ASSEMBLING EXPERIENCE OF THE FIRST TWO HIE-ISOLDE CRYO-MODULES

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Abstract

The assembly of the first two cryo-modules (CM1 and CM2) of the new superconducting linear accelerator HIE-ISOLDE (High Intensity and Energy ISOLDE), located downstream of the REX-ISOLDE normal conducting accelerator, started one year and a half ago. After a delicate assembly phase in the cleanroom which lasted nine months, the first cryo-module was transported to the ISOLDE hall on 2 May 2015 and connected to the existing REX-ISOLDE accelerator, increasing the energy of the radioactive ion beams from 2.8 to 4.3 MeV per nucleon. The superconducting linac supplied the CERN-ISOLDE facility with radioactive zinc ions until the end of the proton run in November 2015. At the beginning of 2016, the second cryo-module was installed in the machine, increasing the energy to 5.5 MeV per nucleon.

During commissioning of the first cryo-module in summer 2015, it was found that the performance of the RF superconductive cavities was limited by the over-heating of their RF couplers. The decision was taken to refurbish CM1 and reinstall it at the end of April.

In this paper, we present the challenges faced and the experience gained with the cleanroom assembly of the first two cryo-modules, especially the construction of the SC RF cavities and their RF ancillaries.

INTRODUCTION

The HIE-ISOLDE project involves a major upgrade of the present REX-ISOLDE linac. To increase the beam energy from 3 MeV/u to 10 MeV/u, it is planned to install 4 cryo-modules based on high β superconducting Quarter Wave Resonators (QWR), made of Nb coated on copper cavities [1]. Each cryo-module is composed of five cavities and one superconducting solenoid operating in a common vacuum at 4.5 K [2]. This constraint imposes to take extreme care of the cleanliness during the preparation and the assembly of all the cryo-module parts.

The first cryo-module (CM1) was mounted in 27weeks and was successfully installed last year. It demonstrated that the assembly process in place is effective [3]. The beam vacuum reached 10^{-11} mbar and all cavities were conditioned without difficulties (weak multipacting and no field emission) until 6 MV/m.

During the commissioning of CM1, a performance limitation was observed due to an over-heating of the RF power coupler [3]. After studies and testing an upgraded [4] version was designed to improve the heat dissipation. The new couplers were installed on CM1 during the first shutdown (beginning of 2016) and implemented for the other cryo-modules.

In parallel, due to the difficulties encountered with the cavity production and in order to face a performance degradation, a new cavity design study aimed to simplify the manufacturing of the substrates has been launched.

This paper will present the HIE-ISOLDE cryo-module assembly, the cavity production for CM1 and CM2 and give a brief status of the new cavity design.

HIE-ISOLDE CRYOMODULE ASSEMBLY

The choice of a common vacuum design (insulation and beam vacuum are the same) implied the need to perform the whole cryo-module mounting in a controlled area, to reduce the contamination risk (dust, metallic particles…). All preparations and the assembly proper are done in soft wall cleanrooms ISO 5. The main clean room is equipped with a horizontal laminar air flow and a dedicated assembly tower capable to precisely handle the heavy equipment [2].

All pieces are degreased and cleaned with alcohol, blown off with filtered N_2 gas, and double packed with plastic bags before entering the cleanroom. The standard cleanroom preparation process could not always be applied due to the size and the weight (few tonnes) of some pieces. Anti-dust rinsing with ultrapure water was only done on the cavities at a pressure of 6 bars before final installation.

Figure 1: Cavities installed on the cryo-module frame in the cleanroom ISO 5.

The assembly sequence is divided in 14 main steps described in detail in assembly procedures and in [2]. The superconducting cavities are installed at the end, in order to minimize the risk of contamination and to make it easier to

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dismount the cavities in case the cryo-modules need to be opened during the life of the accelerator.

The sub elements are mounted vertically, suspended to the cryostat top plate which is hanged to a mobile frame (Figure 1) [2]. To keep control of the work environment during the long assembly time (6 months), particle counting is realized in the cleanroom at different steps along the assembly process of the cryo-module. Measurements done during the cavity mounting on CM1 and CM2 confirmed that the cleanroom standard was preserved in the ISO 5 class range.

EXPERIENCE GAIN ON CM1 ASSEMBLY

The complete assembly of the first cryo-module lasted 27 weeks. It was a big challenge mainly due to the fact that the common vacuum concept was completely new at CERN, and also from the time schedule point of view. The cryo-module was finally installed in the linac on time (in May 2015) for the commissioning campaign and the first physics run.

During the preparation and the assembly of the cryo-module, many difficulties were encountered with different origins (manufacturing errors, mechanical problems, tooling ergonomics, instrumentation fragility, leak tightness, logistics). Furthermore, the team of technicians working for the first time in a cleanroom had to learn all from scratch.

From CM1 and during CM2 mounting, the assembly team continued to gain experience in the cleanroom environment and with the cryo-module assembly specificities. Tooling, assembly procedures, and logistics were updated and improved. The number of non-conformities (NC) was divided by 2, with the same distribution (61 NC for CM1 against 30 NC for CM2). CM2 was assembled in 24 weeks, including the late delivery of the last RF cavity and the integration of the upgraded version of RF power coupler [3].

At the beginning of 2016, it was decided to refurbish CM1 in order to change the faulty couplers and to rinse the cavity 2, which showed field emission close to 5.5 MV/m. This operation lasted 9 weeks. The cryo-module was vented and opened in the cleanroom.

During the commissioning phase, in July 2016, it was observed that the two external cavities of CM1 were contaminated. Both showed strong field emission at 4.5 MV/m. This could be explained by the fact that these two cavities are more exposed to the venting flow and the Nitrogen gas speed flow was probably too high. Helium processing will be attempted after the 2016 physics run in order to recover these two cavities. From this observation it was decided to rinse systematically all cavities at any CM opening.

CAVITY PRODUCTION FOR CM1 AND CM2

The HIE-ISOLDE copper substrates are produced in industry. After reception, they are tuned, coated and RF tested at CERN. As a rule, six weeks are needed for the production and the validation of one cavity after reception at CERN. The production workflow is shown in figure 2.

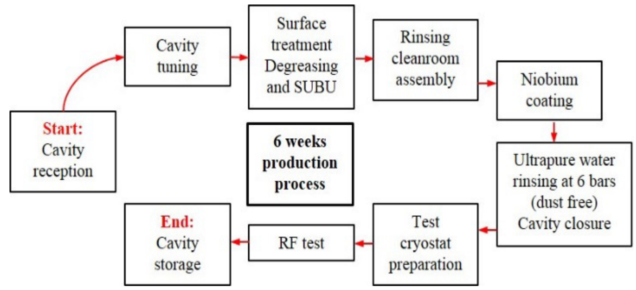

Figure 2: Summary of the 6 weeks cavity production workflow from the copper substrate reception to storage for the cryo-module assembly.

The HIE-ISOLDE specifications call for a Q_0 value of 5.10^8 without field emission at 6 MV/m (corresponding to a dissipation of 10 W) at 4.5 K, under vacuum and at the resonant frequency of 101.28 MHz. Figure 3 shows the Q(E) curves of the cavities XLL2_CAV and XLH1_CAV respectively installed in CM1 and CM2, as measured in the vertical test stand.

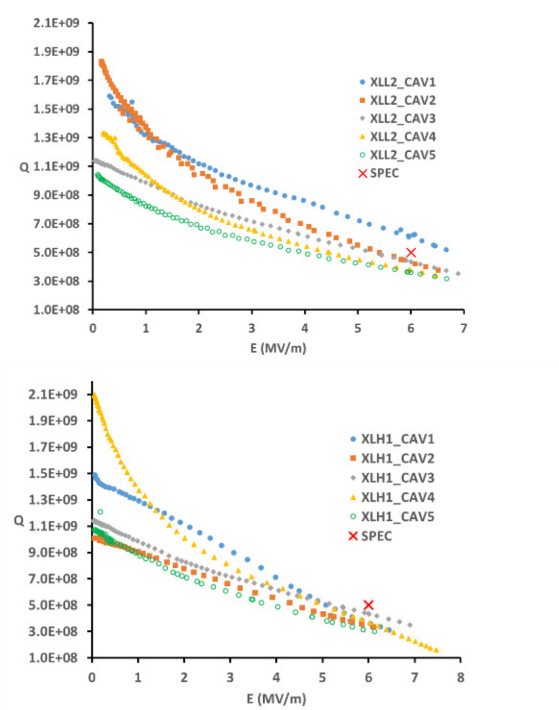

Figure 3: Cavities performances installed in CM1 (XLL2_cav) and CM2 (XLH1_CAV).

Cavity performances in the vertical tests are just below the specification value.

During the commissioning of CM1 and CM2, a significant performance improvement was observed, and most cavities met the specifications [3]. The explanation retained is that the performance gain was the effect of the more homogenous cooling though Tc in the cryo-module [5]. This behaviour was also observed during the vertical test by reducing the thermal gradient on the cavity during the cooldown close to superconducting transition.

NEW CAVITY DESIGN

In the baseline design, the cavity is made of two parts, the inner conductor and the main body. The two parts are assembled by shrink fitting and electron beam welded. The cavities supplied by industry presented defects like cracks, holes or weld projections on the copper surface. It was shown that these cracks can run deep in the bulk material (Figure 4). They are localised on the top part of the cavity close to the weld, in the peak magnetic field region. The defects are accentuated by the chemical etching process and could induce a cavity performance degradation and increase the risk of the niobium layer peel off.

These features probably find their origin in the internal stress and heat induced by at different stages of the manufacturing process, and in particular during the electron beam welding.

Figure 4: Microscopic pictures of the copper cavity substrate at the reception.

In order to improve the cavity performance and make the manufacturing easier, it was decided to launch a new design study, aiming at suppressing the weld. In the new design, the cavity will be machined in one piece from a bulk copper billet. The RF design was fully re-optimized taking into account the usual figures of merit for a superconducting resonator. The details of the design will be the subject of a dedicated paper. The new cavity parameters are shown in Table 1.

Table 1: New cavity design specifications

Frequency	101.28 MHz
Eacc	6 MV/m
βoptimum	0.12
R/Q	525 Ω
Epeak/Eacc	4.9
Bpeak/Eacc	98 G/(MV/m)
G = RsQ	30.79 Ω
U/Eacc2	0.214 J/(MV/m)2
Pc at 6 MV/m	10 W

The first machining test was done in July 2016. Figure 5 shows pictures of the copper bulk substrate inner surface at different positions. A smooth surface was obtained on the top part and some projections appeared on the cylinder part. This first attempt gave a promising result and showed that is technically possible to machine an entire cavity from bulk.

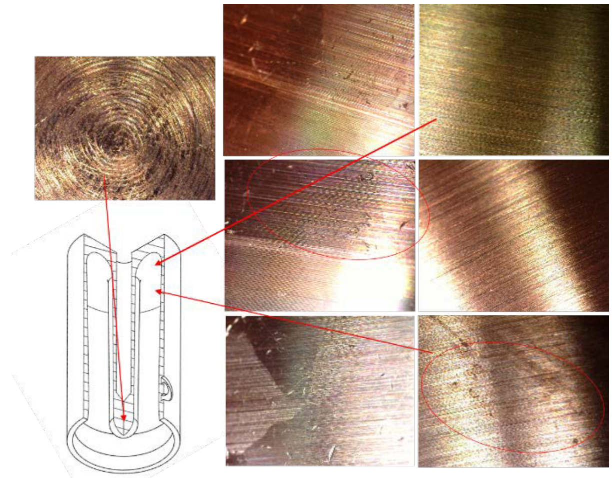

Figure 5: Optical inspection of the copper bulk cavity prototype surface at different positions after machining.

CONCLUSION

The first two high beta cryo-modules of the HIE ISOLDE superconducting linac were assembled and installed at CERN. A first physics run was successfully carried out in October 2015 with one cryo-module. In order to correct a design flaw in the fundamental coupler systems, the cryo-module had to be refurbished during the winter stop. The assembly procedures were refined in the light of the experience with the first cryo-module, and the second cryo-module was completed in less time and with less non-conformities. The cavity performance on line was systematically better than in the vertical tests, due to smaller thermal gradients during cool down. In spite of this, the series cavities performance is degrading since the start of the production, likely due to defects on the copper substrate close the EB weld on the high magnetic field region. In order to cope with this problem a new cavity design is being studied, which will allow to suppress the weld.

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