ADDITIONAL INSTALLATION EFFORT FOR THE 3MW READINESS AT ESS

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Abstract

Since the last installation campaign, additional High-Beta (HB) cryomodules (CM) have been tested and qualified Ready-for-Installation (RFI) at the ESS Test Stand. Their installation was planned for the summer'25, right after the first Beam On Dump (BOD) commissioning phase and a complete warm-up of the accelerator. The number of HB CM has raised to 11 out of 21 allowing for a potential maximum power of the Linac of 3 MW. This paper will present the lessons learned from the previous phase, as well as the necessary measures taken in order to install 6 cryomodules in an RP controlled area in only 3 months.

INTRODUCTION

The European Spallation Source (ESS) in Lund, Sweden [1] has begun its transition towards an operating facility. A major milestone of the first Beam On Dump (BOD) phase was reached in May 2025, when the probe proton beam successfully traversed the superconducting linac and was measured at an energy exceeding 800 MeV. Cryomodule preparation readiness and commissioning activities were previously reported at SRF2025 [2] and an update is given at this conference [3]. This paper focuses on the summer 2025 installation campaign (shown in dark blue in Fig. 1, as well as on improvements implemented to the existing infrastructure.

ADDITIONAL CRYOMODULES INSTALLATION

Motivations

At the beginning of 2025, the ESS P6 plan identified a gap of several months between the end of BOD commissioning and the start of Beam On Target (BOT) commissioning. This period was identified as an opportunity for the installation of additional cryomodules. Installing CMs at this stage provides increased flexibility for future machine shutdown planning, allowing greater focus on the needs of the ESS Neutron Scattering Systems (NSS). Furthermore, the ongoing qualification campaign of elliptical cryomodules [5] enabled the installation of six additional High Beta (HB) cryomodules. It is important to note that these cryomodules will not initially be powered. The RF gallery upgrade from 2 MW to 3 MW was scheduled to start after summer 2025. Once powered, the additional energy margin will provide much needed operational flexibility on the path towards reliable 2 MW operation. Finally, as the main cryomodule installation campaign (27 CMs) had just been completed, the installation teams were still present at ESS. This represented a strong asset for carrying out the installation swiftly and efficiently.

Lessons Learned

As noted in the previous section, the main cryomodule installation had recently concluded [6], and lessons learned were documented to ensure an equivalent or faster installation pace for the six additional HB cryomodules. During the BOD phase, one machine-off day per week was allocated. These periods were used to prepare the infrastructure for the summer installation. It was identified that water cooling piping constitutes a resource-intensive task in the installation schedule. Pre-fabrication of the piping, together with pre-installation of the lower part of the water distribution system, proved to be highly efficient. The risk of equipment damage was significantly reduced, and the working conditions for the fitters were correspondingly improved. Once BOD commissioning was completed and the accelerator was warmed back to room temperature, the main differences compared to the previous installation were the presence of an RP controlled area and the re-use of already installed equipment (Linac Warm Units (LWUs), water cooling manifolds, etc.). As the accelerator had operated for several weeks up to the Tuning Beam Dump (TBD), a total of seven LWUs and six dummy beam pipes had been exposed to beam and had to be removed, temporarily for the LWUs and permanently for the dummy pipes, to allow installation of the additional HB cryomodules.

The LWUs were removed using mobile cleanrooms after the RP group had surveyed and cleared the work area. Activation levels remained very low (<5 µSv/h), even on the flanges connecting the dummy pipes to the LWUs. The preparation of the cryogenic piping followed a similar approach to the previous installation. The CM piping was prepared in advance in the klystron gallery, reusing the existing set of jigs. The preparation of the valve boxes (VBs) was performed after completing the cleanroom work and, in this campaign, with stricter dust containment measures during cutting and grinding operations. A dedicated booth (Fig. 2) was installed for each valve box, ensuring no potential contamination of surrounding areas and including an RP check at the end of the work. A total of four weeks was required to prepare the six positions. Another improvement in the installation sequence concerned the water cooling manifolds, which previously had to be fully disconnected. In this campaign, the manifolds were tilted towards the ceiling, allowing

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Figure 1: Additional HB cryomodules installation (dark blue).

Figure 2: LWUs and dummy pipes removed. Booth when preparing VB piping.

the cryomodules to be slid underneath them. Only the water pipes were disconnected, while the electrical connections remained in place, thereby preserving the validity of existing documentation (QA/QC records, test reports, etc.). At the start of the installation campaign, five out of six cryomodules were ready for installation. One cryomodule was used to proof test all modifications to the installation sequence, resulting in a complete installation within one week:

- 1 day for the CM transport,
- 1 day for the alignment and welding the cryogenic piping,
- 2 days for the piping leak test and the jumper sleeve connection (MLI and thermal shield included),
- 2 days for the RF waveguides (started in parallel to the cryo activities).

Following this approach, the next four cryomodules were installed within two weeks, resulting in a total of five cryomodules installed in three weeks. This represents a significant improvement compared to the installation rate of two cryomodules per month achieved in 2024. With several cryomodules in place, the LWUs were reinstalled and the water distribution system was completed and tested. Once the final cryomodule was qualified as Ready for Installation (RFI) at Test Stand 2 (TS2) in early September, it was installed following the same procedure, completing the linac configuration and bringing the potential energy (once powered) to 1.3 GeV (3 MW).

MAINTENANCE ACTIVITIES

The summer installation period was also used to perform maintenance activities and to complete the RF waveguide certification in the accelerator tunnel.

Safety Valves Leakage

The operational availability of the linac under cold conditions was reported in [7]. One of the main causes of cold compressor filter clogging was identified as air leakage originating from the relief line, where all discharge (spring loaded and controlled) valves are connected to the 2 K environment. Leak tests of each valve box and cryomodule were performed using the partial flow method. By modifying the valve configuration, it was possible to determine whether leaks originated from the high pressure side of the valve box or from the sub atmospheric side of the cryomodule. A summary of the test results is presented in Fig. 3.

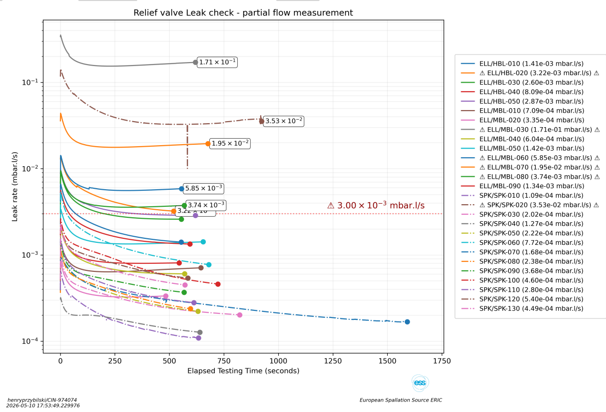

Figure 3: Leak rate summary.

Valves identified as leaky (limit set at 3×10^{-3} mbar l/s) were serviced and tested individually prior to their re-installation. Spare valves were also procured, although the delivery occurred after the completion of the cryomodule installation.

RF Waveguides Certification

In normal conditions, the RF waveguides are already assembled and tuned up to the interface with the power coupler transitions, called doorknobs. For the last HB cryomodule, the last waveguide elements were assembled, mounted and pre-aligned in the accelerator tunnel just before the CM installation. The so-called RF waveguide certification was therefore needed to ensure the proper match. When needed, a cylindrical post is placed in the RF waveguide to maximise the return losses. The example in Fig. 4 illustrates the tuning results, with losses greater than −30 dB at the resonance frequency 704.42 MHz.

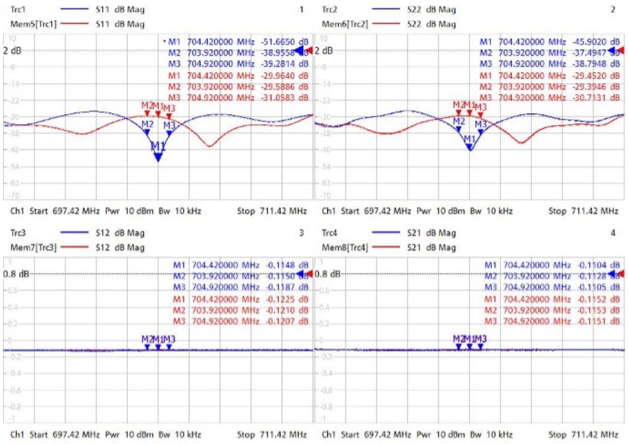

Figure 4: S-parameters for a waveguide line before (red curve) and after tuning (blue curve).

CONCLUSION

The six additional HB cryomodules were successfully installed within the allocated time-frame. Further optimisation of the installation sequence enabled an installation rate of up to two cryomodules per week. All activities performed in the accelerator tunnel complied with RP regulations for controlled areas. Although radiation levels remained low, the teams demonstrated the capability to install the remaining ten HB cryomodules in the coming years. At the time of this conference, the second Beam On Dump phase is ongoing. The newly installed cryomodules have been cooled down, and preparatory work in the klystron gallery is continuing.

ACKNOWLEDGMENT

The summer 2025 installation of six HB cryomodules, together with all associated activities, was made possible by the combined efforts of the ESS Accelerator Division teams, namely Cryo, EPS, ICS, Linac, RF, and Vacuum; as well as ESS centralised services, such as alignment, mechanical systems, and rigging teams. In addition, the commitment of industrial and in-kind partners (IFJ, KrioSystem, PowerHeat) contributed significantly to this success.

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