STATUS OF THE SUPERCONDUCTING RF ACTIVITIES FOR THE HIE-ISOLDE PROJECT

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Abstract

The planned upgrade of the REX ISOLDE facility at CERN will boost the energy of the machine from 3 MeV/u up to 10 MeV/u with beams of mass-to-charge ratio $2.5 < A/q < 4$. For this purpose, a new superconducting post accelerator based on independently phased 101.28 MHz Quarter Wave Resonators (QWR) will replace part of the normal conducting Linac. The QWRs make use of the Niobium sputtering on Copper technology which was successfully applied to LEP2, LHC and to the energy upgrade of the ALPI Linac at INFN-LNL. The status of advancement of the project will be detailed, limited to the SRF activities.

INTRODUCTION

The upgrade of the REX ISOLDE facility [1] relies on a new superconducting Linac to bring the energy of the radioactive beams from 3 MeV/u up to 10 MeV/u with beams of mass-to-charge ratio $2.5 < A/q < 4$.

The project is staged in three phases in order to optimize the beam delivery to the physicists and to take advantage of the scheduled shut down periods of the CERN accelerator complex. The first phase will consist in the installation of two cryomodules, each housing 5 high beta Quarter Wave Resonators (QWR) and a superconducting solenoid for beam focusing.

The core element of the HIE ISOLDE Linac is the QWR, which will make use of the sputtered Nb/Cu technology pioneered at CERN for LEP2 [2], and subsequently developed for the complex QWR shape in INFN-LNL for the energy upgrade of ALPI [3], [4]. The elliptical cavities in use at CERN were coated by magnetron sputtering at relatively low temperatures, whereas the QWR for ALPI were realized by bias diode sputtering at higher temperatures.

The design of the high beta cavity is reported in [5], the main parameters are listed in Table 1.

Work to set up a production chain for sputtered QWR started in CERN in 2008 and the early reached milestones are reported in [6], [7]. The most recent project schedule requires series production of the cavities to start at CERN in early 2013.

Besides the cavity itself, ancillaries like the power coupler and tuning system are being developed. This paper reports on the latest developments in the SRF frame, while a recent and detailed update on the whole HIE ISOLDE project is given in [8]

Table 1: Parameters of the high β HIE ISOLDE QWR

Frequency (MHz)	101.28
β (%)	10.3
Active length (m)	0.3
$\Gamma = Rs\ Q$ [Ω]	30.34
E_{acc} (MV/m)	6
Q_0 @ E_{acc}=6 MV/m	$5\ 10^8$
E_{apk}/E_{acc}	5.4
B_{apk}/E_{acc}(Gauss/MV/m)	96

STUDY OF CAVITY MECHANICAL TOLERANCES

The high substrate temperatures reached during the sputtering process called for a reconsideration of the mechanical tolerances for the manufacture of the cavity. Indeed, it was not clear to what extent the induced mechanical deformations would affect the beam quality. A study was launched in early 2012 to understand the effect of the misalignment of the internal conductor of the quarter-wave resonator on the beam. In previous error studies only misalignments of the ideal cavity were considered, see [9]. In the new study, the outer conductor of the cavity was assumed as ideal but the internal conductor was misaligned in each independent mode: Δx, Δy, Δz and $\Delta\theta_y$, where the magnitude of each error was parameterized at the beam ports. The misalignments were implemented by pivoting the internal conductor about its point of attachment at the top of the cavity. In fact, the field perturbation seen by the beam is dominated by the fringing electric fields in the vicinity of the beam ports. Moving the position of the drift-tube on the inner conductor could attain analogous results. Systematic RF simulations were performed with CST-MWS: many cavities were generated with regular increments in each independent type of misalignment; the field profiles on the axis were extracted and kick factors calculated. An example of these results is shown in Fig. 1.

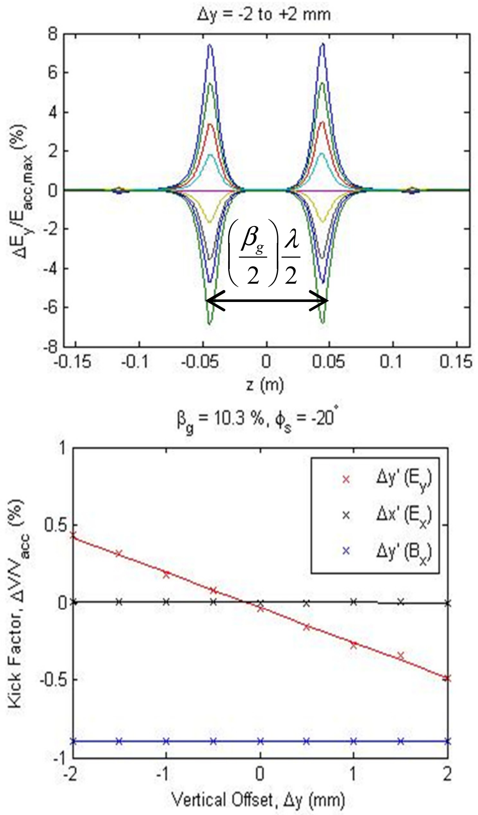

Figure 1: The perturbation to the vertical electric field seen on axis for Δy = -2 to +2 mm in steps of 0.5 mm (top) and the resulting kick factors (bottom), calculated at the geometric velocity of the cavity and at the nominal synchronous phase.

Table 2: Kick factors from misalignment of the inner conductor compared to the kick generated from the misaligned cavity.

Misalignment Type	**$\Delta V/V_{acc}$ (%/mm)** (β = 0.103, φ_s = -20 °)
Δx ($\approx 579.5\Delta\theta_z$)	0.20
Δy	0.21
Δz ($\approx 579.5\Delta\theta_x$)	0.25
Δx ($\approx 45\Delta\theta_y$)	1.10
Ideal cavity misaligned: Δx, Δy	0.41

The intrinsic magnetic field present in the nominal case is largely unperturbed with vertical misalignment and is compensated by systematically offsetting the beam axis in the aperture [9], [10].

As expected, the kick factors for misalignment of the inner conductor are of the same order of magnitude as the kick factors from the misalignment of the ideal cavity, at the level of a few tenths of 1%.

The kick factors per mm of misalignment are collected in Table 2, calculated at the geometric velocity and nominal synchronous phase. The most significant error is the rotation of the inner conductor about its axis. However, this is not likely to occur during the coating process.

In order to avoid any perturbation to the beam, the inner conductor should be aligned to within σ_{rms} = ±0.3 mm. The results allowed relaxing the previous conservatively set tolerances by a factor 5. First metrology results after sputtering indicate that this should be sufficient.

CAVITY PROTOTYPE TESTS

The workflow to produce and characterize a test Nb coated cavity is rather complex and labour intensive. The copper cavity substrate must first be stripped of its previous film; then the surface is chemically prepared, and rinsed with ultra-high purity water in a clean environment. The cavity is then mounted onto the coating system in a class 100 clean room. After pump down and baking the cavity is coated and left to cool down in the sputtering system. It is then removed from the vacuum chamber, rinsed again, dried, and transported to the cold test area where it is mounted into a test cryostat, equipped for the RF measurement at liquid helium temperature.

A total of 6 coating tests have been accomplished since the end of 2011, all with the bias diode method. Different sets of sputtering parameters were adopted as the coating system was being refurbished to allow for higher baking temperatures and higher sputtering power.

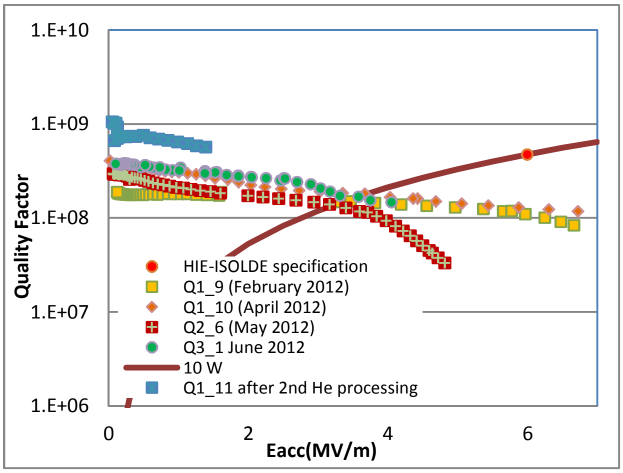

Figure 2: Performance of the test cavities in 2012. The red dot indicates the HIE-ISOLDE specification.

The cavity performances are displayed in Fig 2. Initially the effect of increasing the coating temperature was explored. Following [3] the process temperature was increased from previous 150 ºC to more than 600 ºC, with very encouraging results. The design accelerating field could be reached for the first time, although Q values were still a factor 3-4 below the specification.

The latest test was done at higher sputtering power and resulted in a further improvement of Q_0 without any degradation of the initial slope. The limit in accelerating field which appeared on this last cavity could be shifted up by applying He conditioning. It is believed to be due to a localized area and is still under investigation.

ANCILLARIES

The fundamental power coupler and tuning systems were designed and prototypes are available [11], [12]. However, a continuing effort is being put in reviewing and improving the existing designs, both on economic and on technical grounds.

The first model of fundamental power coupler showed some mechanical problems after several thermal cycles between warm and operational temperatures. At the end of 2011 a redesign of this element was launched and the first prototype was successfully tested in March 2012.

The new design is based on a stainless steel external body to minimize the thermal load on the cavity, an all in one machined copper antenna including N connector inner contact, a movable copper outer line sliding inside the external body, a Vespel© ring to ensure concentricity between the antenna and the outer line, a ceramic ring with an EB weld between outer line and outer N connector, sliding RF contacts, and a displacement system and guidance rails made of stainless steel and brass to ensure positioning of the antenna in the cryogenic environment. A schematic view of the new power coupler is shown in Figure 3.

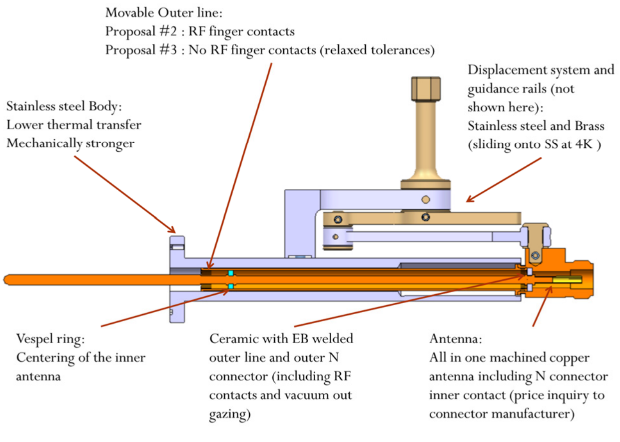

Figure 3: Prototype fundamental power coupler

The available tuning system will have to be tested in the next future with the final – stiffer – cavity design prototype, to assess the level of microphonics which is a necessary input to continue the development of a suitable low level RF system.

CONCLUSION

The SRF program for the HIE-ISOLDE project, focused on the development of Nb sputtered QWR generating 6 MV/m accelerating field at 10 W power dissipation was vigorously pursued in 2012 with encouraging results.

The effect of internal cavity misalignments was quantified and new tolerances were issued. This provided confidence that the high sputtering temperatures will not cause significant beam degradation through cavity deformations. Recent results marked a further step towards the achievement of the cavity specifications.

In parallel, work continues on cavity ancillaries, aiming to be ready for the first cryomodule in summer 2013.

ACKNOWLEDGMENT

We wish to thank all the technical staff at CERN who daily make possible the progress of this work.

The precious support of G. Bisoffi, E. Palmieri, A. Porcellato and S. Stark from INFN-LNL is warmly acknowledged.

We acknowledge funding from the Swedish Knut and Alice Wallenberg Foundation (KAW 2005-0121) and from the Belgian Big Science program of the FWO (Research Foundation Flanders) and the Research Council K.U. Leuven.

We would like to acknowledge as well the receipt of fellowships from the CATHI Marie Curie Initial Training Network: EU-FP7-PEOPLE-2010-ITN Project number 264330.

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