Error and Tolerance Studies for the SSC Linac

D. Raparia, Chu Rui Chang, F. Guy, J. W. Hurd, W. Funk
Superconducting Super Collider Laboratory*
2550 Beckleymeade Ave., Dallas, Texas 75237
and
K. R. Crandall
AccSys Technology, Inc

Abstract

This paper summarizes error and tolerance studies for the SSC Linac. These studies also include higher-order multipoles. The codes used in these simulations are PARMTEQ, PARMILA, CCLDYN, PARTRACE, and CCLTRACE.

I. Introduction

The SSC Linac [1] will deliver a 600 MeV H^- beam with pulse lengths of 2 to 35 μsec at a nominal current of 21 mA for injection into the low energy booster (LEB) with transverse normalized rms emittance of $\leq 0.3\pi$ mm-mrad. 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 find out the tolerance limits to meet the challenge of preserving emittance through the linac.

The errors were divided into the three groups. Beam related errors e.g. displacements of beam with respect to accelerator axis at injection into the accelerator, mismatched beam in phase space, energy shift, energy spread etc. falls into the first group. Since steering is provided in each degree of freedom before each type of accelerator, this group of errors will not be presented here except the radio frequency quadrupole (RFQ). The second group of errors include time independent errors. This group of errors includes manufacturing errors e.g. errors in tank length, cell-length, coupling-slot-length, quad gradient, higher order components in the quad fields, tuning errors e.g. field-flatness, field-amplitude, field-phase, and alignment errors e.g. tank displacements, quad displacements, quad tilt and yaw, quad rotation etc. The third group of errors consists of time dependent errors e.g. amplitude and phase errors from rf source including feed back, mechanical vibrational errors etc. This group of errors is responsible for the jitter in the beam. The tolerance limits presented for these errors are not the limits on *rms* errors but the tolerance limits which are uniformly distributed between the limits.

II. Low Energy Beam Transport (LEBT)

The low energy beam transport (LEBT) works like the matching section for the Radio-Frequency Quadrupole (RFQ), therefore the first and second groups of errors are not considered. Only time dependent errors were considered, to find the voltage tolerance on the einzel lens and helical electrostatic quadrupole (HESQ). First using AXCEL [2] and HESQT, optimum voltages were determined; then voltages on einzel lens and HESQ were varied by $\pm$ 5% and the transmission through the RFQ was calculated using PARMTEQ. Figure 1 shows the curve for transmission vs voltage normalized to design voltage. The tolerance limit on the voltage was set to 0.3%.

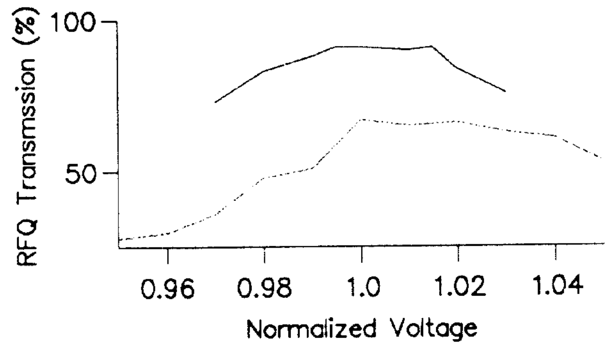

Figure 1: RFQ Transmission vs Voltage normalized to design voltage. solid line: HESQ, dotted line: einzel lens.

III. Radio Frequency Quadrupole (RFQ)

Since the RFQ bore radius is small and there are not enough steering elements in the LEBT, the first group of errors which includes misalignment in the injection of the beam, mismatched beam in the phase space, beam energy fluctuations and energy spread from the ion source were considered [3]. PARMTEQ was revised to include the higher order multipole expansion for the vane tip field [4]. Figure 2a shows the transmission vs x displacement of the beam and figure 2b shows the transmission vs beam angle offset. Figure 3a shows the transmission vs the mismatch factor as defined in TRACE3D. For each mismatch factor there are infinite different sets of twiss parameters (α, β) which lie on the ellipse. However for each mismatch factor, only two sets of α and β lie at the two vertices of the ellipse. In figure 3a, the upper curve corresponds to the choice of α and β such that the initial beam radius is smaller than the matched radius while the lower curve corresponds to the initial beam radius bigger than the matched beam. Figure 3b shows the transmission vs the energy shift from 35 keV in the injected beam. The time dependent errors were

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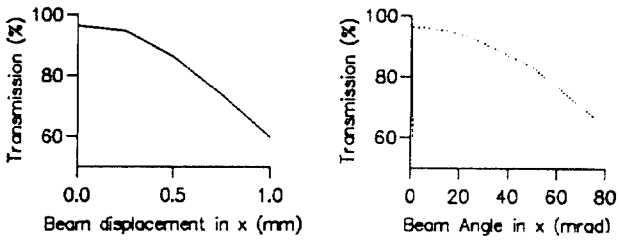

Figure 2: (a) Transmission vs Beam Displacement in x (mm). (b) Transmission vs Beam Angle in x (mrad)

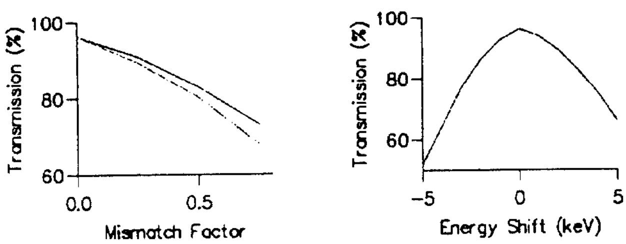

Figure 3: (a) Transmission vs the mismatch factor. Upper curve, the initial mismatched beam radius is smaller then matched beam. Lower curve, the initial mismatched beam radius is bigger than matched beam. (b) Transmission vs energy sgift from 35 keV

amplitude (vane voltage) and phase of accelerating field. Their tolerance limits are 0.5% and 0.5 deg respectively.

IV. Drift Tube Linac (DTL)

In the case of the DTL, the second group of errors includes time independent errors e.g. tank displacement, cell-to-cell phase and field errors, accelerating field tilt, quad displacements, quad tilt and yaw, quad gradient errors, quad rotation and higher-order multipoles. The third group of errors includes time dependent errors e.g. field amplitude and phase errors from the klystrons. Since the drift tubes are mounted on stem they may vibrate. The time dependent and time independent error tolerances are listed in Table 1. Figure 5 shows the probability distribution of the emittance growth for the errors listed in Table 1. This curve was obtained by using PARTRACE [5]. The most sensitive error for emittance growth is quad rotation; the tolerance limit on this error is 0.5 deg. The tolerance limits on the multipoles were obtained using PARMILA. An upper bound was assigned to the amplitude of the n = 3, 4 and 5 components and values are chosen at random between zero and this tolerance limit for each multipole The phase of each of these multipole components was chosen at random. The n= 6 component was assumed to be systematic, and its amplitude was set at the tolerance limit and phase angle to zero. For this study to be realistic, alignment errors as well as multipoles were included. The

Error	Tol. Limit
Time Independent	
Tank disp	±0.25 mm
Quad disp	±0.1 mm
Quad Pitch and Yaw	±1.0 deg
Quad Roll	±0.5 deg
Quad Strength	0.- 5% (Graded)
Multipoles,n=3,4,5,6	1.5% @ 6 mm
Tank Field Tilt	±3%
Cell-to-Cell Field	±3%
Cell-to-Cell Phase	± 0.5 deg
Time Dependent	
Tank Field	±3%
Tank Phase	± 0.5 deg
DT vibration amp(rms)	6.0 μm

Table 1: Tolerance Budget for the SSC DTL.

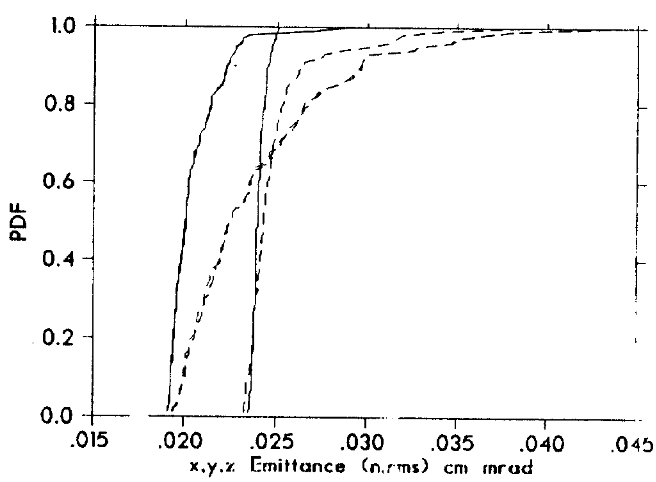

Figure 4: Probability distribution of the emittances (x,y and z) out of the DTL for errors listed in Table 2., dotted curves show the emittances when the errors were twice as large as given in Table 2. Curves show the probavility that the emittances will at or below the plotted value.

M %	QR								
	0.00 deg			0.25 deg			0.50 deg		
	ϵ_x	ϵ_y	ϵ_z	ϵ_x	ϵ_y	ϵ_z	ϵ_x	ϵ_y	ϵ_z
.00	.21	.20	.28	.22	.21	.28	.23	.22	.28
1.0	.21	.20	.28	.22	.21	.28	.23	.22	.28
1.5	.21	.20	.28	.22	.21	.28	.23	.22	.28
2.0	.21	.20	.28	.22	.21	.28	.23	.22	.28

Table 2: Output (average of 50 runs) normalized rms emittances ϵ_x, ϵ_y and ϵ_z are in units of π mm-mrad.

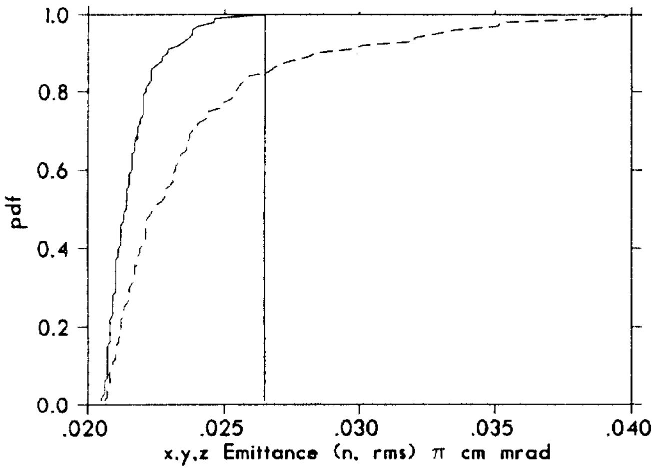

Figure 5: Probability distribution of the emittances (x,y and z) out of the CCL for errors listed in Table 3., dotted curves show the emittances when the errors were twice as large as given in Table 3. Curves show the probavility that the emittances will at or below the plotted value.

results of 12 cases, where each case consited of 50 runs, are summarized in Table 2. The twelve cases were for all combinations of clocking errors (QR) of 0., 0.25, 0.5 degrees and multipole errors (M) of 0.0, 1.0, 1.5, and 2.0% @ 6 mm. The quadrupole displacements of 0.1 mm and tank displacement tolerance of 0.25 mm were used in all cases, and the beam was "steered" back on the axis after each tank.

V. Coupled Cavity Linac (CCL)

The second group of errors for the CCL includes time independent errors in tank displacements, cell-length (cell-to-cell phase) coupling-slot-size (cell-to-cell field), bridge-coupler -slot-size (tank-to-tank field), bridge-coupler-length (tank-to-tank phase), quad displacement, quad tilt and yaw, quad rotation, quad-to-quad field gradient and high order multipoles. The third group of errors includes time dependent errors e.g. amplitude and phase error from the klystron and quad gradient error due to the power supplies. These tolerance limits are listed in Table 3. Figure 6 shows the probability distribution of the transverse emittance for the tolerance limit listed in Table 3. These calculations were done using CCLTRACE [6]. In the case of the CCL, higher order multipoles which are achivable in

Error	Limits
Time Independent	
Tank disp	±0.1 mm
Quad disp	±0.1 mm
Quad Pitch and Yaw	±1.0 deg
Quad Roll	±0.5 deg
Quad Strength	±0.10%
Tank Field	±0.5%
Tank phase	±0.5 deg
Cell-to-Cell Field	±1.0%
Cell-to-Cell Phase error	± 0.5%
Time Dependent	
Quad Strength	± 0.1%
Klystron Field	±0.5%
Klystron Phase	±0.5 deg

Table 3: Tolerance Budget for the SSC CCL.

the electromagnet quad are 0.056, 0.005, 0.0056, 0.00022% for n=3,4,5,and 6 respectively, at the radius of 1 cm. CCL-DYN [6] simulations shows these multipoles have no effect on the emittance growth. The quad and tank displacement used in these simulations are listed in Table 3.

VI. Conclusions

These studies show that if we can achieve specified tolerances, we can meet the challenging requirement of emittance of $\leq 0.3\ \pi$ mm mrad at 600 MeV. The most sensitive error for the emittance growth is quad rotation.

We would like to thank to Jun Wu for his help in PARMTEQ simulations.

VII. References

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