

VACUUM DESIGN OF THE SUPER-FRS AT FAIR

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Abstract

The large-acceptance superconducting fragment separator (SFRS) poses unique challenges for its beam and insulation vacuum systems. These systems must operate in high radiation environments and accommodate dynamically changing experimental setups. Although the vacuum levels ranging from 10^{-5} to 10^{-7} mbar required by this single-pass machine are not particularly demanding, several factors make the design of the vacuum systems challenging. These include highly out-gassing and self-sealing inserts, large volumes not typically encountered in accelerator beamlines, and a high level of prompt and residual radiation in the target and pre-separator area. In this article, an overview of the SFRS vacuum design is presented and handling of the standard and special vacuum components in the system is discussed.

INTRODUCTION

At the Superconducting Fragment Separator (SFRS) at the Facility for Antiproton and Ion Research (FAIR) at GSI in Darmstadt rare isotopes of elements up to uranium will be separated, and delivered to different experimental areas along its three branches [1]. Beam intensities up to 10^{12} /spill at the target station is expected. The layout of the SFRS is shown in figure 1. The beam is focused onto the production target by the beam optics in the pre-target area. The target area is followed by the pre-separator, the main-separator and experimental branches. The vacuum of the SFRS is coupled to the ultra-high vacuum conditions before and after the machine through differential pumping systems [2]. Therefore, besides minimizing the beam scattering due to residual gases, maintaining and monitoring the high vacuum conditions in the SFRS is vital to the uninterrupted operation of the FAIR facility. Several challenges are present in the SFRS-vacuum design due to high out-gassing and leak-rate of special components, dynamic pressure variations during the isotope production, remote-handling and radiation hardness requirements as well as the vacuum interfaces to the experiments. Many of the challenges faced by SFRS are common to that of various "in-flight separation" and "isotope separation on-line" radioactive ion beam facilities world-wide [3–7].

The beamline and the insulation vacuum systems of SFRS are distributed along about 350 meters of length. The main elements in the beamline are 34 superconducting (SC) short and long multiplets, 27 SC-dipole magnets, 5 normal conducting (NC) radiation hard magnets, the target chamber, 3 beam stopper chambers, 20 focal plane chambers, beam pipes, bellows and pumping chambers. The beamline is not

bakeable and constitutes 39 vacuum sectors pumped by 57 ion-getter pumps (IGPs) and 29 turbo-molecular pumping (TMP) stations. The insulation vacuum is generated by 81 TMP stations. The expected radiation levels in different areas of SFRS is given in table 1. Since electronic controllers of all the vacuum components are in racks located farther away to avoid radiation damage and ensure accessibility, additional issues, in particular for TMPs and gauges, arise as the routed cables can be as long as 250 m.

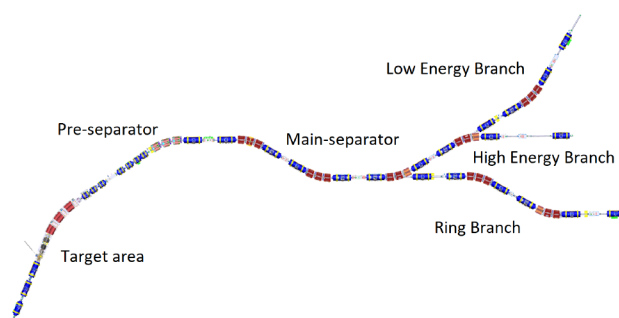


Figure 1: The layout of the SFRS heavy ion spectrometer at FAIR. Superconducting multiplets and dipole magnets are shown in blue and red, respectively.

BEAMLINE VACUUM

The beamline vacuum provides vacuum in the space where the ion beams are transported, as well as to the focal plane chambers. The SFRS beam-pipes have an aperture of 40 cm in diameter to accommodate the large beams. Except for special installations, the vacuum joints use DN400CF flanges with metallic OFHC-Copper sealing as standard. The other type of seals encountered are elastomer o-rings and metal to metal contact seals mostly on the self-sealing inserts and robot-handled units. The requirements vary from the pre-target, the target, the pre-separator and the main separator. A preliminary design study was conducted using both analytical methods and Monte Carlo simulations with MolFlow+ [8] of selected sectors to determine the requirements to achieve an overall vacuum $< 5 \times 10^{-6}$ mbar. The

Table 1: Expected radiation levels at different areas of SFRS. The residual dose rate is after 1 week of cool-down.

Location	prompt [$\mu\text{Sv/h}$]	residual [$\mu\text{Sv/h}$]
pre-target	2×10^5	5
target	2×10^9	5×10^4
pre-separator	2×10^7	5×10^3
main-separator	2×10^5	5

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figure 2 shows some of the first-of-series (FoS) devices on their test benches.



Figure 2: Top-left: Focal plane chamber with an insert and media-board, top-right: superconducting short multiplet, bottom: long multiplet.

Main Separator and Branches

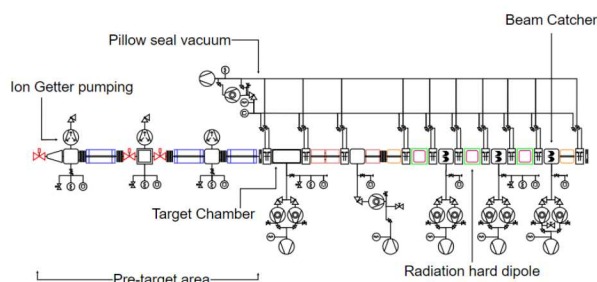


Figure 3: Layout of vacuum systems in the pre-target and target areas of the SFRS.

Pre-target Area

The beam vacuum layout of the pre-target area is shown in figure 3. Although the radiation level in this area is not high, access can be restricted while nearby beam-transport of the FAIR facility is in operation. Therefore, only IGPs and passive gauges are used in these sectors to maintain a pressure below 5×10^{-7} mbar.

Target Area

The target area [9] is a single vacuum sector containing the target chamber, radiation hard quadrupoles and dipoles, steerers, beam catchers, and three SC-multiplets. Inside this heavily shielded area, the vacuum volumes are joined using pillow seals (PS) to enable remote handling [10]. Out-gassing from target-beam interaction and beam losses during the isotope production will create dynamic gas-load. Since the radiation here is significantly higher than any standard vacuum components can tolerate, the components must be located behind the radiation shielding and use pumping ducts (DN300 $\times$ 3 m). This sector is equipped with 9×1000 l/s redundant TMPs to achieve lower 10^{-5} mbar during operation.

A pillow seal makes surface-to-surface contact against a highly polished surface when injected with compressed air in circular grooves machined in the flanges, where the inflated sealing surface is a thin stainless steel wall. The PS design used at SFRS has two independent vacuum grooves, one for rough vacuum and one for high vacuum, compared to the single groove design originally developed at the Paul Scherrer Institute (PSI) in Switzerland [11], and similar device used at RIKEN [12]. DN200, DN500 and race-track type PS with a leak-rate $\leq 1 \times 10^{-6}$ mbar l/s are developed for use in the Target area. The prototype of DN500 PS in its remote handling frame is shown in figure 4.

Pre-separator Area

Prompt dose of 10^4 to 10^5 Gy/year in the vicinity of the focal plane chambers in the pre-separator area is above the specification of many standard vacuum components and sealing materials, which have been therefore replaced by radiation hard versions. Where metallic seals cannot be used, EPDM O-rings with up to 5 MGy radiation hardness are applied and passive Penning and Pirani gauges with radiation resistance up to 1 MGy are specified. The vacuum scheme of the pre-separator area is shown in figure 5. A common roughing line pumped by > 100 m³/h multi-stage roots, located beyond the pre-separator area will be used to evacuate these sectors.

The pre-separator area will be inaccessible for weeks after continuous beam operation due to residual radiation from activated parts. Therefore all devices in the pre-separator area, including the vacuum chambers and pumps, must be remotely maintained. Inflatable bellows (IBs) (figure 4), which seal with an elastomer o-ring between two flat surfaces when compressed air is provided, make the vacuum joints of remote handled devices. The inserts, gate valves, focal plane chambers and pumps are foreseen to be handled by a robotic arm with lifting mechanism. The TMP, valve and associated components form a removable unit and will be interfaced using a manifold for fluids and electrical connections.

Main-Separator and Branches

Due to minimal radiation background, usage of standard vacuum components and manual intervention are possible in

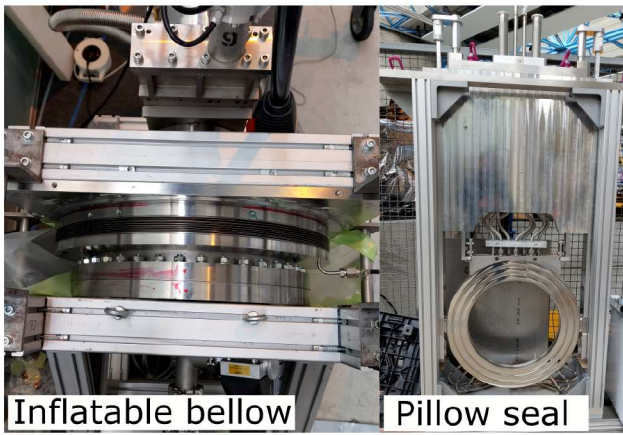


Figure 4: Left: DN400 Inflatable bellow on test bench. Right: DN500 Pillow Seal in its holder.

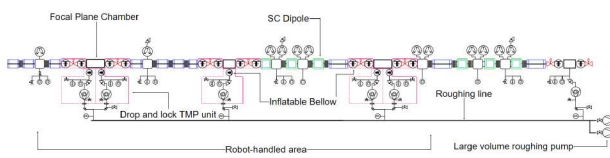


Figure 5: Layout of the beam vacuum system of the pre-separator area of SFRS. Remote handled vacuum units are marked with red

this area. Since there is no additional gas load in the sectors, pumping requirements are accordingly reduced. The vacuum layout of the main-separator is shown in figure 6. The IGP's and 700 l/s TMP stations at the focal plane chambers are able to maintain a vacuum level better than 1×10^{-6} mbar.

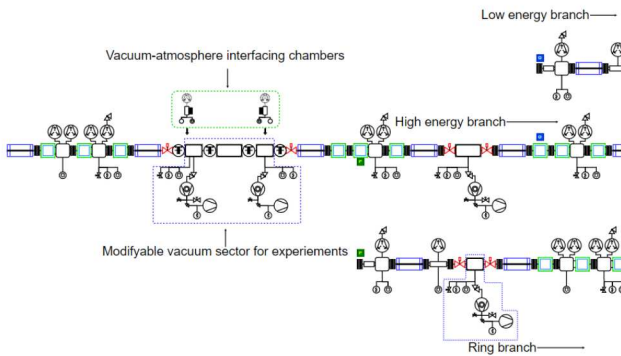


Figure 6: Beam Vacuum layout main-separator and branches. Marked with blue dotted line is the first experimental area. Additional chambers needed for interfacing experimental environment are marked with green dotted line.

In total five experimental areas are located in this region. This requires switching from the beamline vacuum to either experiment's own vacuum environment, or separating the vacuum system from experiments requiring atmospheric conditions. In the former scenario, auxiliary pumping chambers

will be used to keep the pressure gauges connected to the experimental vacuum sector in order to provide the required interlock signals, and in addition will provide a pumping port after the gate valve to maintain the required pressure profile. In the latter case, the auxiliary chamber will provide a beam window. These modifications allow the system to accommodate vacuum requirements of future experiments at the SFRS.

INSULATION VACUUM OF SFRS

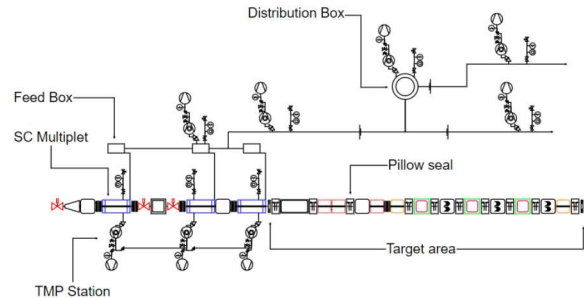


Figure 7: Insulation Vacuum in the pre-target area

The insulation vacuum $< 10^{-4}$ mbar is required is required for an efficient thermal insulation of the sc-multiplets, the sc-dipoles, and the local cryogenic systems. Identical 700 l/s TMP stations are installed on each component requiring insulation vacuum. Due to high radiation in the pre-target and pre-separator areas, the devices belonging to insulation vacuum are specified to be radiation-hard up to 1 MGy. Due to their installation location, these devices are also shielded by the magnets unlike the beam vacuum components directly attached to the beamline. Even though the access restrictions apply equally to insulation vacuum as to beam vacuum in the pre-target and pre-separator areas, no robot handling is possible for the insulation vacuum devices. However, thanks to passive cryo-pumping by the cold walls, the insulation vacuum TMP stations are not run continuously and a failure will not demand an immediate intervention. It is also not practical to benefit from a common roughing line for the insulation vacuum considering the large volumes with significant quantity of condensed water to be evacuated. In view of the existing restrictions to servicing the roughing pumps of TMP stations, redundancy is created by cross-connecting them together as shown in figure 7. This allows valving-off of a defective pump and supporting the corresponding TMP with another roughing pump in the combination. The insulation vacuum system further includes cryogenic distribution boxes, branch boxes, feed boxes to the cryostats, and the cryogenic transfer-lines pumped by 300 l/s TMP stations. Also on these, insulation vacuum conditions rely on passive cryopumping from the cold walls, without a constant active external pumping.

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