BEAM DYNAMICS STUDIES ON THE EURISOL DRIVER ACCELERATOR

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Abstract

A 1 GeV, 5 mA cw superconducting proton/H^- linac, with the capability of supplying cw primary beam to up to four targets simultaneously by means of a new beam splitting scheme, is under study in the framework of the EURISOL DS project which aims to produce an engineering-oriented design of a next generation European Radioactive beam facility. The EURISOL driver accelerator would be able to accelerate also a 100 μA, ^{3}He beam up to 2.2 GeV, and a 5 mA deuteron beam up to 264 MeV. The linac characteristics and the status of the beam dynamics studies will be presented.

INTRODUCTION

The EURISOL-DS project [1] aims at the design of a last generation Radioactive Ion Beam (RIB) facility for nuclear physics experiments, based on the ISOL method, to be constructed in Europe [2]. This facility is based on a 1 GeV, 5 mA primary proton beam feeding 4 RIB production targets. One of them (the high power target) will include a 4 MW neutron converter, able to receive most of the beam power and to create an intense neutron flux to the RIB target. The three remaining ones will accept a proton beam up to 100 kW for RIB production through direct reactions. The radioactive ions will be then extracted from the sources, selected and post-accelerated to the required energy (up to 150 MeV/A) by means of a superconducting linac.

One of the main requirements for the driver accelerator is the possibility of feeding more than one target in parallel, possibly in cw mode with finely tunable intensity to avoid destructive thermal shocks. No apparatus was available for this operation when the EURISOL-DS study started.

New requirements for the Driver, proposed after the first year of studies by the Beam Intensity Calculations Task group with the aim of opening new lines of experiments, are the possibility of delivering to the direct targets a 2 GeV, 100 μA ^{3}He beam, and to a new target station a 250 MeV, 5 mA deuteron beam. This could be accomplished with a rather limited effort taking advantage of the structure of the EURISOL Driver, based on short, independently phased cavities, which allows a rather wide beam velocity acceptance.

EURISOL DRIVER LAYOUT

The EURISOL Driver is a superconducting (SC) linac that includes 5 different sections: Injector, Low-β section, medium-β section, high-β section and CW Beam Splitter (Fig. 2). The lengths of the injector and of the SC part are 12 m and 247 m, respectively, while the 4-way beam splitting section is 55 m long. An additional extraction sector is located at the beginning of the high-β section, giving a beam line for 264 MeV deuterons. All cryostats are planned to work at 4.5K.

Injector

The injector design is rather similar to the SARAF one [3], with modifications required by the different beam types (Fig. 1). Two ion sources are used. The first one is a TRIUMF-type multicusp H^- source [4], located in the straight LEBT line. The second one is an ECR source for production of Deuterons (5 mA) and doubly charged ^{3}He (0.1 mA) beams, located in the 90° LEBT branch to allow A/q selection. The minimum beam parameters at the sources output are listed in Table 1.

beam	H^-	$^3He^{++}$	D^+
E (keV/A)	20	20	20
I (mA)	6	0.2	6
ε_x, ε_y (π mm mrad rms norm.)	0.125	0.125	0.1

Table 1. LEBT input beams specifications.

The LEBT includes 6 solenoids and one dipole. An electron trap is foreseen at the RFQ injection.

The 176 MHz RFQ, resembling the SARAF one, is 3.8 m long and must be able to operate in cw mode. It allows acceleration up to 1.5 MeV/A, requiring a maximum power of 300 kW for acceleration of the Deuteron beam.

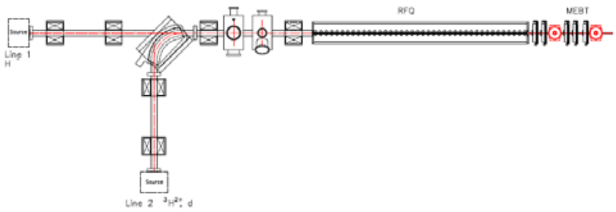

Figure 1. Injector RFQ and MEBT schematic layout

Little emittance growth and relatively small size and cost are its main characteristics, at the price of a not spectacular transmission (92% accelerated beam for H^- and 95 % for D and ^{3}He). However, this appears to be fully acceptable for our application. The transmitted, but not accelerated RFQ particles (about 3%) are lost in the MEBT which is used to match the RFQ beam to the superconducting linac in order to prevent halo formation. The MEBT includes 5 quadrupole magnets and 2 normal conducting HWR bunchers.

Low-β section

The low-β section consists of 9 cryostats, containing 8 176 MHz Half-Wave resonators (HWRs) each.

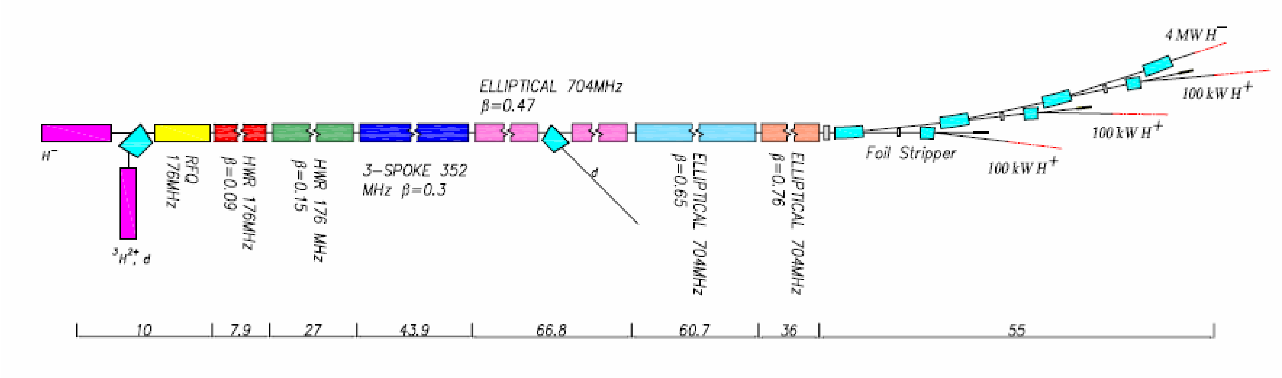

Figure 2. EURISOL Driver schematic layout (not in scale) and length of the different sections.

The required resonators are of 2 types, with β_0=0.09 and 0.15, working at the conservative gradient of 4.5 and 5.5 MV/m, respectively. They are being developed in the EURISOL Task 8 framework [5]. SARAF resonators [6] might also be adapted to this linac. The HWR geometry was chosen because it is steering free. In the first two cryostats every resonator is alternated with one superconducting solenoid; from the third cryostat on, there is one solenoid every two HWRs. The beam vacuum and the vacuum required for thermal insulation are in common to minimize cost. Until now, the most performing low-β heavy ion linacs in operation working at similar or lower rf frequency, are of this type.

Medium-β section

The medium-β section is based on 36, 352 MHz triple-spoke resonators, also developed in the EURISOL Task 8 framework, with β=0.3 and a specified gradient of 8 MV/m [7]. The architecture has been optimized with the GenLinWin code [8]. The cryostats contain three resonators each, and in this case, as usual for this rf frequency value, the beam vacuum and the insulating vacuum are separated. Transverse focusing is provided by conventional quadrupole doublets. The matching between the low- and the medium-β sections is achieved by replacing the first medium-β doublet with a triplet.

High-β section

The high-β section is based on 112, 5-cells elliptical cavities with 3 different optimum β of 0.47, 0.65 and 0.76. These β have been optimized to minimize the length of the linac with the GenLinWin code. The cavities are of the type developed in previous projects and the specified gradients of 12, 18 and 18 MV/m, respectively, were chosen, taking into account the experimental results of the on-line SNS cavities [9]. Transverse focusing is done by conventional quadrupole doublets. In the first subsection, one of the cryostats is replaced by a dipole magnet which allows the deuteron beam extraction at 264 MeV.

THE 1 GeV, CW BEAM SPLITTER

A unique peculiarity of the EURISOL driver is its possibility of delivering parallel cw proton beams to different targets with low losses [10]. This is achieved by using a H^- primary beam (up to 5 MW), neutralizing part of it (up to 100 kW) by magnetic stripping, and then displacing the unneutralized H^- ions to a different beam line by means of a dipole magnet (Fig. 3). When the two beams are sufficiently separated, the neutral one is transformed into a proton beam by means of a stripper foil. From here on, the H- and H+ beams can be transported independently. The 100 kW limit of the extracted beam is dictated by the present RIB direct target technology. The beam losses, mainly due to the stripper foil efficiency, can be limited to a few tens of Watts and collected by a small beam dump. The splitting operation can be repeated by adding more splitting sections, providing multiple cw beams.

A critical component of the system is the special magnetic neutralizer, a simple and unconventional chicane made of 3 short dipoles that can provide partial neutralization without affecting the primary beam emittance and without producing unwanted H^+ ions. Since the neutralization rate is determined by the magnetic field intensity, it is possible to raise slowly the field (thus the secondary beam current) to avoid thermal shocks in the direct RIB targets.

BEAM DYNAMICS

The linac beam dynamics was studied using the TRACEWIN code developed at CEA Saclay [8]. The transport of all the beams (H^-, D^+ and $^3He^{++}$) was simulated from the exit of the ion source to the target (except for D which was stopped at its extraction point) with macroparticles. All the cavities and the solenoids have been simulated with their computed EM field maps.

We chose to use conservative specifications for the linac components (cavity gradients, magnet fields) in order to achieve a reliable design without depending on future technological breakthroughs. We kept the transverse and longitudinal phase advance per period below 90° along the linac, and carefully tried to avoid parametric resonances. The continuity of the phase advance per meter has been also an important criterion in order to simplify the matching at transition. This point is especially relevant to transport different beam currents in a common linac. The frequency jump from 352 to 704

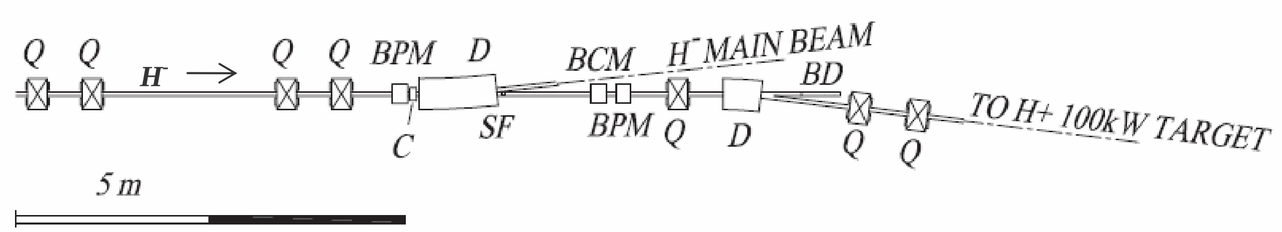

Figure 3. CW beam splitter layout (1 section). The main H^- beam (coming from left) is partially neutralized in a small magnetic chicane (C). In the first bending magnet (D), the main H^- beam is guided to the next splitter section, while the H^0 particles move straight to the stripper foil (SF), to be stripped into H^+ and then transported to the target. Q=quadrupole magnet; BD=beam dump; BCM=beam current monitor; BPM=beam profile monitor.

MHz was managed according to the technique described in [11] in order to avoid a longitudinal bottleneck just before the high energy section. Beam losses could be confined below 1.5 MeV, before entering the superconducting linac.

A special effort was required for transporting the 5 mA H^- beam in the low-β section, where cryostats with different structure introduce discontinuities in the lattice. However, the final layout could allow transport with satisfactory acceptance and emittance growth for all beams (Tab. 2, Fig. 4 and 5). Studies performed in an earlier version of the HWR section showed a moderate (25%), further increase in emittance growth after introduction of errors in the lattice [12]. Error study for the whole accelerator will begin in autumn 2008.

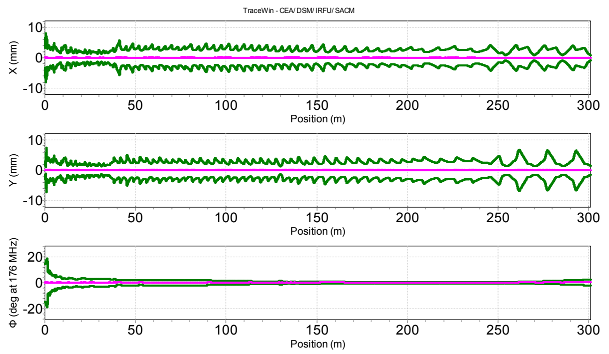

Figure 4. X, Y and phase envelopes for the proton case from the output of the RFQ to the last target location.

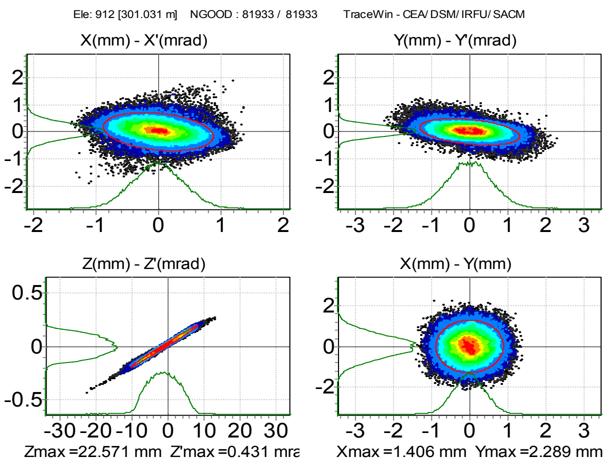

Figure 5. Proton beam at target in the phase spaces.

beam	H^-	$^3He^{++}$	D^+
Tr. emittance growth (%)	75	20	80
Lg. emittance growth (%)	43	12	0

Table 2. Source-to-target rms emittance growth for each beam (Longitudinal: from RFQ output to linac end).

CONCLUSIONS

The EURISOL Driver design has achieved its beam dynamics specifications. The linac, which is only based on the RF superconducting technology above 1.5 MeV/A, is able to accelerate 5mA beams to 1GeV/q (for 1 ≤ A/q ≤1.5) and to 264 MeV (for A/q ≤2). A novel splitting scheme allows to distribute the primary H^- output beam in 4 parallel cw beams which can be used independently in different beam lines.

ACKNOWLEDGMENTS

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