SSCL-311

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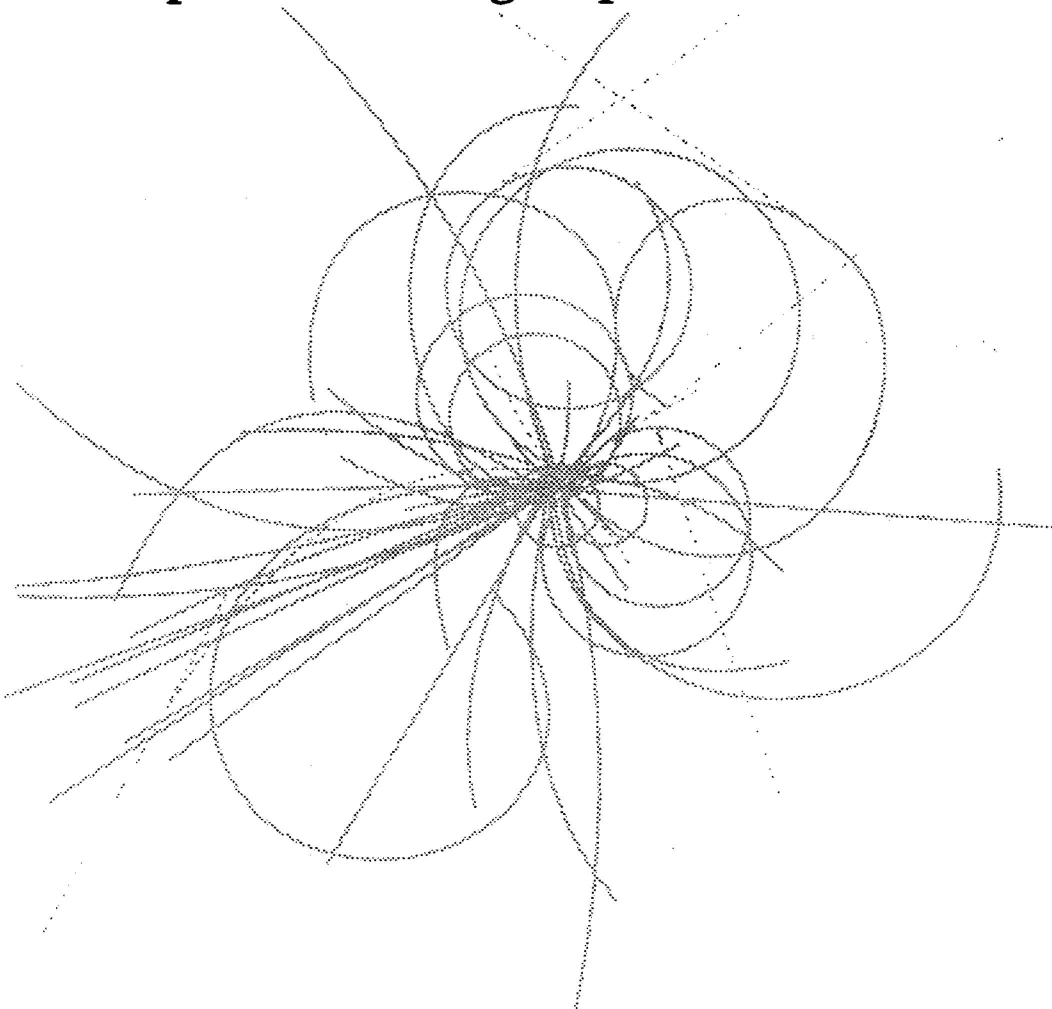

Design Studies of SSC Low-Energy-Beam-Transport System Using Einzel Lenses

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Abstract

A 35 keV preinjector for matching a 30 mA H^- beam into the radio-frequency quadrupole (RFQ) section of the SSC linac has been designed using the SNOW code. The distinguishing feature of this injector is that the conventional gas-neutralized transport and matching units are replaced by two einzel lenses. Some advantages of this approach are discussed.

Introduction

This paper describes the design and simulation results of a dc H^- injector for a 428 MHz RFQ. The system consists of a magnetron H^- source, a single-gap source extraction system and a low energy beam transport (LEBT) system. Normalized rms emittance at the entrance of the RFQ should be kept approximately 0.2 π mm-mrad. In the LEBT system two electrostatic lenses are employed. They perform two major functions: (1) provide sufficient length ($\geq$ 20 cm) for gas pumping; (2) provide proper focusing to match the beam into the RFQ. Major emphasis in the design is to minimize beam emittance and maximize the beam transmission through RFQ.

Electrostatic Focusing

Our new approach for transport of H^- beam uses electrostatic focusing instead of the usual combination of magnets and gas neutralization [1,2]. The benefits of using charge neutralization for focusing of the beam are well known. However, there are many disadvantages such as plasma instabilities, reproducibility and the problem of transition from the neutralized to unneutralized state. More importantly, the neutralization time must be very short compared to the pulse length; otherwise, a large fraction of the beam at the front of the pulse will be lost due to the inadequate focusing. The SSC linac requires a pulse length of 7-35 μs. For such short pulses, we believe it is better to use electric focusing, since it requires no neutralization time. The electric field provides sufficient focusing strength at the low energy. It also prevents the plasma buildup, thus eliminating the associated problems of varying charge neutralization.

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Design and Simulation of the DC Pre-injector

Design Constraints

In our design studies, the minimum spacing d between any two electrodes with potential difference V must satisfy the electrostatic breakdown criterion[3]

$$d_{[cm]} \geq 1.4 \times 10^{-3}\, V^{3/2}{}_{[kv]}$$

Furthermore, in order to minimize the emittance growth, the maximum beam radius should not exceed about 50% of the lens radius.

Source Extraction System

The 35-kV beam voltage is low enough that a single-gap source extraction system is preferred. The parameters of the extraction system are optimized by SNOW and are listed in Table 1. The expected beam envelope is shown in Fig. 1

Table 1: Parameter Values of the Extraction System

Parameter	Value
$R_{source\ aperture}$	1.2mm
Current Density	6.63mA/mm^2
$R_{cone\ tip\ mm}$	2.3 mm
Mim. Gap length	6.0 mm
$V_{breakdown}$	56.8 kV
Extraction Cone depth	35 mm

LEBT System

While there are at least four types of electric lenses that can be used in the LEBT system, the electrostatic einzel lens is the simplest candidate for 30 mA operating current. Since the beam is round both at the source and at the entrance of the RFQ, if axisymmetric lenses are used, only one lens is needed to provide two degrees of freedom to match the beam[4]. At least three lenses are needed if one uses electrostatic quadrupoles[5] or

helical electrostatic quadrupole lenses[6]. We use two einzel lenses to gain extra degrees of freedom and to provide enough spacing between the source and RFQ. We do not use classical thin-plate aperture lenses because we wish to avoid electric field concentrations. To reduce the spherical aberrations, we have carefully shaped all electrodes so that no sharp corners exist. The focusing electrodes in our final design look like rings (near the beam), similar to the "ring lens" at Lawrence Berkeley Laboratory[7]. Fig. 2 shows the physical layout of the two einzel lenses. Note that all insulators are hidden behind conductor electrodes and are shielded from the beam. The center electrode that separates the two einzel lenses is split into four pieces, a different voltage can be applied on each piece. This will create a dipole steering field to correct misalignment errors.

After a systematic search of parameters of the einzel lenses, the parameters of the optimal design given by SNOW are listed in Table 2:

Table 2: Parameter Values of the LEBT

Lens No.	Voltage	R_{lens}	Thickness	R_{beam}
1	-34.5 kV	20 mm	40 mm	8.0 mm
2	-33.7 kV	21 mm	40 mm	10.0 mm

The beam envelope vs distance in the LEBT system is shown in Fig. 3. The overlay of the acceptance ellipse of the RFQ and x-x' phase space distribution at the entrance of RFQ is shown in Fig. 4.

Transport Through RFQ

We have simulated the beam from the exit of the LEBT through the RFQ using PARMTEQ. The conceptual design parameters for the RFQ are listed in Table 3.

From Fig. 4 we see the phase space ellipse of the beam is not perfectly matched with the RFQ acceptance ellipse. This mismatch causes relatively large emittance growth in the RFQ. However, since the particle phase space distribution is contained almost entirely inside the acceptance ellipse, the transmission rate is high. Simulation results show over 93% transmission through the RFQ. The particle distributions in x-y, x-x, y-y' and W-ϕ after the RFQ are shown in Fig. 5.

Table 3: Parameter Values of the RFQ

Parameter	Value
W_i	35 keV
W_f	2.5 MeV
R_{bore}	3.0 mm
Length	2.2 m
E_{max}	1.73 Kilpatrick
I_{in}	30 ma
$\varepsilon_{n,rms,in}$	0.128 π mm-mrad
I_{out}	27.96 mA
$\varepsilon_{n,rms,out,x}$	0.237 π mm-mrad
$\varepsilon_{n,rms,out,y}$	0.211 π mm-mrad

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The author greatly appreciates the encouragement and valuable suggestions from Jerry Watson in this work. Many thanks to Deepak Raparia for many helpful discussions. I also wish to thank Jack Boers for his help in running the SNOW code.

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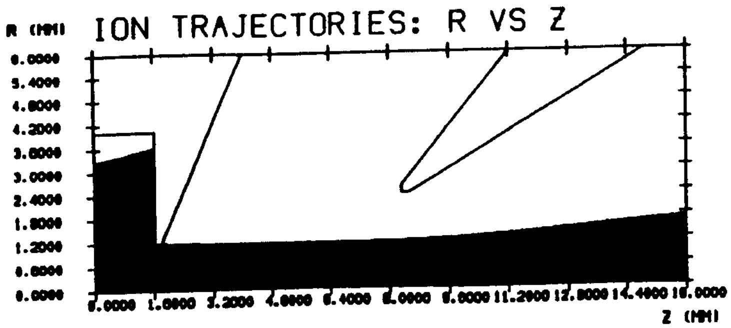

Fig. 1 Beam envelope vs distance in the source extraction system.

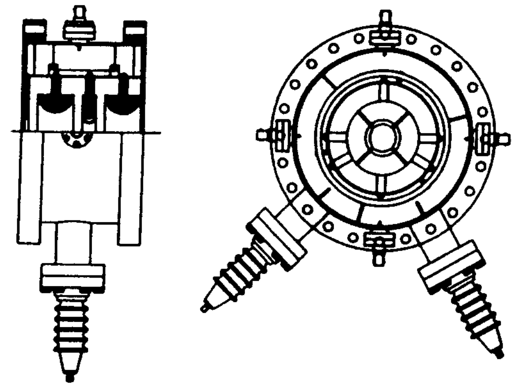

Fig. 2 Physical layout of the LEBT system. Left: y-z crossection at x=0 plane. Right: x-y crossection at the center electrode.

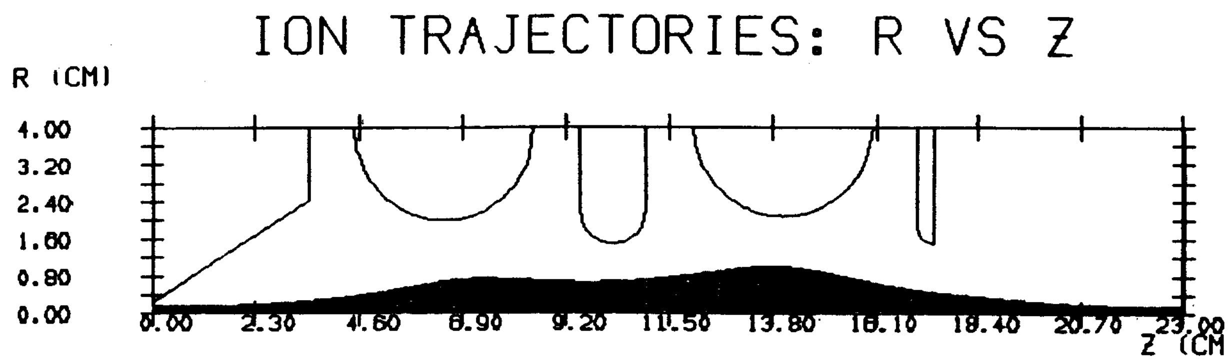

Fig. 3 Beam envelope vs distance inside the low energy beam transport system. The entrance of the RFQ (not shown) is located at z=22.2 cm.

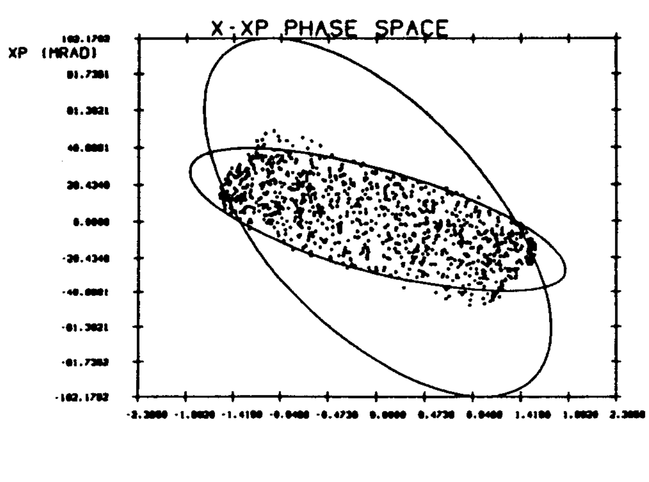

Fig. 4 Overlay of the RFQ acceptance ellipse and x-x' phase space distribution at the entrance of the RFQ. The smaller ellipse is the $4\epsilon_{rms}$ of the particle distribution.

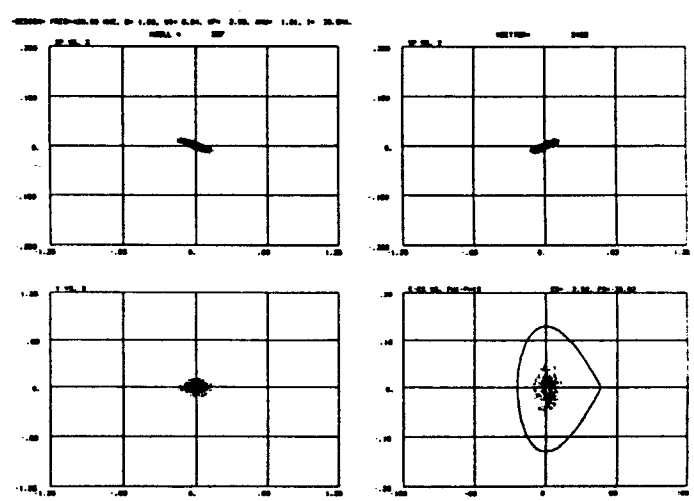

Fig. 5 The Particle distribution after the RFQ in x-x', y-y', x-y and W-ϕ plane.