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PREPARATION OF THE CRYOMODULE ASSEMBLY FOR THE LINEAR IFMIF PROTOTYPE ACCELERATOR (LIPAc) IN ROKKASHO

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Abstract

The staged installation and commissioning of LIPAc is ongoing at Rokkasho Fusion Institute of QST, Japan for validating the low energy section of the IFMIF deuteron accelerator up to 9 MeV. The LIPAc Superconducting Radio Frequency accelerator (SRF) cryomodule is assembled under the responsibility of the EU Home Team, and the assembly work recently started at Rokkasho in March 2019. To fulfil the cleanliness requirements for the assembly process, QST took the responsibility to prepare the infrastructure of a cleanroom and associated devices. In this present paper, the details of the preparation work for the cryomodule assembly made by QST will be presented.

INTRODUCTION

The International Fusion Materials Irradiation Facility (IFMIF) is an accelerator-based D-Li neutron source which will produce high energy neutrons at high intensity for the irradiation of candidate materials for anticipated use in fusion energy reactors [1]. The project is in the Engineering Validation and Engineering Design Activities (EVEDA) phase and continues under the Broader Approach (BA) agreement between Japan and the EU. The missions of EVEDA are to produce a detailed, complete and fully integrated engineering design of IFMIF and at validating continuous and stable operation of prototypes of major IFMIF components.

One of the major technological challenges of IFMIF is the acceleration of the 125 mA CW deuteron beam. Several SRF cryomodules are required for IFMIF to accelerate deuterons from 5 MeV to 40 MeV because of the CW and the high current beam requirements. In EVEDA, the validation of the low energy section of the IFMIF accelerator up to 9 MeV is a mission and the construction and the commissioning of the Linear IFMIF Prototype Accelerator (LIPAc) is being carried out at Rokkasho Fusion Institute of QST, Japan. In LIPAc, the first of these cryomodules is being assembled and will be subsequently installed and tested.

The LIPAc cryomodule consists of 8 Half Wave Resonators (HWR) working at 4.45 K with 175 MHz and RF power couplers supplied by CEA, and the 8 superconducting solenoid magnet packages supplied by CIEMAT. As shown in Fig. 1, the cryomodule includes a vacuum vessel, a magnetic shield and a thermal shield cooled with helium gas. A titanium frame supports the cold mass which includes a phase separator with cryogenic lines, the cavity-coupler assemblies and the solenoid coils [2].

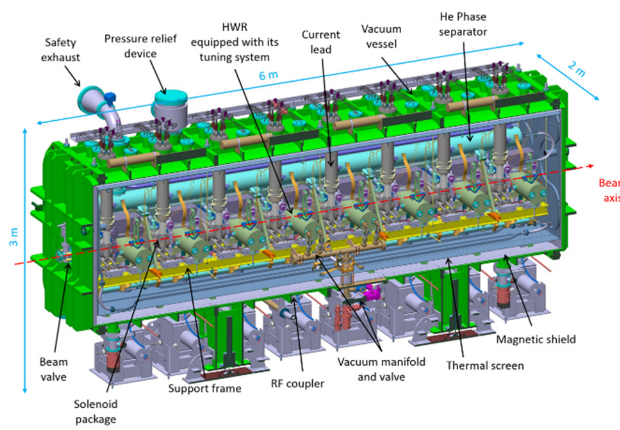

Figure 1: Schematic view of LIPAc cryomodule.

In the initial plan when EVEDA was launched, the cryomodule assembly would have been assembled and tested at Saclay and then shipped from Europe to Japan. In order to mitigate the risk of damaging a critical component, like the ceramic window of the power coupler, and contamination the cavity beam vacuum, it has been decided to assemble the cryomodule in Japan [3]. All the components have been manufactured and qualified in Europe [4]. Most of the components were delivered to Rokkasho in 2018 and beginning of 2019 where they are currently stored awaiting to be assembled.

The cryomodule assembly must be carried out in an extremely clean environment because the superconducting cavity performances can be degraded by field emission induced by particle contamination. Since no suitable space for such a clean assembly work is available in Rokkasho, QST took the responsibility to prepare the infrastructure of the ISO 14644-1 class 5 cleanroom, a dedicated slow pumping system and other ancillary equipment in 2018. In the present paper, the details of the clean environmental equipment prepared for the cryomodule assembly are described.

CLEAN EQUIPMENT

Clean Room

An ISO 14644-1 class 5 clean room is required for the LIPAc cryomodule string assembly. It was decided to construct a clean room with a layout expressly for this cryomodule assembly. The cleanroom consists of three

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areas with a mobile unit as shown in Fig. 2. The red arrows show the movement of a worker, while the blue ones show the movement of the components. The actual installation of the clean room constructed is shown in Fig. 3.

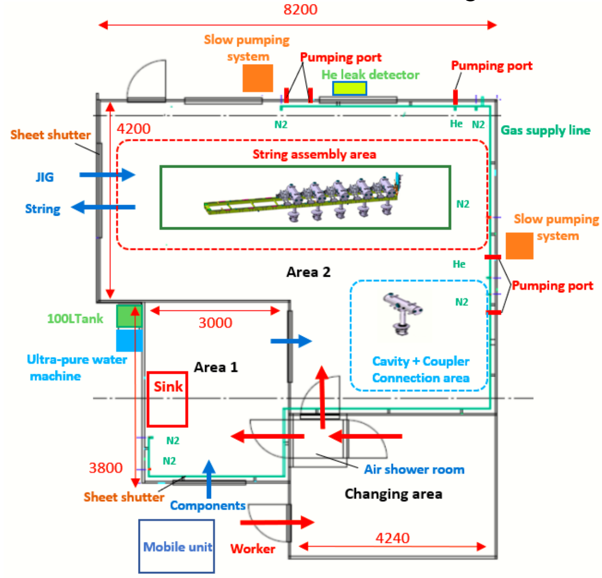

Figure 2: Layout of the clean room.

Figure 3: Inside of the clean room.

The first area is the changing area, where the operators change into cleanroom clothes. The next room is the air shower room to blow dust off the cleanroom clothes.

Area 1 is used for preparing tooling and components for introduction into the assembly area. A stainless sink and cleaning equipment were prepared to wash small tooling and components. A pure nitrogen gas line and an ion gun were installed for particle blowing and drying of components after washing. Once clean, the components can then be introduced to the area 2. In this clean room, a high pressure washing system is not installed because all the components are already cleaned at CEA before shipment to Rokkasho.

The mobile unit is used for unpacking and preliminary cleaning of the components before the introduction to the area 1 to minimize the number of particles brought into the clean room. It is worth noticing that the cavities, couplers and solenoids will be packed in double sealed bags in clean room in Europe and that the cleaning operation at Rokkasho will consist of a rapid wiping with alcohol and cloth.

Area 2 is used for the cavity-coupler connection and the string assembly. In this area, the pure nitrogen line is available mainly for flushing to maintain cavity cleanliness whenever a flange is open. Helium gas is used to check vacuum tightness. The pumping port connects any component inside the cleanroom with the pumping system which is located outside the cleanroom. The large jig and the complete string is transported out of the cleanroom through sheet shutters. All areas are kept at the required level of cleanliness by the FFUs (Fan Filter Unit) vertical (down) flow system with ULPA (Ultra Low Penetration Air) filters. In the acceptance test when the clean room installation was completed, particle measurement was performed at 1 m height, which is the position of the laminar flow limit, and no particles were observed in the entire area. It was confirmed that the installed clean room was suitable for the cryomodule assembly.

Clean Equipment and Pure Gas Line

To generate ultrapure water in area 1, Milli-Q Integral MT 15XL [5] was installed. This machine is very compact and easy to maintain. The production rate of the machine is 15 L/hour, and the storage capacity of the tank is 100 L. These capacities are sufficient for the washing of the small tooling and other small parts.

Different gas lines and outlets are arranged depending on the application of each line as shown in Fig. 2. All the gas supply pipes are of stainless steel welded construction and were electropolished. Two nitrogen bottles are connected to the nitrogen line for the cavity flushing work and switched semi-automatically by a differential pressure valve so as to keep the gas supplied as shown in Fig. 4. The gas outlet consists of a clean regulator, a filter and a flowmeter to adjust the flushing flow rate.

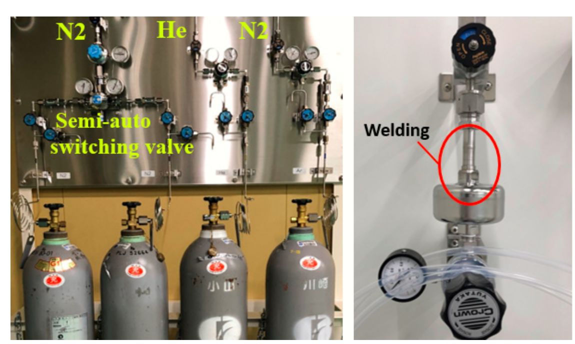

Figure 4: Gas source handling panel and gas outlet.

In the nitrogen purge unit, a filter is installed to remove particles larger than 0.03 µm completely as shown in Fig. 5. Particle measurement was performed at the outlet of the filter by a 0.1 µm particle counter with nitrogen flowing prior to connection to the cavity, confirming there are no particles coming from the supply network.

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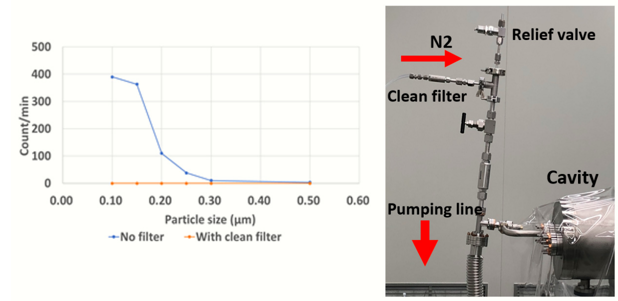

Figure 5: Particle measurement at the nitrogen purge unit.

SLOW PUMPING SYSTEM

Preparation of the Slow Pumping System

One of the possible causes of performance degradation of the cryomodule is due to the particle contamination and diffusion during vacuum operation. To minimize this risk, a slow pumping system dedicated for the cryomodule assembly was prepared.

The slow pumping system was designed by Prof. Dr. Sakai of KEK and assembled in a class 3 super clean room [6]. This pumping system consists of a dry rough pump, a Turbo Molecular Pump (TMP), Mass Flow Controllers (MFC) to adjust pumping speed, and clean vacuum devices. A picture of the system is shown in Fig. 6. The slow pumping system is located outside of the cleanroom and is connected to internal components by flexible bellows via a pumping port on the wall. For convenience of operation during the assembly work, the control panel is installed inside for cleanroom operators.

Figure 6: Slow pumping system and operation panel.

The block diagram of the pumping system is shown in Fig. 7. In slow pumping mode, valve 7 of the main pumping line is closed and the pumping rate is controlled with MFC2 as slow. In main vacuum mode, the nominal pumping starts by opening valve 7. In slow venting mode, nitrogen gas is supplied and the flow rate is controlled with MFC1. Partial pressures are measured by a Q-mass spectrometer. Also, a novel particle monitoring system that can be used in vacuum is installed at the interface of the cavity to visualize particles in the range of 0.3-3.6 μm. The instrumentation was developed by Weex Company [7].

An important feature of this system is that the pumping modes are switched automatically by the simplified control system so as to minimize the risk of incorrect operation.

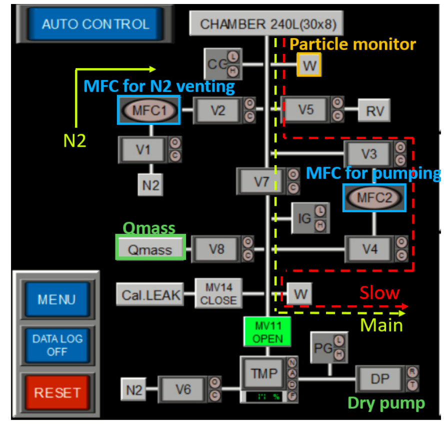

Figure 7: Block diagram of the slow pumping system.

Commissioning of the Slow Pumping System

Particle measurement was performed on the system in a vacuum operation. The result is shown in Fig. 8. At the beginning, the system was operated in slow pumping mode and there was no particle count. At this stage MFC2 was set at 0.6 L/min, at around 600 s in the figure, the operation mode was switched from slow vacuum mode to main vacuum mode, and some 0.3 μm particles were detected due to the gate valve opening. However, an increase of the particle number was not observed during main pump operation. Finally, the slow nitrogen venting started at around 3200 s and no particles were detected. At this stage MFC1 was set at 0.2 L/min. (the MFC values were optimized through a study conducted by KEK). The result successfully demonstrated the clean performance of the present pumping system.

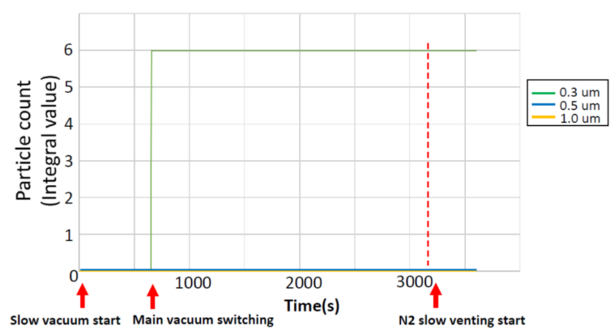

Figure 8: Particle measurement test in vacuum.

TRANSPORTATION

Preparation of the Air Caster System

The LIPAc cryomodule is a very heavy component, weighing more than 14 tons. In the buildings on the Rokkasho site, there are no cranes with the capacity to lift such a component. In order to move it safely, an air caster load module system is utilized. The air caster is a lifting device used to move heavy loads on a flat base. The principle is to reduce friction by floating the component a very small distance from the floor using compressed air [8]. This device is useful not only for the transportation of the heavy components but also for small movements which

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may be required during alignment work or other assembly activities.

Unfortunately, the exhaust air from a screw compressor is slightly dirty and could potentially contaminate cryogenic components. To avoid this risk, oil mist removal filters were installed on the air supply hose satisfying ISO8573-1:2010 class 1 clean compressed air requirements. The transportation apparatus is shown in Fig. 9.

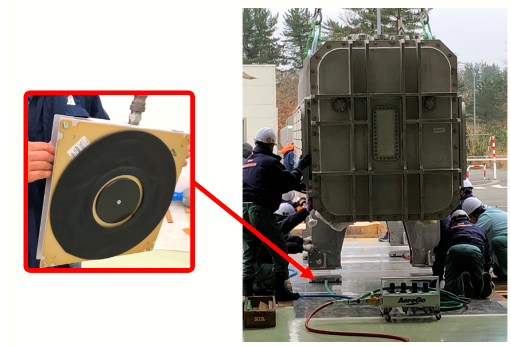

Figure 9: Installation of the air caster module.

Cryostat Transportation by Air Caster System

In March 2019, the vacuum vessel was introduced into the building housing the clean room by the air caster system successfully as shown in Fig. 10. The air caster devices were installed under the cryostat legs. In order to fill gaps and make the ground flat, steel plates were laid as seen in Fig. 9, and the caster system worked well. Working together, ten people were able to manually move the vacuum vessel. In the future, this air caster module system will be used for handling of the cryostat in the assembly area, and subsequently for the installation and alignment in the beam line.

Figure 10: Transportation of the vacuum vessel.

ASSEMBLY

The cavity string assembly in the cleanroom started in March 2019 under the EU Home Team responsibility. At the moment, the cavity and coupler connection work is ongoing as shown in Fig. 11.

Figure 11: String assembly in clean room.

CONCLUSION

In order to fulfil the cleanliness requirements for the LIPAc cryomodule assembly , QST prepared an ISO 14644-1 class 5 clean room (8.2 m x 8 m, Fan Filter Units with ULPA filters) and associated ancillary devices, including ultrapure water generator, pure nitrogen gas line and slow pumping system (tested at pumping rate is 0.6 L/min and venting rate is 0.2 L/min). For transporting the assembled cryomodule with weight larger than 14 tons, a dedicated air caster system was used to transport the vacuum vessel into the building successfully in March 2019. The cavity string assembly in the cleanroom started in March 2019.

DISCLAIMER

Views and opinions expressed herein do not necessarily reflect those of QST, Fusion for Energy, or of the authors' home institutions or research founders.

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