VACUUM STUDY OF THE CAVITY STRING FOR THE IFMIF – LIPAc CRYOMODULE

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Abstract

In the framework of the International Fusion Materials Irradiation Facility (IFMIF), a superconducting option has been chosen for the 5 MeV RF Linac of the engineering validation phase of the project (LIPAc), based on a cryomodule composed of 8 half-wave resonators (HWR), 8 RF couplers and 8 solenoid packages.

The latest developments of the SRF Linac are presented in [1]. This paper will focus on the beam vacuum of the cryomodule. The cryomodule beam line is made of the pattern solenoid package / cavity-coupler, and a valve on each side of the cryomodule. During the installation of the cryomodule on the accelerator system, the cavity string has to be pumped down with the beam valves closed. Thereby a manifold is connected to the cavities during the assembly of the beam line components in the clean room. In previous conferences, the cryomodule was presented with a vacuum manifold connected to each cavity [2]. A study realized on this complex vacuum configuration with Molflow, a test-particle Monte-Carlo simulator for ultra-high vacuum systems, permitted to reduce the number of cavities connected to the manifold and by consequence to reduce the risk of pollution during the clean room assembly.

INTRODUCTION

The installation and commissioning of the first elements of the Linear IFMIF Prototype Accelerator (LIPAc) is starting now at Rokkasho (Japan) [3]. The accelerator (Figure 1) is made of an injector, a radio frequency quadruple (RFQ), a medium energy beam transport line (MEBT), a cryomodule with superconducting niobium cavities, a high energy transport line (HEBT) and a beam dump.

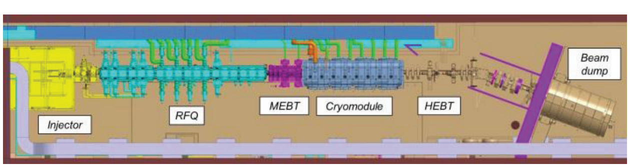

Figure 1: General layout of the LIPAc accelerator.

The beam line of the cryomodule is made of eight patterns solenoid / cavity / RF couplers closed with two valves on each end (Figure 2). Because dust is an issue for the good working of the superconducting cavities [4], it is assembled in a clean room. Furthermore special care must be taken when pumping down and venting [5]. When assembled on the accelerator system, two main reasons prevent to pump down the beam vacuum of the cryomodule through the valves connected to the MEBT or HEBT:

- These two last cited elements are cleaned for ultra-high vacuum but they are not dust particle free. Therefore the pressure difference on both sides of the beam valves must be less than 1 mbar before opening them to avoid the transfer of dust particles to the SRF Linac.
- The pump down system should be as far as possible from the critical elements. But two pumps on the MEBT are closed to the valve of the cryomodule.

Therefore a pumping line must be installed in the cryomodule and connected to a baking pump. As this line has to be installed during the clean room assembly, it has to be easy to clean and handle. The original vacuum manifold was connected to one of the four HPR ports all the cavities (these ports are for the high pressure rinsing process used to clean the niobium cavities). As a consequence it is more than 4 meters long and made of several bits. The connection between the eight cavities and the main collector is done with bellows.

The scope of the vacuum study is to design a simpler manifold.

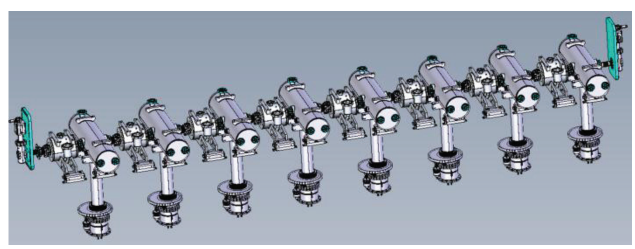

Figure 2: The cavity string of the cryomodule.

VACUUM SIMULATIONS

To calculate the value of the vacuum along the beam axis of the cryomodule, the Monte-Carlo code Molflow developed by R. Kersevan from CERN was used [6].

Molflow contains basic tools to construct geometry. But these ones are not adapted for a complex geometry like the cavity string. Therefore a CAD program is used to construct a simplified geometry which is then imported in the simulation software. Only the vacuum volumes are to be modelled: a half-wave resonator and a coupler are represented by hollow cylinders. The beam pipe of the HWR is represented by a solid cylinder. The whole volume of a HWR is the union of this solid cylinder and the hollow one. All the other elements of the beam vacuum - the solenoids and the bellows between them and the resonators, the warm – cold transitions, the vacuum line – are represented by solid cylinders (Figure 3).

ISBN 978-3-95450-122-9

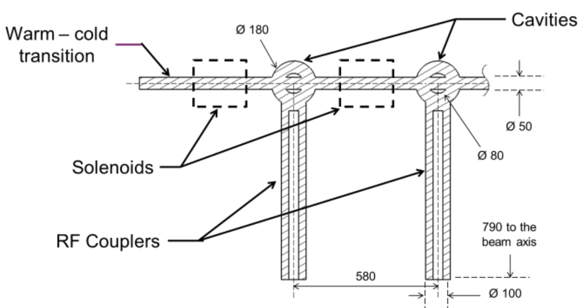

Figure 3: section view of the first elements of the cavity string.

Three pumping configurations are studied:

- The original pumping line which is the reference design: the vacuum manifold is connected to one HPR port of each cavity. It is 4150 mm long; its internal diameter is 60 mm. The tubes connecting the manifold to the cavities are 350 mm long, the diameter being 24 mm. The 60 mm diameter tube connecting the manifold to the pumping system outside the cryomodule is 550 mm long.
- Pumping through the pick-up port of a central cavity: the internal diameter of the pick-up port is 16 mm, and the diameter of the pick-up antenna is 6 mm. The diameter of the tube connected to the pumping system is similar to the previous case (60 mm), it is a little bit longer (760 mm) to keep the same flange connection on the cryomodule.
- A pumping line connected to two HPR ports of the two central cavities. It is now 790 mm long, its diameter is the same as in case 1 (60 mm), as the dimensions of the connection tube (550 mm long, 60 mm diameter). The tubes connecting the manifold to the cavities are 40 mm diameter and 350 mm long.

The simulation parameters are the followings:

- The temperature is 300 K.
- All the facets have the same outgassing rate: 10^{-10} l/s.cm², similar to unbaked stainless steel [7].
- A pumping speed of 70 l/s is set on the ending facet of the 60 mm connection tube to represent the turbomolecular pump which is planned to use.

Please note that the calculated pressures are used to compare different pumping configurations. To calculate the real value of the pressure in the cavity string, the correct outgassing rates and the temperature profile must be set for all the materials used in the system (niobium, stainless steel, copper, and ceramic).

For the three studied pumping configuration the results of the pressure calculations are presented in Figure 4 and the pressure profile along the beam axis is plotted in Figure 5. The pressure in the beam line is constant when pumping through a manifold connected to all the cavities or though the pick-up port of the central cavity. In the first case, the pressure is around 7.8×10^{-7} mbar while it is 4.5×10^{-6} mbar in the second case. The last result can be explained by looking closer the pick-up port: the pressure at the end of the 60 mm diameter part of the pumping tube is 7.8×10^{-7} mbar, while the pressure is 4.2×10^{-6} mbar where the pick-up port joins the cavity body. In a few centimeters the pressure rises by almost one order of magnitude due to the very small conductance of the pick-port.

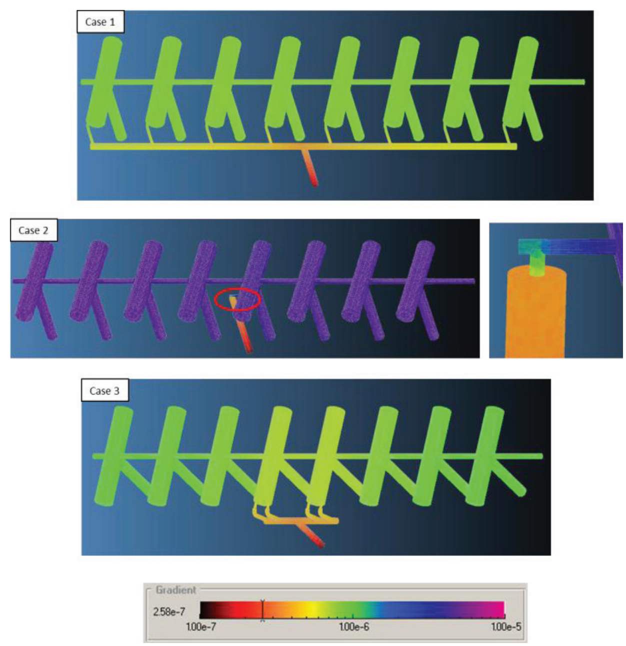

Figure 4: results of the pressure calculations for the three studied configuration: vacuum manifold connected to all the cavities (case 1), pumping through the pick-up port of the central cavity (case 2), vacuum manifold connected to two central cavities (case 3).

When pumping through a manifold connected to the two central cavities, the pressure profile along the beam axis is almost constant: the pressure in the middle of the cavity string is 6.5×10^{-7} mbar and slowly rises to 9×10^{-7} mbar when moving to the first or to the last cavity exposed to the beam.

There is a very small difference in the pressure profiles along the beam axis for the configuration with a manifold connected to all the cavities or for the one with a manifold connected to the two central cavities. In both cases, the ultimate pressure is limited by the conductance of the HPR ports of the cavities, the smallest conductance of the whole system. Therefore the choice between the two configurations is based on the constraint in the clean room. The manifold connected to only the two central cavities is easier to clean and to handle due to its shorter length. And only two cavities instead of all the cavities are to be opened to connect it.

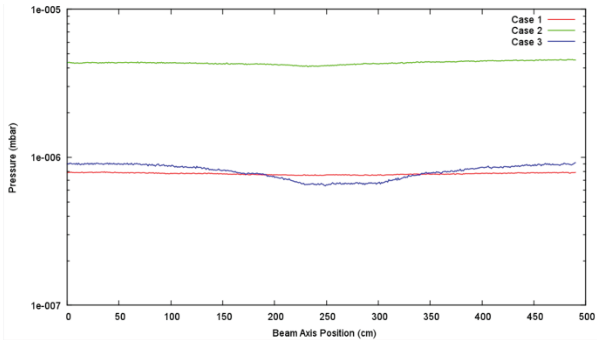

Figure 5: pressure profile along the beam axis depending on the pumping configuration: vacuum manifold connected to all the cavities (case 1), pumping through the pick-up port of the central cavity (case 2), vacuum manifold connected to two central cavities (case 3).

MANIFOLD DESIGN

The way of cleaning the pieces was the most important constraint when designing the vacuum manifold. First the pieces are cleaned in an ultrasonic bath with detergent and rinsed with pure water. In the ISO 7 entry hall of the clean room, the inner and outer surfaces of the pieces are blown with dry nitrogen and cleaned with alcohol and clean room cloths. The same operation is realized when the pieces enter the ISO 5 part of the clean room.

The vacuum manifold is presented on Figure **6**. It is made of several stainless steel parts which will be baked out to reduce the outgassing [8]:

- A main collector which is opened on each side to ease the flow of the cleaning water and the drying air.
- The parts with bellows are as short as possible. As said before, the bellows are difficult to clean due to the wavy shape. When possible, high pressure rinsing is done in the clean room. Otherwise, an additional manual cleaning with a bottlebrush and water with detergent must be done after the ultrasonic bath process.
- To avoid a joint, the connection flange of the pumping line with the vacuum tank and the warm –cold transition could be one piece. But due to the weight of the flange (about 20 kg without the all-metal valve) it was decided to make two pieces to ease the handling and the cleaning of the warm – cold transition.

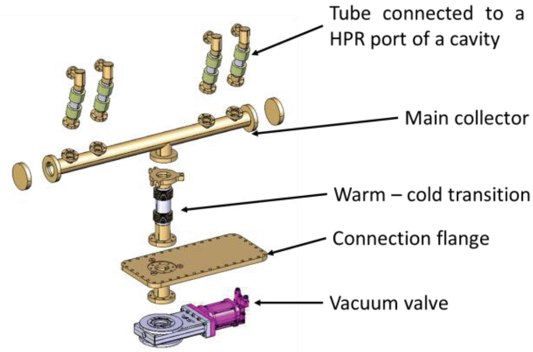

Figure 6: The vacuum manifold.

CONCLUSION

The calculation of the pressure along the beam axis of several pumping configuration were done using a Monte-Carlo program. This leads to a simplification of the pumping manifold: it can be connected to only two central cavities instead of all the eight cavities. Thereby the risk of dust contamination when mounting the manifold to the cavities in the clean room is reduced.

The mechanical design of the vacuum manifold is now frozen. It was made to be easy to clean and to handle in the clean room.

The calculations were done with a uniform outgassing rate, which is sufficient to compare the different pumping configurations. The next step would be to set the proper outgassing rates for the different materials of the beam vacuum to calculate the real value of the pressure in the beam vacuum of the cryomodule.

ACKNOWLEDGMENT

The authors are deeply thankful to P. Carbonnier for the fruitful discussions about the pumping techniques and to P. Hardy and J. Neyret for the artist view of the vacuum manifold.

REFERENCES

[1] F. Orsini et al., “Vertical tests preliminary results of the IFMIF cavity prototypes and cryomodule development”, SRF 2011, Chigaco, USA, THIOB02, p.667 (2011).
[2] F. Orsini et al., “Progress on the SRF Linac Developments for the IFMIF – LIPAC Project”, IPAC 2013, Shanghai, China, THPFI004.
[3] J. Knaster et al., “The Installation and Start of Commissioning of the 1.1 MW Deuteron Prototype Linac for IFMIF”, IPAC 2013, Shanghai, China, TUOAB101.
[4] D. Reschke, “Final Cleaning and Assembly”; Proc. of the 10th Workshop on RF Superconductivity, Tsukuba, Japan, 2001.
[5] K. Zapfe et al., “Particle free pump down and venting of UHV vacuum systems”, Proc. of the 13th Workshop on RF Superconductivity, Beijing, China, 2007.
[6] http://test-molflow.web.cern.ch/
[7] P. Chiggiato, “Physics of outgassing”, proceedings of the CERN Accelerator School on “Vacuum in Accelerators”, 2006.
[8] P. Chiggiato, “Thermal outgassing”, proceedings of the CERN Accelerator School on “Vacuum in Accelerators”, 2006.

ISBN 978-3-95450-122-9