colour code). [4]

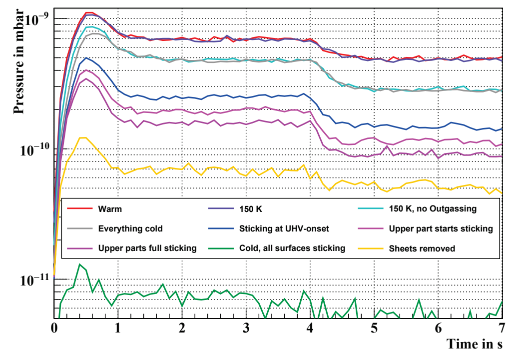

Figure 3: Simulation of PDV-pulses for different configuration of the test setup. Explanation in the text.

UNDERSTANDING THE PROTOTYPE WITH MOLFLOW-SIMULATIONS

During measurements at the prototype, it could be demonstrated, that artificially generated short pressure pulses by a piezzo dosing valve (PDV) completely disappear during cooldown, see Fig. 2 and [4]. The dynamical part of MolFlow [5] was used in order to understand the pressure evolution. The geometry shown in Fig. 1 was used to simulate the pressure pulses. Outgassing of all chamber walls was chosen as measured[1] and the pumping speed of the pump was chosen to 100 l/s to account for the measured pressure[2].

The simulated pressure pulse has a peak value of $1.4 \cdot 10^{-7}$ mbar l/s and a plateau value of $3 \cdot 10^{-8}$ mbar l/s for 3 s. The values were trimmed to reproduce the room temperature measurement in Fig. 2. The results are shown in Fig. 3. Different, than in the measurement, the simulated pressure evolution curves start at zero, as the outgassing of the walls also only starts with the beginning of the simulation. Different effects can be disentangled in the simulation:

- **Warm**: All surfaces have an outgassing. This is the reference, which has been fitted to the measurement.
- **150 K**: Cryogenic surfaces are cooled to 150 K. The temperature-effect of the gas has nearly no effect on the pressure.
- **150 K, no Outgassing**: While cooling down, the outgassing of surfaces vanishes. This effect shifts the base pressure at the end of the simulation down.
- **Everything cold**: All cryogenic surfaces have their final temperature (35 K for stage 1, 15-20 K at stage 2). The pressure evolution remains unchanged wrt. the last curve, the temperature of the gas has no effect.
- **Sticking at UHV-onset**: At first, the contact surface of the UHV-onset (blue disc in Fig. 1) gets cold enough to start Hydrogen-pumping. This surface has a sticking coefficient of one. This small surface significantly reduces the pressure pulse.
- **Upper part starts sticking**: The purple connection rod starts pumping with $S = 0.5$
- **Upper part full sticking**: The purple connection rod finally pumps with $S = 1$.
- **Cold, all surfaces sticking**: The complete stage 2 has now reached a temperature, where significant Hydrogen pumping is available. The pressure peak has disappeared completely and the base pressure is in the 10^{-11} mbar regime, similar to the cryogenic pressure evolution curves in Fig. 2.
- **Sheets removed**: Case study, are the sheets around the collimator block necessary? For this simulation they got removed (switched to transparent, did not block gas particles) and only pumping of the connection rod is available. Obviously the sheets significantly contribute to the pressure reduction.

The overall findings are, that cooled surfaces reduce their outgassing and the temperature of the (green) sheets around the collimators is sufficiently low to significantly contribute to an overall pumping. Removing these sheets for the sake of simplicity would reduce the positive effect.

MEASUREMENTS IN SIS18

During the shutdown in 2024, the cryogenic surfaces were installed in SIS18 in section 1. This is the section subsequent to the injection area, where typically most systematical beam loss happens. Hence, most charge exchange can be measured on the ion catcher in this section. At this location the effect of the cryogenic surfaces therefore shows maximum effect.

The cryogenic surfaces are still equipped with temperature sensors. All components are remote controllable, no access to the accelerator tunnel is required during measurements.

Figure 4 shows temperature and pressure evolution during a cooling test. The pressure readout was recorded in the

[1] $6 \cdot 10^{-12}$ mbar l/s cm^2

[2] The TMP type Agilent TwissTorr 304 FS with 250 l/s was not directly mounted to the chamber, but via a reduction adapter and an all-metal gate valve.

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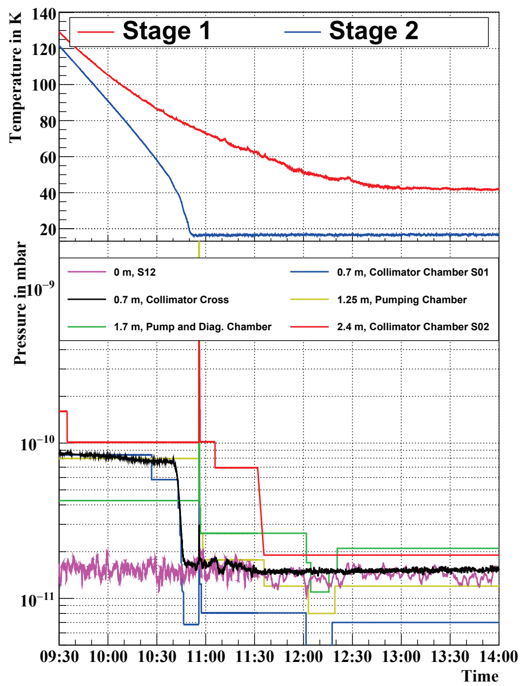

Figure 4: Temperature and pressure (N_2-equivalent) evolution during a cooling test in SIS18. Around 10:55 the neighboring valve was opened (spike in all pressure curves). The croygenic pumping is now available for the whole section, resulting in a pressure drop in the adjacent pressure gauges. The positions in meter refer to Fig. 5.

UHV-control-system, except for the pressure gauge at the cross-chamber on top of the ion catcher. At room temperature, both gauges at the collimator (blue and black) show the same pressure, while at cold temperatures the pressure at the beam axis drops to less than $5 \cdot 10^{-12}$ mbar. Shortly after reaching minimal temperatures, the valve next to the ion catcher was opened. The opening process releases gas, which produces the spike in all pressure gauges. After opening the beam pipe, the pressure in the neighboring vacuum chambers drops due to the additional pumping speed of the cryogenic surfaces.

The pressure values of Fig. 4 before the pressure drop, as well as before and after opening the valve (around 10:45 and 11:30) were used to present the pressure profiles in Fig. 5. The measurement before the first dipole pair is unaffected by the cryogeninc inserts. Directly at the cryogenic inserts (690 cm) the effect is obviously the highest. Before opening the valve at 740 cm, the right side of the vacuum system remains constant. At the right end of the profile the pressure is constantly dropping, not caused by these measurements. Opening the valve significantly reduces the pressure of the considered section.

A MolFlow model of the ring section has been created and adapted by means of pumping speed of pumps and NEG-coating to reproduce the measured values. A pure Hydrogen atmosphere was assumed, the measured Nitrogen-equivalent

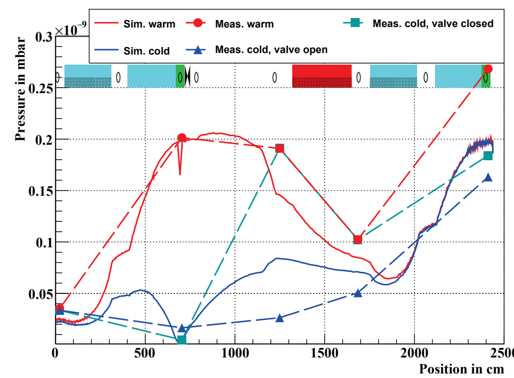

Figure 5: Simulated and measured Hydrogen pressure around the warm and cold cryogenic inserts in section 1 of SIS18. The lattice below the legend is shown for orientation: Dipoles (cyan), quadrupole-triplett vacuum chamber (red), ion catcher chamber (green), pumps (circles). Vacuum chambers with NEG-coating in the simulation have a hatching on the lower half.

values were corrected by a factor of 2.49 [6]. To score a pressure profile along the curved dipole chambers, several straight profiles were approximated in the dipole chambers and composed to the continuous profiles shown in Fig. 5.

The two simulated pressure profiles "warm" and "cold" differ in the temperature on the cryogenic surfaces and hence in outgassing and the sticking coefficient, as determined in the previous simulation. The measured influence on the pressure profiles is still stronger, than in the simulation.

PLANNED MEASUREMENTS WITH BEAM

Measurements with U^{28+} beams are scheduled for July 2025. The real influence of the cryogenic surfaces onto the medium charged heavy ion beam will be measured. A beam based pressure measurement in section 1 by the help of the ion catcher in section 2 will be carried out the same way as in [2]. This type of measurement is based on the measurement of ionization loss [7]. Another measurement will use the lifetime of stored U^{28+} beams. Finally the influence on the maximum achievable intensities will be investigated.

SUMMARY AND OUTLOOK

Cryogenic inserts for the room temperature synchrotron SIS18 have been developed and tested in the laboratory. The reduction of artificially generated pressure pulses has been understood by the help of MolFlow-simulations. The cryogenic inserts have been installed in SIS18 and first measurements without beam have been performed. The measurable pressure reduction exceeds the expectations. The influence on the heavy ion beams will be measured soon.

Meanwhile, considerations for a series production are made with regard to simplification of the production. The cryogenic surfaces not necessarily have to be bent round, but could be shaped hexagonal or octagonal.

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REFERENCES

[1] P. J. Spiller, L. H. J. Bozyk, and P. Puppel, “SIS18 – Intensity Record with Intermediate Charge State Heavy Ions”, in *Proc. IPAC’11*, San Sebastian, Spain, Sep. 2011, paper WEPS003, pp. 2484–2486.

[2] L. Bozyk and P. Spiller, “SIS18 Operation with U^{2} ”, in *Proc. IPAC’24*, Nashville, TN, USA, May 2024, pp. 1661–1664. `doi:10.18429/JACoW-IPAC2024-TUPS13`

[3] L. H. J. Bozyk and P. J. Spiller, “Ionization Loss and Dynamic Vacuum in Heavy Ion Synchrotrons”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, pp. 2201–2204. `doi:10.18429/JACoW-IPAC2017-TUPVA056`

[4] L. Bozyk, S. Aumüller, and P. Spiller, “Cryogenic surfaces in a room temperature SIS18 ion catcher”, in *Proc. IPAC’23*, Venice, Italy, May 2023, pp. 4283–4286. `doi:10.18429/JACoW-IPAC2023-THPA139`

[5] R. Kersevan and M. Ady, “Recent Developments of Monte-Carlo Codes Molflow+ and Synrad+”, in *Proc. IPAC’19*, Melbourne, Australia, May 2019, pp. 1327–1330. `doi:10.18429/JACoW-IPAC2019-TUPMP037`

[6] Karl Jousten (ed.), *Handbuch Vakuumtechnik*, Wiesbaden, Germany: Springer Vieweg, vol. 12, 2018. `doi:10.1007/978-3-658-13386-3`

[7] L. H. J. Bozyk and P. J. Spiller, “Measurement of Beam Ioniziation Loss in SIS18”, in *Proc. IPAC’14*, Dresden, Germany, Jun. 2014, pp. 864–866. `doi:10.18429/JACoW-IPAC2014-MOPRI104`