A SC UPGRADE FOR THE REX-ISOLDE ACCELERATOR AT CERN

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Abstract

The High Intensity and Energy ISOLDE (HIE-ISOLDE) proposal is a major upgrade of the existing ISOLDE and REX-ISOLDE facilities with the objective of increasing the energy and the intensity of the delivered radioactive ion beam. For the energy increase a staged construction of a superconducting linac based on sputtered quarter wave cavities is foreseen downstream of the present normal conducting linac. A funded R&D program has been launched at the end of 2007 in order to prepare a full Technical Design Report covering all the issues of such linac, including cavity prototyping and testing, cryomodule design, beam dynamics and beam diagnostics. We report here on the status and planning of the R&D activities for the SCREX-ISOLDE linac.

INTRODUCTION

Radioactive ion beam production at the ISOLDE facility at CERN is based on the ISOL (Isotope Separation On-Line) method where a max 2.8 kW proton beam, extracted at 1.4 GeV from the Proton-Syncrotron Booster (PSB), impinges upon a thick, high temperature target. The radioactive nuclei can be produced in two different target stations (GPS and HRS) via spallation, fission or fragmentation reactions. ISOLDE has been continuously developing targets and ion sources for four decades, introducing several new technologies (e.g. the resonance ionization laser ion source) so that there are now available more then 700 radioisotopes from 65 elements. These beams are accelerated to 60kV and steered to different experimental stations. In the present REX-ISOLDE facility [1] the RIBs are accelerated to higher energies with a compact Normal Conducting (NC) linac, making use of a special low energy preparatory scheme where the ion charge state is boosted so that the maximum mass to charge ratio is always $3 < A/q < 4.5$. This scheme consists of a Penning trap (REXTRAP), a charge breeder (REXEBIS) and an achromatic A/q separator of the Nier spectrometer type. The NC accelerator is designed with an accelerating voltage for a corresponding maximum A/q of 4.5 and it delivers a final energy of 3 MeV/u for $A/q < 3.5$ and 2.8 for $A/q < 4.5$. After charge breeding, the first acceleration stage is provided by a 101.28 MHz 4-rod Radio Frequency Quadrupole (RFQ) which takes the beam from an energy of 5 keV/u up to 300 keV/u. The beam is then re-bunched into the first 101.28MHz interdigital drift tube (IH) structure which increases the energy to 1.2 MeV/u. Three split ring cavities are used to give further acceleration to 2.2 MeV/u and finally a 202.58 MHz 9-gap IH cavity is used to boost and to vary the energy between $2 < E < 3$ MeV/u. Fig. 1 illustrate the scheme of the present linac.

The HIE-ISOLDE project contains three major parts: higher energies, improvements in beam quality and flexibility, and higher beam intensities. This requires developments in radioisotope selection, improvement in charge breeding and target-ion source development, as well as construction of the new injector for the PSB, LINAC4 [2]. The most significant improvement in the physics program [3] will come from the energy upgrade which aims at reaching a minimum energy of 10 MeV/u.

The present NC machine was developed in order to deliver beams at specific energies whilst taking advantage of the high accelerating gradient that pulsed NC IH structure could achieve. This concept is nevertheless not without some limitations: 1) very limited energy variability; 2) operation restricted to pulsed mode; 3) inefficient use of the installed power when running light ions; 4) non variable longitudinal beam parameters, such as energy spread and bunch length.

To overcome the above limitations and to open the possibility of different longitudinal beam parameters, a superconducting linac based on Nb-sputtered SC Quarter Wave Resonators (QWRs) has been proposed [4]. The fact of having 2-gaps cavity independently phased assures both a very high flexibility in term of velocity acceptance and at the same time a small number of cavity types to cover the whole energy range.

THE SUPERCONDUCTING LINAC

The superconducting linac is designed to deliver an effective accelerating voltage of at least 39.6 MV with an average synchronous phase ϕ_s of -20 deg. This is the minimum voltage required in order to achieve a final energy of at least 10 MeV/u with $A/q = 4.5$. Because of the steep variation of the ions velocity, at least two cavity geometries are required in order to have an efficient acceleration throughout the whole energy range. A total number of 32 cavities are needed to provide the full acceleration voltage. The geometries chosen corresponding to *low* ($\beta_0 = 6.3\%$) and *high* ($\beta_0 = 10.3\%$) "β" cavities maintain the fundamental beam frequency of 101.28 MHz and their design parameters are given in Table 1. The design accelerating gradient aims at reaching 6 MV/m with a power consumption of 7 W per low β cavity and 10 W per high β cavity.

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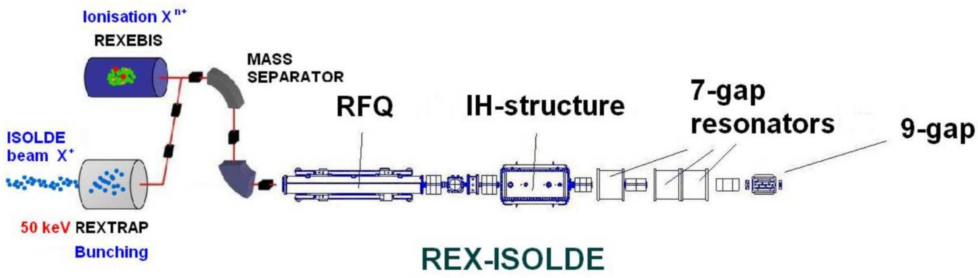

Figure 1: REX-ISOLDE present scheme.

These values have been already achieved by the two available technologies for the QWRs, namely the *bulk* Nb and the *sputtered* cavity [5], [6].

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 $E_{\rm acc}$(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
$U/E_{\rm acc}{}^2$ (mJ/(MV/m)^2	73	207
$E_{\rm pk}/E_{\rm acc}$	5.4	5.6
$H_{\rm pk}/E_{\rm acc}$ (Oe/MV/m)	80	100.7
$R_{\rm sh}/Q$ (Ω)	564	548
$\Gamma = R_{\rm S} \cdot Q_0$	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

Because each cavity is independently phased, we can apply the maximum voltage available in each cavity so that lighter ion will reach higher final energies. Figure 2 shows a plot of the energies reached by the ions with different A/q. The focussing scheme foresees the employment of SC solenoids, which allows a higher mismatch factor tolerance with respect to standard triplet or doublet focussing scheme [7]. The low β cavities have been grouped into two cryomodules of six cavities each, while the high β cavities have been grouped in four cryomodules of five cavities each. Beam dynamics studies are ongoing to assess optics parameters and to optimize emittance growth control [8].

Cavity Technology

The Nb sputtering technology wil be used for the HIE-LINAC cavities. A distinct advantage of the sputtering technology is that, because of the dominant copper base, the cavities can be made with thick walls so to ensure high

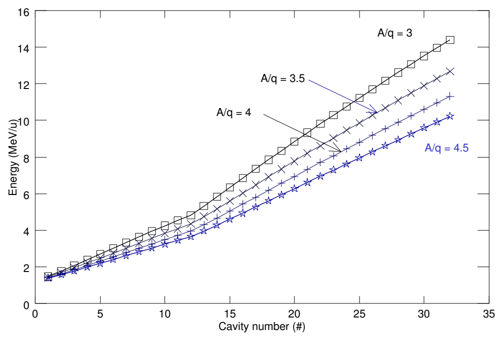

Figure 2: Beam energy as a function of the cavity number. For the $A/q = 3$ the maximum energy achieved is 14.4 MeV/u

thermal conductivity and a high mechanical stability. The former guarantees an excellent thermalization of the cavity avoiding hot spots that could break the superconducting state. The latter allows substantial simplification of the tuning system. A prototype cavity is under fabrication and a detailed study for the mechanical assembly and procedures has been performed in order to avoid any copper annealing so to maintain the mechanical rigidity of the copper [9]. The established procedures allows a substantial reduction of the cost of the copper material, and critical e-beam weldings have all been tested. An important part of the cavity manufacturing is the actual sputtering of the Nb layer onto the copper base. The bias technology developed at LNL-INFN will serve as a starting point [10] but a development towards magnetron sputtering is planned. The plan foresees the completion of the copper base manufacturing by the end of October 2008, chemical treatment and Nb deposit by the end of the year. First cold tests are expected beginning 2009.

Cryomodule

The choice of having a SC solenoid as focusing element allows to reduce the intermodule distance with respect to a scheme where the focusing elements are made of warm quadrupoles. The advantage is a more compact linac, saving precious space for the experiments and simplify the lon-

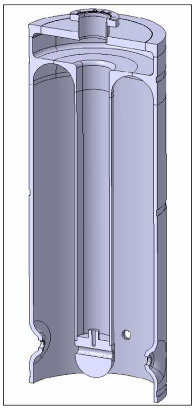

Figure 3: High β cavity 3-D section.

gitudinal beam dynamics. The result of this scheme sets several constraints on the cryomodule layout, for which a conceptual design is ongoing. An important design issue of low energy SC ion linacs is whether the beam vacuum is shared with the insulation vacuum or not. This former brings as a consequence a strict control on the fabrication and cleaning procedures, as well as the assembly. The latter brings as a consequence an additional layer of interconnection with an increased engineering complexity. Details about the conceptual design are reported in ref. [11].

Cryoplant

The cryoplant needed to supply liquid helium at 4.5 K will require an additional building - located next to the experimental hall - to house the compressor station and its cold box. We are looking at the possibility of reusing an existing refrigerator which was connected to the ALEPH magnet during the LEP operation from 1989 to 2000. The cold box was capable in 1989 to provide an isothermal refrigeration power of 630W at 4.5K plus an additional shield load of 2700 W between 55K and 75K. Fig. 4 shows a first concept design of the cryoplant. The total heat load of the system required for the complete ISOLDE energy upgrade is very close to the maximum power that the cold box can provide. Nevertheless, we have to evaluate precisely this possibility as it would allow a substantial cost saving with respect to the purchase of a new unit. The transfer line needed to supply the liquid helium is 35 m long and will be equipped with 6 *jumper* modules (one per module) to allow the isolation of each module from the common distribution line without interruption on the remaining modules.

INSTALLATION PLAN

The first stage of the upgrade plan consists of installing two *high* β cryomodules downstream the present NC linac so to reach a final energy of a least 5.5 MeV/u. The position of these two cryomodules is set to be also the final one, so that no additional removal will be required for the installation of the complete linac. Accordingly, a modular trans-

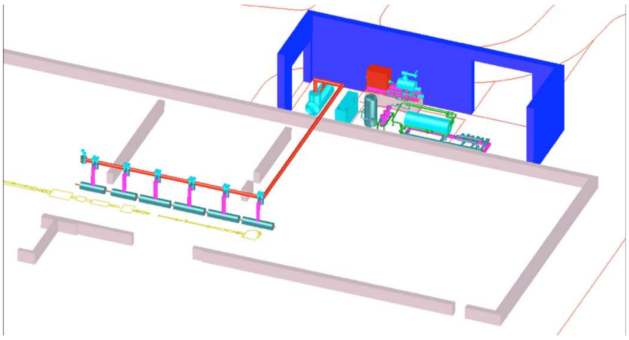

Figure 4: Cryoplant 3-D layout

fer line will be in place in order to accomodate the beam transport as the linac energy will increase. The position of the experimental facilities like Miniball and the planned recoil spectrometer will also be fixed at the position of the full installation. Assuming the financing is approved by mid of 2009 the first stage of the upgrade is planned to be completed in the fall 2012. The remaining high and low β cryomodules will then be installed subsequently with the aim of completing the commissioning of the HIE-LINAC by mid 2013.

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