Commissioning of the helium cryogenic system for the HIE- ISOLDE accelerator upgrade at CERN

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Commissioning of the helium cryogenic system for the HIE-ISOLDE accelerator upgrade at CERN

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Abstract. The High Intensity and Energy ISOLDE (HIE-ISOLDE) project is a major upgrade of the existing ISOLDE and REX-ISOLDE facilities at CERN. The most significant improvement will come from replacing the existing REX accelerating structure by a superconducting linear accelerator (SC linac) composed ultimately of six cryo-modules installed in series, each containing superconducting RF cavities and solenoids operated at 4.5 K. In order to provide the cooling capacity at all temperature levels between 300 K and 4.5 K for the six cryo-modules, an existing helium refrigerator, manufactured in 1986 and previously used to cool the ALEPH magnet during LEP operation from 1989 to 2000, has been refurbished, reinstalled and recommissioned in a dedicated building located next to the HIE-ISOLDE experimental hall. This helium refrigerator has been connected to a new cryogenic distribution line, consisting of a 30-meter long vacuum-insulated transfer line, a 2000-liter storage dewar and six interconnecting valve boxes, one for each cryo-module. This paper describes the whole cryogenic system and presents the commissioning results including the preliminary operation at 4.5 K of the first cryo-module in the experimental hall.

1. Introduction

The HIE-ISOLDE project is a major upgrade of the existing ISOLDE (Isotope mass Separator On-Line facility) and REX-ISOLDE facilities at CERN. The Radioactive ion beam EXperiment (REX) at ISOLDE has provided the nuclear physics community with a wide range of post-accelerated Radioactive Ion Beams (RIBs) since 2001 and can currently deliver beams with energies up to 2.8 Mega electron Volt per nucleon (MeV/u) using a normal conducting linear accelerator [1].

The HIE-ISOLDE project proposes a staged upgrade of REX-ISOLDE with higher energies up to 10 MeV/u, together with higher beam intensities and beam quality. The most significant improvement will come from replacing the existing REX accelerating structure by a superconducting linear accelerator (SC linac) composed ultimately of six cryo-modules installed in series, each of them containing superconducting RF cavities and solenoids operated at 4.5 kelvin (4.5 K).

In order to provide the cooling capacity between 300 K and 4.5 K for the six cryo-modules, an existing helium refrigerator, manufactured in 1986 and previously used to cool the ALEPH (Apparatus for LEp PHysics) magnet during LEP (Large Electron-Positron collider) operation from 1989 to 2000, has been refurbished, reinstalled and recommissioned in a dedicated building located next to the HIE-ISOLDE experimental hall. This helium refrigerator has been connected to a new cryogenic distribution line, consisting of a 30-meter long vacuum-insulated transfer line, a 2000-liter storage dewar and six interconnecting valve boxes, one for each cryo-module.

Figure 1 presents a simplified Process Flow Diagram of the helium cryogenic system connected to the first HIE-ISOLDE cryo-module.

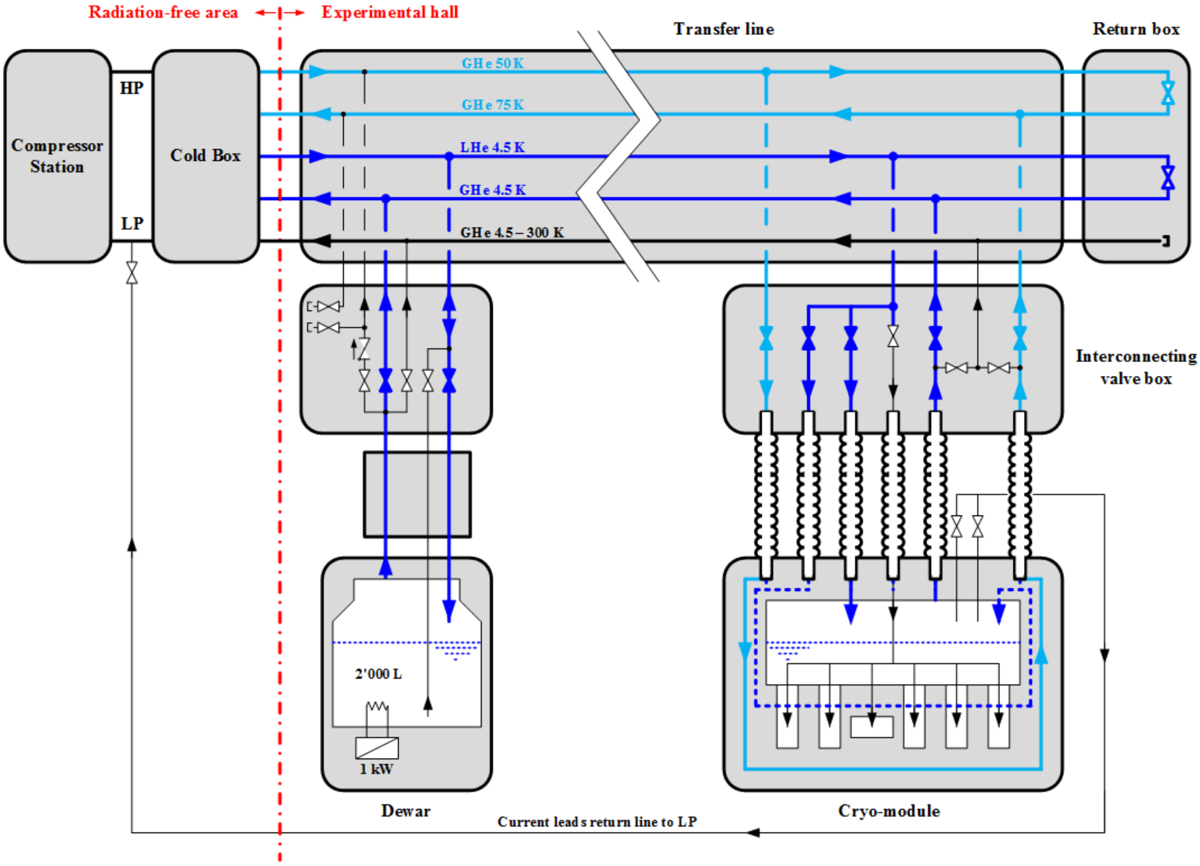

Figure 1. Simplified Process Flow Diagram of the HIE-ISOLDE helium cryogenic system.

2. The helium cryogenic system

The HIE-ISOLDE helium cryogenic system consists of one helium refrigerator which has been connected to a dedicated cryogenic distribution line (see figure 1).

2.1. The helium refrigerator

In order to reduce the HIE-ISOLDE project overall cost, a 30-year old helium refrigerator, manufactured by *Linde Kryotechnik AG* in the 1980's, has been refurbished, reinstalled and recommissioned to supply the cooling capacity at all temperature levels between 300 K and 4.5 K.

This refrigerator cold box was capable in 1989 of providing simultaneously an isothermal refrigeration power of 630 W at 4.5 K, a shield cooling of 2700 W between 50 K and 75 K and a helium liquefaction rate of 1.5 g/s [2].

Two screw compressors, mounted on the same motor shaft and working as two stages, provide a total mass flow of 0.156 kg/s (156 g/s) compressed from 0.104 MPa (1.04 bar abs.) up to 1.59 MPa (15.9 bar abs.).

The refrigerator cold box is based on a two-pressure Claude cycle and is equipped with two turbines in series which expand successively the cycle helium from 1.47 MPa (14.7 bar abs.) to 0.545 MPa (5.45 bar abs.) and then from 0.519 MPa (5.19 bar abs.) down to 0.125 MPa (1.25 bar abs.). The discharge temperature of these turbines is respectively 51 K and 11 K. The final expansion is performed in a Joule-Thomson valve producing two-phase saturated helium at 0.130 MPa (1.30 bar abs.).

Figure 2 presents a simplified Process Flow Diagram of the refrigerator cold box.

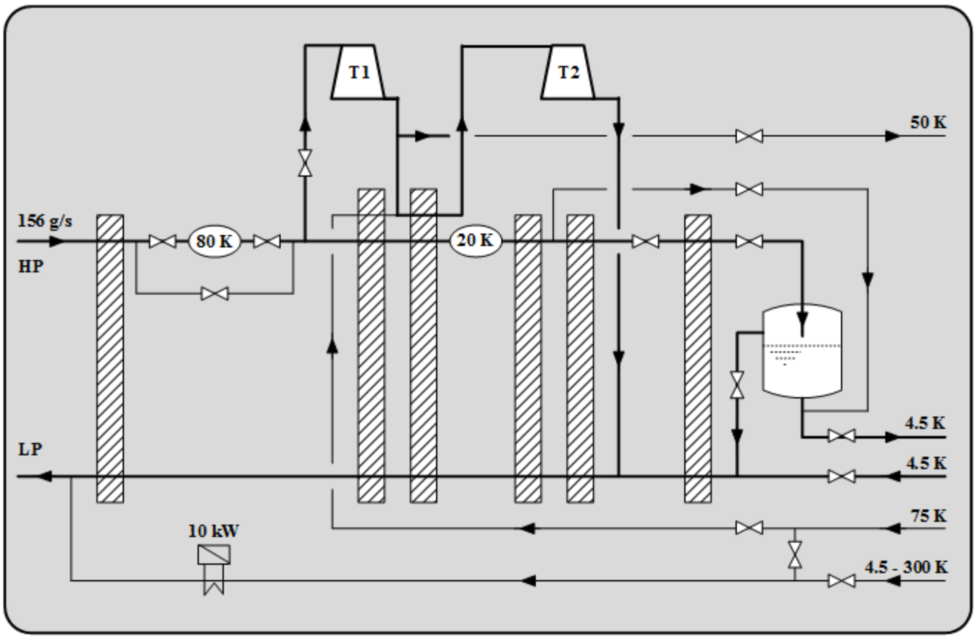

Figure 2. Simplified Process Flow Diagram of the refrigerator Cold Box.

The refurbishment work of this cold box, decided jointly by CERN and the original manufacturer, has consisted in the replacement of the following items:

- the 80 K and 20 K adsorbers. The 80 K adsorber has been equipped with a bypass line allowing a regeneration without stopping the liquefaction process;
- the existing Rh-Fe temperature sensors by new TVO sensors and their transmitters;
- the electric heaters inside the phase separator vessel;
- the two turbines coolers and their associated brake valves;
- the O-ring on the cold box shell and all vacuum feedthrough connectors;
- cones, gaskets, actuators and positioners of every cryogenic valve.

The refurbishment lasted six months and the cold box was returned to CERN in November 2014.

2.2. *The cryogenic distribution line*

A contract for the supply of a new cryogenic distribution line, consisting of a 30-meter long transfer line, a 2000-litre storage dewar and six interconnecting valve boxes, has been awarded to *Criotec Impianti Srl* after a competitive tendering process among CERN's member states.

The design of this transfer line, housing five cold pipes in the same vacuum vessel, should allow very low-loss liquid helium transfer, typically a heat load less than 0.3 W/m^2 on the 4.5 K pipe.

Each interconnecting valve box has been designed to provide independent feeding of the cryo-modules and operational flexibility, allowing cool-down, warm-up, disconnection via bayonet connections and removal of individual modules in case of need [3].

The 2000-litre dewar has been installed to provide a cold buffer in case of refrigerator stop.

3. Cryogenic operation and first cool-down results

As the cryo-modules housing the RF cavities are of a "common vacuum" design where the cavity interior space is common with the cryo-module insulating space, it is of the utmost importance to avoid contamination through gas condensation on the cavities RF surfaces, which would limit their performance. This contamination imperative requires a sequential cool-down of the cryo-module inner parts to ensure cryo-pumping onto the shield of a maximum of residual gas away from the surfaces of the RF cavities.

Figure 3 presents the first phase of this sequence corresponding to the thermal shield cool-down.

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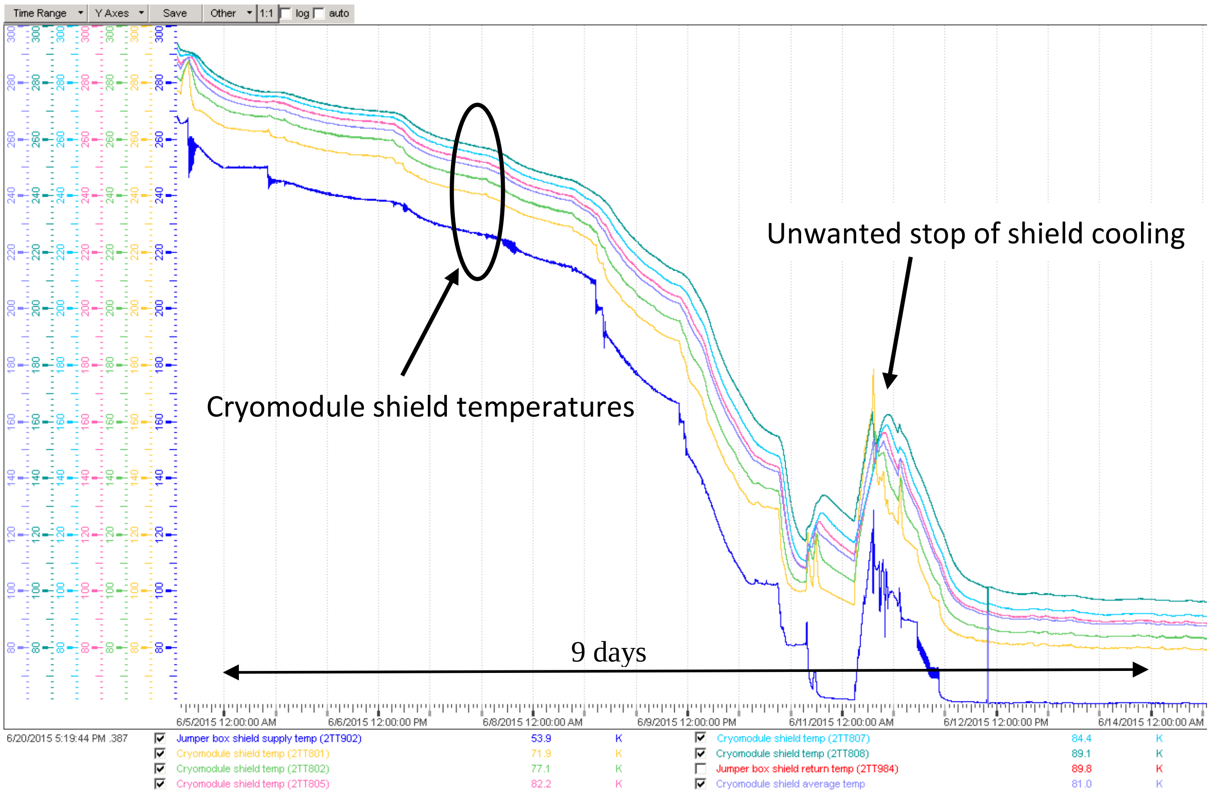

Figure 3. Thermal shield cool-down from ambient temperature down to 90 K.

The first phase started on 05th June 2015 and was finished one week later, when all shield temperatures were below 90 K. During this phase, the supplied helium was maintained constantly 50 K lower than the maximum temperature measured on the shield in order to avoid excessive thermal stresses induced by a large temperature gradient in the circuits. Cavities cooled down by radiation.

Once the thermal shield has reached its nominal working conditions, the second phase of the cool-down started, with the cooling in series of the supporting frame and the helium reservoir down also to about 90 K. A maximum temperature gradient of 50 K was also imposed during that second phase.

After all cryo-module inner components have reached a temperature below 90 K, the supply of liquid helium (LHe) initiated the third phase of cooling until LHe appears in the horizontal reservoir.

Figure 4 shows the cool-down of cavities down to 4.5 K.

From the cryogenic point of view, steady-state operation at 4.5 K was reached on 18th June 2015.

The first cryo-module is presently (June 2015) undergoing commissioning tests in the HIE-ISOLDE tunnel to determine, among other parameters, the individual quality factor (Q-factor) of its five cavities.

4. Next important milestones

Once the beam commissioning will have been performed in September 2015, physics runs with the first HIE-ISOLDE cryo-module will start in October 2015.

At the same time, the assembly of the second cryo-module is underway since May 2015 and should be completed by November 2015. The second cryo-module will be installed and commissioned in the HIE-ISOLDE tunnel by April 2016.

The assembly of the third and fourth cryo-modules are expected to cover the whole year 2016.

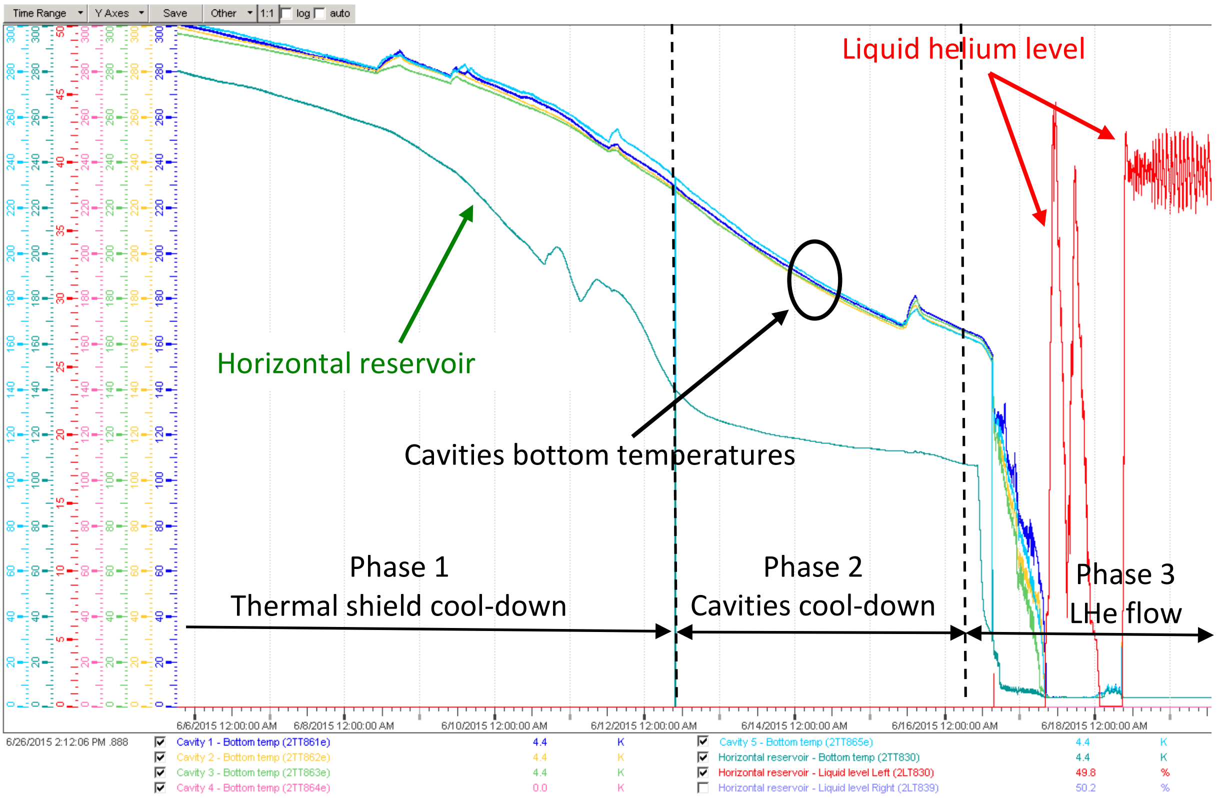

Figure 4. Cavities cool-down to 4.5 K.

5. Conclusions

The complete helium cryogenic system has been successfully commissioned, except the filling and performance test of the 2000-liter dewar due to lack of time.

The first cryo-module has been cooled down to 4.5 K in twelve days, a rather long period interrupted by different measures to check different parameters, e.g. cavities and solenoid alignment with respect to the beam line.

Performance tests of the helium cryogenic system will take place in September 2015, together with the beam commissioning.

Physics runs with the first HIE-ISOLDE cryo-module are scheduled by the end of 2015.

Acknowledgments

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