STATUS OF RADIOACTIVE ION BEAM POST-ACCELERATION AT CERN-ISOLDE

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Abstract

The HIE-ISOLDE project (High Intensity and Energy ISOLDE) reached an important milestone in September 2016 by accelerating radioactive ion beams at 5.5 MeV per nucleon (MeV/u). This is the first stage in the upgrade of the REX post-accelerator, whereby the energy of the beams was increased from 3 to 5.5 MeV per nucleon for A/q = 4.35. The facility will ultimately be equipped with four high-beta cryomodules that will accelerate the beams up to 10 MeV per nucleon for the heaviest isotopes available at ISOLDE.

The first two cryomodules of the new linac, each hosting five superconducting cavities and one solenoid, were commissioned in August 2016. Besides demonstrating the experimental capabilities of the facility, this successful first run validated the technical choices of the HIE-ISOLDE team and provided a fitting reward for eight years of rigorous R&D efforts. At the start of 2018, HIE-ISOLDE is expected to complete the energy upgrade, reaching 10 MeV/u and becoming an attractive facility for a wide variety of experiments.

This contribution focuses on the results of the commissioning and operation, highlighting the main technical issues that arose.

INTRODUCTION

In September 2016, radioactive ion beams were accelerated in the upgraded ISOLDE facility to energies up to 6.7 MeV/u (A/q = 3) for the first time. This important milestone was the result of a long-standing effort on the part of the HIE-ISOLDE project to increase beam energy and, by that extension, the range of experiments and studies that can be conducted at the facility. At the time, the HIE-ISOLDE linac was equipped with two high-beta cryomodules, each containing five superconducting RF cavities [1] and one superconducting solenoid.

Following the successful commissioning campaign and physics run of 2016, the HIE-ISOLDE project continued as planned, with the addition of one more high-beta cryomodule, the installation of the ISOLDE Solenoidal Spectrometer (ISS) and major consolidation (addition of 3rd experimental beam line) and modification works at the services and systems of the facility. The commissioning campaign for the 2017 physics run is now under way and experiments are expected to start in early July. Plans for the 2018 phase of the upgrade have also been laid down.

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2016 COMMISSIONING & OPERATIONS

Before the start of hardware commissioning, the already installed cryomodule (CM1) was removed and taken to the assembly hall, where it was vented in an ISO5 clean room and fitted with new RF couplers. One of its cavities was also removed and rinsed, as it had shown mild indications of field emission. In May 2016, CM1 was added again to the linac along with the second cryomodule (CM2). Due to extended works on the cryogenic systems, the cooling of the two cryomodules had to be carried out in several stages, interspersed with floating periods. Multipacting levels at low field (up to 60 kV/ m) were conditioned when cavities reached 200 K. In CM2, a spontaneous rise of vacuum pressure was noticed after a few days at 4.5 K; pressure was stabilised at 10^{-9} mbar, but investigations could not pinpoint the origin of the increase. When the cool-down process was completed, cavities were tuned close to the target frequency and then couplers were moved to reach critical coupling at superconducting state in order to perform precise RF tests at cold. The measurements (Fig. 1) revealed that all cavities, except the first and the fifth in CM1, reached the expected accelerating field of 6 MV/m, close to the nominal power dissipation of 10 W and, notably, their performance exceeded the performance demonstrated in vertical tests. The degraded performance of the two cavities, which were found to emit X-rays above 3.5 MV/m, limited their maximum fields to 3.5 and 2.5 MV/m respectively. A suitable optics solution was found to permit the physics run and, after the end of the experiments, the two cavities underwent helium processing in situ, improving RF performance to 5 MV/m.

Following the Q-E measurements, the LLRF loops were set up individually, with their operational bandwidths ranging from 5 to 10 Hz depending on the cavity. A strong perturbation caused by extra heat load in the cryogenic distribution system and correlated with the control system of the cryogenics plant posed challenges in achieving stable operation. However, the problem was successfully tackled by changing the operational conditions.

During the commissioning of the superconducting solenoids, a short circuit to ground was observed in the circuit of the CM1 magnet. Investigations revealed that the fault was located in one of the busbars. The issue was addressed by displacing the connection to the ground from the power converter to the current lead. Magnetic stored energy was limited by reducing the maximum operating current to 50 A, which was adequate for good beam transmission through CM1 for the expected emittances. The second solenoid achieved its nominal current of 110 A, after a training quench at 60 A.

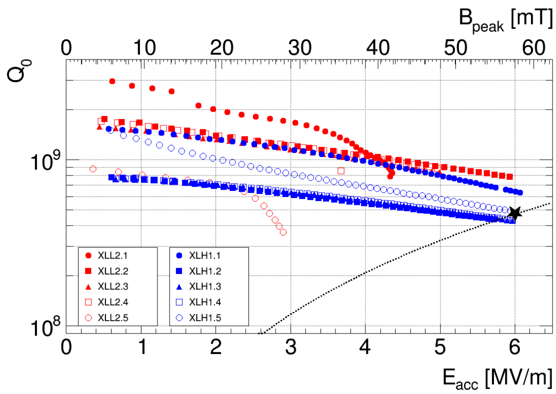

Figure 1: Q vs E_{acc} curves of diode sputtered cavities, data from July 2016. Label XLL2 refers to CM1 and XLH1 to CM2.

The MATHILDE (Monitoring and Alignment Tracking for Hie-IsoLDE) system was used to monitor the positions and alignment of the active elements. An expected vertical shift of approximately 4.3 mm was observed, caused by the thermal contraction of the supporting structure, while lateral movement was minor. See [3, 4] for more details on the 2016 hardware commissioning.

Beam commissioning started as soon as alignment work was completed. The set-up beam consisted of a combination of helium, carbon, oxygen, neon and argon with A/q = 4. It was drifted from the REX post-accelerator through the cryomodules of the HIE-ISOLDE linac and into the high-energy beam transfer lines (HEBT) to commission the diagnostic boxes. Phasing of the superconducting cavities followed, confirming the accurate calibration of the accelerating gradients. Several measurements were performed as part of the beam commissioning with the various diagnostic elements of the linac. Silicon detectors, the first dipole of the HEBT and scanning slits were used to determine the beam energy and energy spread (Fig. 2), beam current and transverse beam profiles. More information on the 2016 beam commissioning can be found in [2, 3, 5].

The first experiment of the 2016 physics run used a $^{110}Sn^{26+}$ beam, post-accelerated to 4.5 MeV/u, to measure excitation states of tin isotopes. Five more experiments followed, investigating a wide range of isotopes, from ^{9}Li to ^{142}Xe, and producing a rich harvest of data to the experimental teams. In total, six radioactive ion beams and three stable beams were sent to the experimental stations [2]. Data from the ^{142}Xe run (Fig. 3) showed that the upgraded facility clearly enhanced the yield for multiple Coulomb excitation compared to REX-ISOLDE, provided a very clean spectrum and almost pure beam. The post-accelerator presented a high degree of reliability and ran for 685 hours with radioactive beams. Following the physics run, recommissioning works took place, refining the overall performance of the linac. The performance of the two degraded cavities was improved thanks to in situ helium processing and leak detection at warm was performed at CM2 to identify the origin of the vacuum pressure increase. The amount of desorbed gas, the gas load at room temperature during accumulation tests and Helium leak detection did not show any difference between CM1 and CM2. It was concluded the different behaviour between CM1 and CM2 was related to thermal oscillation related to the cryogenic system.

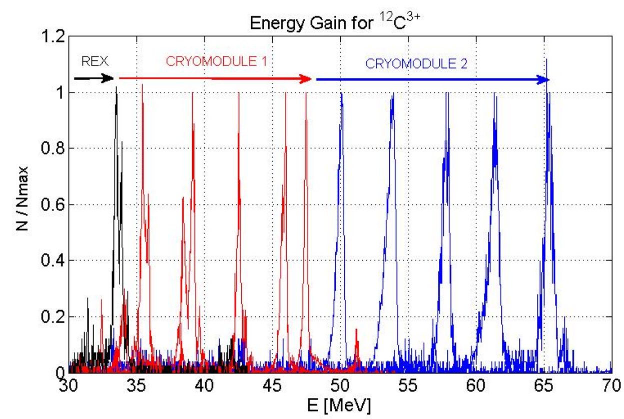

Figure 2: $^{12}C^{3+}$ beam energy spectrum for all cavities [2].

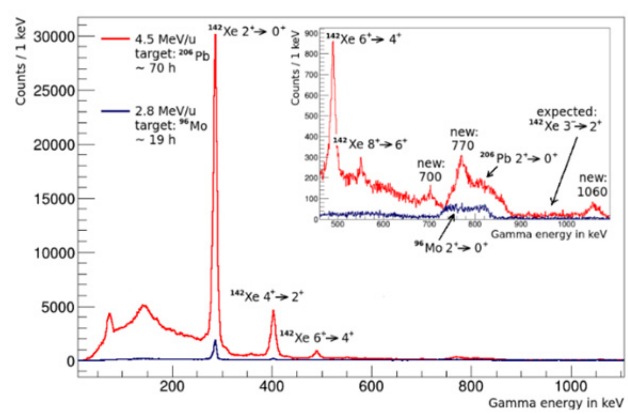

Figure 3: Doppler-corrected gamma ray spectrum of 4.5 MeV/u ^{142}Xe beam Coulomb excited on ^{206}Pb target (in red) and the equivalent gamma spectrum for 2.8 MeV/u ^{142}Xe beam on a ^{96}Mo target (in blue). The higher energies of HIE-ISOLDE markedly improve the population of higher-lying states (Courtesy of C. Henrich) [6].

INSTALLATION WORKS IN 2017

During the Extended Year-End Technical Stop (EYETS) at CERN, various installation and modification works were performed at the HIE-ISOLDE linac, HEBT and cryogenics system. The third cryomodule (CM3) was transported to the ISOLDE hall and added to the linac on 24 January (Fig. 4).

Work on the HEBT also included the extension of the second beam transfer line (XT02) for the installation of

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the ISOLDE Solenoidal Spectrometer (ISS). The 4 T ISS magnet, a decommissioned MRI scanner, underwent an extensive programme of preparatory work and was cooled to liquid helium temperatures before being moved to the ISOLDE hall in early March. In preparation for its installation, the experimental set-up of XT02 was dismounted and removed. With ISS in position, it was possible to start the installation work for the third beam transfer line.

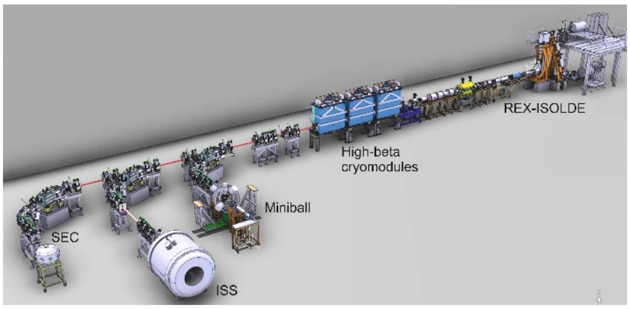

Figure 4: A 3D visual of the HIE-ISOLDE linac, composed of three cryomodules, and the three experimental stations in the HEBT. At the end of the first beam line, XT01, Miniball is located, at the second (XT02) the ISOL Solenoidal Spectrometer, ISS, and the third, XT03, is reserved for movable setups. In the drawing, XT03 is occupied by the ScattEring Chamber, SEC [2].

In the context of the EYETS, extensive work was done on the cryogenic system, which consists of a compressor station, a LHe refrigerator (630 W at 4.5 K) and a Cryogenic Distribution System (CDS) [7]. The compressor station underwent 10,000 hours of preventive and corrective maintenance. Consolidations were performed to improve its operation, including reviews of the safety chains and the logic of the control system. As a result, the compressor reached its nominal performance and the process and control system were completely updated. The CDS required several improvements, as major issues were identified during the cool down and commissioning of the cryomodules in 2016, namely strong oscillations in the 4.5 K return line. Analysis indicated that heat loads were three times higher than expected, but investigations in situ did not show evidence of the problem at the time. In February 2017, the jumper boxes were opened to allow endoscopic examinations of the transfer line. These revealed that the cause for the increased heat loads was the contact of the 4.5 K process pipes with the shield. In addition, holes in the multilayer insulation system were also found. To mitigate the issue, all jumper boxes were opened and spacer material was inserted to remove direct contacts. The consolidation of the liquid helium process pipe was successful, but it was not possible to fully correct the contact in all points of the gaseous helium process pipe, as there was a risk of breaking due to the high forces required. There are plans to redesign and repair the CDS, scheduled for YETS 2017-2018. More information on the performance of the HIE-ISOLDE cryogenics system can be found in [8].

2017 COMMISSIONING

Hardware commissioning began on March 20 with warm tests. Cool-down started one week later and all cavities reached 4.5 K on April 18. Multipacting conditioning and radiofrequency measurements were done on all 15 cavities (Fig. 5). While the overall RF performance is very good, two cavities were found to suffer from field emission: the fifth cavity of CM1 (XLL2.5), which was known to be vulnerable from the previous year, and the second of CM3 (XLH2.2). Their field emission onsets were at 4 MV/m and 3 MV/m respectively. Once again, a frequency perturbation was detected in the superconducting cavities, correlated to the liquid helium temperature and pressure oscillations, although it was less severe than the one observed in 2016. As the cavity frequency shift was slow (repeating 10–20 minutes) and limited to only about 10 Hz, it could be easily corrected by the cavity tuning system. The cryogenics capacity tests performed recently indicate that the consolidated cryoplant is now operating at nominal conditions and can accommodate a fourth cryomodule.

In the next few weeks, the LLRF system will be set up and the solenoids will be powered. Beam commissioning at the HIE-ISOLDE linac will start at the end of May with the physics run scheduled to begin in early July and last until November.

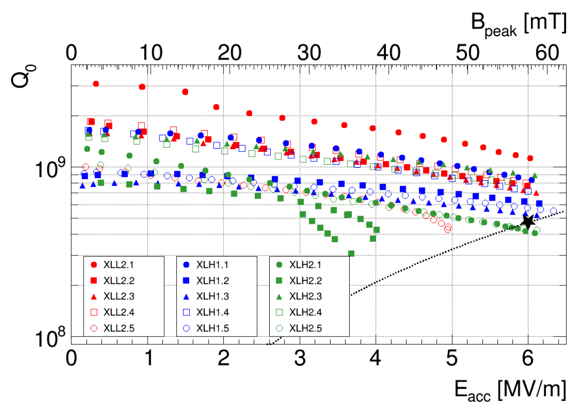

Figure 5: Q vs Eacc curves of the HIE-ISOLDE linac cavities.

OUTLOOK

A busy physics run is in line for 2017 with 13 scheduled experiments in 136 days. Most of them plan to use the Miniball spectrometer, mainly to conduct Coulomb excitation studies, while others will take advantage of the scattering chamber and visiting setups. A wide range of isotopes will be studied, from ^{9}Li to ^{206}Hg [9].

Phase 2 of the HIE-ISOLDE energy upgrade will be completed in 2018, with the installation of the fourth high-beta cryomodule, which is currently being assembled. Cavity production for CM4 has almost been concluded. It will be ready for bunker tests in September. Its addition to the linac will allow beam energies up to 10–15 MeV/u, opening up new physics opportunities and making ISOLDE the only facility in the world capable of accelerating medium to heavy radioactive isotopes in this energy range.

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