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THE HIE-ISOLDE VACUUM SYSTEM

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Abstract

The High Intensity and Energy Isolde (HIE-Isolde) project aims at increasing the energy and intensity of the radioactive ion beams (RIB) delivered by the present Rex-Isolde facility. Energy up to 10MeV/amu will be reached by a new post-accelerating, superconducting (SC) linac. Beam will be delivered via a HEBT to three experimental stations for nuclear physics. To keep the SC linac compact and avoid cold-warm transitions, the cryomodules feature a common beam and insulation vacuum. Radioactive ion beams require a hermetically sealed vacuum, with transfer of the effluents to the nuclear ventilation chimney. Hermetically sealed, dry, gas transfer vacuum pumps are preferred to gas binding pumps, for an optimized management of radioactive contamination risk during maintenance and intervention. The vacuum system of the SC-linac is isolated by two fast valves, triggered by fast reacting cold cathode gauges installed on the warm linac, the HEBT and the experimental stations. Rough pumping is distributed, while the HEBT turbomolecular pumps also share a common backing line. Slow pumpdown and ventilation of the cryomodules are studied to avoid particulate movement in the viscous regime.

INTRODUCTION

The ISOLDE (**I**sotope **S**eparator **O**n **L**ine **DE**vice) radioactive ion beam (RIB) facility has been in operation at CERN PS Booster since 1992 [1]. After its start-up in 2001, the post-accelerator REX-ISOLDE has opened new fields of research with radioactive ion beams at energy of 2 MeV/u [2]. With the HIE-Isolde superconducting linac, energy will ultimately be increased to 10 MeV/u by 32 quarter wave cavities hosted in 6 cryomodules. Beam will then be transferred to 3 experimental stations via a HEBT system. The superconducting linac will be installed after the existing warm linac in a staged schedule and will start producing beam in late 2015. Space limitations have imposed the choice of a common beam and insulation vacuum for the cryomodules, a choice already implemented at INFN-Legnaro with ALPI and at TRIUMF with ISAC II. This design determines the layout of the vacuum system and imposes a tight cleanliness and vacuum specification to all items entering into the cryostat assembly, as well as carefully studied pumpdown, venting and cooling procedures. Operation with radioactive ion beams imposes a fully hermetical vacuum system, with controlled release of the effluents to atmosphere and no accumulation of potentially contaminated gas along the vacuum system. As in Isolde, the users will be in charge of operating the facility, so vacuum controls must be simple and safe.

VACUUM SPECIFICATION

The cryomodules will operate at cold at a pressure below 10^{-8} mbar, while the HEBT lines will operate below 10^{-7}mbar. For the warm sections between cryomodules, operation pressure must be the same as for cold cryomodules, below 10^{-8} mbar. Cooldown, which begins with the thermal screen of the cryostat, will not start until pressure hasn't reached 10^{-7}mbar. These values impose a necessary limitation on the outgassing rate of all cryostat's components. Prototype outgassing measurements have brought to dimensioning of mechanical pumping speed, which in turn has determined a total outgassing "budget". With a significant cryopumping speed by large cold surfaces, the limit to total outgassing has been settled by comparing the non-condensable fraction of residual gas and the installed pumping speed. The total outgassed rate after 10h of pumping must therefore be lower than $2{\cdot}10^{-4}$ mbar l s^{-1}.

To keep with this restriction, all seals with the exception of the large rectangular top-flange will be metallic. Permeation through the top-flange seal will be drastically reduced by a double seal design with interseal pumping. All items installed in the cryostat's vacuum have first undergone an outgassing qualification, including time behaviour and residual gas analysis. Likewise, to ensure the proper treatment and handling of metallic components, cleaning procedures are qualified by outgassing measurements and residual gas analysis. For these, acceptance value is the typical outgassing of stainless steel, cleaned for UHV, 3.10^{-10} mbar·l·s^{-1}·cm^{-2} at 10h pumping. In addition, the intensity of every peak between masses 18 and 44 – excluding mass 28 and 44 – must be at least 100 times lower than peak 18, and the intensity of all peaks between 44 and 100 must be 1000 times lower than peak 18.

Electrons produced by field emission and X-rays determine a radiation field, with a maximum of 10^6 μSv/h at the beam axis [3]. Radiation hardness is thus paramount at the warm sections, while it becomes less critical (10^5 μSv/h) at the top and bottom of the cryomodules, where vacuum equipment will be installed.

Assembly in clean room does not prevent aerosols to deposit in the cryostat, although the assembly procedure is conceived to preserve the cavities from exposure to air. All gas flow must be limited to avoid dust to be lifted and moved around in the cryostat [4]. As discussed below, a maximal flow velocity of 4 m/s is determined by this condition and by the typical size of residual aerosols in the clean room. Similarly, in the HEBT any gas flow during pumpdown and venting must remain in the laminar regime to avoid breaking the numerous charge stripping foils.

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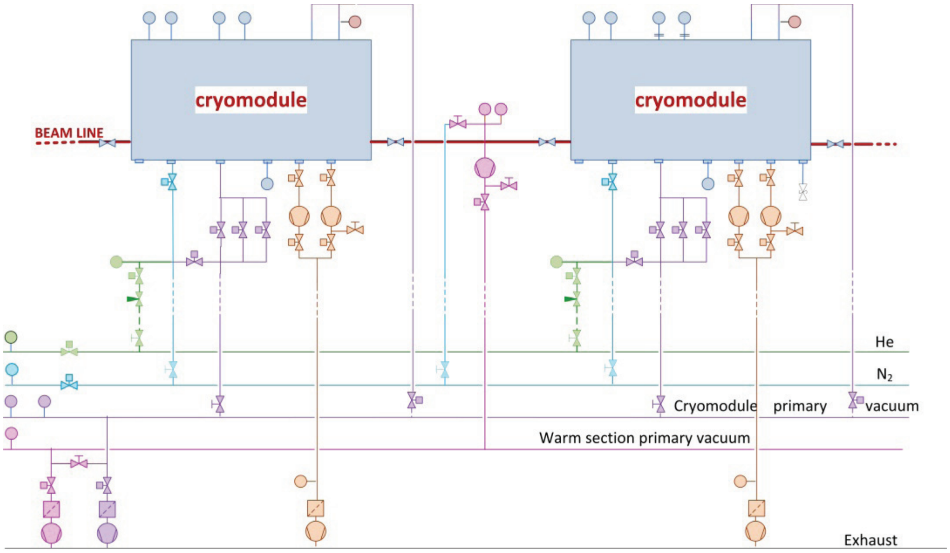

Figure 1: Vacuum layout of the superconducting linac and warm sections.

Even if radioactive contamination risk is very low, the vacuum system must be compatible with RIB operation. The whole system must therefore be hermetically closed and the effluent gases are collected and sent to the nuclear ventilation duct.

LAYOUT

The layout of the cryomodule and warm section vacuum system is presented in Figure 1. Each cryomodule is rough pumped via a distributed primary line, with reduction of flow velocity by 2 valves equipped with a calibrated orifice. UHV pumping is by two turbomolecular pumps, each of 500l/s pumping speed. Primary pumps are dry, hermetical multiroots. A gas injection line is supplied with nitrogen for slow venting and helium for cavity processing. The HEBT lines are also pumped by turbomolecular pumps, with distributed dry primary pumping and flow reduction for rough pumping and venting.

Vacuum chambers of the HEBT are in austenitic stainless steel. Drift chambers are in AISI 304L. To avoid perturbation to the magnetic field, AISI 316L without longitudinal weld is chosen for quadrupole and steerer circular chambers, while AISI 316LN is chosen for the bending dipole chamber (see Figure 2).

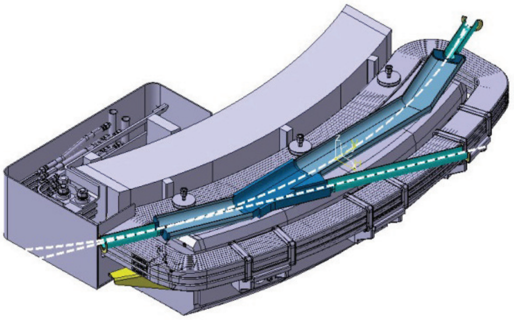

Figure 2: Half section of bending magnet with vacuum chamber.

The C-design of the bending magnets has permitted to increase the transverse gap, allowing for a design based on straight segments with racetrack section, presenting the advantage of construction simplicity.

Challenging integration in the small gap between cryomodules is the most salient feature of the warm sections, Figure 3.

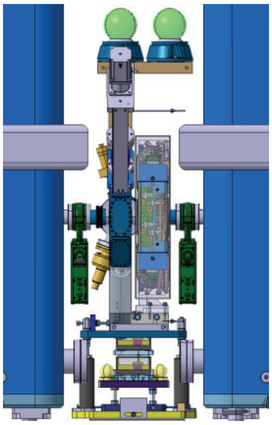

Figure 3: Warm section.

Two gate valves, one diagnostic box, and one steerer have to fit within 320mm. It was therefore necessary to opt for elastomer sealed seat valves, featuring a smaller thickness than all-metal ones. Two welded-wave bellows permit installation and adjustment of the short (58mm) diagnostic box [5], one of the bellows crossing the gap of the thin (90mm) steerer [6]. Each warm section is pumped to UHV by a dedicated turbomolecular pump of 80l/s.

The HIE-Isolde vacuum controls is an independent system built on vacuum device controllers driven by Programmable Logic Controllers for logics and interlocks and a Supervisory Control and Data Acquisition application for operation, logging, alarms and diagnostics. Vacuum controls hardware and software are designed to operate hardware interlocks, pumping and gas injection processes, sectorization valves and high vacuum measurement.

LINAC PROTECTION AGAINST AIR INRUSH

The HEBT conveys beam to three experimental stations. Air inrush from manipulation errors on the experimental stations threatens the cleanliness of the conditioned cavities. Protection is achieved by two DN40 fast valves, closing in less than 15ms and installed at the extremities of the cold linac. The downstream valve is piloted by four fast reacting Penning gauges. To ensure the fastest reaction time, three of these are installed close to the experimental stations. The fourth is installed at the first switchyard between transfer lines. A numerical and experimental study [7] has shown that propagation time of an air front is sufficiently slow to permit closure of the valve before the air from a large leak reaches the cold linac.

SLOW PUMPDOWN AND VENTING

In presence of dust on their inner surface, high field superconducting cavities are subject to field emission, leading to quality factor degradation. The assembly sequence of the cryomodule in a class 100 clean room is conceived to preserve the cavities to long exposure to ambient air. Assembly of the cryostat, though, lasts several days during which dust deposits in the vessel. To avoid shuffling dust around in the cryostat, pumpdown and venting are throttled, thereby reducing flux velocity. Indeed, the onset of motion of aerosols occurs when adhesion forces are overwhelmed by aero dynamical forces, i.e., lift and drag forces.

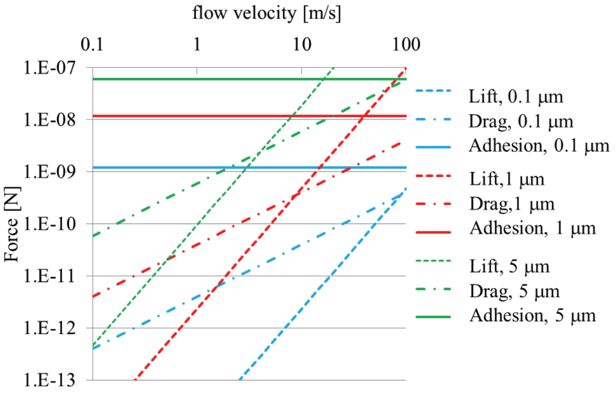

Figure 4: Drag, lift and adhesion forces versus flow velocity, for different aerosol sizes.

Introducing a form factor C_f and Cunningham correction factor Cu to the no-slip condition typical of viscous flow, we obtain the corrected Stokes drag force:

$$F_{drag} = \frac{C_f}{Cu} 3\pi\mu w D_p$$

where μ is the dynamic viscosity, D_p a characteristic dimension of the particle and w the flow velocity. Lift force is empirically described in [8]:

$$F_{lift} = 4.2 \frac{\rho^{1.31}}{\mu^{1.31}} w^{2.31} {D_p}^{2.31}$$

with ρ density of the carrier fluid. Like drag force, lift also strongly depends on fluid velocity. Consequently, a safe pumpdown and venting procedure requires a reduction of flow velocity at the entrance of the cryostat to a typical value of 4m/s, guaranteeing no movement of particles of a size inferior to 5µm. While pressure decreases, Cunningham factor sets a cut on drag forces and the choke can be opened to accelerate pumpdown. A considerable simplification on the pumpdown process is obtained with respect to [4], as neither analog devices nor feedback control loops are required.

CONCLUSION

The vacuum system for the HIE-Isolde upgrade of the REX-Isolde facility is well under way: design, procedures and layouts have been worked out. Outgassing measurements have been performed on most materials entering the cryomodule. Vacuum chambers have been designed and production is under way.

REFERENCES

[1] E.Kugler, "The ISOLDE facility at the CERN PS Booster", Nucl. Instrum. Methods Phys. Res., B 79 (1993) 322.

[2] O.Kester et al., "Accelerated radioactive beams from REX-ISOLDE", Nucl. Instr. and Meth. in Phys. Res. B 204 (2003) 20.

[3] S. Giron, J. Vollaire, "Radiation Protection study for the HIE-ISOLDE project at CERN" SATIF 12 Proceedings, 28-30 April 2014.

[4] K. Zapfe et al., "Particle Free Pump Down and Venting of UHV-Vacuum System", Proc.of the 13th Workshop on RF Superconductivity, Beijing, 2007, pp. 681-684.

[5] A. Sosa et al., "Beam Instrumentation for the HIE-ISOLDE Linac at CERN", IPAC'12, MOPPR048.

[6] J.Bauche, "Status of the beam transfer line magnets for the HIE-ISOLDE project", IPAC'14.

[7] M.Ady et al., "Leak Propagation Dynamics for the HIE-Isolde Superconducting Linac," IPAC'14.

[8] Techniques de l'ingénieur, A.Renoux, D.Boulaud, Physique des Aerosols, partie 1 et 2.