SC Nb SPUTTERED QWRs FOR THE REX-ISOLDE ACCELERATOR AT CERN: PROTOTYPE DESIGN AND MANUFACTURING

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Abstract

The HIE-ISOLDE activity aims to construct a superconducting linac based on 101.28MHz niobium sputtered Quarter Wave Resonators (QWRs), which will be installed downstream of the present REX-ISOLDE linac. The current design considers two basic cavity geometries (geometric β_0 = 6.3% and 10.3%) for which a mechanical and a chemical treatment and niobium coating design study has been performed. We report here on the status of the high β prototype cavity and sputtering chamber.

INTRODUCTION

In the framework of a general upgrade activity, named HIE-ISOLDE [1], of the Radioactive Ion Beams (RIBs) facility ISOLDE at CERN, a new superconducting linac based on QWRs (see Fig. 1) is planned [2]. Presently, the REX linac is delivering beams with mass to charge ratio of $3 \leq A/q \leq 4.5$ at a final energy of 3 MeV/u by means of a combination of several normal conducting structures. The energy upgrade will happen in two stages; in a first stage the final energy will be limited to 5.5 MeV/u while for the second stage the required final energy will be 10 MeV/u. The superconducting linac will also replace part of the normal conducting one so the energy span covered by the SC cavities will be between 1.2 and 10 MeV/u. In order to efficiently accelerate the beams in this velocity range two cavity geometries have been studied, one with a geometrical $\beta_0 = 6.3\%$ and the other with a geometrical $\beta_0 = 10.3\%$ (units are in % with respect of the speed of light). These values were optimized in order to allow an optimum acceleration efficiency for the heaviest A/q ratio (A/q=4.5).

CAVITY RF DESIGN

For the electromagnetic simulation of the two cavity geometries the `MWS` [3] code was used. The design aims at minimizing the peak surface electric field to accelerating field ratio ($E_{\text{pk}}/E_{\text{acc}}$), and the peak magnetic field to accelerating field ratio ($H_{\text{pk}}/E_{\text{acc}}$). The actual optimization is a trade-off between the RF performances and a simple shape that is better suited for the Nb sputtering. Another important aspect for this type of cavity is the magnetic steering effect due to a non-negligible magnetic field component at the beam axis. A special race-track shape, of the beam port (see Fig. 2) has been designed in order to minimize this effect. The beam axis position is in fact

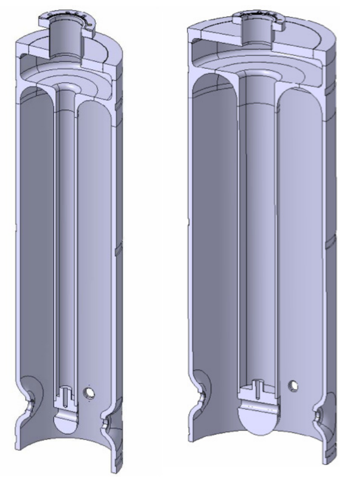

Figure 1: Low and high β cavities.

not centered vertically but shifted upwards by 4 mm. The vertical component of the electric field can in fact compensate the effect of the magnetic field on the beam so that the remnant steering kick is less then 0.1 mrad. The nominal gradient required is 6 MV/m over an active length of 195 and 300 mm respectively for the low and high β cavity. A residual resistance R_s of 50 nΩ is considered as a normally achievable value [4]. All the main cavity parameters are listed in Table 1

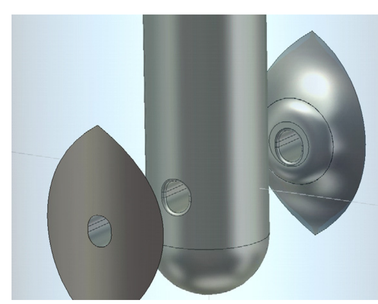

Figure 2: Details of beam port.

CAVITY MECHANICAL DESIGN

The basic technological choice for the HIE-ISOLDE cavities lies in the use of the Nb/Cu sputtering technology [5] and [6]. Compared to bulk niobium cavities, copper ones can easily be made massive and stiff in order to reduce microphonics effects, and to prevent the deformations due to the mechanical actions of the tuning system,

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Table 1: Cavity design parameters

Cavity	**Low β**	**high β**
No. of Cells	2	2
f (MHz)	101.28	101.28
β_0 (%)	6.3	10.3
Design gradient E_{acc}(MV/m)	6	6
Active length (mm)	195	300
Inner conductor diameter (mm)	50	90
Mechanical length (mm)	215	320
Gap length (mm)	50	85
Beam aperture diameter (mm)	20	20
$U/E_{acc}{}^2$ (mJ/(MV/m)^2	73	207
E_{pk}/E_{acc}	5.4	5.6
H_{pk}/E_{acc} (Oe/MV/m)	80	100.7
R_{sh}/Q (Ω)	564	548
$\Gamma = R_s \cdot Q_0$ (Ω)	23	30.6
Q_0 for 6MV/m at 7W	$3.2 \cdot 10^8$	$5 \cdot 10^8$
TTF max	0.85	0.9
No. of cavities	12	20

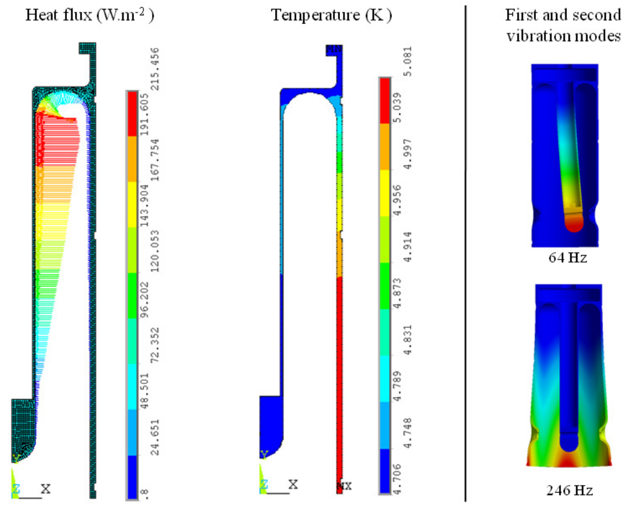

Figure 3: Heat flux input and resulting temperature distribution in the cavity, considering the thermal conductivity of copper RRR=100 and 4.5 K He I pool boiling cooling in convection and nucleate boiling regimes. First and second vibration mode shapes and corresponding frequencies.

at a fraction of the cost. This is done at the expense of the added complication of the sputtering of the niobium film, a technology that has been established for several years already. A further advantage of the thick copper substrate is that the liquid helium cooling circuits in the cryostat are simplified. The cavity can in fact be cooled only by pool boiling He I within the inner stem and over the top part, the thick external copper wall ensuring an adequate heat transfer by conduction. A thermal analysis has been carried out with a non-linear finite element model taking into account the dependence on temperature of the copper thermal conductivity and the helium film convection coefficient (Fig. 3). With the expected power dissipation distribution the temperature does not rise above 5.1 K, the design criterion being that the calculated temperature should always remain below 6 K, corresponding to an expected increment of surface resistance of about 20%. The study of the natural mechanical frequencies of the cavity also led to a choice of a thick-walled structure in order to increase the resonant frequencies, which should be beneficial in terms of RF operation.

Following CERN experience, the copper specifications used for manufacturing the cavity are Cu-OFE grade (UNS C10100), at least in the half-hard state, either in the form of rolled sheets or 3-D forged pieces, in order to minimize porosities which are harmful for the niobium film coating process. Common extruded pieces have an inferior degree of compaction, with pores aligned with the extrusion direction. Appropriate surface processes, which will be discussed later, must be applied prior to coating. Several critical manufacturing choices have been made in order to maximize the benefits of the cavity design such as not to perform any brazing on the main body of the cavity. Experience from INFN-LNL suggests in fact that the brazing alloy in the active RF regions may contaminate the niobium film. Second, copper softening due to the high temperature treatment would hinder the mechanical stability and accuracy of the cavity. Manufacturing the cavity from one single copper piece by turning or milling of the complete shape would be extremely expensive because of the cost of a 3-D forged billet of the required size. This leaves the option of using standard metal working techniques and then joining the pieces by e-beam welding. The chosen manufacturing sequence comprises the following main steps: rolling and e-beam welding of the external tube, together with the external half of the top plate, machining and welding of the central conductor with the internal half of the top plate, manufacturing of the beam ports by plastic deformation, joining of the two pieces by an internal e-beam welding (Fig. 4).

Figure 4: Manufacturing sequence of the cavity. The top half of the drawing illustrates the shape of the raw pieces, the bottom one the final shape. The arrow indicates the region of the final circular long-throw welding.

The manufacturing of the beam ports by drawing is a critical process that has been validated on flat copper test pieces. This is done by progressive deformation of copper with punches of different shapes into a fixed die, until the final shape is reached (Fig. 5). Development work has shown that with appropriate design of the tooling, the thickness of the wall is never reduced below 8 mm from the starting 10 mm. Local intermediate annealing steps are used in the process, the copper being cold worked at the final step thus recovering good mechanical properties. The e-beam welding of the top shorting plate needs to be done from the inner surface exposed to RF, in order to minimize porosities and projections of molten material, as the LEP/LHC experience has shown. It has been demonstrated in full scale simulation on test pieces that this can successfully be done with the e-beam gun kept outside the cavity, at a distance of about one meter. The quality of the welding has been monitored by ultrasound testing, and the surface roughness after 20 μm material removal by SUBU [5] chemical polishing was reduced to the expected value of 0.8 μm (average roughness R_a), common for this type of processing.

Figure 5: Sequence of the different drawing steps leading to the final form for the beam ports, and full scale test piece for the long-throw e-beam welding.

Surface preparation prior to coating will be carried out by SUBU chemical etching. Since all surfaces will be milled or turned with high accuracy, only minor material removal is necessary in order to achieve an optimum surface state. The treatment will benefit from the CERN existing infrastructure, with adaptations in order to make it compatible with the present goal. It is worth mentioning that dust-free water rinsing and clean room preparation will require only new tooling, without investments for modifications of the available basic infrastructure.

As already mentioned, the coating will follow generally the same bias diode sputtering procedure developed by INFN-LNL, which was itself based on previous CERN experience. A UHV coating system has been designed based on a vacuum jar of size sufficient to host both the low beta and high beta cavities. It is an all-metal system, compatible with standard vacuum bakeout, except for two Viton O-ring gaskets sealing the large diameter flanges (Fig. 6). Experience has already shown that such a configuration allows reaching vacuum levels in the 10^{-9} mbar range with standard turbomolecular pumping and bake-out while limiting heating of the gaskets in the 120 °C range. In order to keep the cold-worked copper state, the cavity will be cooled during coating by circulating a suitable coolant in the central stem. The study of the coating parameters will confirm whether this solution will bring all the benefits that are expected.

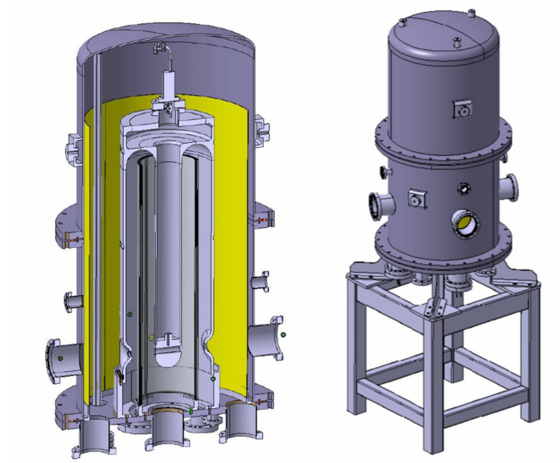

Figure 6: 3D views of the coating system.

Delivery of the first finished copper cavity and of the coating system vacuum components is expected by end of October 2008 and tests of surface treatments and of coating on small scale samples will follow immediately. The first coated cavity is expected to be tested for RF performance in early 2009, with the goal of delivering a prototype working at full specifications by end 2009.

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