STUDIES ON A 100 MEV/A SUPERCONDUCTING POST-ACCELERATOR LINAC FOR EURISOL

D. Berkovits, A. Facco, M. Comunian, Z. Lipeng, A. Pisent, F. Scarpa, V. Zviagintsev, INFN-LNL, 35020 Legnaro, Italy

Abstract

A superconducting (SC) linac for radioactive beam acceleration up to 100 MeV/u has been studied in the EURISOL framework collaboration. The linac, fed by a high charge state breeder, is based on high gradient SC quarter (QWR) and half-wave (HWR) resonators and includes SC RFQs. It was designed for ion acceleration of all masses and especially studied for mass number 132. Two stripping stages are foreseen along the linac. Multi-charge beam transport dynamics simulations have been performed with resonators realistic field distribution.

1 INTRODUCTION

The EURISOL project is aimed to a preliminary designing of the next-generation European Rare Isotope Separation On-Line facility [1]. For most of the scientific applications a post-accelerator is needed in order to accelerate the rare isotopes to a wide range of energies. The main requirements for this accelerator are: tuneable final energy up to 100 MeV/u, good beam-quality, high transmission efficiency, isobar separation capability and affordable construction and operation cost. For the design of this post-accelerator a test case of $^{132}Sn^{25+}$ radioactive beam, generated by a charge breeder, was given. In this work we propose a design of an independently phased SC cavities linear accelerator for this EURISOL post-accelerator. Recent developments in the field allow high transmission efficiency after stripping due to multi-charge beam transport [2] and high acceleration gradient [3]. Both achievements enable the design of a competitive construction and low operation cost accelerator.

2 POST-ACCELERATOR LAYOUT

A schematic layout of the proposed post-accelerator is shown in Fig.1. The linac starts with 3 SC RFQs [4] in 2 cryostats, at a total length of 6 m. The RFQ is designed for A/q≤10 (up to $^{132}Sn^{13+}$). A CW ion beam enters the RFQ section at 2.3 keV/u and exit in bunches of 80 MHz at 670 keV/u. The ion transmission through the RFQ section is close to 95 %. The calculated rms emittances at the RFQ exit are 0.1 (π mm mrad) normalized and 0.1 (π keV/u ns) [4].

The three linac sections (low (LE), medium (ME) and high-energy (HE)) are optimised for different velocity and q/A. The LE section has 4 cavities optimised for β=0.047 and 14 of β=0.055. The ME section cavities are optimised for β=0.11 and 0.165 and the HE cavities for β=0.28 (figs. 1,2). The basic linac module consists of a cryostat containing 4 or 8 SC cavities and a SC solenoid in the center. This configuration allows a compact design. A 40 cm gap between each two cryostats is reserved for bellows and a diagnostics box. The cavities are 2-gap QWRs or HWRs operated at acceleration field of 7 MV/m and with 10 W power dissipation at 4.2 K [3]. The design includes two intermediate stripping stations to increase the linac energy gain efficiency and reduce its length. After each stripper the beam goes through a parallel matching section that match the multi-charge beam to the next linac section and allows beam extraction and charge selection (when required) [5]. The design was optimised for ^{132}Sn ions at charge states 25, 37 and 47 at the LE, ME and HE sections and for multi-charge beam transport.

According to the required beam energy, the beam is extracted at the intermediate positions or at the end of the linac, and one, two or no strippers can be used. In any of these modes, the final beam energy can be finely tuned to any intermediate value. When 2 strippers are used the total ion transmission is 74 %. Nevertheless, for higher transmission and better beam quality (but lower final energy) only single stripper or no stripper mode can be used (see table 1). The large acceptance of the designed linac enables the acceleration of all radioactive beams that allow charge breeding. For example, $^{33}Ar^{8+}$ would acquire a final energy of 127 MeV/u and $^{210}Fr^{25+}$ 100 MeV/u. The strippers make the linac relatively insensitive to the charge breeder performance. With initial charge of 13+ the final energy would be 95 MeV/u.

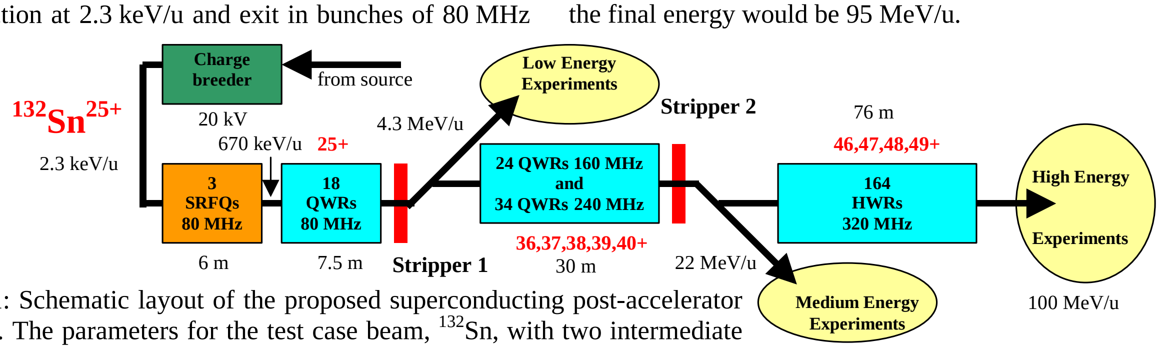

Fig 1: Schematic layout of the proposed superconducting post-accelerator linac. The parameters for the test case beam, ^{132}Sn, with two intermediate stripping stations, are presented.

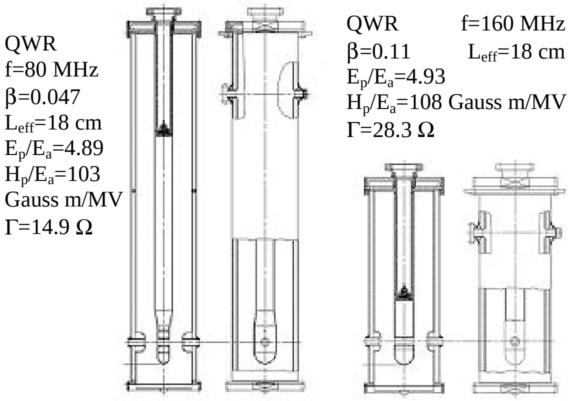

Figure 2: Example of two LNL SC cavities.

3 BEAM DYNAMICS SIMULATION

Beam dynamics in the different sections of the nominal linac have been simulated by means of the LANA 3D code [6]. LANA includes simulation possibility with realistic, non-symmetric, electric and magnetic field distributions (calculated by means of the HFSS code). QWRs present transverse components of electric and magnetic field that cause beam steering [7]. This effect is more pronounced at lower velocity; however, being proportional to q/A, it is reduced to tolerable values by the low charge state in the beginning of the linac.

The multi-charge transport, first proposed and tested at Argonne [2], and later optimised for a driver accelerator [8], is an effective way to transport most of the beam after stripping. The beam dynamics was adjusted for a reference charge state and studied in order to obtain a large q/A acceptance. Our results show that the linac design, at a given set of the tuneable parameters, allows a q/A acceptance of ±5.5 %, using a phase of -20^0 for the reference charge and adjusted synchronous phases for the other charges. The synchronization is accomplished by using the first cavities after each stripper at a debunching-bunching mode.

In a "QWR+solenoids" lattice the phase advance in *x* is larger than in the *y* direction due to the cavities *y* steering. Keeping the average phase advance constant, at 100^0, was found to be a good method for smooth beam transport and for minimizing beam envelope. Relatively strong focusing is needed in order to hold the low rigidity beam with only one solenoid per 4 cavities. The maximum beam envelope is kept below a radius of 6 mm inside the cavities, while the cavities have a 10 mm bore radius (fig.3). The solenoids are 30 cm long in the LE and ME sections and 45 cm at the HE section. The solenoids field, for the ^{132}Sn beam and 2-stripper mode, could be kept below 10 T (2/3 of the solenoid rated value).

Carbon foils at thickness of 0.2 and 3 mg/cm^2 are used as the first and the second stripper respectively. The linac energy gain efficiency and transmission are affected by the stripper properties. Relatively thick foils are needed in order to ensure equilibrium. The stripping probability was calculated at the LE and HE stripping stations using refs. [9] and [10] respectively. The energy loss rate, energy and transversal straggling were calculated using IRMA [11] and SRIM [12]. In order to reduce the emittance growth, the beam is focused and bunched on the strippers (fig.3). The bunching on the second stripper required a long bunching-debunching section in order to extract the different charges from their synchronous phases. The longitudinal emittance growth due to these strippers was found to be smaller than 5 % but the transversal growth goes up to 30 % in the second stripper (table 1). The strippers contribution to the emittance growth and energy loss was included in the simulation. The simulation parameters and results are summarized in table 1. For the 2-stripper mode the emittances are given. In this mode a significant emittance growth is presented in the ME section due to the QWR steering, multi-charge beam transportation, imperfect phase synchronization and due to partial lost of synchronization in the change of frequency in the middle of this section. This growth could be reduced if a bebunching-bunching section is used after each change of cavity frequency. The stability of the proposed configuration was studied with an off-axis displaced initial beam. The transversal emittance grows quadratically with the displacement of the beam and is equal to about 10 % growth for a 7 mm off-axis initial displacement in the ME section.

Table 1: Beam dynamic simulation parameters, of the $^{132}Sn^{25+}$ case, for the three possible operation modes. The reference charge states are bolded. (I/O=input and output of section).

Energy section		**Low**		**Medium**		**High**	
Two strippers mode	Transported charge states	25		36,**37**,38,39,40		46,**47**,48,49	
	I/O Energy (MeV/u)	0.67	4.3	4.2	22.4	21.6	100
	Ion transmission (%)		100		78		95
Initial and final Emittance	I/O X (π mm mrad) rms norm.	0.101	0.107	0.123	0.159	0.210	0.208
	I/O Y (π mm mrad) rms norm.	0.102	0.107	0.123	0.136	0.177	0.182
	I/O Z (π keV/u ns) rms	0.103	0.109	0.113	0.263	0.276	0.335
One Stripper mode	Transported charge states	25		25		45,**46**,47,48,49	
	I/O Energy (MeV/u)	0.67	4.3	4.3	17.0	16.3	93
	Ion transmission (%)		100		100		96
No stripper mode	Charge states	25		25		25	
	I/O Energy (MeV/u)	0.67	4.3		4.3	17.0	60
	Ion transmission (%)		100		100		100

In the “one stripper” mode the final transversal and longitudinal emittances are 65 % and 70 % and in the “no stripper” mode 55 % and 35 % respectively, relative to the “2-stripper” mode of operation.

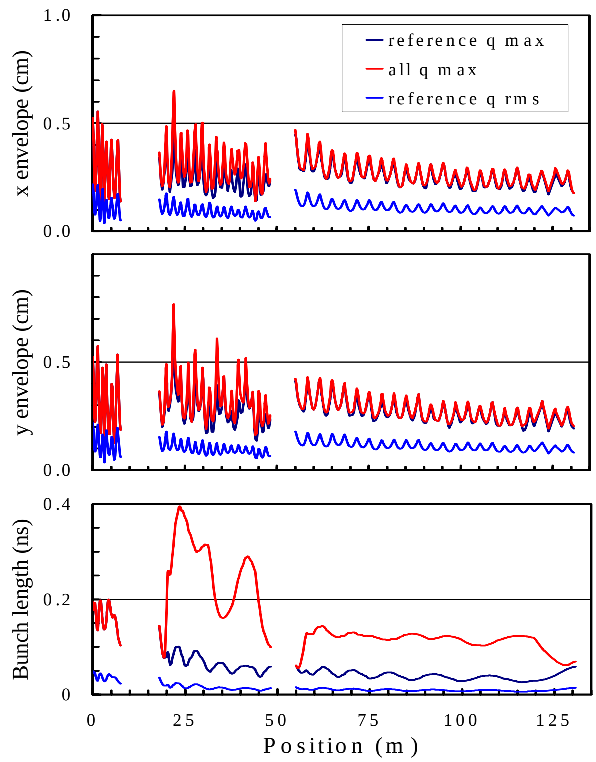

Figure 3: beam envelopes along the three sections of the linac for multi-charge beam transport in the “2-strippers” mode of operation. The reference and the transported charge states (q) are given in table 1. The large change in the bunch length after the strippers reflects the multi-charge phase synchronization.

For the “no-stripper” mode the beam intensity is limited only by the power of the RF power amplifiers. The 500 W amplifiers allow beam intensity up to 300 eμA. However, for the stripper modes there are also other constraints, as heat loss and beam straggling. The energy and transversal straggling were simulated using SRIM [12] with 10^4 ^{132}Sn particles. Assuming a linac acceptance that is 3 times the nominal beam size, the extreme particles transversal straggling will cause a 0.17 % beam loss. These straggled particles have a continuous spectrum that is hard to block by slits and may activate the entire accelerator. Such a high loss has important consequences when strippers are used in a high beam intensity linac [13].

4 ISOBAR MASS RESOLUTION

The ISOL production target produces, together with the desired radioisotope, a large number of isobars. We assume that most of the isobars can be eliminated from the beam by the low-energy high-mass resolution separator (M/ΔM=20000 [14]). However, for the low intensity radioactive beam, some stable isobars can be reproduced at the charge breeder in a non-negligible amount. Due to its large acceptance the linac has only little mass resolution power. Nevertheless, the transport of a single charge in the 2-stripper mode of operation allows some isobaric selection due to the difference in stripping efficiency and energy loss in the stripping foil. For ^{132}Sn, by choosing charge states 37+ and 47+ in the first and second strippers the Xe isobar is attenuated by a factor of 700. At the exit of the 3 mg/cm^2 stripper-2, the energy difference between the two isobars will be 114 (±3.3 stripping straggling and ±13 beam width) keV/u. This large energy difference is equal to a mass difference of M/ΔM=190. By closing the slits of the matching sections after the strippers, the Xe isobar is attenuated by more than four orders of magnitude relatively to the ^{132}Sn beam. However, the single- charge beam total transmission is decreased to 6.7 %.

5 CONCLUSION

The design of the linac and the beam dynamics simulation show that the proposed post-accelerator scheme could reach the EURISOL demands. The beam quality and transmission are excellent in the non-stripper mode of operation, where most of the experiments are expected. In the 2-strippers mode of operation, the beam emittance and transmission can be considered satisfactory and the particles reach the maximum energy. Interfering isobars can be attenuated by several orders of magnitudes at the price of transmission.

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