STATUS OF THE CRYOMODULE TESTS AS A PART OF POLISH IN-KIND CONTRIBUTION TO THE EUROPEAN SPALLATION SOURCE (ESS) REALIZED BY IFJ PAN

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Abstract

The European Spallation Source (ESS) is next-generation neutron source, that require testing, installation and commissioning of various systems and components. In this paper, the current status of cryomodule (CM) testing is presented including the Scope of Work (SoW), assigned to group of engineers and technicians from the Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Science (IFJ PAN).

INTRODUCTION

The ESS is one of the Europe's largest research infrastructure. Superconducting linac at ESS is designed to provide 5 MW of average proton beam power with an energy of 2 GeV. The main acceleration of the proton beam is achieved by use of the superconducting part of linear accelerator (SCL). The SCL part of the linac consists of 13 spoke, 9 medium beta (MB) and 21 high beta (HB) cryomodules [1].

IFJ PAN, as an in-kind partner for ESS, has provided resources for testing of the accelerator components, building the infrastructure and developing different systems. The Polish institute was involved i.e. in the installation of Low Level RF (LLRF) and Local Protection System (LPS), testing and installation of RF Distribution Systems (RFDS), testing and installation of RF Power Stations (RFPS) [2-4] as well as commissioning and development of the cryogenic control system [5-9]. Apart from these works, the IFJ PAN team was also involved in reception check, testing, troubleshooting and support with installation of the cryomodules in the tunnel [10]. Nevertheless, the largest resources provided by the IFJ PAN was assigned to the work package related to Site Acceptance Tests (SAT) of the MB and HB elliptical cryomodules (Fig. 1). These tests took place at ESS in Test Stand 2 (TS2) and were realized jointly with team of ESS SRF Section [11-13].

IFJ PAN CONTRIBUTION TO SAT

The SAT has been foreseen at ESS for testing of the elliptical cryomodules at TS2. The facility in TS2 includes an RP bunker, a test stand, a dedicated cryoplant and RF power sources that allow for testing both types of the cryomodules (MB and HB) at nominal temperatures. Both cryogenic and RF operability were evaluated at the time of testing. Since the arrival of the cryomodule to ESS, the processes were jointly controlled by IFJ PAN and ESS SRF crews until the cryomodule was approved for further installation in the tunnel. IFJ PAN provided specialists in electrical, mechanical, cryogenic and vacuum fields for that purpose. The scope of work for the cryomodule testing contains various operations that can be divided into different phases. Depending on the type of activity, it is performed in different areas of TS2 (Fig. 2). Below, the main activities supported by the crew from the Polish institute for cryomodule testing at TS2 are described.

Initial Inspection of the Cryomodule

At the early stage, after the cryomodule arrives at ESS two types of the inspections are carried out: electrical and mechanical incoming inspections. This is the first stage of the cryomodule check before any further activities. During the electrical inspection, various measurements are performed. The goal is to confirm that electrical instrumentation of the cryomodule shows no signs of damage and can be approved for further use during cold tests in the bunker. The electrical measurements include checking temperature sensors, liquid helium level gauges, electrical heaters, stepper motors and piezo actuators. Mechanical inspection allows verification of whether any obvious defects of the cryomodule are present. Mainly a visual inspection is performed at that time. External components are verified such as: the cryomodule's vacuum vessel, cryogenic valves, vacuum valves, beam equipment in the bells section, auxiliary line ports, instrumentation flanges etc.

Preparation of the Cryomodule for the Cold Tests

Preparation of the cryomodule for further cold tests consists of installation of the instrumentation and cryomodule equipment. In parallel, vacuum tests of the cryomodule are performed. The work is carried out in the TS2 area, which has two slots available for these activities (Fig. 3).

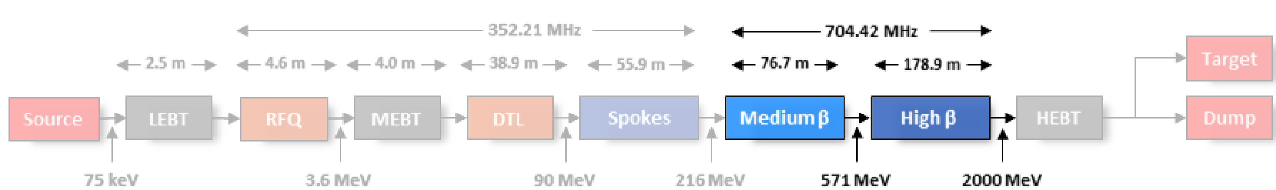

Figure 1: Block diagram of the ESS accelerator with the medium and high beta cryomodule sections highlighted, being tested during SAT at ESS TS2.

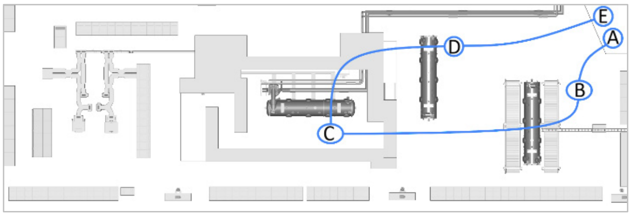

Figure 2: Operations on the cryomodule at TS2 depending on location: A – reception, B – initial inspection, preparation to the test bench, C – installation for the test bench, initial testing, cool-down, SRF operations, heat loads measurements, warm-up, disconnection, D – preparation for the tunnel, E – dispatch. The preparation areas are used alternately.

The installation of components includes control and signal cables for the cryogenic valves, rupture discs at the auxiliary ports, vacuum pumping sets attached to the cryomodule's vessel ports, doorknobs transition, line for helium guard system installation. Closing of the thermal windows with MLI and trap doors is required. Installation of the actuators for the beam gate valves is required, as well as a set of pressure sensors previously assembled and inspected.

Pre-testing, focused on leak testing of the cryomodule vessel and the beam volume is handled before installation in the bunker. The beam volume tests consist of leak testing of the available vacuum connections. Similarly to the leak testing of the cryomodule vessel, the available connections that belong to beam volume are sprayed with helium gas. Leak tightness of the two crucial vacuum gate valves installed at beamline extremity is also verified at TS2. Purity of the cavity string is verified after the particle free pump station is connected to the beam volume. Residual Gas Analyzer (RGA) is launched to identify residual gas present in a beam vacuum. Another kind of leak test for the beamline is performed during pumping of the insulation vacuum of the cryomodule vessel. At this stage, the beam volume is monitored by use of RGA with the Multiple Ion Detection (MID) mode. This provides an instantaneous view of the gas composition at the moment of the scan. Selected air masses are monitored while pumping of the vessel is ongoing. This allows exclusion of leak suspicion at an early stage.

Figure 3: TS2 area with two slots available (Preparation 1 and Preparation 2). Elliptical cryomodules already in place.

Installation on the Test Bench

From that moment, various systems need to be connected to the cryomodule unit. The IFJ PAN crew performs connections of the power couplers to the RFDS, cryogenic supply and return lines to the Valve Box (VB) system, water cooling system for the power couplers, vacuum pumping system for the insulation vacuum and the beam vacuum (Fig. 4), auxiliary lines for the coupler outlets, rupture discs, power and signal cables, etc.

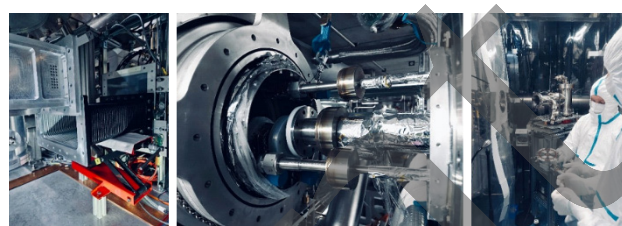

Figure 4: Example of the cryomodule connections to the test bench systems. On the left, waveguide during connection to the power coupler. In the middle, cryogenic interconnections. On the right side, a combination of the Non Evaporable Getters and Ion Getters Pump connecting process to the beam volume in an ISO 5 class cleanroom.

Initial Testing

At this stage, cryogenic vacuum and RF systems are checked. In parallel with cryogenics related activities the vacuum systems are verified. After the DN450 semi-flexible muff in jumper section is closed and insulation vacuum pumping is launched, leak test of the connections needs to be performed. Also, a leak test and additional RGA check need to be performed for the pumping system connected to the beamline before gate valve opening to its volume. After achieving the vacuum conditions at the cryomodule vessel, an integral leak test can be performed. The test consists of pressurising the cryogenic lines with pure helium and monitoring helium leak signal at the insulation vacuum. During the integral test, tightness of the cryogenic lines into the insulation vacuum is verified, but also tightness towards ambient is checked by use of the leak detector in sniffing mode. Coupler outlets, rupture disc and safety valve ports are leak tested with this method. While the cavity baths are pressurised with helium, leak tightness into the beam volume is inspected. Leak tests without irregularities observed will allow the cryomodule for further cooling process.

Cool-down

Cryogenic operation phases from the start of the cooling are controlled from the Local Control Room (LCR). The thermal shield (TS) circuit can be cooled either simultaneously with the 4 K / 2 K volume or separately. Most of the cooling processes are automated but require vigilance. The target operational temperatures for the cryomodule are 50 K on the TS and 2 K in the cavity tanks. From the start of cryomodule cool-down at TS2 at least two days are required before further SRF activities. At a certain point, during the cool-down process, when the liquid helium in the cavity tanks reaches its nominal level the cryogenic operator reduces the pressure in the cavity tanks to ~31 mbar.

The pumping down operation results in lowering the temperature of the helium in the bath from 4.2 K to 2 K, achieving superfluid helium at the same time. From this moment, the Joule-Thomson (J-T) valve is used for refilling the liquid helium (LHe). The actual helium level is measured by two LHe level gauges – LT-001 and LT-002.

Heat Loads Measurements

The amount of heat energy that must be removed to maintain the desired cryogenic temperature is defined as heat loads. In case of static heat loads, the dominant contributions come from thermal radiation and conduction from the outside environment. The dynamic heat loads are caused by RF power, beam losses, and the helium cooling of the power couplers. In order to determine the cryogenic heat loads of the cryomodule, several methods have been developed based on measurement data from the available sensors. IFJ PAN has participated with developing the strategy of heat loads measurements [14].

Warm-up

The warm-up process, similarly to the cool-down, requires couple of days. Usually it takes 3-4 days until the cryomodule is fully warmed up. After the detuning of the cavities, complete LHe evaporation from the cavity tanks is performed first. The helium supply valves remain closed and the LHe level decreases due to heat loads in the cryomodule. After the liquid is evaporated, the pressure in the tanks is restored to about 1.0 bar and warm gas flow from the TICP is started. The process continues until all the temperature sensors inside the cryomodule indicate at least room temperature.

Disconnection

Before the disconnection process of the cryomodule, a couple of crucial tests are performed. After the warming up of the cryomodule, the helium leak signal is measured at the insulation vacuum with the cryogenic lines supplied with helium gas. Afterwards, the vessel is vented with pure nitrogen gas. This helps to warm regions that are still not fully warmed up inside the cryomodule. Additionally, the nitrogen gas provides a variety of benefits. It is non-flammable, dry and moisture-free. The homogeneous nitrogen gas used for venting of the insulation vacuum also serves as a tracer gas for the tightness check of the beam volume after cold operations. The outgoing mass spectrometry of the beam volume is performed after various dynamic SRF processes and warming of the cryomodule. An additional leak test of the ceramic windows in the power couplers section is performed and just after the disconnection process can begin. The IFJ PAN crew starts the disconnection of the auxiliary lines, waveguides, vacuum pumping systems, water cooling system, power and signal cables, etc.

Preparation for Installation in the Tunnel

After the disconnection, the cryomodule is moved out from the bunker and outgoing inspection is performed. Temporarily installed components are dismounted. Fragile connectors and cryomodule outlets are secured. A general inspection is performed at that time. The cryomodule is ready for further storage.

Documentation Collection

Operations on each cryomodule are documented and shared with ESS by means of the Collaboration Home of ESS system database (CHESS). Various reports on each phase of testing are prepared. There are reports related to incoming, outgoing inspections as well reports dedicated to pre-tests and actual tests in the bunker. The IFJ PAN work is based on a quality system implemented using a dedicated database and procedures with instructions. Irregularities related to cryomodules are documented in Non-Conformance Reports (NCR) and shared with predefined, responsible people at ESS.

STATUS OF THE CRYOMODULE TESTS

After the commissioning and start-up of the test stand in 2021, the SAT for series cryomodules began. On average, 6 cryomodules were tested per year (Table 1).

Over the course of a couple of years of cryomodule testing, some irregularities were noticed. Among the major NCRs, cold leaks on two cryomodules can be highlighted. Leaks from the inner cryogenic volume into the insulation vacuum were preventing Ready For Installation (RFI) status. Another deviation was related to the leak tightness of the beam volume at one of the CM, further solved in situ by CEA specialists with ESS/IFJ PAN support [15, 16]. One of the CM requires intervention to resolve the inner leak irregularity on the gate valve at the beam volume. Various minor deviations were documented, troubleshot and resolved at the ESS site.

Table 1: Cryomodules Test Progress

Year of Testing	Number of Cryomodules Tested
2021	1 MB
2022	5 MB + 1 HB
2023	1 MB + 5 HB
2024	2 MB + 3 HB
2025	6 HB
2026	3 HB + 3 HB ongoing

CONCLUSION

Tests for the elliptical cryomodules (30 pieces in total) are now 90 percent complete. Most of them are already installed and operational in the tunnel. Three cryomodules have already been tested this year and another three are scheduled to be tested within the current year.

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