Beam Dynamics through the CONCERT-ESS Linac

N. Pichoff*, R. Duperrier, D. Uriot, CEA/DSM/DAPNIA/SEA, France

Abstract

The CONCERT concept aims to deliver high power pulsed beams to a various number of applications : mater studies with spallation neutrons, waste transmutation, exotic beam production, irradiation tools… It is one of the extension of the European Spallation Source project (ESS) dedicated to spallation neutrons production for mater studies. Both protons and H- have to be accelerated and guided to each target. Two 50 mA H^- branches are funnelled with one 100 mA H^+ branch at around 23.5 MeV. A low energy H^- branch is constituted of one RFQ from around 50 keV to 2 MeV, a chopper line (for ring injection at high energy), an other RFQ to 5 MeV, and a DTL to the funnel line. The low energy H+ is constituted of one RFQ from around 95 keV to 5 MeV and a DTL to the funnel line. The beams are then accelerated through a SDTL, a CCL and a Superconducting cavity Linac (SCL). The goal of this paper is to present the results of beam dynamics calculations through the CONCERT linac.

1 INTRODUCTION

The specificity of the CONCERT concept is that its accelerator has to be able to accelerate both H^- and H^+ beams. The H^- beam is injected into a ring (stripped to protons) and compressed to a 650 ns high intensity pulse. It is used to create short spallation neutrons pulses for mater study (ESS project). The H^+ beam is used for the others applications: long spallation neutrons pulse, waste transmutation, exotic beam production, irradiation tools… For consideration of power, 100 mA beams are needed. The H^- pulsed is about 1 ms long, 70% chopped (@2.05MeV), with 50Hz repetition rate. As 5% duty-cycle H^- sources, with emittance lower 0.3 π.mm.rad and high reliability are highly challenging at 100 mA peak current, it has been chosen to funnel two 50 mA H^- beams lines at about 23.5 MeV [1]. Because high duty-cycle (>5%) are challenging even at 50 mA for H^- sources, H^+ line is necessary for the other applications.

After the funnel line, H^- and H^+ beams are accelerated to 1.34 GeV in the same structures : Separated Drift Tube Linac (SDTL); Coupled-Cavity Linac (CCL); Superconductive Cavity Linac (SCL).

2 LINAC BASELINE

The low energy part [2] (until the SDTL) is represented on figure 1. The RF frequency of each structure as well as the transition energies are given.

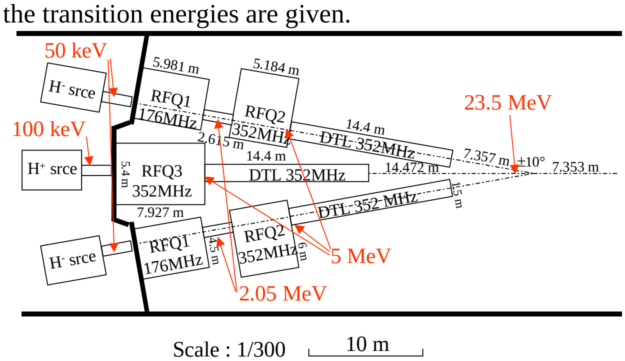

Figure 1: Low energy baseline.

The 23.5MeV beams are then injected in a 352.2 MHz separated DTL (SDTL). This kind of structure allows an easier alignment of quadrupoles than in classical DTL as they stand outside the small DTL tanks. Moreover it allows an easier matching. The doublet lattice scheme is used. The beam is then accelerated to 90 MeV. At this energy 24-cells 704 MHz coupled-cavities replace the 5-cells drift-tube cavities, as their shunt impedance becomes higher. The doublet focusing scheme is kept for an easier matching. The beam is then accelerated to 186 MeV. At this energy, 5-cells 704.4 MHz superconducting cavities are used. The first section contains 14 cryomodules with 3 β=0.658 cavities. It goes to 430 MeV. The second section contains 24 cryomodules with 4 β=0.846 cavities. It goes to 1.334 GeV. In each cavity the peak magnetic field has been limited to 50mT which corresponds to about 23.5 MV/m peak electric field. the superconducting sections are described in a companion paper [3].

3 MATCHING

In beam dynamics driven by space-charge, it is now well known that mismatching is one of the main halo source observed in simulations [4]. A good matching between the structures is then very important. It is achieved in 3 stages :

- Try to keep the same focusing scheme (here, doublet) in each section,
- Keep the phase advance per meter continuous through the linac,

* Email: nicolas.pichoff@cea.fr

- Match the Courant-Snyder parameters of the channel through the transitions by adjusting quadrupoles and cavities strength (beam rms matching).

The H^-/H^+ common channel has been matched using TraceWIN [5] code with H^- beam. This matching has been kept for H^+ beam.

Because of different source performances, the initial H^- beam normalised transverse rms-emittance is assumed to be 0.3 π.mm.mrad as it is only 0.25 π.mm.mrad for H^+ beam. The longitudinal emittances at the RFQ exits are different because the bunching RFQ frequencies are different (176.1MHz for H^- and 352.2MHz for H^+).

Multiparticle simulations have been done, in the RFQ with TOUTATIS code [6], and with PARTRAN code and the PICNIC 3D space-charge routine [7] in the rest of the linac.

On figure 2 are represented the H^+ beam envelopes in X and longitudinal directions from the exit of the last RFQ. The matching, even if it has been done with H^- beam, is very correct.

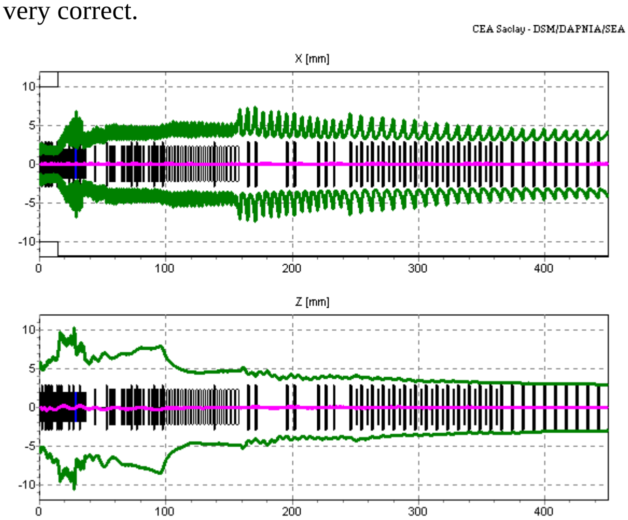

Figure 2: H^+ transverse and longitudinal envelopes.

The rms emittance growth and the halo parameter [8] evolutions of both beams are presented on figures 3 and 4. The main emittance growth and halo formation happen in the funnel line.

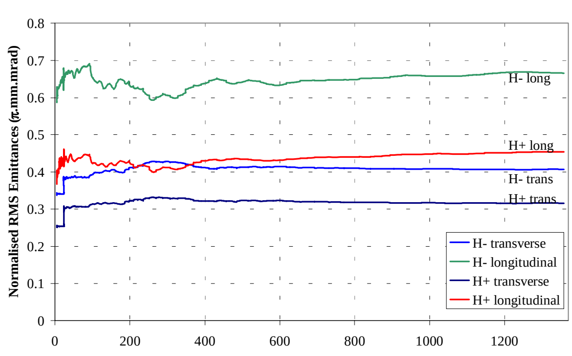

Figure 3: H^+ and H^- rms emittances evolution.

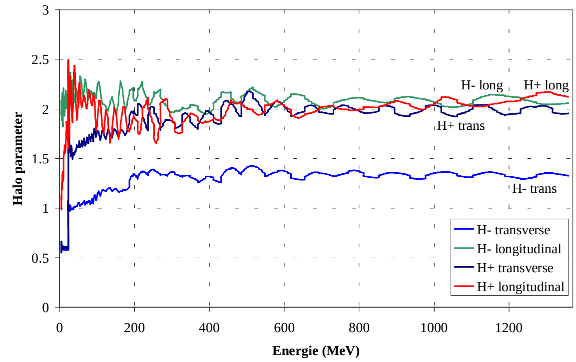

Figure 4: H^+ and H^- halo parameters.

The output phase-space distributions (H^- on figure 5 and H^+ on figure 6) exhibits a small but negligible halo.

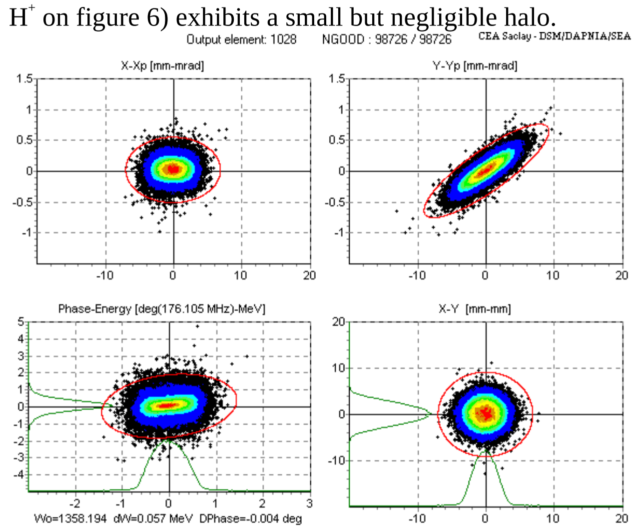

Figure 5: H^- output phase-space distribution. In red are the 20 times the rms-emittance ellipses.

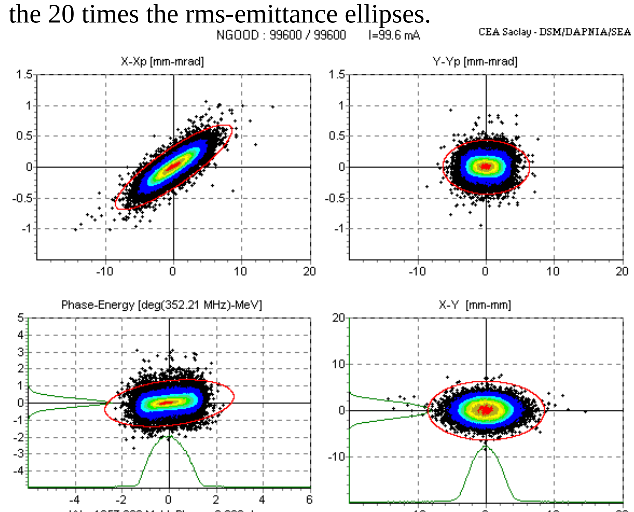

Figure 6: H^+ output phase-space distribution. In red are the 20 times the rms-emittance ellipses.

4 MISMATCHED BEAM

To test the linac "robustness", a simulation with a 20% initially mismatched has been done. This mismatch has been introduced in RFQ exit by increasing the β and α beam Twiss parameters by a 1.2^2 factor in all directions. The evolution of rms emittances is plotted on figures 6.

An initial small emittance growth occurs. As the beam matches itself to the channel through space-charge forces, their is no more emittance growth in the high energy part.

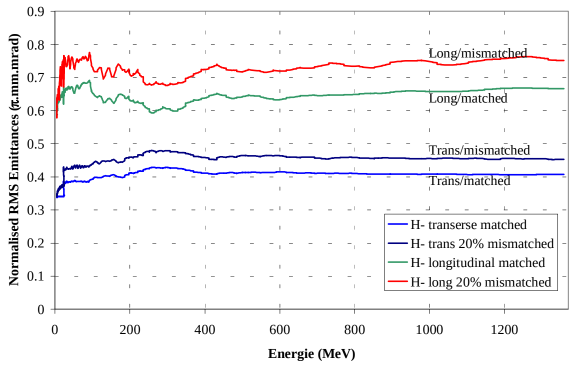

Figure 6 : Emittances of matched and 20% initially mismatched H^- beam.

5 QPOLE GRADIENTS ERRORS

In order to set the tolerances on quadrupole gradients, a statistical study with a variable quadrupole gradient error amplitude A_g has been done. A set of 500 different linacs with A_g varying from 0 to 1% (each quad has a gradient error between –A and +A, with a uniform probability distribution) has been simulated with H^+. The induced extra emittance growth has been plotted as a function of A_g on figure 7. No matching correction scheme has been implemented as we don't know at that time how it could be measured.

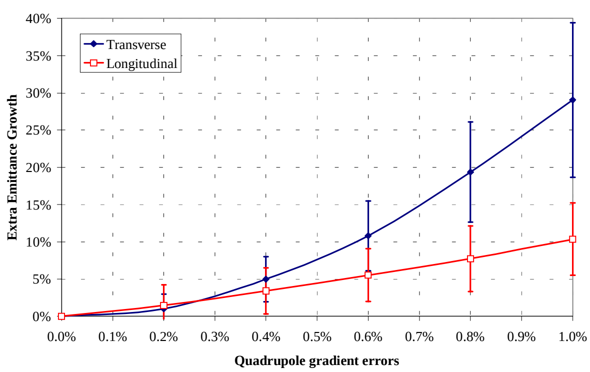

figure 7 : Extra emittance growth as a function of quadrupole gradient amplitude error.

A tolerance on quadrupole gradients lower than 0.2% will be certainly sufficient.

CONCLUSION

Both H^- and H^+ CONCERT-ESS linacs have been designed. The matching of each line has been calculated. The matching of common part have been calculated with H^- and applied successfully with H^+ beam. End-to-end simulations, with a water-bag matched distribution at RFQs entrance, have been done. The "robustness" test consisting of injecting a 20% mismatched beam at the linac input has been passed. An error studies on quadrupole gradients have been done giving a 0.2% tolerance (or less). An other study have exhibited that a 1% error on superconducting cavities field and a 1° on their phases gives 700 keV and a 1° (@704.4Mhz) standard deviations on the final energy and beam phase, with no losses. Other errors studies should be investigated, from which an efficient measurement/correction scheme should to be found.

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