SSC DRIFT-TUBE LINAC DESIGN

D. Raparia, G. Leifeste, F. Guy, and W. Funk
Superconducting Super Collider Laboratory*
2550 Beckleymeade Ave., Dallas, Texas 75237

Abstract

This paper describes the beam-dynamics design of the Drift-Tube Linac (DTL) at SSC. The DTL is designed to accelerate a H^- beam of 25 mA from 2.5 MeV to 70 MeV, with transverse emittance of 0.2 π mm-mrad (n,rms) at 427.617 MHz. The DTL consists of four tanks stabilized by post couplers. Transverse focusing is provided by permanent magnet quadrupoles (PMQs) in a FODO array. Inter-tank spacing is 3 $\beta\lambda$ to provide space for the beam diagnostic equipment. Inter-tank longitudinal focusing is provided by shifting the gaps in the two end cells of both neighboring tanks. The rf field is ramped in the first tank but held constant through the reminder of the DTL.

I. Introduction

The SSC Linac provides a 600 MeV H^- beam of pulse length 2 to 35 μsec at a nominal current of 25 mA for injection into the low energy booster. The Linac consists of an ion source (0-35 KeV) ,a 35 KeV electrostatic low-energy beam transport (LEBT), a 2.5 MeV (428 MHz) radio-frequency quadrupole (RFQ), a 70 MeV (428 MHz) drift tube linac (DTL), and a 600 MeV (1283) MHz coupled cavity linac (CCL). The length of the linac is about 142 m in which DTL length is about 24 m.

The DTL will accept the 2.5 MeV output of the RFQ and accelerate the H^- ions to the relativistic velocities needed by the CCL. The DTL will consist of four tanks, each powered by a single klystron. The DTL design uses conservative parameters for electric and magnetic fields and yet accommodates a wide range of currents and emittance. Isolation valves, variable gradient permanent magnet quadrupoles, and beam diagnostic boxes are placed between the tanks. The DTL tank are being built by AccSys Technology Inc.

II. Physics Considerations

The most fundamental parameters for the DTL are the zero-current longitudinal and transverse focusing strengths per unit length. These quantities at the entrance of the DTL are chosen to be similar to those at the RFQ exit. This helps in making the RFQ-DTL matching section [1] nearly current independent. Accordingly the transverse and the longitudinal zero-current phase advances are kept approximately at $\sigma_{0t} = 22.5°$ per $\beta\lambda$ and $\sigma_{0l} = 14°$ per $\beta\lambda$ respectively. Figure 1 shows the transverse and longitudinal phase advance per focusing period along the DTL.

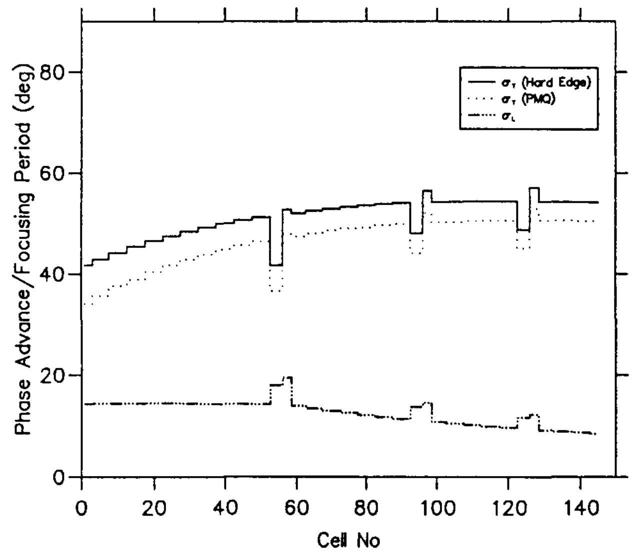

Figure 1: Zero-current transverse and longitudinal phase advances in the DTL as function of the cell numbers.

To avoid emittance growth it is desirable to keep the physical beam size approximately constant. To keep longitudinal beam size constant E_0T and ϕ_s have to obey following equation:

$$\frac{E_0 T \sin\phi_s}{\beta\gamma^3} = constant$$

where E_0 is the average accelerating field over a cell, T is the transit time factor, β and γ are the relativistic parameters of the beam. This would results in ramp in E_0T throughout the DTL, but power and peak surface field requirements limit this approach. In Tank 1 E_0 is linearly ramped from 2.4 MV/m to 4.6 MV/m, approximatly the E_0 ramp require by the equation above. The upper limit of E_0 is set by the limit on peak surface field, is chosen to be a conservative value of 28 MV/m (1.4 Kilpatrick). The synchronous phase, $\phi_s = -30°$, is chosen to be the same as at the exit of the RFQ. In Tanks 2, 3, and 4, E_0 is held constant at 4.6 MV/m and $\phi_s = -30°$. This results in a slow longitudinal expansion of the beam size in physical space.

A space of 3 $\beta\lambda$ is provided between the tanks to accommodate an isolation valve, two variable gradient permanent magnet quadrupoles which also provide steering, and

*Operated by the Universities Research Association, Inc. for the U.S. Department of Energy, under contract No. DE-AC02-89ER40486

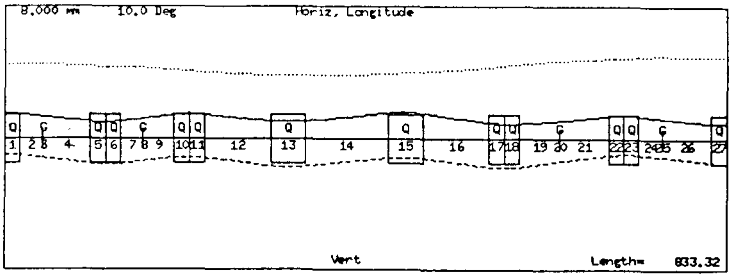

Figure 2: TRACE 3D beam envelope for the space between Tank 1 and 2.

a beam diagnostic station. To compensate for the absence of longitudinal focusing in this space, the gaps in the two end cells of both neighboring tanks are shifted upstream to produce a phase shift of as much as 45°. These displacements of the gaps from the approximate geometrical centers of the cells causes frequency errors and significant perturbations in the fields in the vicinity of these cells. Crandall and Raparia [2] have described the technique to reduce these field perturbations.

Transverse focusing is provided by PMQs. At 2.5 MeV the ion beam has sufficient velocity that PMQs have ample strength to control the beam. The focusing lattice is FODO. The PMQs in the drift-tubes have a gradient of 137.2 T/m with a pole tip field of 1.3 T and bore radius of 8.25 mm. These PMQs are 35 mm long and will be manufactured with field tolerance of 0-5%, sorted and placed in the DTL in descending order. Since PMQs at low energy end in Tank 1 are very near to each other, the fringe fields from neighbouring quadrupoles overlap, resulting in reduced phase advance. The dotted curve in Figure 1 shows the reduced phase advance per FODO cell as calculated by TRACE 3D

Between the tanks, there are two variable and movable permanent magnet quadrupoles located at $\beta\lambda$ apart. Figure 2 shows the beam envelope predicted by TRACE 3D for the space between Tank 1 and 2.

III. DTL DESIGN PARAMETERS

The parameters of the DTL are listed in Table 1. Individual cells were designed using SUPERFISH with several interrelated constraints; (i) peak surface-field (E_p) not to exceed 1.4 Kilpatrick field (E_k), (ii) desirability of a large bore size, (iii) PMQs of limited strength, (iv) tank power not to exceed 3 MW. The 'rg gap length' to 'cell length' was varied from cell to cell to attain the resonating frequency of 427.617 ± 0.050 MHz. A typical drift tube is shown in Figure 3. Table 2 shows DTL tank parameters.

IV. SIMULATION RESULTS

Simulation studies were carried out for the DTL geometry and field configuration discussed above using PARMILA. A typical PARMILA run was made with 1000 macro-particles

Table 1: DTL Design Parameters

Parameter	
Frequency	427.617 MHz
Injection Energy	2.5 MeV
Output Energy	70.0 MeV
Output Current	25 mA
Output tran. emitt. (n,rms)	0.21 $\pi mm - mrad$
DTL Length	24.33 meter
Number of cells/tanks	152/4
Magnetic lattice	FODO
Synchronous phase	-30 °
Accelerating field E_0	2.4 to 4.6 MV/m
MPSEF	28 MV/m 1.4E_k
Total peak rf power	12 MW

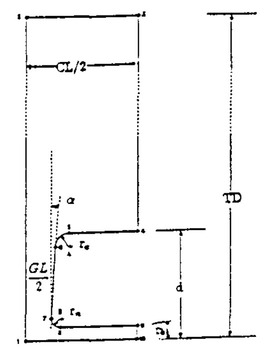

Figure 3: Cross-section of a drift-tube. CL:cell length, TD: tank dia, d: drift-tube dia, r_b: bore radius, GL: gap length r_n: nose corner radius, r_c: corner radius α: face angle

Table 2: DTL Tank Design Parameters

Parameters	Tank 1	Tank 2	Tank 3	Tank 4
Cell no.	56	40	30	26
E (MeV)	13.4080	32.8411	51.5858	70.0010
TL (m)	4.49908	5.95595	6.06304	6.25809
E_0 (MV/m)	2.4 - 4.6	4.6	4.6	4.6
Tran. Time	0.72-0.87	0.87-0.85	0.85-0.80	0.80-0.75
CL (cm)	5.1-11.6	11.8-18.0	18.2-22.2	22.4-25.6
GL (cm)	0.98-2.43	2.76-4.61	5.02-6.85	7.28-9.13
D (cm)	42.0	42.0	42.0	42.0
d (cm)	8.0	8.0	8.0	8.0
BR (cm)	0.8	0.8	0.8	0.8
r_n (cm)	0.325	0.325	0.325	0.325
r_c (cm)	0.75-2.0	2.0-2.75	2.75	2.75
α (deg)	1.0	1.0-10.	10.- 15.	15.0
Power (MW)	1.187	2.333	2.360	2.387

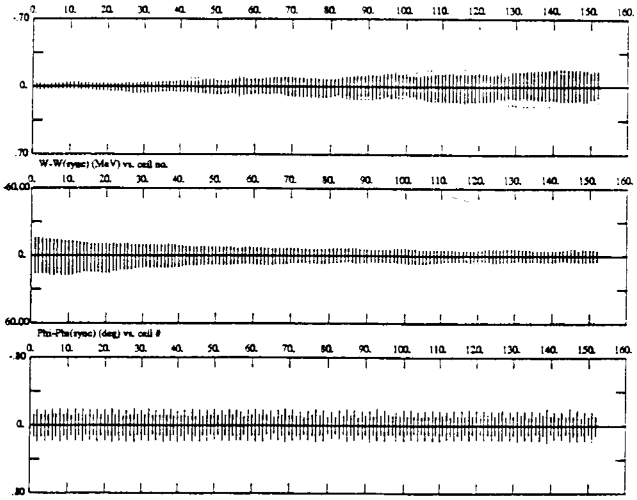

Figure 4: Beam size, phase and energy profiles as beam traverses the DTL

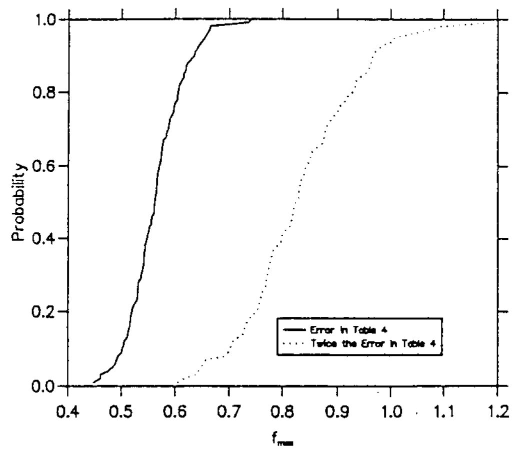

Figure 5: Probability distribution of f_{max} ($r_{max} \div$bore radius) for a combination of random errors described in Table 4. Graph shows the probability that f_{max} will be at or below the plotted value.

uniformly filling a six-dimensional hyperellipsoid in input phase-space. Figure 4 shows the beam size, phase and energy profiles as the beam traverses the DTL. Other PARMILA runs were made using input phase-space distribution from the RFQ-DTL matching section [3]. Emittance results are shown in Table 3. There is very little growth in emittance. PARTRACE [4] calculations were done for the errors listed in Table 4. These are not rms errors but the tolerance limits which are uniformly distributed btween the limits. Figure 5 shows that the beam only fills half the bore radius of the drift tube. The dotted curve shows the bore radius used by the beam when errors were twice as large as given in Table 4; in this case there ia a 6% probability that f_{max} will excced 1.

V. Summary

The DTL Design specified above is a well-optimized conservative design for acceleration from 2.5 MeV to 70 MeV with an output beam of the required quality. There is essentially no emittance growth in the absence of fabrication errors and the beam occupies only one-third of an bore for a uniform input beam. The design for the magnets and drift-tubes is within the scope of available technology. The design power requirement for each tank is less than 75% of the available power of the klystron (4 MW). The DTL tanks will be delivered to the SSC between November 1993 and June 1994.

Table 3: Normalized rms ϵ_x, ϵ_y (π mm-mrad) and ϵ_z (MeV deg).

Input Dist.	I mA	INPUT ϵ_x	INPUT ϵ_y	INPUT ϵ_z	OUTPUT ϵ_x	OUTPUT ϵ_y	OUTPUT ϵ_z
6-D uni-	10.	.190	.190	.134	.179	.199	.139
	25.	.190	.190	.128	.183	.195	.145
	50.	.219	.219	.122	.217	.226	.186
From RFQ	10.	.201	.189	.135	.191	.196	.150
	25.	.204	.163	.129	.190	.185	.156
	50.	.227	.231	.122	.237	.228	.153

Table 4: Tolerance Budget for the SSC DTL.

Error	
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.- 5% (Graded)
Tank Field	±3 %
Tank Field Tilt	±3 %
Cell-to-Cell Field	±3 %

VI. References

[1] R.C. Sethi, *et al*, "Design of the RFQ-DTL Matching Section for the SSC Linac," these Proceedings.

[2] K. R. Crandall and D. Raparia, "Reducing the Field Perturbations Produced by Shifted Gap in a Drift-Tube Linac," these Proceedings.

[3] D. Raparia, *et al*, "End-to-End Simulation for the SSC Linac," these Proceedings.

[4] K. R. Crandall, "Error Studies using partrace, A New Program that Combines PARMILA and TRACE 3-D," 1988 Linear Accelerator Conference Proceedings, CEBAF-Report-89-001, p 335, Newport News, Virginia, Oct 3- 7 1988.