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INVESTIGATIONS ON CRYOPANELS IN THE ROOM TEMPERATURE HEAVY ION SYNCHROTRON SIS18

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Abstract

The heavy ion synchrotron SIS18 at GSI will serve as injector ring for the FAIR-facility and provide high intensity heavy ion beams. The operation of such beams requires the usage of low charge states, which have high cross sections for ionization. To overcome this issue, many upgrade measure have been realized in the past decade, such as the installation of an ion catcher system with low desorption surfaces and coating 65% of the circumference of SIS18 with NEG to lower the static gas pressure. Since the vacuum dynamics during operation prevent the achievement of the intensity goals for FAIR, new concepts have to be developed, to increase the beam intensity.

One idea is the installation of additional pumping speed in the form of cryogenic surfaces. Heavy residual gas components, which have the highest ionization cross sections can be cryopumped at moderate temperatures, i.e. already at 50-80 K. In fact, the only typical residual gas component which can not be pumped via cryosorption in this temperature regime is Hydrogen, which has a factor 50 lower ionization cross sections than Argon, the heaviest residual gas component. In this paper, we present a study of the integration of cryopanels into the vacuum chambers of SIS18.

INTRODUCTION AND MOTIVATION

The FAIR-facility will provide high intensity heavy ion beams for various experiments. Medium charge state heavy ions will be used to reach the intensity goals of $5 \cdot 10^{11}$ heavy ions per pulse out of SIS100. Their usage avoids stripping losses and shifts the space charge limit to higher intensities. However, the cross section for charge exchange in collisions with residual gas molecules are much higher compared to higher charge states. Ions which underwent a charge exchange process, i.e. which lost or gained an electron, will get lost, since they do not match the ion optical lattice any more. Beam loss produces gas via ion-impact induced gas desorption, which in turn increases the probability for further charge exchange. Above a certain beam intensity a self-amplification develops, which can lead to complete beam loss and such limits the achievable beam intensity. The principle of ionization loss and dynamic vacuum is sketched in Fig. 1.

In SIS18, the existing heavy ion synchrotron at GSI, several upgrade measures have been realized in the past decade to shift the maximum beam intensity [1]. These measures include the installation of an ion catcher system, which provides low desorption surfaces for lost ions, and NEG-coating of all magnet vacuum chambers, 65% of the circumference,

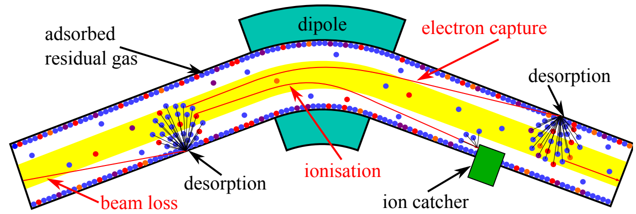

Figure 1: Principle of ionization loss and dynamic vacuum.

to lower the static gas pressure. The low desorption surfaces are called ion catcher and minimize the amount of released gas per incident lost ion, with respect to uncontrolled loss onto the vacuum chamber walls. The NEG coating lowers the static pressure, which minimizes the initial ionization loss. The NEG coating also increases the pumping speed to remove gas particles desorbed by ion loss. All upgrade measures did lead to a significant improvement of the maximum beam intensity [2], presently limited by the injector linac UNILAC. However, simulations show, that the intensity goal of $1.25 \cdot 10^{11}$ particles per pulse in 3 Hz operation can not be reached with the current UHV system [3].

Simulations of the new heavy ion synchrotron SIS100 of the FAIR-facility show, that it will be capable to store much higher intensities and the vacuum system will withstand the design intensity of $5 \cdot 10^{11}$ particles per pulse. This synchrotron is a superconducting machine with cryogenic magnet chamber walls, providing very high pumping speed. Simulations for a SIS18 with cryogenic vacuum chamber walls also suggest, that such a measure would lead to a stable operation with higher intensities [3].

Since replacing the existing magnets of SIS18 by superconducting magnets to generate cryogenic environments for the beam pipes is not the easiest solution, the installation of cryogenic surfaces inside the existing synchrotron is investigated.

NEG-coatings do not provide high areal pumping speed for noble gases and light hydrocarbons [4]. Even conventional getter pumps have only low pumping speed for Argon. But charge exchange cross section especially for Argon are quite high, see Fig. 2 and [5]. Simulations on the transmission in SIS18 strongly depend on the Argon partial pressure in the residual gas composition. From past measurements it is known, that most residual gas components experience a pumping speed already at temperatures of liquid Nitrogen (LN2, 77 K). Hydrogen is the only gas species among usual constituents in UHV, which requires temperatures below 20 K to get pumped. As Hydrogen gets pumped by the NEG-coating and its cross sections are a factor 50 lower than for Argon, cryogenic surfaces at LN2-temperatures al-

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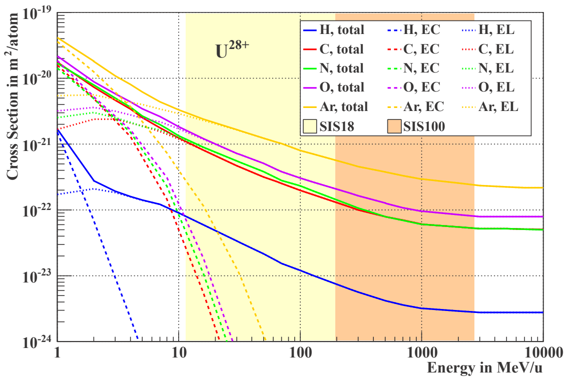

Figure 2: Cross sections for charge exchange for U^{28+} for different targets, distinguished for electron capture (EC), electron loss (EL) and total cross section. The energy regimes of SIS18 and SIS100 are marked. Note, that the cross sections for Argon are the highest.

ready should result in an improvement of the synchrotron's vacuum quality and hence in the transmission.

The simulation of cryogenic surfaces in SIS18 in dynamic vacuum simulations using StrahlSim is not yet possible but will be integrated soon. It requires adaptation of the code to account for surfaces at different temperatures in the same vacuum element. This has impact on the vacuum conductance and gas temperature in such elements and thermal transpiration has to be considered correctly.

FEASIBILITY STUDY

In order to investigate the feasibility of cryogenic surfaces in a room temperature environment, a study has been ordered from ILK Dresden. The first question addressed in this study is the required temperature. A temperature for sufficient pumping capacity would be 50 K, which requires cooled gaseous Helium. 68 K could be reached with sub-cooled LN2. Bare LN2 would yield in temperatures above 77 K.

It is assumed, that the cryogenic surfaces in SIS18 could get supply from the cryoplant of GSI's test facility for superconducting magnets for SIS100. This requires a supply line of 120 m length. A supply line around SIS18 would have a length of 216 m. Including all return lines and an estimated thermal load of 1 W/m the cryogenic infrastructure system yields in a total heat load of 762 W. Additional heat loads by radiation and conduction onto the cooling pipes inside the thin-walled vacuum chamber are listed in Table 1.

The cooling pipes inside the vacuum chambers must not restrict the acceptance of the machine. Therefore they have to be placed either at the "edges" of the elliptical cross section of the existing quadrupole chambers, or star-shaped chambers have to be produced, which have additional volume to house two cooling pipes. At these positions the eddy current losses would also be minimized and can be neglected for further heat load estimations. Since ionization beam loss happens in the vertical plane, it should be avoided to have cooling pipes covered with gas particles at the loss positions.

Table 1: Total Amount of Expected Heat Loads for Four Cooling Pipes Inside Thin Walled Vacuum Chambers

Contribution	Heat Load
Thermal radiation	280 W
Thermal conduction	600 W
Eddy currents	0 W
Cryogenic pipelines	762 W
Total	**1.642 W**

For SIS18 a star-shaped quadrupole chamber with cooling pipes on the top and the bottom therefore is most suitable.

The distance of the stiffening ribs has been optimized in order to get a sufficient stable chamber design.

Figure 3 shows a sketch of four possible cooling pipes integrated into a star-shaped SIS18 quadrupole-chamber.

PROTOTYPE TEST SETUP

In order to verify the assumptions and to investigate different issues, a prototype test setup will be built. Some of the questions to be examined are:

- Form and magnitude of the pressure profile and residual gas composition for different modes of operation, with and without cooling, before and after NEG-coating of the inner surfaces
- Temperature profile along the cooling pipes, comparison with simulations
- Dependence on the cryogenic surface, i.e. number of cooling pipes, investigation of the gas capacity
- Heat load onto the cryogenic system
- Ice over of the vacuum chamber's outer surfaces and its prevention

The design of the prototype test setup has to accommodate all these questions. Figure 4 shows a first sketch of the test-setup, which will be described in the following sections in more detail.

Mechanical Layout

Different than in SIS18, not a continuous thin walled chamber will be built, but a segmented chamber. In between the segments, thick walled measuring chambers will be installed, which allow the installation of vacuum gauges to estimate the pressure profile. Another advantage of a segmented thin walled vacuum chamber is the more simple and faster production process. Thin walled chambers are required nevertheless, to investigate effects of freeze out on the outer surfaces. By the combination of thin- and thick-walled chambers this issue can be studied with the same test setup.

On both sides, the test setup will contain pumping chambers. In SIS18 magnet vacuum chambers are also adjacent to pumping chambers, i.e. a SIS18-like geometry will be

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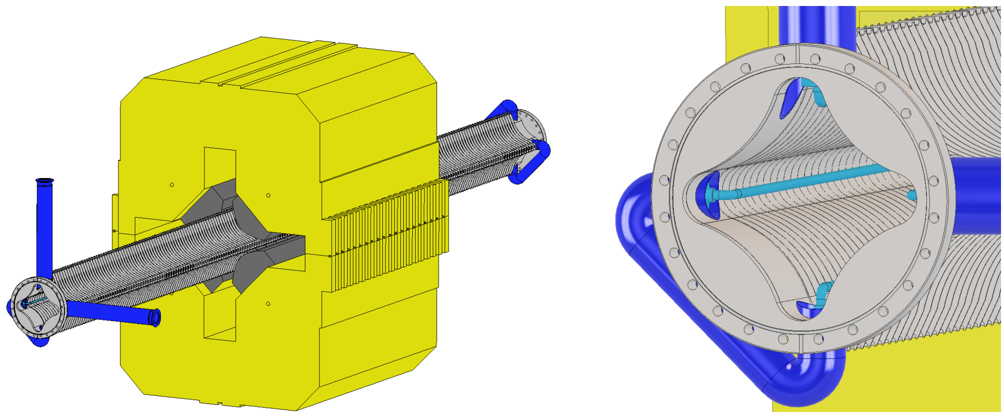

Figure 3: Sketch of four cooling pipes integrated (turquoise) into a star-shaped vacuum-chamber (gray) of a SIS18 quadrupole magnet (yellow), including feedthrough and interconnections (blue).

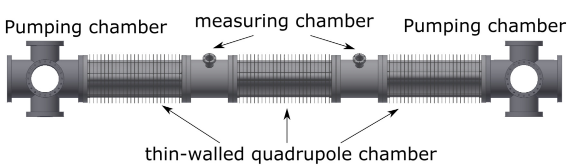

Figure 4: Sketch of a prototype test setup.

obtained. These pumping chambers will also be used to install vacuum gauges and a gas inlet system. Additionally, feedthroughs for the cooling medium will be installed.

Planned Measurements

The measurements will cover questions on the expected vacuum quality, i.e. the pressure profile under different circumstances:

- Static pressure for different operation modes: without and with cooling, both before and after NEG-coating of the inner surfaces
- Influence of the cooling medium and the temperature of the cooling pipes
- Temporal evolution of the pressure profile in the dynamic case: Heavy ion beam operation in SIS18 will be simulated by dedicated gas inlet systems with a fast dosing valve
- Capacity and saturation effects of the cryogenic surfaces
- Long term evolution of the residual gas composition

Another question to be investigated is connected to the heat load onto the cryogenic system. Not only the heat entry into the cooling system, but also the heat output from the warm vacuum chamber walls is an issue. It will cool down the vacuum chamber walls and eventually lead to icing of the outer surfaces. This has to be prevented.

SUMMARY AND OUTLOOK

Although a dedicated upgrade program has been conducted in SIS18, the intensity goals for FAIR will not be reached. Ionization loss by interaction with the residual gas is the limiting factor, therefore new concepts to reduce the residual gas density have to be investigated, which can be integrated into the existing machine. Since cryogenic surfaces provide a very high pumping speed and sticking probability, the integration of such surfaces will be studied.

A feasibility study has been performed, which shows, that such cryogenic surfaces in principal could be possible. In the next step, a dedicated test-setup will be built to study different questions and investigate assumptions. First measurements are expected in the beginning of 2020.

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