END TO END SIMULATION FOR THE SSC LINAC

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Abstract

This paper summarizes the results of the end-to-end beam dynamics simulations for the SSC linac [1]. A 4D waterbag distribution of 1000 macroparticles corresponding to 10, 30, and 50 mA beam current with RMS normalized transverse emittance of $\epsilon_x = \epsilon_y = 0.1$ and 0.2 π mm-mrad is assumed at the input to the low-energy beam transport (LEBT). Codes used in these simulations are TRACE 2D, TRACE 3D, HESQT, SNOW, PARMTEQ, PARMILA, and CCLDYN.

I. Introduction

The SSC Linac will deliver a 600 MeV H^- beam with pulse lengths of 2 to 35 μsec at a nominal current of 25 mA for injection into the low energy booster (LEB) with transverse normalized rms emittance of $\leq 0.4\pi$ mm-mrad. The linac consists of an ion source (0-35 KeV) [2], a 35 KeV electrostatic low energy beam transport (LEBT) [3,4], [4], a 2.5 MeV (428 MHz) radio frequency quadrupole (RFQ) [5], a 70 MeV (428 MHz) drift tube linac (DTL) [6], and a 600 MeV (1283) MHz coupled cavity linac (CCL) [7]. There are two matching sections, one between the RFQ and the DTL [8], called M1, and another between the DTL and the CCL, called M2. The length of the linac is about 142 m.

Emittance from the magnetron ion-source is about 0.18 π mm-mrad for 30 mA and the requirement at the end of the CCL is 25 mA with an emittance of $\leq 0.3\pi$mm-mrad. This means that emittance growth budget for the entire linac is only about 67% ! The purpose of this work was to see whether we can meet the challenge of preserving emittance through the linac; and also to see whether this linac can handle twice the nominal current, to provide an adequate safety margin and allow future upgrades. Figure 1 is the block diagram of the major components of the linac with major system parameters and simulated performance shown. σ_{0t} and σ_{0l} are range of zero current transverse and longitudinal phase advances per focusing period for the given structure, except for the RFQ. For the RFQ, these values are given at the exit. E_K is the peak surface field in terms of Kilpatrick limit.

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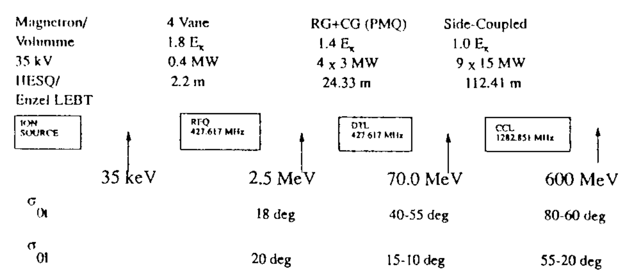

Figure 1: SSC linac block diagram.

II. Simulations

The magnetron source and helical electrostatic quadrupole (HESQ) LEBT is chosen for the baseline design. We are also considering an rf-excited volume source and einzel lens LEBT. End-to-end simulations were done for two source emittances (0.2 and 0.1 π mm mrad) and for both the LEBTs with nominal current (25 mA). For 10 and 50 mA beam current, end-to-end simulations were done using emittance of 0.1 and 0.2 π mm-mrad and the HESQ LEBT. A 4D waterbag distribution of 1000 macroparticles with appropiate beam parameters is assumed at the input of the LEBT. Particle distributions obtained from one section of the linac were fed to the following section.

For the HESQ, TRACE2D was used to determined the required voltages for matched beam into the RFQ, then these voltages were used in the program HESQT. The SNOW code was run for the einzel lens, and particles coordinate were transform from r r' to x x' and y y'. This is done by the projecting r, r' coordinates of particles into x, x' and taking into account the azimuthal velocity V_θ produced by thermal motion of particles [9].

The PARMTEQ code was used to simulate the RFQ. For one run (nominal current and emittance) the multipole version of PARMTEQ was run. For other cases standard PARMTEQ was run. Figure 2 shows beam size, phase and energy profiles as the beam traverses the RFQ.

M1 has 4 quadrupoles and two bunchers. First, using Twiss parameters and emittances from PARMTEQ, TRACE 3D was run to find quadrupole strengths and buncher voltages for matching the beam into the DTL.

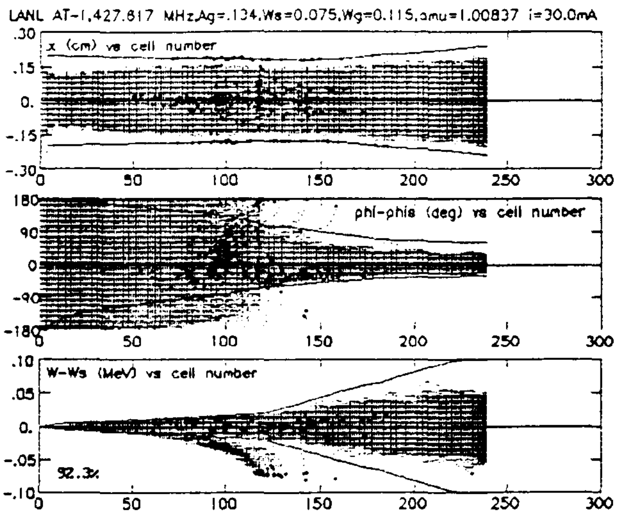

Figure 2: Beam size, phase, and energy profiles through the RFQ

Then PARMILA was run to push the particles through M1.

TRACE 3D runs were made to find out equivalent quadrupole strengths for hard edge quadrupole corresponding to the permanent magnet quadrupole phase advance. Intertank quadrupole strengths were also determined by using TRACE 3D. These values were used in PARMILA runs to simulate the DTL tanks. Figure 3 shows the beam size, phase and energy profiles as the beam traverses the DTL.

M2 has a total of 9 electromagnetic quadrupoles and two buncher tanks (1282.851 MHz). The first six quadrupoles are paired with the same polarity, providing six 'knobs' for transverse matching. Two buncher tanks will have 7 and 5 cells respectively providing two 'knobs' for longitudinal matching. To determine quadrupole strengths and buncher voltages for matching the beam into the CCL, TRACE-3D was run. TRACE 3D beam envelopes through M2 is shown in Figure 4. Again for this region PARMILA was run to get the particle distribution for the CCL input. At the input of M2, longitudinal co-ordinates were redefined with respect to the new frequency of 1282.851 MHz.

To push the particles through the CCL, CCLDYN was used. Figure 5 shows beam size, phase and energy profiles as the beam traverses the CCL.

Table 1 shows output normalized rms emittances for nominal current(25 mA) and for different emittances and LEBTs. Other end-to-end simulations were done using a HESQ LEBT for different emittances and currents. Table 2 shows output normalized rms emittances for 10 and 50 mA beam currents for two different emittances.

III. Summary

Simulation results show that in the absence of errors, the SSC linac can provide a 25 mA beam with normalized rms emittance of 0.235π mm-mrad for an ion source emittance

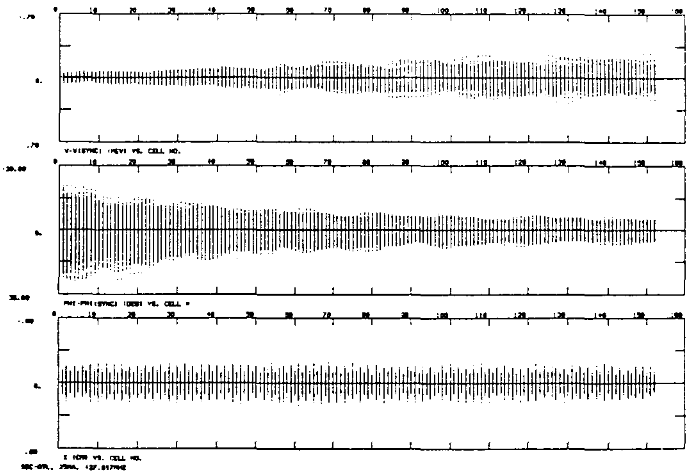

Figure 3: Beam size, phase and energy profiles as beam traverses the DTL

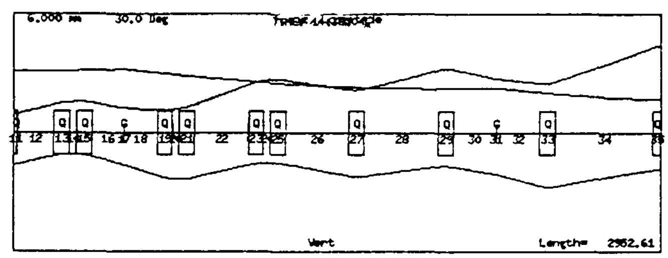

Figure 4: TRACE 3D Beam envelope through M2.

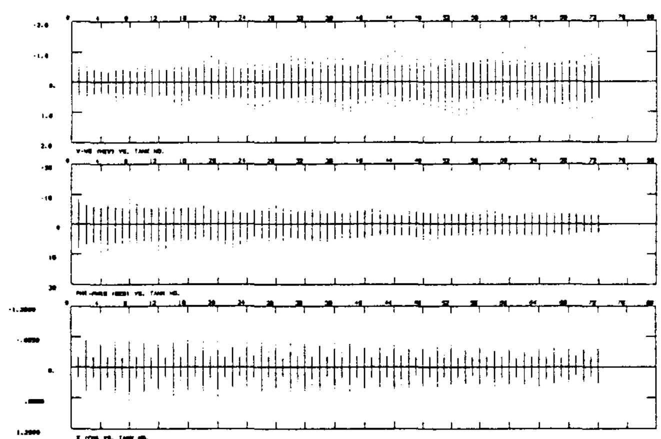

Figure 5: Beam size, phase and energy profiles through the CCL

Linac Sec.	HESQ				EINZEL LENS			
	I	ϵ_x	ϵ_y	ϵ_z	I	ϵ_x	ϵ_y	ϵ_z
0.2 πmm-mrad								
IS	30.	.18	.18		30.	.12	.12	
LEBT	30.	.19	.17		30.	.20	.19	
RFQ	27.	.19	.17	.13	23.	.16	.14	.14
M1	27.	.20	.16	.13	23.	.15	.19	.14
DTL	27.	.19	.19	.16	23.	.18	.19	.17
M2	27.	.20	.19	.15	23.	.19	.18	.16
CCL	27.	.22	.24	.14	23.	.24	.23	.15
0.1 π mm-mrad								
IS	30.	.08	.08		30.	.06	.06	
LEBT	30.	.10	.12		30.	.09	.09	
RFQ	28.	.11	.11	.10	26.	.11	.08	.11
M1	28.	.11	.12	.11	26.	.10	.15	.12
DTL	28.	.12	.12	.14	26.	.13	.15	.15
M2	28.	.13	.13	.14	26.	.16	.16	.14
CCL	28.	.17	.20	.12	26.	.19	.25	.13

Table 1: Output normalized rms emittances. ϵ_x, ϵ_y are in units of π mm-mrad, ϵ_z is in units of MeV deg @427.617 MHz, and I is in units of mA.

Linac Sec.	10 mA				50 mA			
	I	ϵ_x	ϵ_y	ϵ_z	I	ϵ_x	ϵ_y	ϵ_z
0.2 π mm-mrad								
IS	10.	.18	.18		50.	.18	.18	
LEBT	10.	.19	.19		50.	.22	.21	
RFQ	9.7	.19	.19	.14	45.	.23	.22	.12
M1	9.7	.20	.19	.14	45.	.23	.23	.12
DTL	9.7	.19	.20	.15	45.	.24	.23	.15
M2	9.7	.19	.20	.15	45.	.25	.23	.15
CCL	9.7	.21	.22	.14	45.	.22	.24	.14
0.1 π mm-mrad								
IS	10.				50.			
LEBT	10.	.10	.10		50.	.10	.10	
RFQ	9.8	.11	.10	.12	44.	.12	.12	.10
M1	9.8	.11	.10	.13	44.	.13	.12	.11
DTL	9.8	.11	.12	.13	44.	.15	.13	.18
M2	9.8	.11	.12	.13	44.	.15	.15	.17
CCL	9.8	.14	.15	.11	44.	.18	.26	.15

Table 2: Output normalized rms emittances. ϵ_x, ϵ_y are in units of π mm-mrad, ϵ_z is in units of MeV deg @427.617 MHz, and I is in units of mA. The HESQ LEBT was used for these runs.

of 0.2 π mm-mrad and 0.185 π mm-mrad if source emittance is 0.1 π mm-mrad.

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