A Compact Double Einzel Lens LEBT with Steering for H^+ Beams*

Chun Fai Chan and John W. Staples
Lawrence Berkeley Laboratory
1 Cyclotron Road, Berkeley, Calif 94720

Abstract

We have designed a six-electrode double-einzel lens low-energy beam transport (LEBT) system with several unique features. It will extract and transport a 30–50 mA, 40 keV proton beam from an rf-driven ion source to an RFQ accelerator and is only 11 cm long. Special features include: 1) Independent adjustment of beam radius and convergence angle (Twiss parameters) at the entrance of the RFQ by using two einzel lenses; 2) Beam steering to correct misalignment by using four-way split electrodes; 3) The all-electrostatic design avoids the problem of beam neutralization entirely; 4) Diagnostic instruments and a gate valve can be inserted into the beam line. Results of computer simulations with 2D and 3D codes will be presented, along with an engineering design. A slight variation of this design can be used for H^- beams.

Introduction

The transport and matching of a proton or H^- ion beam from an ion source to an RFQ is simplified if the proton beam can be kept unneutralized by using an all-electrostatic LEBT. Keeping the distance between einzel lenses short decreases the beam size in the lenses, decreasing the spherical aberration. Short LEBTs offer the advantage of keeping emittance blowup under control but the introduction of beam steering and diagnostic devices is difficult.

The LEBT presented here partially addresses some of these issues. Two einzel lenses allow some range of adjustment in α-β (Twiss parameter) space. Splitting the einzel lenses into four quadrants allows some degree of steering without introducing too much aberration, and a short space left immediately in front of the RFQ entrance allows the introduction of a gate valve and simple beam diagnostic.

Advantage of an Electrostatic LEBT

Injection into an RFQ usually requires a large convergence angle with the beam focused to a small spot beyond the beginning of the RFQ vanes. Reducing the distance between the last lens and the RFQ vane will reduce the beam size in the lens, which reduces the emittance growth introduced.

Electrostatic LEBTs are mechanically relatively simple and easy to fabricate, and avoid plasma build-up and instabilities. Three-dimensional computational tools to model the ion optics design of an electrostatic LEBT with segmented elements are now becoming available, so one can confidently predict the performance of relatively complex, three-dimensional configurations.

Specific Design Example

The design example shown here matches an rf-driven bucket H^+ source [1] to a 400 MHz, 800 keV RFQ [2]. The ion source parameters are:

Ion	H^+	
Extr aperture radius	0.21	cm
Current density	0.217	amp/cm^2
H^+ fraction	>90	%
Thermal energy kT_i	1.0	eV

The RFQ parameters are:

Ion	H^+	
Frequency	410	MHz
Input Energy	40	keV
Output Energy	800	keV
Length	1.0	meter
Foc Parameter B	4.77	
Avg radius r_0	0.304	cm
Initial α (Twiss)	2.25	
Initial β (Twiss)	6.29	cm
ε_{4rms} acceptance	0.05	π cm-mrad, norm
Beam spot radius	0.185	cm
Convergence angle	72	mrad
Peak current	40	mA

The LEBT is optimized to provide a match to the default Twiss match parameters given in the table, with sufficient range to accommodate variations due to changes in ion source parameters, beam current and RFQ characteristics.

Ion Beam Optics Computations

We use the axisymmetric 2D code WOLF [3] to compute the charged particle trajectories without steering and without the electron beam deflection magnet used in the H^- source. In order to compute the rms projected emittance in each phase plane properly, it is necessary to use the version of WOLF with skew beam dynamics [4]. Here, each beamlet is launched with axial, radial and azimuthal velocities, the last two quantities representing the thermal temperature of the ion from the source.

For the 3D beam optics computation including the effects of the split einzel lenses used to steer the beam, we use the ARGUS code developed by SAIC [5].

The result of the 2D beam optics computation is shown in Figure 1. After the match point coordinates of the beam are calculated from the raytrace code by the usual equations:

$$\varepsilon_{4rms} = 4\beta_0\gamma_0\left[(x^2_{rms})\,(x'_{rms})^2 - (xx')^2\right]^{1/2}$$

and

---

*This work was supported by the Director of Energy Research, Office of High Energy and Nuclear Physics, Division of Nuclear Physics of the U.S. Department of Energy under contract number DE-AC03-76SF00098

$$\alpha = -4\frac{\beta_0\gamma_0(xx')}{\varepsilon_{4rms}}, \qquad \beta = 4\frac{\beta_0\gamma_0(x_{rms})^2}{\varepsilon_{4rms}}$$

where $\beta_0\gamma_0$ is the usual relativistic factor.

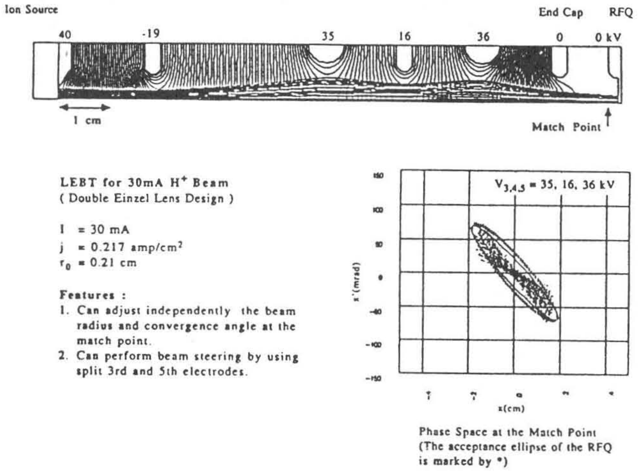

Figure 1. 2D Beam Optics for 30 mA Beam

The computed parameters corresponding to the figure are ε_{4rms} = 0.038 π cm-mrad, α = 3.12 and β = 8.89 cm for a 30 mA beam. (We have assumed that the initial beam thermal energy kT_i = 1.0 eV, thus the initial intrinsic emittance is ε_{4rms} = 0.014 π cm-mrad.) The ion source current density is 0.217 amp/cm^2 with an aperture radius of 0.21 cm. The small extraction aperture insures a high fraction of over 90% of H$^+$ [6].

Variation of the Twiss parameters α and β is achieved by varying the potential of the two einzel electrodes (35 and 36 kV in Figure 1). The double einzel system allows the beam radius and convergence angle to be varied somewhat independently, as shown in the four examples in Figure 2.

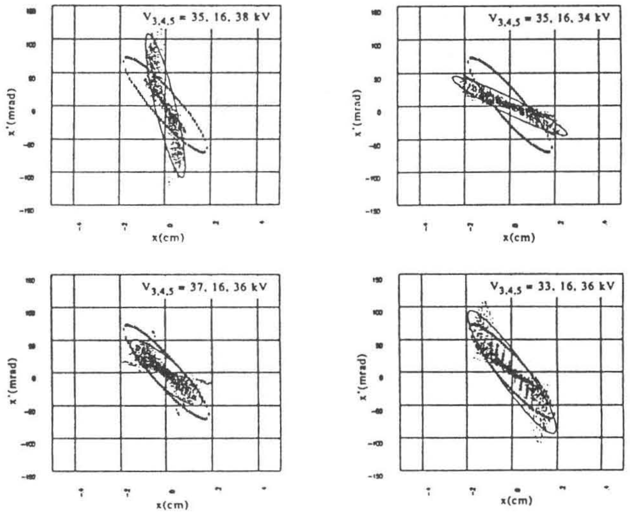

Figure 2. Exit Beam Variation vs. Einzel Potentials

The match for variations in beam current from 30 to 50 mA can be accommodated by varying the extraction electrode potential from -19 to -44 kV to restore the Child-Langmuir relation. The beam envelope for 50 mA is shown in Figure 3.

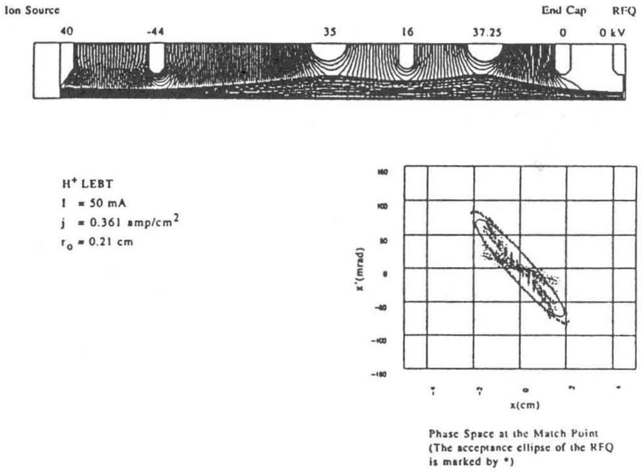

Figure 3. 2D Beam Optics for 50 mA Beam

Beam Steering with Split Electrodes

Two steering stations can be accommodated by splitting each of the two einzel lenses into four quadrants, split vertically and horizontally, allowing the presence of a transverse electrostatic field with additional power supplies. Figure 4 shows an ARGUS mesh for the electrodes, with one quadrant removed for clarity.

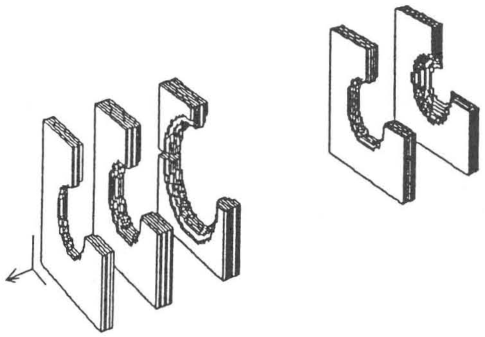

Figure 4. ARGUS Mesh of Split Electrodes

A balanced potential offset is applied to the split electrodes, each for the two transverse planes, producing a x- or y-steering of the beam. Two sets of split electrodes, i.e. each of the two einzel lenses, allows some correction of both position and angle over small limits at the entrance of the RFQ.

An example is shown correcting the deflection of the extraction of an H$^-$ beam by the electron sweep magnet in the ion source extraction electrode using one split einzel lens [7]. Figure 5 shows the effect of a 0.5 kV potential difference across a split first einzel lens in the y-z plane, Figure 6 show plot in the x-z plane. The offset angle due to the sweep magnet is corrected, with a small residual offset in the y-direction.

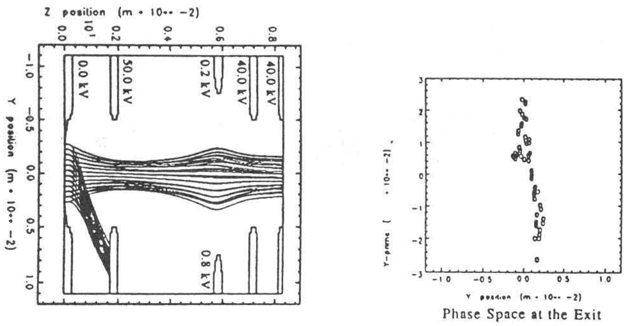

Figure 5. Steering Beam to Correct Sweeping Magnet Deflection in the y-z Plane

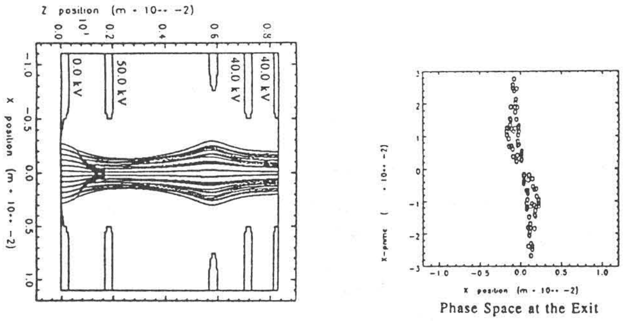

Figure 6. x-z Trajectory Plot and the Phase Space x-x'

Gate Valve and Diagnostic Instruments

By designing the second einzel lens (the one immediately in front of the endcap of the RFQ) so it can be taken down to ground potential, a gate valve or diagnostic instrument can be placed in the 1-cm space between the lens and the RFQ entrance endcap. Figure 7 shows the ion source and LEBT placed in front of the one-meter-long RFQ.

The gate valve swings in from the side on a pivoted arm and rests against the valve face machined into the end of the RFQ. This valve will hold with gas pressure on the ion source/LEBT side only. This allows the ion source to be brought to air for servicing while keeping the RFQ under vacuum.

A small five-segmented Faraday cup can also be swung into the beamline at this position with the last einzel lens operated at ground potential. The beam optics at the last einzel lens will be altered but can be calculated, and a segmented cup gives rough measurement of the zero, first and second moments of the beam.

Summary

This double-einzel split-electrode all-electrostatic LEBT is undergoing engineering development at present and will be tested on an existing ion source and RFQ. It offers beam unneutralized transport with steering and some range of adjustment in $\alpha-\beta$ Twiss space. A gate valve and beam diagnostic are all accommodated in a 11 cm axial length.

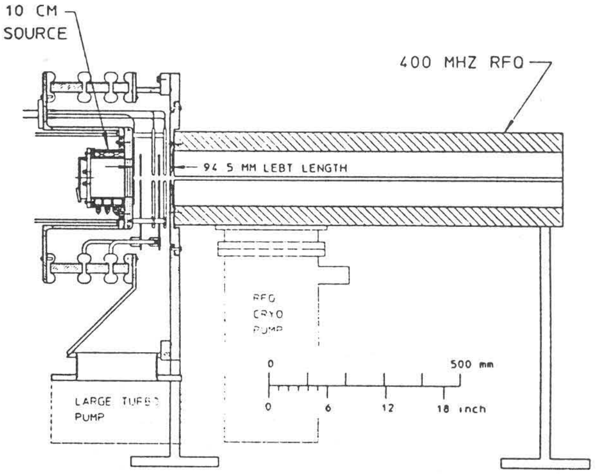

Figure 7. Ion Source, LEBT and RFQ

The authors acknowledge the contributions of Matt Hoff for the mechanical design, and Rick Gough and Ka-Ngo Leung for support.

References

[1] K.N. Leung et al, in Proceedings of the Conference on High Energy Accelerators 1992, Hamburg, Germany, Int J. Mod. Phys. A (Proc Suppl.) 2 (1993), p. 200; J. Rossbach, ed.

[2] S. Abbott, R. Caylor, R. Gough, D. Howard, R. MacGill and J. Staples, Design of an Integrally Formed RFQ, 1989 PAC, Chicago, 1989, p. 953

[3] W.S. Cooper, K. Halbach and S.B. Magyary, Proc. 2nd, Symp on Ion Sources and Formation of Ion Beams, Berkeley, LBL-3399, 1974.

[4] C.F. Chan et al, Nucl. Instr. Met. Phys. Res. A306, (1991), p 112

[5] Science Applications International Corporation, 1710 Goodridge Drive, McLean Va 22101

[6] K. Leung, private communication.

[7] C.F. Chan and K.N. Leung, Particle Accelerators, Vol 43(3), 1004, p. 145-158.