An ESQ Lens System for Low Energy Beam Transport Experiments on the SSC Test Stand

S. K. Guharay, C. K. Allen, M. Reiser
Laboratory for Plasma Research, University of Maryland, College Park, MD 20742, USA
and K. Saadatmand
SSC Laboratory, Dallas, TX 75712, USA

Abstract

A low-energy beam transport system is designed with the aim of transporting a 30 mA, 35 kV H^- beam from a volume source and focusing it into an RFQ. The characteristics of the beam from the source are determined analyzing the emittance data. The behavior of the beam through the LEBT is studied using simulation codes. The system parameters are optimized so that the LEBT has a very modest contribution to the emittance growth (here a factor of about 1.5) and the emittance budget of the linac section is maintained.

I. INTRODUCTION

One of the vital considerations in modern high-energy accelerators is related to the design of an efficient low-energy beam transport (LEBT) section so that an intense, high-brightness beam (here we consider an H^- beam) can be transported over certain distance and finally focused into the commonly used RFQ accelerator in the linac section. The emittance growth in the LEBT is the key issue in developing a good scheme at the low-energy end of the accelerator chain. Thus, in order to achieve a good beam quality and match it to the acceptance of an RFQ a systematic study of beam dynamics in the preceeding sections including the extraction optics of the ion source is warranted. We have experienced that emittance measurements of the beam from an ion source and an analysis of the data to characterize the beam at the extraction electrode are two important problems in the context of designing an efficient LEBT. Earlier we reported [1,2] on the beam characterization and beam dynamics through a LEBT for H^- beams from a Penning-Dudnikov type [3] and magnetron type sources. In recent years significant progress has been made in the performance of volume sources [4,5]; normalized beam brightness approaches about 10^{11} A/(m-rad)^2 for H^- beams. This article highlights on the study of H^- beams from the SSC volume source with the aim of designing a LEBT system to deliver a 30 mA, 35 kV beam matched with the RFQ input.

0-7803-1203-1/93$03.00 © 1993 IEEE

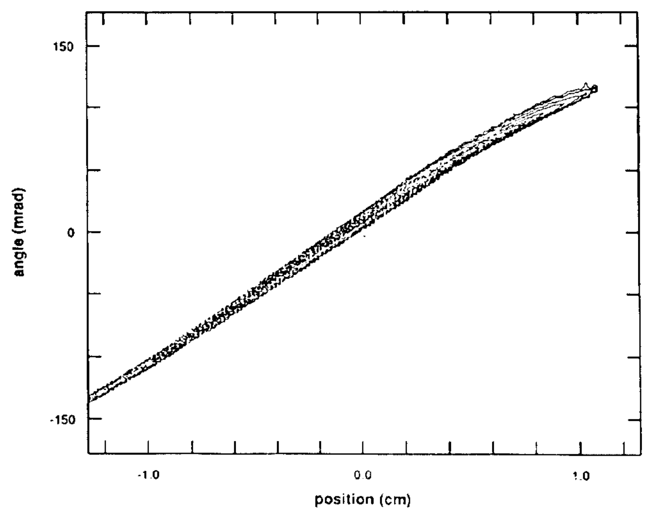

Figure 1: Contour emittance plot.

II. BEAM CHARACTERISTICS

A. H^- Beam from the Ion Source

The H^- beam from the SSCL volume source is measured at 10.13 cm downstream after the electrons (ratio of initial electron to ion current ~ 40) are deflected away from the extracted beam current by a 10 cm long magnetic trap. Figure 1 shows the contour plots in the $x - x'$ space from emittance diagnostics; the flattening of the distribution in the upper half is possibly caused by the space-charge force due to the electrons deflected upward. The beam parameters at z = 10.13 cm are: beam size D = 2.38 cm, full divergence $\Delta\theta$ = 260 mrad, $\pi\tilde{\epsilon}_n$ = 0.1537π mm-mrad. These data are used in an envelope simulation code to estimate the beam characteristics at the extraction electrode; space-charge effects due to the electrons in the extraction region are included. Figure 2(a) shows the assumed space-charge correction factor, f, due to the electrons. Note that f is

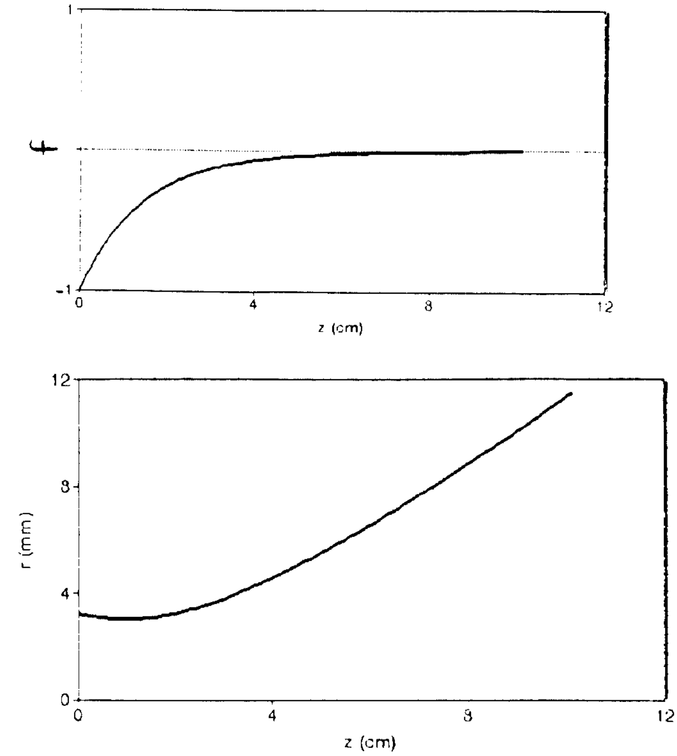

Figure 2: (a) Space-charge correction factor f; (b) beam envelope. z = 10.13 cm corresponds to the location of emittance measurements.

negative here and the beam perveance is to be multiplied by the factor $(1 - f)$. The beam envelope in Fig. 2(b) is evaluated by integrating the K-V envelope equations using a fourth-order Runge-Kutta method. This analysis suggests that the beam at the extraction electrode emerges nearly parallel, and the beam size is close to the aperture radius (= 4 mm).

B. Desired Output Beam Parameters from the ESQ LEBT

The purpose of the LEBT section is to isolate the RFQ from the ion source for a clean operation and also to deliver a matched beam to the RFQ. The SSC RFQ acceptance for a 30 mA, 35 kV H^- beam is given by the Twiss parameters: $\alpha = 1.26$, $\beta = 1.86$ cm/rad, $\pi\tilde{\epsilon}_n = 0.2\ \pi$ mm-mrad. As the normalized rms emittance of the H^- beam from the source is about 0.1537 π mm-mrad (Fig. 1), the LEBT is to be designed under a very tight emittance budget. The matching condition dictates that the beam parameters at the tip of the RFQ vane should be: beam radius = 1.3 mm and the corresponding slope of the beam envelope = -89 mrad; this is located at about 3 cm downstream from the front wall of the RFQ. It has been shown earlier that a short (about 5 cm long) single einzel lens module between an ESQ LEBT and the RFQ will be a good choice in satisfying the aforementioned stringent conditions of the RFQ [2]. The ESQ LEBT transforms the highly diverging beam from the ion source into a moderately converging one without any significant emittance dilution, and the einzel lens provides the final strong focusing. This analysis showed that the parameters of the output beam from the ESQ LEBT should follow: beam radius $\sim$ 3 to 5 mm, the corresponding slope of the beam envelope ~ -30 to -50 mrad.

III. BEAM TRANSPORT THROUGH THE ESQ LEBT

The design principles of the ESQ LEBT follow the scheme as discussed earlier [1,2]. The present configuration of the magnetic trap in the extraction region of the SSCL volume source restricts the ESQ LEBT's distance to the extraction aperture to about 10 cm. This causes the beam to blow up significantly (Fig.1). After a detailed analysis with such a beam it is recognized that the goal to deliver a matched beam to the RFQ for the full beam current (30 mA) is a very difficult task. Our analysis suggests that a shorter magnetic trap (about 5 cm long) will be a better choice. Figure 3 shows the beam envelope through the ESQ LEBT when a hard-edge focusing function for the external field is assumed. An initial drift space of 5 cm long is considered, and a profile of the space-charge correction factor due to the electrons (Fig. 3, bottom) is assumed. The beam parameters at the extraction aperture are taken from the analysis of Fig. 2. The maximum aperture radius of the quadrupoles is 22 mm; it was taken as 12 mm when the LEBT was closer (1.5 cm) to the extractor [1].

The distribution of the beam particles through the ESQ LEBT is estimated using a modified PARMILA code [6]. Figure 4 shows the particle distribution in phase space for I = 30 mA. The estimated output beam parameters are: X = 3.5 mm, Y = 3.5 mm, X' = -51.7 mrad, Y' = -50.8 mrad, $\tilde{\epsilon}_n^f/\tilde{\epsilon}_n^i = 1.5$. The emittance growth is primarily due to chromatic aberrations.

IV. CONCLUSIONS

Emittance measurements of a 30 mA, 35 kV H^- beam from the SSCL volume source have been studied. The simulation results suggest that the H^-

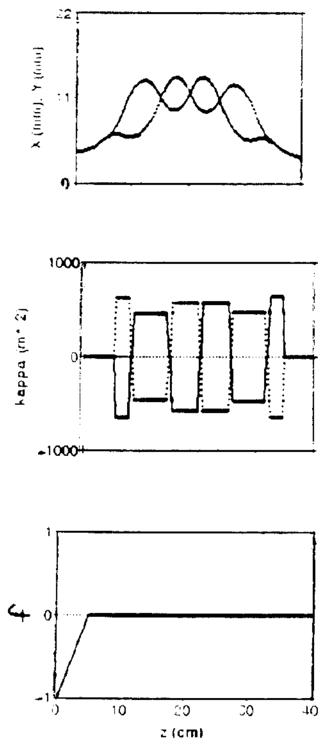

Figure 3: K-V envelope solution.

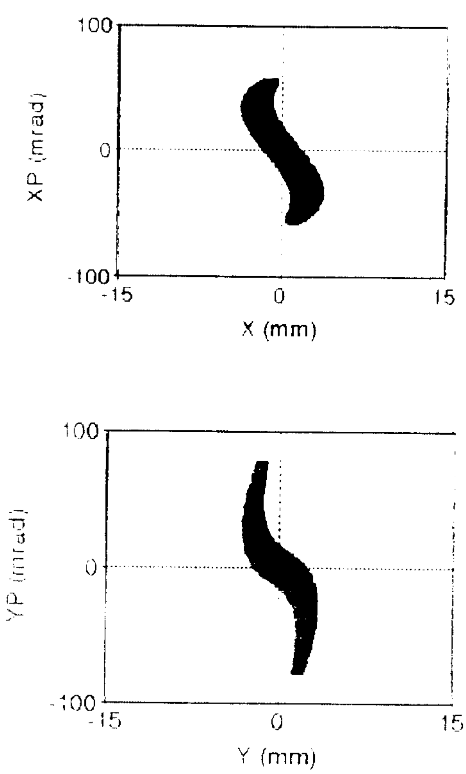

Figure 4: Particle distribution at the output of the ESQ LEBT.

beam envelope has a waist at the extraction aperture. With this definition of the input beam and a given set of characteristic parameters of the RFQ acceptance, we have designed a LEBT system. The particular design of the LEBT consisting of six ESQ lenses and a short einzel lens can transport the full beam current and match it to the RFQ.

Beam transport experiments with a prototype ESQ LEBT will be conducted to validate the simulation predictions. Further, the 3-D LAPLACE simulation scheme is being improved using a method of moments where any arbitrary boundary can be represented numerically and the practical problems will be simulated more realistically [7].

This work was supported by ONR/SDIO and DOE.

IV. REFERENCES

[1] S. K. Guharay, et. al., *Proc.1991 Particle Accelerator Conf.*, p. 1961.
[2] S. K. Guharay, et al., *BNL Conf. on Production and Neutralization of Negative Ions and Beams*, Nov. 1992 (to be published in AIP Proc.).
[3] P. G. O'Shea, et al., *Nucl. Instrum. & Meth. in Phys. Res.* **B40/41**, 946 (1989).
[4] K. N. Leung, *BNL Conf. on Production and Neutralization of Negative Ions and Beams*, Nov. 1992 (to be published in AIP Proc.).
[5] K. Saadatmand, these proceedings.
[6] C. R. Chang, Ph. D. Thesis, Univ. Maryland, 1989.
[7] C. K. Allen, et al., these proceedings.