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THE FIRST-OF-SERIES SIS100 CRYOCATCHER

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Abstract

The superconducting heavy ion synchrotron SIS100 of the FAIR-facility will be equipped with 60 cryocatcher, to suppress dynamic vacuum effects. A prototype cryocatcher has been designed, manufactured and underwent several tests. The results yielded in the design of the series cryocatcher. Recently, the first-of-series cryocatcher has been manufactured and tested. Results from the manufacturing process and the site acceptance tests, including cryogenic test with liquid helium are presented. The FoS cryocatcher successfully passed all tests and the series production will be released.

INTRODUCTION

The ion optical layout of the FAIR synchrotron SIS100 has been optimized such, that stripped reference beam ions (U^{28+}) are lost at well defined and highly localized positions in the cryogenic arcs. At these positions, ion catcher, providing a perpendicular low desorption surface, will be installed to suppress dynamic vacuum effects. They operate in a cryogenic environment, which gave the name 'cryocatcher'.

The chamber of the cryocatcher acts as a cryopump, providing a high pumping surface. Desorbed gases are bound quickly, minimizing further charge exchange of beam ions. A homogeneous low temperature distribution is achieved by a copper plating of the outer surface of the stainless steel vacuum chamber. A special support structure of the actual cryocatcher block allows keeping it at a higher temperature, than the chamber, in order to avoid gas particles to be bound at the ion impact area. This support will be connected to the thermal shield of the cryostat, whereby the heat, deposited by the lost beam ions, is lead away by the shield cooling at 50 K - 70 K, instead of the magnet cooling at 4.2 K.

A prototype cryocatcher has been developed [1], built, and tested [2–4]. For the series cryocatchers, several modifications had to be implemented, which will be described in the following section. The contract for the manufacturing of 60 series components has been awarded to the industrial partner Pfeiffer Vacuum Components & Solutions.

Photographies of the first-of-series cryocatcher are shown in Fig. 1.

PRODUCTION OF THE FIRST-OF-SERIES CRYOCATCHER

The following modifications w.r.t the prototype have been implemented, as the machine has different requirements, than the prototype test setup:

- Chamber support: In SIS100 the cryocatcher-units will be installed between a common girder system, which also supports the quadrupole doublet magnets. A precise alignment is required as well as compensation of thermal contraction of the cryocatcher chamber.
- Cooling scheme: After the prototype has been built, an independent cooling circuit for the cryogenic SIS100 beam vacuum chambers has been added. Instead of a thermal contact to the common helium return line of the cryostat, a dedicated helium-pipe is soldered onto the copper coating.
- At the upstream and downstream side of the chamber, bellows are installed. They compensate not only longitudinal thermal contraction of neighbouring magnet chambers, but also lateral displacement, which is required for the adjustment of the quadrupole magnets.
- For the series cryocatchers, less instrumentation is required. Only one temperature sensor will be installed on the insulation vacuum side of the support structure. Test with the prototype showed, that this measurement position is sufficient to draw conclusions about the thermal state of the cryocatcher block. This also avoids the necessity of a vacuum feedthrough and an UHV-compatible sensor.

The low desorption surface is coated with gold and a nickel diffusion barrier. Before coating the cryocatcher block, the procedure has been qualified. Test samples were galvanically coated and investigated with a raster electron microscope (REM) and energy dispersive X-ray spectroscopy (EDX) before and after thermal treatment at 350 °C for 24 h in a vacuum furnace. The EDX-spectra showed a 10% contamination of phosphor in the nickel plating. But since this layer is covered by gold and the phosphor-content did not change after the thermal treatment, it was not considered as an issue and the coating procedure could be released. A dedicated research program currently investigates different coating techniques and layer combinations [5]. Preliminary results show that the chosen coating is fine. [6]

Brazing of copper components onto the explosive plated copper surfaces required some pretests to optimize the geometry. After the plating process, the surface is not regular enough, to provide a homogeneous brazing gap in the range of 20 μm -50 μm or a surface roughness of $R_Z \simeq 6.3$. Such a surface yields in an irregular area connection and leakage of the solder material. Therefore it is absolutely necessary to rework the explosively plated copper surface, before vacuum brazing.

Reworking of the junction areas allows to take precautions for an examination of the soldered seams. Figure 2 (left) shows, that the milling around the shell surface for the connection rings is larger, than the rings. The welding seams connecting both stainless steel parts are bridged by copper rings, connecting the chamber's shell surface with the front

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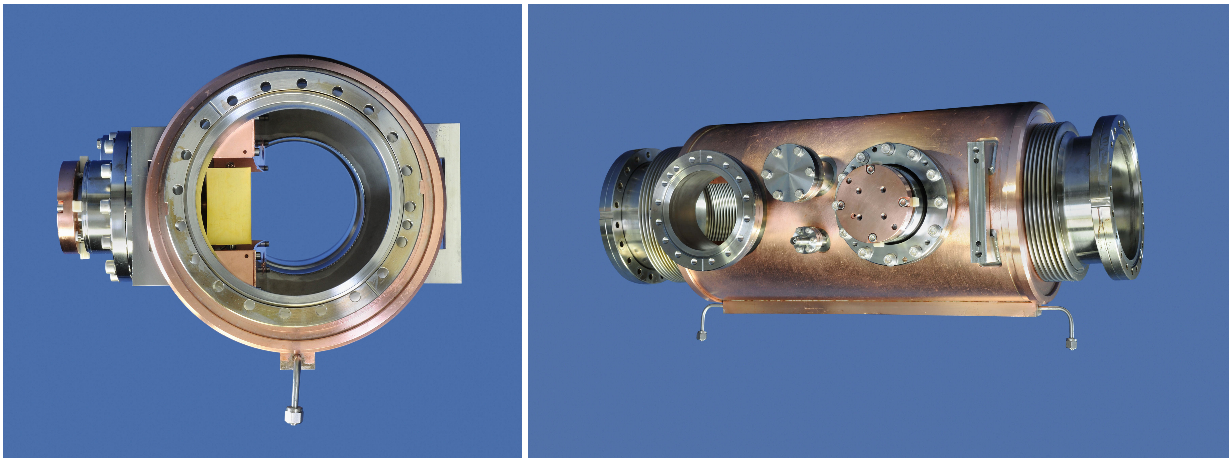

Figure 1: Photographies of the first-of-series cryocatcher. Left: Front-view, seen in beam-direction. The goldish surface catches lost beam ions. Right: Side-view, showing some features like the copper-plating of the chamber and the cooling-profile (bottom). Beam direction is from right (upstream, US) to left (downstream, DS).

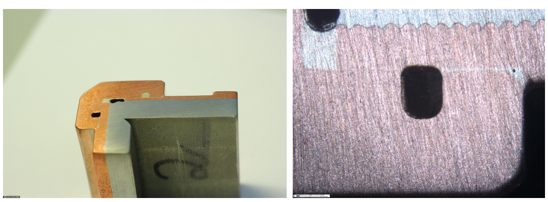

Figure 2: Close views of a cut through brazed junctions of a soldering ring, which connects the chamber's shell surface with the front surfaces.

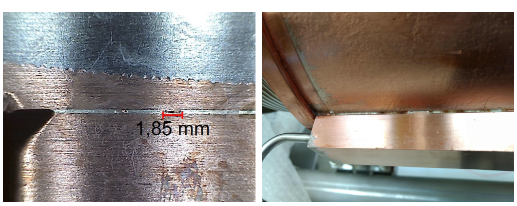

Figure 3: Close view of a cut through the junction of the cooling profile (left) and the cooling profile itself (right).

surfaces. Several cuts through a test dummy allowed the examination of the hidden junctions. A close view in Fig. 2 (right) shows a complete coverage of the junction areas and a reliable brazed connection. The hole in the centre of the picture is an empty solder depot. The wave structure on the top is the explosively plated binding zone between stainless steel and copper. The connection area for the cooling profile has been milled flat on the shell surface, see Fig. 3 (left). A chamfer on both sides of the cooling profile allows the subsequent inspection. Two interruptions in the chamfers on both sides serve to position the cooling profile onto the chamber in the brazing furnace (see Fig. 3, right).

SITE ACCEPTANCE TESTS

After the successful factory acceptance tests, including an UHV-test, the first-of-series cryocatcher was delivered to GSI. Here it underwent another set of acceptance tests.

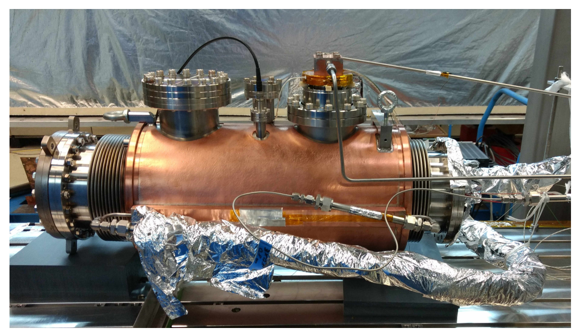

Figure 4: Cryocatcher mounted inside the universal cryostat.

Mechanical Measurement

The mechanical measurement of interfaces was repeated at the Technology Laboratory of GSI. The dimensions measured during the factory acceptance test could be reproduced.

UHV Tests

The vacuum acceptance test requires a bakeout of the vacuum chamber for five days at 250°C. The sectoral outgasing rate was determined via the applied pumping speed and the inner surfaces, as well as via the pressure rise method. The required value of $\leq 5 \cdot 10^{-10}$ mbar l/s was reached. Also the residual gas spectrum fulfils the specified requirements.

Cryogenic Tests

The first-of-series cryocatcher also underwent several cryogenic tests with liquid helium. The vacuum chamber was installed into the universal cryostat at the prototype test facility at GSI, see Fig. 4. Two independent helium circuits have been used: One for the cooling pipe at the chamber, and another connected to a copper block, which was mounted onto the copper connection of the collimator block. This circuit did simulate the thermal shield cooling in SIS100. A heater included into this copper block allowed to set a different temperature onto the collimator, than for the chamber.

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Table 1: Temperature Achievements During Cryogenic Tests at the Cryocatcher.

Copper shell, opposite to cooling profile	5.6 K
Difference cooling profile - copper shell	0.1 K
Secondary chamber plate inside	6.7 K
Flange US (2 weeks cooling)	37.5 K
Flange DS (3 weeks, not yet in equilibrium)	61 K

Another heater mounted to the collimator-block allowed to simulate energy deposition by the beam.

Minimal achievable temperatures have been measured and are shown in Table 1. It is possible, to vary the collimator temperature between 10 K and 80 K without significantly influencing the chamber temperature. This temperature is sufficiently low to ensure a high and reliable pumping capacity in SIS100. The temperature homogeneity agrees with preceding simulations. Also the secondary chamber plates will provide reliable pumping speed due to their temperature. The flanges upstream (US) and downstream (DS) are only cooled by radiation and poor thermal conduction via the stainless steel bellows. This cooling is very inefficient and therefore the flanges beyond the bellows did not reach temperatures sufficiently low for hydrogen pumping. US the bellow is shorter than DS, the equilibrium temperature was reached after two weeks of cooling. On the DS side, after three weeks an equilibrium had not yet been reached. Not actively cooled parts of vacuum chambers therefore cannot be assumed as cryogenic hydrogen pump.

The total heat load of the chamber has been estimated using super critical helium in the main cooling circuit. Via temperature and corresponding pressure at inlet and outlet respectively, the enthalpy difference can be estimated between these two points out of the substance data of helium [7]. Multiplication by the mass flow yields in power or heat load: 0.95 ± 0.17 W. Since this value represents the total heat load of the setup, including support, cabling and radiation, no statement concerning the bare heat load induced by the support structure can be made. This has been investigated dedicated by shutting down the auxiliary cooling circuit for the collimator block, applying additional thermal load by the heater, and measuring the resulting temperature of the collimator block, see Fig. 5.

For each applied heating power at the support, an equilibrium temperature was determined via exponential extrapolation. The decay time is in the order of days, therefore the actual equilibrium could not be awaited. The measured temperature curve does not start at the chamber temperature, but higher. This is due to the instrumentation cabling, which represents an additional heat load. The simulation shown in Fig. 5 tries to accommodate for the instrumentation cabling.

Test Integration

Finally the cryocatcher unit was mounted onto the common girder system. No issues were found, which need to be considered for the series production.

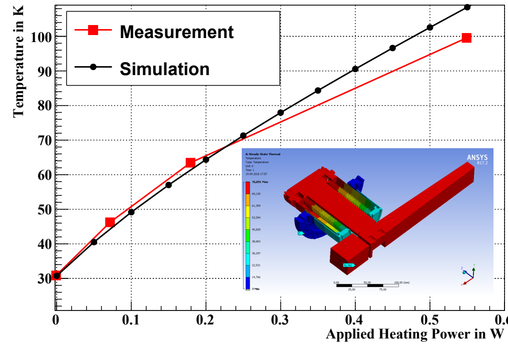

Figure 5: Temperature of the collimator block as a function of the applied additional heating power.

MODIFICATIONS FOR THE SERIES PRODUCTION

The manufacturing and testing of the first-of-series cryocatcher showed potential to improve the design by minor modifications:

- The indium foil, maximizing the thermal conductance between the collimator blocks and the insulating ceramic disc can cause an electric short circuit. Therefore cut-outs for the screws were enlarged.
- Reverse mounting of the cryocatcher block was possible. The junction between collimator-block and support structure has been redesigned, such that the block can be mounted only in the right direction.
- The welding connection between the US bellow and the chamber is simplified to gain more process stability.
- The ceramic spacers have been replaced by stainless steel spacers, which renders the transportation lock unnecessary.

SUMMARY AND OUTLOOK

The first-of-series cryocatcher for SIS100 has been successfully manufactured and it passed all its acceptance tests. The temperatures measured during cryogenic tests of all components are sufficiently low, to provide a reliable and high pumping speed in SIS100. This is of essential importance, since the cryocatchers produce gas during heavy ion operation via ion-impact induced gas desorption. Moreover the chamber also has to adsorb gas inflow through the roughing-cwt, mounted at the CF100-flange at the DS side.

The series cryocatchers will be delivered in six batches, each consisting of ten components. First delivery is expected at the end of 2018.

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