A PROPOSAL FOR POST ACCELERATION, MATCHING AND MEASURING THE H- ION BEAM AT CERN'S LINAC 4 TEST STAND

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Abstract

CERN's future Linac 4 is a 160 MeV H- Linac injecting into the Proton Sychrotron Booster. The ion source parameters (80mA, 500µs pulse length, 2Hz rep rate) could be achieved by improvements to a 2MHz RF multicusp source. In this report, we note the proposal to post-accelerate the beam to 95keV, and to focus the beam into the RFQ while avoiding emittance growth.

INTRODUCTION

CERN plans to upgrade the proton injection chain to increase the available intensities for the LHC and other experiments. The first link in this upgrade is to build a new Linac [1] accelerating negative hydrogen ions to 160 MeV energy, which will be charge-exchange injected into the present Proton Synchrotron Booster (PSB).

The specifications call for a maximum ion intensity of 80mA from the source, with a pulse length of 500µs to be matched into the 352 MHz RFQ, with a nominal emittance of 0.25 mm.mrad (1rms normalized). A repetition rate of 2Hz is called for.

In order to reach this goal it is planned to build a 2 MHz RF multi-cusp ion source, based on the external antenna design of DESY. The upgrades to the source require an increase of the source potential to 95kV and the increase of the pulse length to the required value [2]. Development will be required to increase the source intensity to the 80mA specified for the project, to which end the available RF power will be increased to 100kW.

POST-ACCELERATION

In order to avoid making modifications to the source body, a post-acceleration system will be used to increase the beam energy from 35keV to 95keV. This allows the multi-Ampere electron beam to be removed from the H- beam at an energy of 35keV, after which a post acceleration diode is installed.

The electrode design of the post-acceleration system has been developed based on input conditions given by beam measurements at DESY. This emittance is then tracked backwards towards the ion source (without space charge, under the assumption that the beam is fully compensated in this region).

These starting conditions are then the input for simulations using both IGUN (2D with cylindrical symmetry [3]) and KOBRA (for 3D calculations [4]).

With the 2D simulations we have investigated the general rules for the acceleration of the beam keeping both the emittance growth to a minimum, and aiming to reduce as much as possible the divergence of the beam. This second point is required as the beam should fill as little of a downstream solenoid as possible, to avoid spherical aberrations.

These simulations are made with 40mA space charge, and take a laminar beam as input. A typical output from the simulation is shown in Figure 1.

Beginning with a shaped two electrode system, the beam divergence as a function of some of the parameters of this system, is given in Figure 2.

The divergence of the beam is reduced by choosing the smallest possible apertures in the electrodes, and by reducing the acceleration gap. However, practically these parameters are limited by the beam size and the smallest gap over which the 60kV can be reliably held (in the presence of beam) without breakdown.

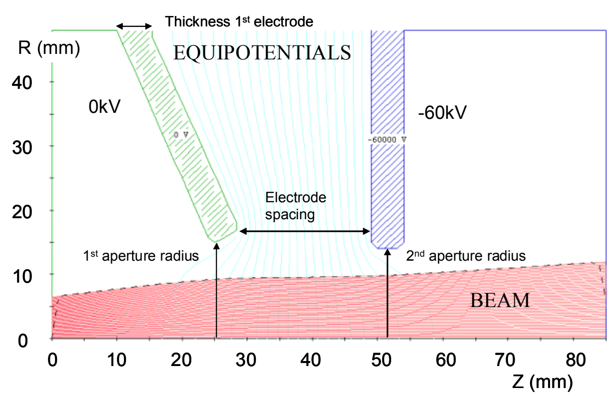

Figure 1: Simulation of post-acceleration system.

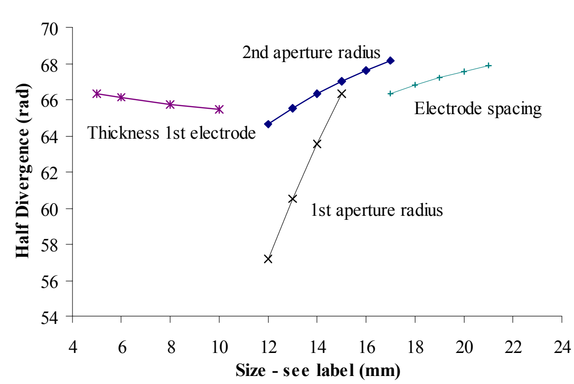

Figure 2: Beam divergence as a function of the parameters of a diode post-acceleration system.

The simulations also show that the focusing leads to an increase in emittance. However, with the 2D simulation the absolute increase is difficult to quantify.

Further simulations were made in 3D with KOBRA to see more accurately the effect of the parameters on the emittance.

Table 1 gives the emittance and divergence for two electrode configurations, with an electrode spacing of 2cm. In the first case the input beam distribution was a waterbag, with 40mA beam current. Data is also given for different beam currents starting with a uniform beam distribution.

The simulations show an important effect of the beam distribution, with the emittance growth in the post-acceleration being significantly larger when a waterbag distribution is used instead of a uniform input in real transverse space. This is caused by two effects, i) the non-linear space charge field of the waterbag distribution, and ii) the fact that some particles are at a larger radius and see more of the non-linear focusing force of the electrodes. These two effects contribute equally to the emittance growth in this case.

In conclusion, the minimisation of the emittance growth and the beam divergence requires knowledge of the beam distribution, and must take into account practical considerations of beam loss and possible discharges. Therefore, starting from the geometry simulated above, the system should be designed to allow flexibility of the electrode apertures and the electrode spacing, which will finally be optimised with the beam.

Table 1: Emittance and divergence of H- beam simulated with KOBRA, for two configurations

	Emittance (mm.mrad)	Half diverg. (mrad)
Small - wb	19.6	77.8
Large - wb	18.7	85.8
80mA - uni	17.8	84.3
50mA - uni	17.8	75.5

Small: 3, 3.5cm apertures for 1st and 2nd electrode
Large: 4, 4.5cm apertures for 1st and 2nd electrode
50mA, 80mA: With small apertures and uniform beam.
Emittance in 10^{-6} m.rad - 1rms – geometric
wb – Waterbag distribution; uni – uniform distribution.

LEBT – SOLENOID SIMULATION

The beam emerging from the RF H- source is supposed to be circularly symmetric, and therefore it is proposed to use a two solenoid focusing system for the low energy beam transport (LEBT) to match the beam to the RFQ.

Experience with many low energy, quasi-DC beams with high space charge has shown that the beam space-charge will be heavily compensated by the capture of positive ions released from collisions with the rest-gas. Soloshenko [5] suggests that the ideal pressure for suppressing space-charge is approximately 5×10^{-5} torr (the exact value depending on beam parameters). Therefore the Linac 4 LEBT should control the pressure with the injection of gas (initially using H_2, but allowing tests with other gases).

Other laboratories have estimated the space-charge compensation degree to be higher than 95%. Therefore for the CERN Linac 4 LEBT it is assumed that 90% can be reached. For simulations the space charge is assumed to be uniformly compensated.

CERN already uses many solenoids, so several solutions have been simulated, either to recover existing solenoids, or use ones of the same design (therefore saving design costs, and reducing the number of spare parts that must be kept).

A layout of the proposed LEBT with ports for diagnostics is shown in Figure 3, and the main parameters of the three solenoid designs that have been tested are given in Table 2.

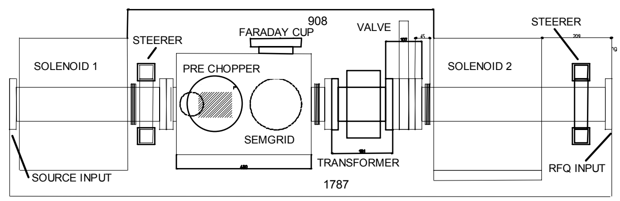

Figure 3: Proposed layout of the Linac 4 LEBT.

Table 2: Main parameters of the solenoid types considered for the Linac 4 LEBT

	Linac2	Linac3	LIL
Aperture (mm)	60	110	180
Length (mm)	190	320	205
Coil	Stepped	Block	Block
Shielded	Yes	Yes	No
	Pulsed	DC	DC

The three different types have been simulated with PATH [6], a multi-particle code. Field maps have been used for the solenoids, and the beam has been generated with a uniform distribution, corresponding to an early design of the post-acceleration. The results at the RFQ matching plane, for 50mA with 90% beam compensation, are listed in Table 3.

Table 3: Summary of the matching and emittance growth of 3 solenoid solutions, at the RFQ input. Beam input regenerated at LEBT input with uniform distribution

	α	β	ε	ε growth
Linac2	1.5	0.076	23.7	20%
Linac3	1.4	0.067	21.0	6.6%
LIL	1.41	0.060	20.8	5.6%

β in mm/mrad; ε in 10^{-6} m.rad - 1rms - geometric
ε growth: Emittance growth in LEBT.

The small aperture of the Linac 2 solenoids is almost completely filled by the high divergence beam from the source and post-acceleration, and results in a considerable increase in the emittance. Initial layout of the source, post-acceleration and solenoid suggest that the solenoid cannot be brought any closer to the post-acceleration unit without compromising the pumping speed of the source area.

The Linac 3 type solenoids lead only to a small emittance growth of the beam, and do not require any great compromises on the post-acceleration system.

The LIL solenoids give an even smaller emittance growth. However, they presently lack any magnetic shielding (the addition of shielding may introduce additional non-linearities) and the electrical current and water cooling would have to be pushed significantly past their design values. In view of the very small improvement in emittance, and the considerably more expensive power supplies, these solenoids are not considered any further, unless the beam size and divergence is found to be higher than expected.

Further comparison of the Linac 2 and Linac 3 solenoids is made with a direct particle transfer from the post-acceleration simulation to the LEBT calculations (see Table 4), both for beam with a uniform x-y distribution, and Gaussian distribution (extended to 3 sigma).

Table 4: Emittance growth (%) in the LEBT as a function of solenoid type, beam distribution and compensation degree (c)

ε growth	c=90%		c=50%	
	Uniform	Gaussian	uniform	Gaussian
Linac2	24%	59%	19%	81%
Linac3	11%	32%	9%	68%

The results continue to show the benefit of the larger aperture solenoids, however a large emittance growth is present for both solenoid designs for Gaussian distributions. This growth is mostly due to the larger radius of some particles.

Further simulations have shown that there is little additional emittance growth caused by misalignment of the beam up to 2 mm and 10 mrad. It is necessary to steer the beam into the acceptance of the RFQ.

DIAGNOSTICS

The following diagnostics are foreseen in the LEBT system (or as temporary installations) in order to characterize the beam from the source.

Retractable Faraday Cup: For reliable measurement of the beam intensity, this should be the first diagnostic available during the first commissioning of the source. A suppression system is required to be sure that any 95keV electrons are removed from the beam. This may only require initial installation in order to confirm the absence of electrons.

Emittance Measurement: A simple and reliable stepping slit and Profile monitor device is prefered. This will be used to make initial confirmation of the beam emittance after post-acceleration (possibly in comparison with a non post-accelerated beam), and also to measure the emittance growth of the beam through the solenoids. It will finally confirm the RFQ matching parameters. It should also be well aligned to allow the beam steering to be confirmed.

Profile Measurement: A profile harp is foreseen, with a stepped spacing in order to allow higher precision on focused beam, and still measure the full width of the beam in the normal mode of operation.

Energy spread: Using a spectrometer magnet, loaned by CEA, Grenoble, and the profile measurement system noted above, the energy spread of the beam can be measured to a resolution of 100eV (at an average energy of 95keV). Gating the profile measurement will allow the source droop to be quantified as a function of time.

CONCLUSION

The conceptual design of the Linac 4 post acceleration and LEBT is almost complete. However, the final results critically depend on the beam characteristics emerging from the source, and sufficient flexibility must be foreseen to allow the beam to be optimized. High quality measurements of the beam will also be necessary to achieve a low emittance growth.

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