

ASSEMBLY OF THE IFMIF SRF LINAC CRYOMODULE

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Abstract

Complementing its contributions to the JT-60SA and ITER fusion reactors, Fusion for Energy contributes to the R&D for material characterization facilities. Under the Broader Approach agreement, Europe and Japan are developing the Linear IFMIF Prototype Accelerator (LIPAc) in Japan [1,2] — a deuteron accelerator demonstrator producing neutrons by nuclear stripping reactions on a liquid lithium target, part of the International Fusion Materials Irradiation Facility (IFMIF) project.

In 2024, LIPAc prepared for the installation of the SRF cryomodule, concluding its construction. As first prototype, the cryomodule assembly faced challenges at various stages. Started in March 2019, the assembly was paused during its cleanroom phase due to quality issues with the superconducting solenoids, resuming in Aug. 2022. Further issues delayed the completion of the cleanroom activities until Sept. 2024.

In 2024, the cryomodule assembly progressed at a good rate. The clean room worked concluded in Sept. and by late 2024 the cold mass was ready for insertion into the vacuum vessel, with transfer to the vault planned for early 2025.

In this paper, we will outline the critical steps of this assembly process.

INTRODUCTION

The LIPAc is preparing its next phase with the installation of the cryomodule [3], last stage of the deuteron beam acceleration, which is currently under assembly on the Rokkasho site of QST in Japan and, will drive the energy of the beam from 5 to 40 MeV.

The cryomodule will run 8 Half-Wave Resonators (HWR) [4,5], β 0.094, E_a 4.5 MV/m operating at 4.45 K and 175 MHz, with pre-focusing and steering of the beam at each stage done by 8 superconducting solenoid packages [6], designed to operate up to 6 T.

All parts were procured by CEA Saclay, France, with the exception of the solenoids and their current leads that were delivered by CIEMAT, Spain who also conditioned the Fundamental Power Coupler (FPC) [7-9]. Assembly is performed by Research Instruments GmbH (RI). The leak rate requirements were lower than $1E-10$ mbar.l/s at $1E-6$ mbar for the beam vacuum and lower than $1E-10$ mbar.l/s at $1E-5$ mbar for the cryogenic circuit.

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CLEANROOM ASSEMBLY

Cavity Coupler Assembly

After the construction of the cleanroom in QST, the assembly started early 2019 by the connection of the HWRs to the FPCs. HWRs were delivered already cleaned by High Pressure Rinsing (HPR) and were sealed in double bags. The FPCs were also delivered ready for a cleanroom assembly. The first three HWR/FPC assemblies were impacted by rising helium background during the leak tests while in the meantime, the solenoids had to return to the workshop to correct some welds and their surface aspect [10,11] detected during their HPR. The assembly was therefore postponed in order to improve the slow pumping system and wait for the return of the solenoids.

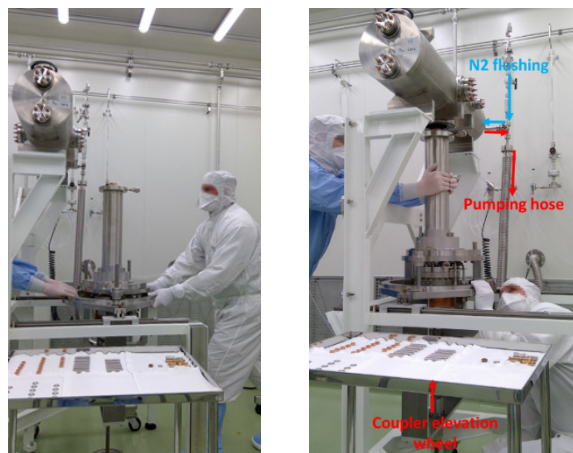


Figure 1: FPC sliding under the HWR (left), connection of the HWR with FPC (right).

The cleanroom assembly could only resume in August 2022 after the reopening of the borders in Japan and the return of the solenoids from the HPR done by Mitsubishi Heavy Industry (MHI) during which new issues were identified [11,12] but mitigated. The helium background issue appeared again but was quickly identified as a faulty valve on a calibrated leak. The HWR/FPC assemblies resumed quickly and were successfully leak tested. An upgrade version of the tooling made by CEA [10], Fig. 1, was used. The assemblies were made with nitrogen flushing through the HWRs and the pumping and leak test done immediately after closing the interface. A control of the torque was made

at least 12h later. Each assembly was then preinstalled on the titanium support frame.

In parallel of the HWR/FPC assemblies, the solenoids and vacuum components of the beam line were inspected, and leak tested. As one solenoid could not get its BPM leak tight and additional reworks were needed on the vacuum lines [11], the assembly was paused from November 2022 to March 2024, time to solve the different issues.

Beam Line Assembly

The beam line assembly [11] was sub divided in four parts. Three assemblies for the beamline itself and one more for the pumping line. Intermediate leak tests validated each sub-assembly. Starting by a Cold Warm Transition (CWT) and the last HWR (assembly done downward with respect to the beam line), Fig. 2, a nitrogen flushing was applied each time a HWR was added. From the second HWR assembly, a double flushing was the rule for the connection of a new HWR.

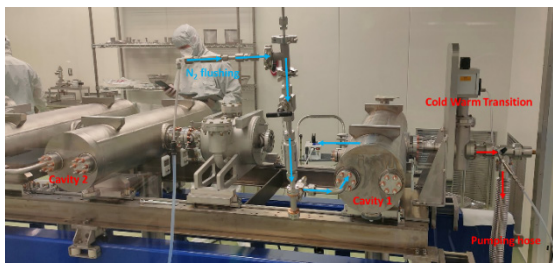


Figure 2: Solenoid1 connection to HWR1.

During the assembly of the pumping line, a crack opened in a weld of the main pumping flange [11]. This issue was detected during a preliminary leak test, before connection to the HWRs and after the assembly of the main gate valve. Assembly had to be stopped but could resume after three months in September 2024 and was concluded by the final integral leak test.

The whole beam line was covered with a PE film which was filled with helium at different points. A first leak test of 10 min was realized before refilling helium for 10 min and continue the test for another 10 min. The Test was repeated the next day, and both were successful granting the beam line to leave the cleanroom for the cold mass assembly stage.

COLD-MASS ASSEMBLY AND INSERTION

f_0 Control, Alignment, and Tuning System

The first step outside the cleanroom was to check the f_0 of the HWRs after such a long time. All of them were in line with the measurements done at CEA.

The final supports of the beam line were installed, and the cleanroom ones removed, allowing then the first alignment of the beam line during which an unexpected lateral bending of the frame was noticed. An invar rod associated with bearings in C-shape supporting elements [13] are used for the alignment and managed the thermal shrinkage at 4 k.

The assembly of the tuners was the third step, Fig. 3, with a permanent monitoring of the f_0 during the assembly to detect any excessive mechanical constrain on the HWRs at room temperature. The design of the tuners also offers a good protection of the bellows sitting between the HWRs and the solenoids.



Figure 3: Tuner frame installation (left), tuning screw assembly (right).

Phase Separator and Cryogenic Piping

The phase separator [14] was the next step, sitting on top of the beam line, it was then connected to the HWRs and solenoids helium outlets. Two manifolds were then installed at the lower part, each of them dedicated to the HWRs or the solenoids. Connections on the beam line elements use Helicoflex interface while the ones on the feeding manifold use VCR connectors. Finally, the FPCs were connected to the phase separator, from which cold helium gas will be used to manage the thermal gradient of the external conductor of the FPCs. During the leak tests two leaks were found on two welds. A first one on a connection box of a solenoid was quickly repaired but the second leak on a pipe feeding a power coupler was more challenging. Ultimately, the pipe was cut and replaced by a Swagelok union to fix it.

Ancillaries and Vacuum Vessel Preparation

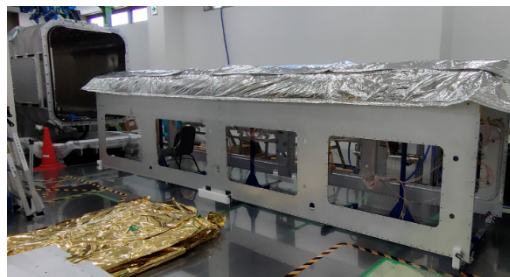


Figure 4: Thermal screen upper part ready for insertion.

The central bottom part of the thermal screen was pre-installed under the beam line around the FPC. The heat sink elements (copper collars and braids) used to thermalise the support frame and tuners were among the last elements to be added with the thermometry instrumentation (PT100, Cernox and CLTS). Indium foils were added at the interfaces of the heat sink elements to improve the thermal conductivity. Finally, the cryogenic motors of the tuners were installed and protected from dust.

During the cleanroom assembly, a second team from RI joined to prepare the vacuum vessel. Delivered with the magnetic shield already installed [14], the vessel had to be

equipped with the upper part of the active thermal screen on which, the instrumentation electrical harness was attached and glued to thermalize the cable around 50 k. The screen assembly was covered by the first MLI blanket, Fig. 4, and hanged inside the vessel waiting for the cold mass insertion.

Cold Mass Insertion and Finalisation of the Assembly

Lifting tests of the cold mass were done to check its behaviour but no excessive lateral tilt was noticed. A jig matching the dimension of the one supporting the cold mass during its assembly was installed in the vacuum vessel. The cold mass jig was raised and both jigs connected together. A system using winches to move back and forth then allowed the cold mass to roll onto the other jig, Fig. 5.



Figure 5: Cold mass ready for insertion.

The cold mass was then lowered close to its final height and transferred on the vertical supporting titanium tie rods [3]. At this point a second alignment was done. It was noticed that the lateral deformation of the first alignment bended backward after being hanged to the tie rods and a complete re-alignment had to be done. The FPCs and the pumping line were then connected to the vacuum vessel.

Finally, the earthquake damper tripods [1] the missing lower parts of the thermal screen and MLI blankets were installed as well as additional instrumentation cables and flanges. The Main Cryogenic Transfer Line (MCTL) feeding the cryomodule was the last part mounted before closing of the doors and transport of the cryomodule.

TRANSPORT TO THE ACCELERATOR VAULT

Closing of the Cryomodule

The closing of the cryomodule should have been definitive regarding the two main doors. Because of a non-conformity on connecting elements of the cryogenic piping, it was decided to fix it in the vault as there was no time left before the transport. Both main doors were closed using a dedicated tool, Fig. 6, that maintains the relative alignment of the doors, the Cold Warm Transition, and the vessel. All the elements of the beam line were then locked to the support frame and the frame itself was locked to the vacuum vessel. The 8 lateral windows were finally closed, and the ceramic windows of the FPC covered. Two shock detectors were installed to record any event above the 0.8 g

threshold. The Shinkai Transport System company, who operated the transport, packed the cryomodule in a double layer PE film before the transport.



Figure 6: Main door closing with support of the CWT.

The first step was to get the 12 t cryomodule outside of its assembly building. This was done using an air caster system under its feet. Once pulled out on the outside platform, the cryomodule was loaded and locked on the truck trailer to travel the 250 m to the accelerator vault. The cryomodule was unloaded and electrical rollers were installed under its feet to better managed the difference of floor level and access its new assembly position inside the vault, Fig. 7.

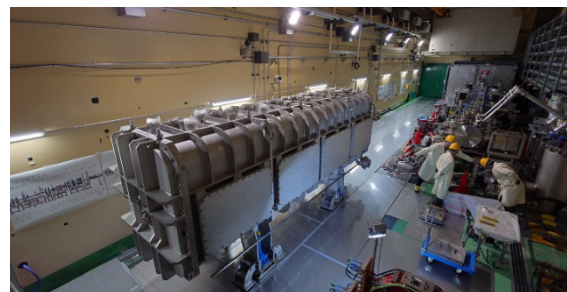


Figure 7: Cryomodule ready for its last assembly step.

CONCLUSION

The assembly of a cryomodule designed and manufactured by several European partners associated with a long storage time of components brought up many technical and coordinating challenges. With the remote support of the European partners, the team onsite gained experience in resolving non-conformity or technical issues encountered with local companies in Japan but also on site by getting access to a small mechanical workshop.

Currently on hold, the cryomodule assembly is waiting the delivery of the last cryogenic piping parts and the installation of the superconducting solenoid packages current leads. The completion of the assembly is expected to be reached by the end of 2025.

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