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HIE ISOLDE cryogenics operation results and recent upgrades

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Abstract. The High Intensity and Energy ISOLDE (HIE-ISOLDE) enables the acceleration of medium to heavy radioactive isotopes at energies reaching 10 MeV per nucleon, a significant increase from the previous configuration limited to 2.8 MeV per nucleon. The journey towards this achievement involved a progressive deployment of radiofrequency cryomodules starting in 2015. In 2018, the final configuration was reached with successful operation of four high-beta radiofrequency cryomodules in series. This paper presents an overview of the operational results over the last 8 years, but especially focuses on the recent enhancements made in 2023 to the cryogenics system and tested during the last physics run. A comprehensive overhaul of the cryomodule operation process was implemented to minimize restart times following unexpected interruptions, to facilitate operators handling and to harden the process control structure. Hardware modifications have also been implemented to improve equipment availability and were successfully commissioned.

1. Introduction

The High Intensity and Energy Isotope Separator On-Line DEvice (HIE-ISOLDE) project started in 2010. The main aims are boosting the energy of the post-accelerated beams and increasing the production of radioactive beams with higher intensity and energy of the proton injector. The new superconducting linear accelerator (LINAC) first deployed one superconducting radiofrequency cryomodule (CM), operational in 2015 [1]. Successive upgrades were applied from 2016 to 2018, with installation and commissioning of an additional CM every year. In spring 2018, with the installation of the fourth superconducting high-beta cryomodule in series, figure 1, HIE ISOLDE reached an important milestone by completing the second phase of the energy upgrade project.

The cryogenic system consists of a refurbished cryogenic plant of 630 W at 4.5 K without LN2 precooling capacity that was recovered for budgetary reasons from the former ALEPH (Apparatus for LEp PHysics) experiment operated from 1989 till 2000 on the LEP (Large Electron-Positron collider), and a new cryogenic distribution system (CDS). Figure 1 shows the layout of the cryogenic components: a 30m-long transfer line (TL) that connects the cold box (CB) to a 2’000-liters liquid helium storage dewar and six distribution valve boxes (i.e. jumper boxes - JB), one for each CM, and a return box (RB) containing bypass valves at the end of the TL.

After successive installations of one cryomodule each year from 2015 to 2018, followed by commissioning campaigns that were perturbed by major issues [2], the successful final commissioning in 2018 underlined that the refurbished cryogenics station is adapted for the cool down and operation of up to four cryomodules.

The control logic of the cryogenics station has been completely revised in 2022 and its commissioning has been made during the 2023 cool down with the four cryomodules. A compressed air back up system has also been installed during the HIE ISOLDE shutdown end-2022 to beginning-2023 and tested before the cryoplant restart.

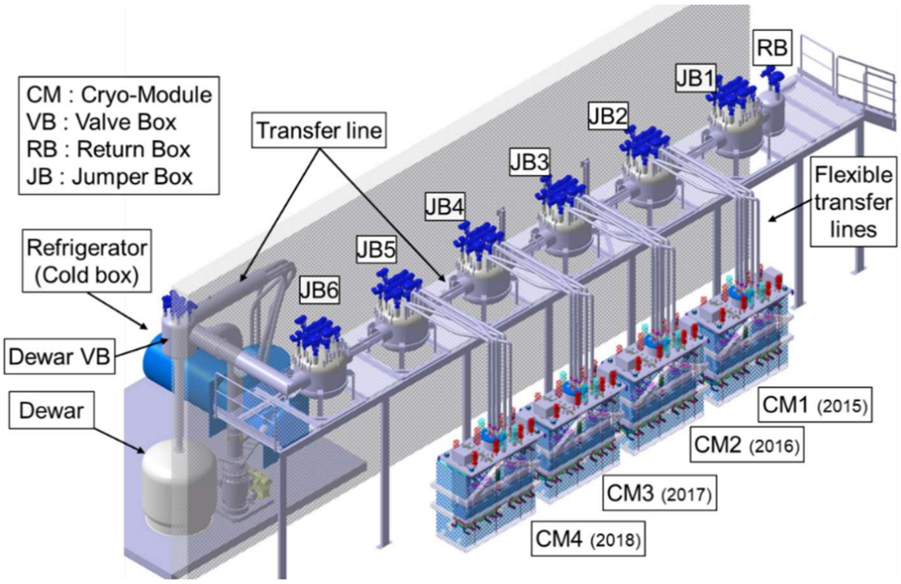

Figure 1. HIE-Isolde Cryogenic Distribution System (CDS) at the end of Phase 2 (2018)

2. HIE ISOLDE cryogenics process for operation from 2015 to 2022

2.1 Description of the former cryogenics control process

For the very first cool down performed in summer 2015, with one cryomodule in HIE ISOLDE bunker, a first version of cryogenics process control was already operational and commissioned for the compressor station and the refurbished cold box. However, no automated process was available neither for the transfer lines, nor for the jumper boxes. Henceforth, significant manual tunings and permanent careful follow up of the key parameters were mandatory all along the continuous cool down phase of about three weeks.
In 2016, a first automated cryogenics process version has been developed and commissioned for the cool down and operation with two cryomodules. Improvements were progressively applied for the physics run of 2017 and 2018 [2]. The design and the development of the process control software are performed through the CERN UNICOS framework [3].
The control logic was based on a standard stepper adapted to specifications for cool down and warm up of the RF cryomodule structures [4]. The specific CM design with common vacuum [5] imposes strong constraints for the lifespan of the superconducting LINAC. The concept allows a compact design and a simpler mechanical assembly [6], but it requires a slow cool down and warm up to respect temperature differences between the main radiofrequency cryomodules mechanical components: the shield, the supporting frame, the vessel, the cavities and the solenoid as shown in figure 2.

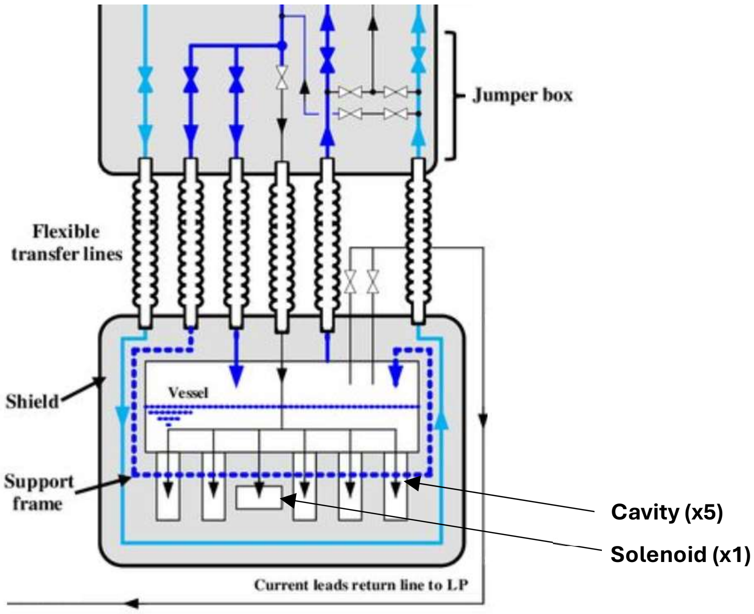

Figure 2. HIE-Isolde cryomodule main components and circuits description

2.2 Key cryogenics control process developments form 2015 to 2022

In 2015 and 2016, the cryomodules shields were cooled down in parallel of the cold box and the transfer line. After temperature stabilization of the shields, part of the circulating gas in shield's circuits was diverted to participate to the active cool down to about 110K of the frame, the vessel and finally the cavities and the solenoids.

In 2017, a first significant cold box control process improvement was applied to guarantee a progressive cool down of the cryomodules without diverting part of the cold gas from the shields but using the main vessel manifold. With this control logic the cryomodules are smoothly cooled down in parallel of the cold box thanks to a temperature difference controller implemented on inlet valve of the first turbine of the cold box set at 40K.

The same cool down principle has been retained for the upgrade in 2023, but the control logic has been revised as well as the process hierarchy.

3. HIE ISOLDE cryogenics process upgrade in 2023

3.1 Change of the process hierarchy and control logic refurbishment

The active cold helium circulation in the cryomodules must be continuously maintained during the physics run. A complete rework of the process structure, including alarms and interlocks has been made early 2023 to ease and optimise helium recirculation after a stop.

The hierarchy of the Process Control Objects (PCO) has been modified to simplify the system. The cryomodules are divided in three PCO as follow:

- SHJB, PCO for **SH**ield circuits with circulation from **J**umper **B**oxes,
- CAV (**CAV**ities) for the structure englobing Cavities, frame, vessels and solenoid,
- CL for the **C**urrent **L**eads.

The **J**umper **B**ox PCO (JB PCO) is the direct parent PCO in the hierarchy.

The stepper has been replaced by a more flexible structure with eight option modes.

The main options to be selected by the operators by means of a command mode on supervision are limited to:

- ''Off'',
- ''Operation'' up to CM filling then nominal operation with liquid helium level regulation,
- ''Warm Up''.

If the PCO of the considered object is turned on and the main requested measured values of the cryomodules like temperatures, temperature difference, pressures, levels, satisfy the requested conditions, then the process progresses through the last possible mode. This approach guarantees an automated evolution in a reduced timeframe as no manual intervention is needed and the process automatically evolves to the most advanced possible step. The operation mode includes a progressive evolution respecting the control of temperature differences, especially during the pre-cool down phase, where only shields are cooled by active gaseous helium circulation.

Before the on-site commissioning of the new process control, a validation testing platform so called ”mirror PLCs” (Programmable Logic Controller) was used by developers and cryogenic operators to check the logic specification compliance of the new control process implementations and to review the operation correctness. It also served as training purposes before the cool down.

A careful selection of the most adapted interlocks and alarms has been made to cross check all possible errors and faults without blocking the smooth progression of the process up to finalisation.

The implemented logic, with new controllers and increased robustness in case of sensors failure, allows for a more autonomous recovery of the station in case of breakdown. The significant progress of the software production process for CERN's cryogenic control applications [7] directly contributed to make such a control more reliable for HIE ISOLDE.

3.2 Commissioning results in 2023

The new control process was commissioned during the CM cool down, starting in 2023 March 9th. The four CM have been cooled down in parallel, respecting the main phases.

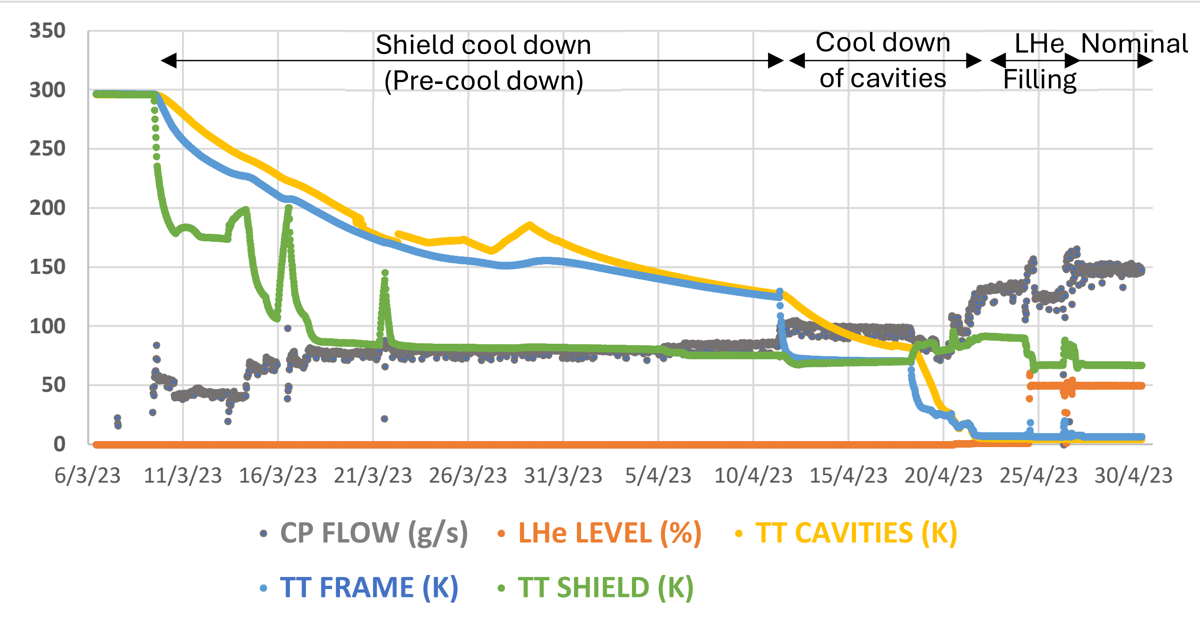

Figure 3. HIE-Isolde cool down in 2023 with four radiofrequency cryomodules (51 days total)

In figure 3 is presented the total cool down period of 51 days, including several sequences with no active cool down, as requested by Users, to perform RF tests and conditionings of the multipacting levels at low fields and stable temperatures. These requests imposed breaks in the cool down phases. Consequently, the total cool down period from March 06 to April 26 (51 days) is much longer than the effective duration of approximately 20 days if the active cool down would not have been stopped for radiofrequency conditioning.

The effective durations, taking into account only the active cool down periods, for the successive cool downs over the last years are reported in table 1.

Table 1. Effective cryomodules cool down durations (no physics run in 2019 nor 2020)

i.e : Necessary active cool down duration taking into account no breaks in the cool down sequence.

Physics run	2016 (2xCM)	2017 (3xCM)	2018 (4xCM)	2021 (4xCM)	2022 (4xCM)	2023 (4xCM)	2024 (4xCM)
300K down to 5K (days)	15	9	11	17	18	20	19
LHe filling	5 days	8h	10h	18h	20h	20h	20h

During the physics Run 2023, no perturbation was due to the new process. However, in June 2023 the run was perturbed by a global electrical cut on CERN Meyrin site. The cryogenics operating conditions (Cryo-OK) was recovered approximately 12 hours later and the automated process eased the reconnection to the CM. In August, the cryo-OK signal was perturbed several times for ~2 hours due to temperature interlocks during RF parameters modifications. Finally in September 2023, the cryo-OK signal was lost for 13 hours. At the origin of that unexpected stop, a water cut impacted HIE ISOLDE during several hours and we decided to intervene in parallel on the compressor to replace an exchanger of the gearbox and to remove a clog in a water circuit. Thanks to the process, the transitions for each phase of the re-cool down was easier. These improvements led in 2023 to a cryogenics availability of 99.4% with 4 cryomodules in operation.

Table 2. Cryogenics availability (no physics run in 2019, 2020)

Physics run	2017 (3xCM)	2018 (4xCM)	2021 (4xCM)	2022 (4xCM)	2023 (4xCM)
Availability (cryo-OK)	100%	98.6%	99.0%	98.5%	99.4%

HIE ISOLDE cryogenics availability over the last 7 years are detailed in table 2.

4. New compressed air back up system

It was shown that, among the external cryogenics causes, 25.2% of the HIE ISOLDE cryogenics availability losses from 2018 to 2023 were related to compressed air defaults. It represents 16.6% of the total causes, i.e. internal to cryogenics system and external. As the average cavity temperature rises to ~25K after only 13 hours of stop, a palliative solution was proposed by implementing a compressed air back up system. Its capacity should allow for maintaining in operation about 120 controlled valves distributed in 3 buildings. A compressed air rack offering a total buffer of 120m3, has been installed in the compressor building. The system was successfully tested before the cool down in 2023. Estimations made during this test revealed that it should compensate for a stop of the normal compressed air system during approximately 6 to 8 hours, but a full test until emptying of the rack was not performed to confirm that evaluation.

5. Conclusions

The process control with completely renewed architecture for the HIE ISOLDE CM cool down has been successfully commissioned in 2023. Several reconnections from cold box to cryomodules were necessary during the run in 2023, especially due to several utility losses. These events were finally opportunities to demonstrate the efficiency and robustness of the new process control, especially by facilitating the tasks for the operators and bringing robustness for cryogenics operation. A compressed air back up system was also commissioned to compensate for possible failure of the main system, as it was at the origin of critical stops in the past years. That system will be an efficient back-up during 6 to 8 hours. The cool down beginning 2024 with four cryomodules confirmed the efficiency of the automated process.

6. Acknowledgments

Samuel Kacej was strongly involved as technical student for cryogenics group at CERN from September 2022 to October 2023 in the process overhaul of the four HIE ISOLDE cryomodules and Cold Distribution System.

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