Low Energy H^- Beam Transport Using an Electrostatic Quadrupole Focusing System*

S.K. Guharay, C.K. Allen, M. Reiser, V. Yun
Laboratory for Plasma Research
University of Maryland
College Park, MD. 20742

Abstract

An experiment is designed to transport a round and diverging H^- beam, with beam current of 30 mA and voltage of 35 kV, over a length of about 30 cm with the aim to match it to an RFQ with a modest emittance growth. The low energy beam transport system consists of six electrostatic quadrupole (ESQ) lenses. A linear KV code, in conjunction with a 3-D Laplace solver, is used to configure the electrode geometry. Fringe field integrals from the Laplace solver are given as input to a modified PARMILA code to evaluate the influence of the nonlinear forces and calculate the emittance growth. The ESQ system is designed with a mechanical tolerance of < 1 mil; the critical issue of alignment of the apparatus with respect to the beam is addressed. Details on the design and construction of the ESQ system and some preliminary experimental results are presented.

I. INTRODUCTION

In accelerator research, designing an efficient low energy beam transport (LEBT) section is of great relevance even today. The electrostatic quadrupole (ESQ) lens system presents a good prospect in this regard in handling beam current up to $\lesssim$ 30 mA at acceleration voltage of 35 kV. In this context, several experimental efforts are currently in progress, e.g., at the SSCL using helical quadrupole lenses[1], in this laboratory with conventional configuration of the ESQ lenses[2].

The beam transport section is designed here to transport a 30 mA, 35 kV H^- beam over a length of about 30 cm, and eventually to match this beam into a radio frequency quadrupole (RFQ). This experiment is planned following the beam parameters of a modified Penning-Dudnikov source[3] on the AT-1 test stand at Los Alamos National Laboratory. The design of the LEBT section is developed through computer code simulations. Results from a linear beam optics code solving the well-known K-V envelope equation, and an analysis of the focusing function and fringe-field matrices from a 3-D Laplace solver form the basis of the lens design. A modified PARMILA code[4] calculates the emittance growth in the system.

The key features of the present system are: (1) The lens assembly consists of six quadrupole lenses in a symmetric triplet configuration. (2) The entire unit is adjustment-free mechanically. This points to ruggedness of the system. (3) Estimated emittance growth is about 78%.

In an earlier paper, design procedure of the LEBT section is described in detail[2]. The emphasis of this article is on issues related to fabrication of components, interfacing the LEBT section with the ion source and beam diagnostics. Some characteristic test results of a prototype lens system are given.

II. THE LEBT SYSTEM

A. Essential Design Issues

The LEBT system is designed to transport a high-brightness (normalized brightness $= 7.98 \times 10^{10}$ A/(m-rad)^2) H^- beam from the aforementioned ion source at Los Alamos. The input beam, carrying a current of 30 mA, is taken as round and diverging with beam radius = 1 mm and divergence of the beam envelope = 20 mrad. It is aimed to generate a round, converging beam (radius ~1 mm, convergence angle ~20 mrad) at the output of the transport channel. Details of the design are described earlier[2]. The key points in this regard are mentioned here and some important modifications of the previous design are highlighted.

A linear beam optics code, solving the K-V equation and coupled with a 3-D Laplace solver, generates parameters of the ESQ lenses. In order that the influence of spherical and chromatic aberrations as well as nonlinear image fields may be minimized, some design constraints are imposed on the maximum radius of the beam envelope in various sections of the transport channel, dimensions of the quadrupole lenses, and applied voltage on the quadrupoles[2]. Table 1 presents characteristic lens parameters.

The symbols carry their usual significance. Effective length, $l_{\rm eff}$, of the quadrupoles is calculated from the 3-D Laplace solver following the relationship $l_{\rm eff} = 1/\kappa_0(\int_{z_1}^{z_2} \kappa(z)dz)$. Here z_1 and z_2 correspond to the zero-crossing points of the focusing function $\kappa(z)$ at the entrance and exit ends of the lens respectively; the maximum value of κ is κ_0. V_q is obtained from the K-V code using the

---

*Research supported by ONR/SDIO.

0-7803-0135-8/91$01.00 ©IEEE

Table 1: Lens parameters from linear code analysis and 3-D Laplace solver.

Quad number	1/6	2/5	3/4
l (mm)	15.00	59.00	47.00
L^* (mm)	6.00	6.00	6.00
R_q (mm)	8.00	12.00	12.00
l_{eff} (mm)	14.50	55.40	42.90
V_q (kV)	8.08	3.98	3.92

*The drift space between lenses, L, is longer here compared to the previous design[2].

Table 2: RMS normalized emittance values and emittance growth .

$\tilde{\epsilon}^{(i)}_{nx,ny}$	$\tilde{\epsilon}^{(f)}_{nx}$	$\tilde{\epsilon}^{(f)}_{ny}$	$\bar{\tilde{\epsilon}}^{(f)}_{n}$	$\bar{\tilde{\epsilon}}^{(f)}_{n}/\tilde{\epsilon}^{(i)}_{n}$
0.069	0.107	0.138	0.123	1.78

quadrupole length as l_{eff}, when an almost round, converging output beam envelope ($X_f = 1.04$ mm and $Y_f = 0.98$ mm; $X'_f = -26.4$ mrad and $Y'_f = -25.6$ mrad) is generated at a distance of 15 mm downstream from the last lens. The beam envelope and the focusing function are shown in Fig. 1. The beam convergence gets appreciably high moving the end point very little towards the last lens– at $z = 29.8$ cm, i.e., moving the end point 4 mm closer to the last lens, $X'_f = -42.4$ mrad and $Y'_f = -42.2$ mrad, while $X_f = 1.19$ mm and $Y_f = 1.13$ mm. This feature may be exploited in coupling the LEBT system to an RFQ, when a highly convergent beam (e.g., about -76 mrad for BEAR RFQ) is usually required. However, the aim of our initial effort is to study effectiveness of transport of a high-brightness beam through the ESQ lens system and identify the various control parameters.

A modified PARMILA code is used to simulate the beam envelope in the presence of nonlinear fringe-field forces; this code estimates the emittance growth in the LEBT system as well. Initially, the code is run with input parameters corresponding to Table 1. Next, voltage on the quadrupoles is adjusted to establish a round, converging output beam. Figure 2 shows phase space plots of particle distribution at $z = 30.2$ cm in the most optimized attempt made here so far. Here, $X_f = 1.25$ mm, $Y_f = 1.31$ mm, and $X'_f = -30.6$ mrad, $Y'_f = -19.2$ mrad. Shifting the endpoint 4 mm closer to the last lens, i.e., at $z = 29.8$ cm, the beam envelope shows $X_f = 1.4$ mm, $Y_f = 1.4$ mm, and $X'_f = -44.4$ mrad, $Y'_f = -34.5$ mrad. The maximum deviation of the new set of voltages from the respective V_qs in Table 1 is about -14%. The code analysis thus appears to yield sufficient guideline to the possible range of voltage setting on the quadrupoles to generate a round, converging output beam in the beam transport experiment. Results on beam emittance in mm-mrad are given in Table 2. Emittance growth appears to be quite modest.

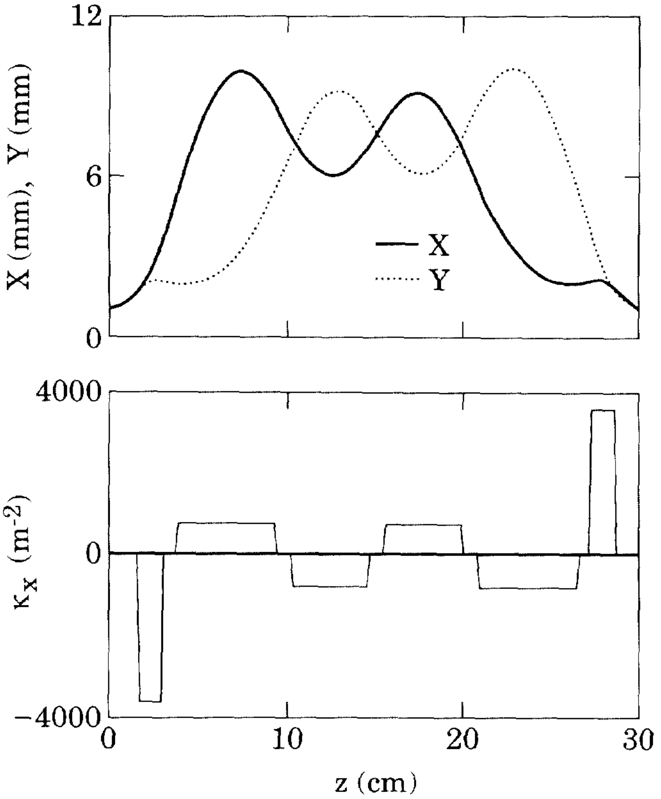

Figure 1: K-V beam envelope solution (top), hard-edge focusing function (bottom).

We have also studied the influence of the boundary of the cylindrical grounded body containing the lens assembly. It appears that the radial dimension of this housing plays an important role in determining focusing function in the transport channel. In context of our particular lens geometry and beam parameters, significant mutual influence of neighboring lenses is noted for radius of the housing less than about 8 cm, and effectiveness of the ground plates between lenses is reduced. This weakens the focusing function within the lens and may cause a deleterious effect on the beam envelope in terms of emittance dilution. Further studies on this issue are warranted.

B. Construction of ESQ Lenses and Hardware Assembly

The ESQ lens system in the present experiment is shown in Fig. 3. The three principal elements of the lens system are: (1) six lenses, each consisting of four quadrupoles, (2) ground plates between the lenses, and (3) precision ceramic insulator balls. The four quadrupoles of each lens are machined out of a single piece of finished cylindrical aluminium rod. The dimensional tolerance of each electrode is held within 0.2 mil, which is checked by a precision micrometer. The electrodes are contoured in a manner to reduce field nonlinearities[2]. The aluminium ground plates are 2 mm thick. Ceramic balls are used here to develop an adjustment- free, self-aligned lens assembly. Two

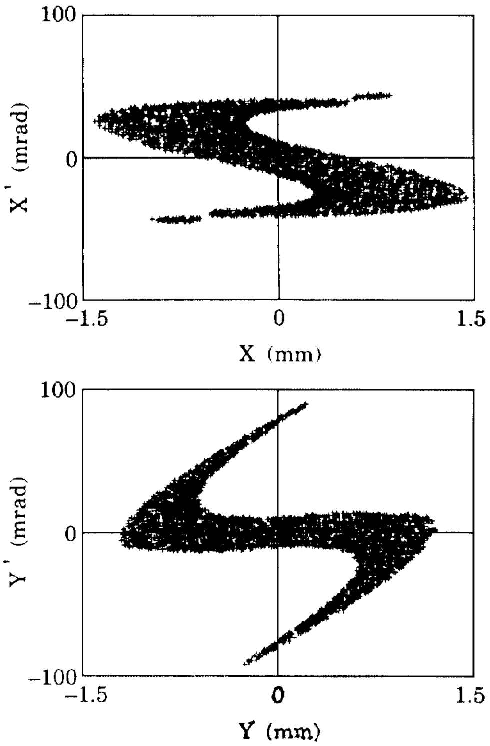

Figure 2: Particle distribution in phase space at $z = 30.2$ cm from modified PARMILA code.

sets of precision balls, having tolerance in sphericity within ±0.025 mil, are used. Larger balls of 3/8 inch diameter are used between two opposing quadrupoles of adjacent lenses; smaller ones of 1/8 inch diameter are placed between a quadrupole and its neighboring ground plate. Such an arrangement delivers much better alignment than the earlier one[2]. The entire lens assembly is mounted in a cylindrical housing, which is installed in a vacuum vessel.

Currently, efforts are being made to build up mechanical hardwares to interface the front end of the vacuum vessel with the ion source. The back end will be connected to a diagnostic box equipped with emittance scanners.

III. TEST RESULTS AND EXPERIMENTAL PLANS

A prototype lens system has been constructed and voltage hold-off tests were done. At a hydrogen gas pressure of about 3×10^{-4} Torr, a voltage level of ±12.5 kV can be maintained between quadrupoles of opposite polarities in a lens. In this effort, corona discharges occurred quite frequently at lower voltage initially. With gradual conditioning of the surface of the electrodes, the lens system could be driven at higher voltage without any noticeable voltage breakdown. This insures practicability of the present compact ESQ lens design.

Preparations are being made to characterize the H^- beam from the ion source using Faraday cup and emittance scanners. Afterwards, the LEBT system will be coupled to the ion source and efficiency of beam transport with ESQ lenses will be studied.

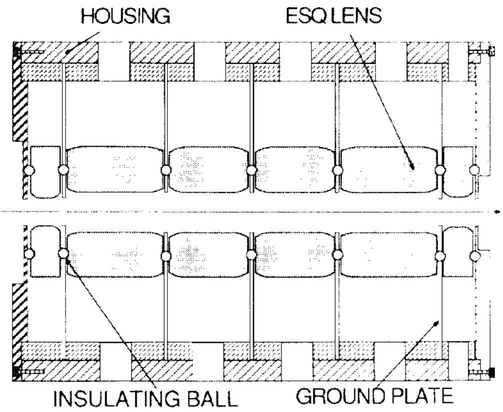

Figure 3: ESQ lens assembly.

IV. REFERENCES

[1] C.R. Meitzler, P. Datte, F.R. Huson, P. Tompkins, D. Raparia, "Progress on the TAC ion source and LEBT," Proc. LINAC Conf., Albuquerque, N.M., September 1990, pp.710-712.

[2] S.K. Guharay, C.K. Allen, and M. Reiser, "Electrostatic focusing and RFQ matching system for a low energy H^- beam," Proc. SPIE Conf. on Intense Microwave and Particle Beams, Los Angeles, CA, January 1991, vol.1407, pp.610-619.

[3] P.W. Allison and J.D. Sherman,"Operating experience with a 100 keV, 100 mA H^- injector", Proc. 3rd Symp. on Production and Neutralization of Negative Ions and Beams, AIP Proc., 1983, vol. 111, p. 511.

[4] C.R. Chang, E. Horowitz, and M. Reiser, "Conceptual design of an electrostatic quadrupole transport system for high-brightness H^- beams", Proc. SPIE Conf. on Intense Microwave and Particle Beams, Los Angeles, CA, January 1990, vol. 1226, pp. 483-498.