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CLEANROOM ASSEMBLY OF THE LIPAc CRYOMODULE

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Abstract

In complement to the development activities for fusion reactors (JT-60SA & ITER), Fusion for Energy contributes to the R&D for material characterisation facilities. The LIPAc is the technical demonstrator for the production and acceleration of a D^+ beam that will be used for neutron production by nuclear stripping reaction on a liquid Li target. Since its first beam in 2014 [1, 2], the LIPAc construction and commissioning continues and will be concluded with the cryomodule installation, aiming for beam validation at nominal power.

The cryomodule assembly, started in March 2019, was paused due to welding issues on the solenoid bellows. The slow pumping group used for the cleanroom assembly also needed improvement to overcome helium contamination. Two and half years were devoted to the pumping improvement and, repair, cold tests and high pressure rinsing of the solenoids.

In August 2022, the cleanroom assembly resumed with the mounting of all power couplers to the SRF cavities. Despite good progress, the assembly had to be paused again to fix leaks on different vacuum components and a solenoid BPM port.

This paper presents the issues faced and their solutions along the cold mass assembly.

INTRODUCTION

The Linear IFMIF Prototype Accelerator (LIPAc) is the technical demonstrator for the production and acceleration of a Deuteron beam that will be used for neutron production by nuclear stripping reaction on a liquid lithium target.

The assembly of the accelerator will reach its conclusion with the addition of the SRF cryomodule, aiming for beam validation toward nominal power (125 mA D+, 9 MeV, CW).

Started in March 2019, the assembly of the cryomodule had to be paused to manage technical issues on the superconducting solenoids sitting between the cavities and a strong helium background on the slow pumping system used for the cleanroom assembly.

Two and half years later, the assembly could restart after the end of travel ban in Japan.

The different issues encountered during the different assembly periods and their solutions as well as the different progress done on the cleanroom assembly are hereinafter presented.

THE SUPERCONDUCTING SOLENOIDS PACKAGES

The SRF cryomodule of the LIPAc contains eight superconducting solenoids to focus the beam before each acceleration by the SRF cavities. Provided by CIEMAT as part of the Spanish contribution to the LIPAc, each of them is equipped with a Beam Position Monitor (BPM) similar to the ones used in LHC and were delivered with their current lead interface. The strong fields produced by the inner coils necessary to focus the high intensity beam are actively shielded by bucking outer coils to minimize the fringe fields and avoid remnant magnetization of material inside the passive magnetic shield [3]. The final solenoid configuration therefore consists of two concentric coils and four steering coils to correct the beam orbit.

Material and Welding Issue

During a first High Pressure Rinsing (HPR) some solenoids presented different aspect defects that can be categorised as follow: rust dots, weld quality issue, material trapped in bellows, external surface finishing, Figure 1.

Figure 1: From top right to bottom, rust dots on bellow, oversized weld seam, trapped material in bellow.

These defects were considered as critical knowing the sensitivity of the SRF cavities with metallic particulate

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contamination and the requirements for a cleanroom assembly.

The less qualitative welds were grinded and polished and then, together with the rusted area treated by pickling and passivation. In addition the solenoids were pressure test again to meet the HPGSL* requirements. Despite an improvement, black oxidation marks appeared and the procedure was applied a second time. Result can be seen in Figure 2.

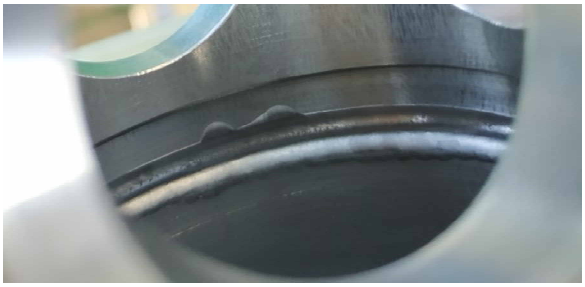

Figure 2: Fully treated weld next to the BPM.

In parallel of the weld treatment, the trapped materials in the bellows were hardly removed due to the Omega shape of the bellows, see Figure 3. Finally, all the solenoid helium vessels were polished to get a smooth finishing compatible cleanroom environment.

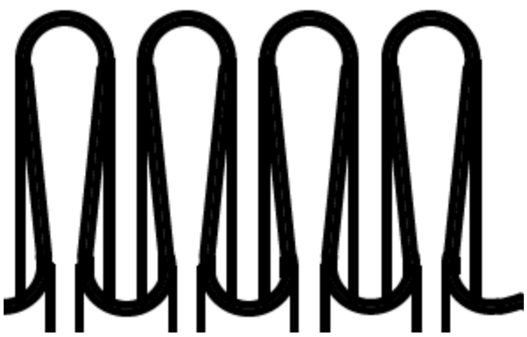

Figure 3: Omega shape bellow.

Solenoid V06 Bellows and Threaded Hole Issue

Additional work was needed on the solenoid denominated V06. A chain of events occurred and can be summarised as follow: one BPM threaded hole leaked into the beam vacuum, the hole was recharged by welding without notification by the supplier, a leak was then detected from the bellows seam next to the repaired hole after trapped material removal, the bellow was changed by a new one, Figure 4 , the thread started to leak again, the thread was repaired a second time, Figure 5, a small volume was occluded when recharging by welding. Finally the solenoid was leak tight again and could be sent for its cleaning in an ultra-sonic bath before a one hour passivation bath.

Note on the Magnetic Permeability

Due to the proximity of the SRF cavity, great care was taken not to increase the magnetic permeability of the steel. The measurements done on the threaded hole before were already very close to the final value of 1.26 after the second recharge. When moving away from the affected area the value quickly decreases to the acceptable value of 1.02, 1.01. This indicates that the repair done in first place during the manufacturing was carried out without taking care of the magnetic permeability and an excessive heat was applied. Additionally, the helium vessel of solenoid V06 presented a deviation with an excessive value of 1.21. A second solenoid presents also excessive magnetic permeability on its helium vessel with a value of 1.21.

Figure 4: Welding of the new bellow on solenoid V06.

Figure 5: Threaded hole at different stages of charging and its final result (bottom picture).

* High Pressure Gas Safety Law

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Cold Leak Test

Following the repaired of the different solenoids it was decided to cold leak test them all. The tests were carried out in Germany, with the following requirement:

- Cooling speed < 60 K per hour
- T monitoring of Helium inlet and outlet, and both end plate
- ΔT between all four sensors < 50 K
- ΔT between both end plates < 25 K
- Cooling down at 10 K for 30 min
- Three critical solenoids had to be tested 3 times
- The rest of the solenoids had to be tested one time

The test insert was prepared to test the solenoid in a vertical configuration as shown in Figure 6.

Figure 6: Solenoid installed on the test insert.

The first three tests done on two solenoids were disappointing with strong helium signal in the Dewars each time in the range of 70 K. It was suspected an improper configuration of the current lead interface. Indeed O-ring gaskets were found in place of the Helicoflex mentioned on the configuration document. Once the correct gasket installed and after overcoming issues with strong helium background the tests could resume. However the helium consumption during the test was higher than foreseen, especially to maintain the temperature below the 10 K. It was therefore decided to release this parameter with 10 min of cooling under 30 K. All solenoids managed to pass the cold leak test successfully.

CLEANROOM SLOW PUMPING SYSTEM

In March 2019 the cleanroom assembly started with the cavity/coupler assembly. A chapter is dedicated later on to detail the assembly work done in cleanroom. One problem that appeared during this first assembly period was the difficulty to leak test the assemblies. A strong helium background was always noted during the tests. The cleanroom in Rokkasho was designed without air recirculation and without double floor due to space constrains. The first Slow Pumping System (SPS) was sitting near one the air exhaust of the cleanroom and was also equipped with a few ISO KF O-ring connection. After a couple of trials the O-ring gaskets started to permeate helium in the pumping line, making impossible to get an helium background better than the 1 E-10 mbar.l/s, maximum leak rate value for the components.

As the solenoids needed some repairs, the assembly was paused and it was decided to procure a new SPS using only metal gaskets. This second SPS was tested and fully validated during the visit preceding the restart of the cleanroom assembly, in June 2022.

SOLENOID HPR AND TOMOGRAPHY

HPR and BPM Assembly

After the completion of the cold leak test in Germany, the solenoids were sent to a supplier in Japan to be prepared for the beam line assembly. The solenoids went for a first cleaning with an Ultra Sonic bath (US bath). Each of them had their helium flanges water tighten to prevent the leaking of alkali solution during the US bath. They were then immersed in water to check the tightness by absence of bubble production before proceeding to the US cleaning. During their handling, two solenoids were reported having rattling noise coming from the helium vessel. Before the High Pressure Rinsing (HPR), the two solenoids were inspected with an endoscopic camera, Figure 7. A screw was found in the first one when opening the helium inlet flange, Figure 8. In the second solenoid, nothing was found and the rattling noise disappeared.

Each solenoids were high pressure rinsed and let dry in cleanroom before the assembly of the PBM pick-ups in cleanroom. In the meantime, the root cause of the rattling noise where analysed. The screw found in the first solenoid appeared to be used during the assembly to keep the outer coil in position. It has therefore no other use, especially for the geometrical positioning of the coil. However, after the HPR the second solenoid presented again a rattling noise.

In order to prevent further issues during operation, it was decided to send all height solenoids for a tomography after the BPM assembly to check the condition of the different assembly screws and centring pins.

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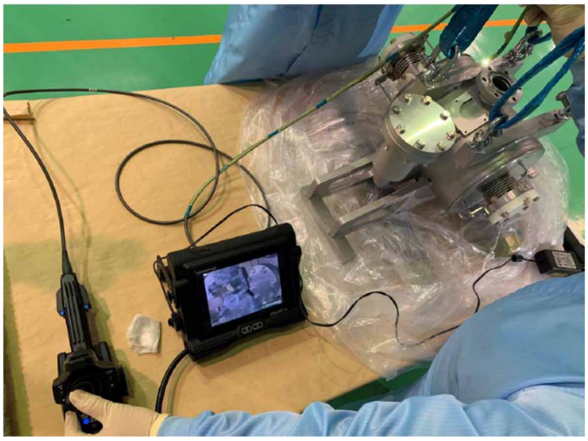

Figure 7: Endoscopic inspection of the helium vessel.

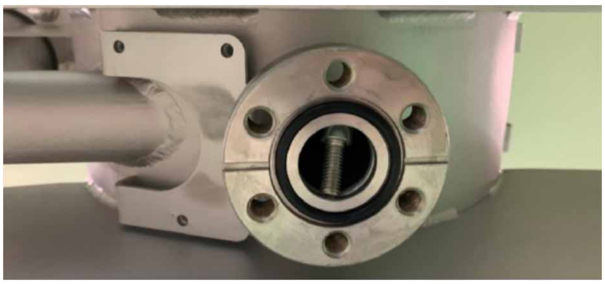

Figure 8: Screw found in solenoid V06 helium inlet.

The BPM pick-ups assembly proceed smoothly, except for one of the 32 sensors. Indeed, for the repaired solenoid, V06, it was impossible to insert the pick-up on the BPM side that had one thread repaired by welding, Figure 9. It was quickly suspected that the different repairs led to some stress released in the BPM, where the tolerances are extremely tight. The measurements of the faulty BPM socket confirmed the deformation on one of its side. It was therefore decided to proceed to a light polishing of the pick-up head by 50 µm and to proceed to its assembly once the solenoids back on Rokkasho site. The polishing of the pick-up head did help a lot, but small gap subsisted to get it closed entirely. Finally the head was adjusted on a lathe machine by removing an additional 150 µm on the head diameter. This last step allowed a complete insertion of the pick-up in the BPM. However, after many attempt it was impossible to get leak tight within the specifications. This last aspect will be described in a later part dedicated to leak issues.

Solenoid Tomography

All solenoids passed tomography examination in Japan. Fifteen cut view were obtained to get the position of the different set of assembly screws and centring pins.

Assembly principle of the solenoids The solenoids where assembled following the principle shown in Figure 10. The inner coil and steerer magnets are positioned around the beam tube on one helium vessel wall. This sub assembly is positioned with centring pins and keep in position with screws. The opposite side of the sub-assembly is equipped with another set of centring that must fit the opposite wall. The external coil follows the same principle on the opposite helium vessel wall. This two sub-assemblies are then assembled through the helium vessel, each free centring pins fitting in the sockets of the opposite wall with fine mechanical tolerance to keep the best alignment of each coil.

Figure 9: Solenoid V06 faulty BPM pick-up.

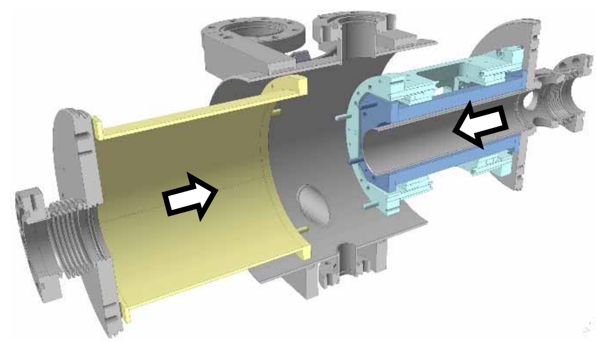

Figure 10: Assembly principle of the solenoids. In blue the inner coil and steerer magnet. In yellow the outer coil.

Tomography results The scanner revealed that for some solenoids, some of the pins free before assembly were push out partially or totally. Thus, for the second solenoid presenting a rattling noise, it was found that three centring pins of the inner coil were totally removed and are now sitting in the space between the two coils, Figure 11. These three pins are now enclosed and cannot be removed.

Based on the result of the scanner, two solenoids were considered as sensitive for the good operation of the SRF Linac. Rather than delay the assembly for several years by manufacturing new solenoids, it was decided to find the best positioning for each of them to be able to operate in a degraded mod if any limitation occurs during operation. This work is described in [4] of the present conference.

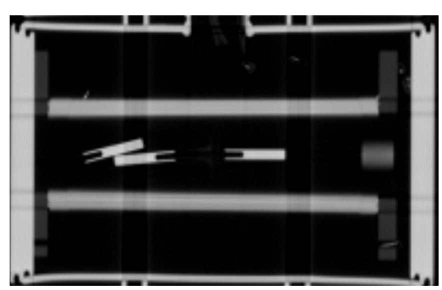

Figure 11: Centring pins laying on the outer coil.

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CLEANROOM ASSEMBLY

Cavity/Coupler Assembly

The cleanroom assembly, carried out by a contractor, was first started in March 2019. It follows the sequence tested by CEA [5, 6] and using the same tooling with minor modification following the return of experience. The two first assemblies were validated with difficulty because of a strong helium background. The third one waited two and half year consequently to the solenoids issue combined with the pandemic. In June 2022, the new SPS was beneficial for the assembly. The third cavity/coupler was validated and in August, when the assembly finally resumed, all remaining cavities and couplers were assembled and leak tested successfully.

All solenoids but one, were leak-checked again successfully. All cavity/coupler assembly are now positioned the main support frame with a couple of solenoids, and pre-aligned for the string assembly.

Beam Vacuum Component Leaking Issues

During the cleanroom assembly, additional components were reported having leaking issues.

The solenoid V06 had its last BPM pick-up leaking. Two attempts of repolishing the seal groove in cleanroom to preserve the HPR failed. A first 3D analysis, Figure 12, showed a deformation of the body surface of the BPM, having the reference surface tilted with respect to the seal groove.

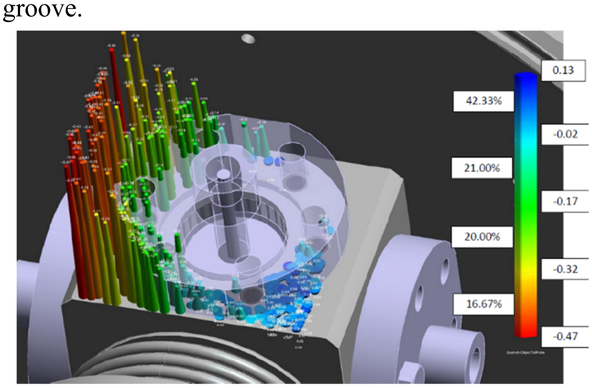

Figure 12: Parallelism between BPM body and sealing groove.

The reason of the leak was found in two scratches that were removed by an appropriate third polishing. A diamond shape gasket was then used in place of the Helicoflex whose sealing groove requirements were not fulfil anymore. Solenoid V06 is now ready for a new HPR prior to come back in cleanroom.

The two Cold Warm Transitions (CWT) used to transfer the beam to and from the cryomodule presented inappropriate sealing surface finishing, Figure 13, required for the double Helicoflex gasket interface. A first polishing attempt did improve a bit the situation by getting one the gasket leak tight. A second attempt failed and did not succeed to have both gaskets leak tight at the same time. Another attempt is currently ongoing. New gasket designs are also being procured as alternative solution.

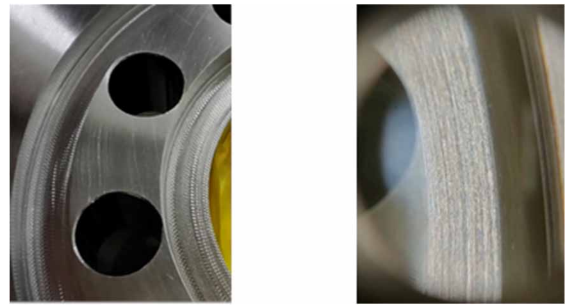

Figure 13: CWT before (left) and after (right) polishing.

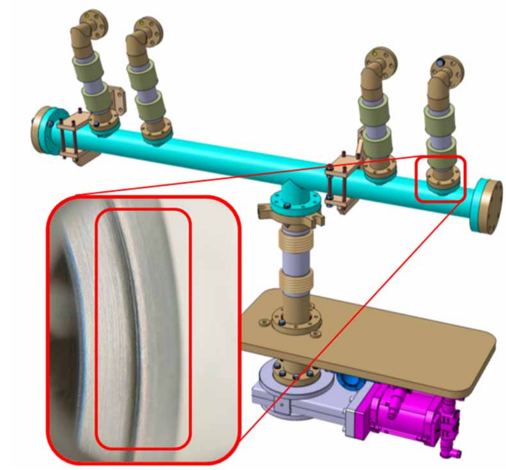

Figure 14: Rounded edge knife from the pumping manifold (in blue).

The pumping manifold used to pump the beam line from the two middle cavities is the last component failing to be leak tight at inspection. Four of the seven CF interfaces leak. A close inspection revealed that most of the knife edges of the CF flanges are actually rounded, Figure 14. It is suspected an issue during the passivation of the manifold with an improper protection of the different flanges. Regarding the number of flanges damaged and the heavy processing to change them, it is decided to procure a new manifold.

CONCLUSION

Despite strong technical issues on some components of the SRF Linac, many actions have been engaged to correct in most cases the problems encountered. As paper is being written, a few actions are still on going to correct the last vacuum leak issues.

A consequent work was also done to mitigate any issue with the solenoids and allow, if necessary, to control the beam [4]. A new procurement was recently launched by CIEMAT for a new set of solenoids if any of the original needs to be replaced during a long maintenance period. Additional procurements are also in preparation to get additional spare components (SRF cavity and power coupler).

Thanks to the new slow pumping system, the cleanroom assembly progressed very well. The cleanroom assembly is expected to be resumed by November 2023 and should last only three weeks to complete the assembly of the cavity string and pumping line, and thus conclude the cleanroom work.

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