A COMPACT ESQ SYSTEM FOR TRANSPORT AND FOCUSING OF H^- BEAM FROM ION SOURCE TO RFQ*

S.K. Guharay, C.K. Allen, M. Reiser
University of Maryland, College Park, MD 20742 USA
and
K. Saadatmand and C.R. Chang
Superconducting Super Collider Laboratory, Dallas, TX 75237 USA

Abstract

A compact, 6-lens electrostatic quadrupole (ESQ) LEBT system has been constructed at the University of Maryland to transport a 30 mA, 35 kV H^- beam over a distance of about 30 cm. A short einzel lens section is included at the end of the ESQ LEBT to establish a good matching of the beam to the radio-frequency quadrupole (RFQ) accelerator, and to meet the emittance requirements of the linac in the Superconducting Super Collider. Computer code predictions on the beam dynamics through the LEBT with experimentally measured input beam data are discussed.

Introduction

An efficient ion source-cum-low energy beam transport (LEBT) section is highly desired to deliver a good-quality beam to the low-energy booster (LEB) in the collider ring chain of SSCL. The intrinsic emittance of the H^- beam from an ion source, volume-ionization or magnetron type, is typically about 0.12 π mm-mrad (rms normalized value); the LEB requires that the transverse beam emittance at the output of the linac section be $< 0.3\pi$ mm-mrad [1]. The components of the linac between the ion source and the LEB are: LEBT, radio-frequency quadrupole (RFQ) accelerator, drift-tube linac (DTL) and coupled-cavity linac (CCL). Computer code analyses of the beam dynamics through the DTL and the CCL suggest that the emittance growth in these two sections is not significant, being in the range of 10-15% [2]. The performance of the RFQ, e.g., beam transmission and emittance growth, depends primarily on the Twiss parameters of the beam at its input; the transverse rms normalized emittance of the input beam is desired to be $< 0.2\pi$ mm-mrad. Hence the LEBT's contribution to the emittance budget must be maintained within a factor of 1.6 of the input beam emittance. This suggests that the ion source-cum-LEBT section plays a critical role in the performance of the linac.

*Supported by ONR/SDIO and DoE Contract #DE-AC35-89ER40486.

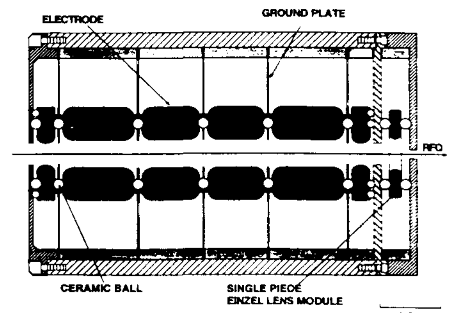

Figure 1: The LEBT system.

This article addresses some important problems in designing an efficient LEBT system. Here, an ESQ lens system is primarily considered; two other variants of the LEBT system, einzel lenses and a helical quadrupole lens, are also being investigated in the present context at SSCL [3]. The analyses are based on computer code simulations, where the input beam parameters are mostly taken from experimental measurements.

Beam Dynamics, Design of LEBT and Discussions

In our previous paper [4], we described a 6-lens ESQ LEBT system developed at the University of Maryland. The predicted performance of the ESQ LEBT are now examined in the light of beam parameters relevant to the SSCL program. Two types of H^- sources are considered in the SSCL injector development – a volume source and a magnetron source.

In the context of the volume source, we have used the beam parameters corresponding to a Brookhaven National Laboratory (BNL)-type source [5]. A 30 mA, 35 kV H^- beam is extracted through a 1 cm^2 circular aperture. A parallel beam is assumed to emerge from the extraction aperture. The beam envelope through a compact 6-lens ESQ LEBT section (Fig.1), which has been constructed in-house at

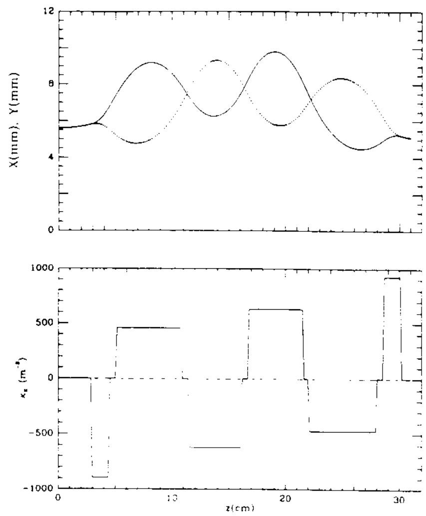

Figure 2: Linear beam optics result for a parallel input beam. Top: Amplitude (X, Y) of the beam envelope through the ESQ LEBT along x (solid line) and y (dotted line); bottom: focusing function, κ. z is the direction of propagation of the beam.

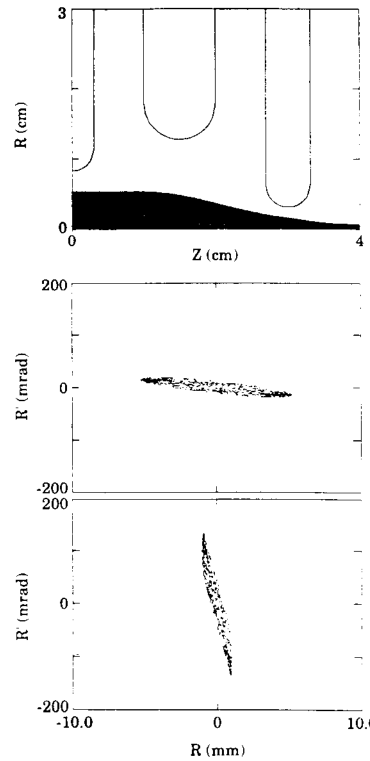

Figure 3: SNOW-2D results for the einzel lens module. Top: Beam trajectory through the einzel lens module. The center electrode is at -36 kV and the two end electrodes are grounded. Middle: Phase-space distribution of the input beam. Bottom: Phase-space distribution of the output beam.

Maryland, is computed by integrating the K-V envelope equations using a fourth-order Runge-Kutta method. Figure 2 shows the beam envelopes, when a linear external focusing force represented by a hard-edge focusing function, $\kappa(z)$, is assumed. As mentioned in the previous article [4], the SSCL RFQ requires a circular beam of about 1.3 mm in radius and a beam convergence of about -90 mrad at r_{max}. To match these conditions without sacrificing the emittance growth, an additional unit, a single-piece einzel lens module, is included at the end of the ESQ LEBT section (Fig.1). The particle distribution at the output of the ESQ LEBT is computed using a modified PARMILA code [6], and it does not show any significant emittance growth, $\lesssim 5\%$. Results in a similar situation have been shown earlier [4]; this point is not elaborated further. The einzel lens turns the moderately convergent (~ -20 mrad) beam from the ESQ LEBT into a strongly convergent (~ -110 mrad) beam with a negligible emittance dilution, $\lesssim 5\%$. The behavior of the beam through the einzel lens section, predicted by the SNOW-2D code, is shown in Fig.3.

The aforementioned analyses have been carried out using the parameters of a 30 mA, 35 kV H^- beam extracted from the SSCL magnetron source. The characteristics of the beam are measured at a distance of 11.75 cm downstream from the tip of the extraction cone. Using these results as initial beam conditions, the beam parameters at the tip of the extraction cone are predicted. A plausible estimate of the beam parameters at the tip of the extraction cone is: beam radius = 1.1 mm, and divergence at $r_{\text{max}} = 72$ mrad.

The lens aperture in the ESQ LEBT in Fig.1 is not large enough to accommodate the highly diverging H^- beam from the magnetron source. A preliminary design study reveals that the aperture of the ESQ lenses, second through fifth in Fig.1, is to be increased by a factor of 2; this demands a higher voltage on the quadrupoles. The beam dynamics through the ESQ LEBT is followed using the modified PARMILA code. Figure 4 shows the output beam distribution (bottom figure), when a K-V type input beam (top figure) is assumed. The ground plate in front of the second lens in Fig.1 has been used as a beam scraper to reject about 15% of the beam particles, which contribute significantly to the emittance growth. The output beam in Fig.4 still suffers from some distortions, giving rise to an emittance growth by a factor of about 1.5. Further optimization of the ESQ LEBT is warranted to improve the present situation. Nevertheless,

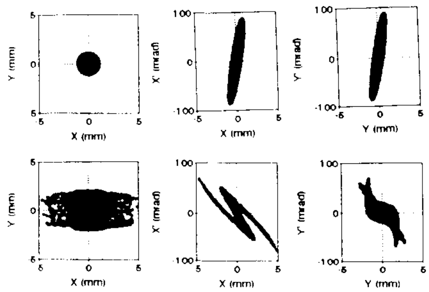

Figure 4: Modified PARMILA results on particle distribution for H^- beam from the SSCL magnetron source. Top: input to the ESQ LEBT. Bottom: output from the ESQ LEBT.

an output beam current of $\gtrsim$ 25 mA, as required for the SSC RFQ, is achievable from the ESQ LEBT. In regard to matching the beam to the RFQ, an einzel lens module is included at the end of the ESQ LEBT. Figure 5 shows preliminary results of beam transport through the einzel lens module. The smooth nature of the input beam is an artifact of modeling it from an estimate of the effective values of beam parameters in Fig. 4. The einzel lens does not contribute to the emittance growth; the beam parameters at the front end of the third electrode (at ground potential) match closely to the acceptance ellipse of the SSCL RFQ.

The above analyses for the LEBT have been done in two separate stages– first the ESQ lenses with modified PARMILA and then, the einzel lens with SNOW-2D. The simulation predictions will hold well, if the matching between the two codes is complimentary. An effort is being made to include the option of an einzel lens in the modified PARMILA, when a more reliable design tool will be available.

Conclusions

The problem of low-energy beam transport and its matching to an RFQ has been studied in reference to two special cases of the input H^- beam: (i) a parallel beam, and (ii) a highly divergent beam. The computational results suggest that the key point in designing an efficient H^- injector (ion source-cum-LEBT) relates to achieving a well-conditioned beam, e.g., unaberrated and near-parallel, from the ion source. An emphasis is laid here to develope an LEBT apparatus with compactness, mechanical stability and flexibility for easy modifications. A combination of a 6-lens ESQ module and one short einzel lens module, as adapted in the present LEBT design, appears to be a good choice in this respect. An experiment is being planned on the SSCL test stand to study the beam characteristics through the ESQ LEBT system developed at Maryland, and test the reliability of simulation predictions.

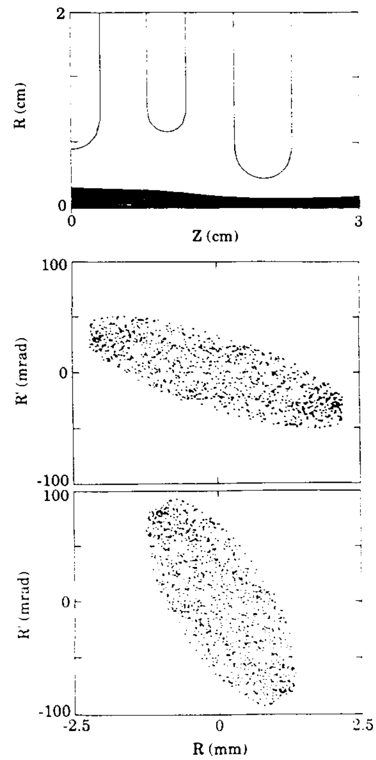

Figure 5: SNOW-2D results for the einzel lens module. Top: Beam trajectory. The center electrode is at −36 kV. Middle: Phase-space distribution of the input beam (Effective values from Fig. 4 are used to model it.) Bottom: Phase-space distribution of the output beam.

References

[1] L.W. Funk, these Proceedings, paper #MO1-2.

[2] D. Raparia, et al., these Proceedings, paper #MO4-65; ibid, paper #MO4-66.

[3] K. Saadatmand, et al., these Proceedings, paper #MO4-20.

[4] S.K. Guharay, et al., Proc. 9th International Conf. on High-Power Particle Beams, Washington, D.C., May 25-29, 1992, paper #PB36 (to be published).

[5] J.G. Alessi, private communication.

[6] C.R. Chang, et al., SPIE Proc. on Intense Microwave and Particle Beams, vol.1226, p.483 (1990).