A COMPARISON OF BEAM-DYNAMICS SOLUTIONS FOR THE SSC 1284-MHz COUPLED-CAVITY LINAC*

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Abstract

Two beam dynamics design examples for the SSC 1284-MHz, 70-600 MeV coupled-cavity linac (CCL), are described. The first of these examples consists of singlet quadrupole focussing with a constant accelerating gradient while the second example uses doublet focussing. Ramping the field gradients cell by cell in the first two tanks, for both the singlet and the doublet focussing examples, leads to a smooth transition from the DTL into the CCL. Comparison shows that the doublet focussing scheme offers some advantages.

Introduction

The proposed SSC linac is shown in the block diagram in Fig. 1. A 30-mA beam of H^- ions is accelerated to 2.5 MeV in a 428-MHz radio-frequency quadrupole (RFQ). Using a suitable matching section (MS1), the beam is then injected into a 428-MHz drift-tube linac (DTL), which accelerates it to 70 MeV. The proposed beam-dynamics design of the DTL is discussed in a companion paper.[1] Following a second matching section (MS2), the beam is accelerated to 600 MeV in a 1284-MHz coupled-cavity linac (CCL). In this paper we describe and compare two example beam-dynamics solutions for the CCL that meet the desired performance requirements for injection into the low-energy booster ring (LEB) of the SSC.

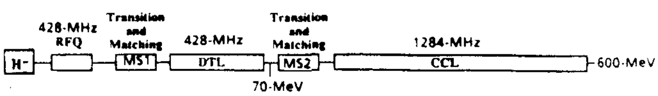

Fig. 1. Block diagram of the proposed SSC Linear Accelerator.

Singlet Design Example

The CCL design example included in the 1989 Site Specific Conceptual Design Report (SCDR)[2] consisted of a 70 to 600 MeV linac with constant accelerating gradient determined by $E_0T = 6.5$ MV/m; it employed a singlet quadrupole focusing lattice (FODO). This design was based on a tank geometry of 20 cells per tank with 5/2 $\beta\lambda$ intertank spacing. The parameters for this example are given in column 1 of Table 1 and are discussed in detail in the SCDR.

A slight variation of this design is obtained by ramping the field gradient in the first two tanks, cell-by-cell, from $E_0T = 1.0$ MV/m to 6.5 MV/m. All subsequent tanks are held constant at $E_0T = 6.5$ MV/m. The parameters for this two-tank ramped singlet design are given in column 2 of Table 1. A nearly current independent matching section between the DTL and the CCL (MS2) can be designed as a result of the ramping. Beam-dynamics simulation studies of the two singlet designs shown in Table 1 indicate that a linac built to these specifications could meet the desired performance requirements of the LEB.

Doublet Design Example

In an attempt to improve the beam dynamics performance and perhaps to reduce the cost of the SSC linac, we have considered a solution for the CCL design based on a doublet-focusing lattice (FDO). The general parameters for this design example are given in column 3 of Table 1. In this example, the field gradient was ramped, cell-by-cell, from 1.3 MV/m to 6.5 MV/m over the first two tanks. All subsequent tanks were held constant at $E_0T = 6.5$ MV/m, as in the singlet example. Furthermore, we have held the phase-advance per period constant at 70° throughout the CCL. The transverse focusing period is reduced by a factor of 2 if doublet focusing is used, thus increasing the phase-advance per unit length. This results in a smaller rms beam size throughout the linac. Preliminary error studies, where random quadrupole rotations and displacements are distributed along the linac, indicate that the bore radius of the CCL can be reduced by 20% to 30% if doublet focusing is used. By reducing the bore radius to 1 cm, the resulting increase in shunt-impedance leads to a smaller total power requirement. We have forced the tank geometry to be 24 cells per tank, which allows a reduction in the total number of accelerating tanks required. For example, it may be possible to eliminate 12 accelerating tanks and their two associated klystrons.

In order to preserve the overall footprint of the CCL, the intertank spacing could be varied over different sections of the linac (See Table 1). We determined that a minimum distance between tanks of 11/2 $\beta\lambda$ is required at 70 MeV in order to conservatively provide adequate space for the quadrupole doublet, vacuum flanges, bellows, and beam diagnostics. The effective length of the quadrupoles was chosen so that a identical electromagnetic quadrupole could be used throughout the CCL. The pole-tip field chosen for this example is conservative. Our study shows that a future upgrade of the CCL to an output energy of 1 GeV is feasible.

Comparison of Singlet and Doublet Designs

Beam-dynamics simulations were run for both the singlet and doublet design examples using as input an rms-matched uniform distribution (uniform ellipsoid in real space and approximately uniform in velocity space) of 1000 pseudoparticles. The coupled-cavity code, CCLDYN,[3] was used for the simulations. This code is a particle-in-cell code incorporating both linear and nonlinear rf defocusing and two dimensional space-charge forces. Figure 2 shows the 3σ beam size as a function of tank number along the CCL for both cases. No error conditions were used in these simulations. Clearly, doublet focusing achieves a smaller beam size, as was to be expected. Figure 2 also shows the phase and energy spread of the beam as a function of tank number. Figure 3 shows phase-space plots at 600 MeV for both designs. Table 2 shows input and output emittances for the two cases. The doublet design example results in a factor of 3.3 (2.9) reduction in transverse (longitudinal) emittance growth when compared with the singlet design. A comparison of the structure parameters for the singlet and doublet design examples appears in Table 3. In addition to providing slightly better beam dynamics performance, the doublet example seems to have potential cost savings through a reduction in the total power, number of accelerating tanks, and number of bridge-couplers required.

Effects of Gradient Ramping on Longitudinal Matching

There will be a factor of three increase in rf frequency between the 428-MHz DTL and the 1284-MHz CCL. The longitudinal focusing forces will therefore be greater in the CCL. Mills, et al.[4] have shown that nearly current independent rms matching between accelerating structures can be achieved if both the transverse and longitudinal focusing strengths are held constant during the transition. The transverse focusing strength can be maintained by keeping the phase-advance per unit length similar in both the DTL and the CCL. Because the length of the doublet focusing period more closely equals the DTL period than

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TABLE 1

General Parameters for the 70-600 MeV, 1284 MHz Coupled-Cavity Linac Design Examples

Focusing Lattice:	Singlet FODO	Singlet FODO	Doublet FDO
Phase-advance/period:	70°	70°	70°
Effective Quad Length:	6 cm	6 cm	15.3 cm
Interquad Spacing	N/A	N/A	6 cm
Quad Gradient:	37.5-38.2 T/m (600 MeV) 38.2-44.5 T/m (1 GeV upgrade)	28.4-38.2 T/m (600 MeV) 38.2-44.5 T/m (1 GeV upgrade)	27.0-49.4 T/m (600 MeV) 49.4-66.0 T/m (1 GeV upgrade) ($B_{poletip,max}$ = 0.85T)
Number of Cells/tank:	20	20	24
Starting Energy:	70 MeV	70 MeV	70 MeV
E_0T	6.5 MV/m (no ramp)	1.0-6.5 MV/m (2-tank ramp)	1.3-6.5 MV/m (2-tank ramp)
Total Number of Tanks:	66 (600 MeV) 101 (1 GeV)	66 (600 MeV) 101 (1 GeV)	54 (600 MeV) 83 (1 GeV)
Tank Lengths:	86.8–185.1 cm (600 MeV) 185.8-204.2 cm (1 GeV)	85.8–185.1 cm (600 MeV) 185.8-204.2 cm (1 GeV)	104.5–222.0 cm (600 MeV) 223.0-245.3 cm (1 GeV)
Synchronous phase (ϕs):	–30°	-30°	–28°
Bore Radius:	1.27 cm	1.27 cm	1.0 cm
Linac Length:	120 m (up to 600 MeV) 207 m (1 GeV upgrade)	120 m (up to 600 MeV) 207 m (1 GeV upgrade)	130 m (up to 600 MeV) 210 m (1 GeV upgrade)
Bridge Coupler Length:	5/2 $\beta\lambda$	5/2 $\beta\lambda$	11/2 $\beta\lambda$, 70 to 117 MeV 9/2 $\beta\lambda$, 117 to 219 MeV 7/2 $\beta\lambda$, 219 to 608 MeV (7/2 $\beta\lambda$, 608 to 673 MeV, 5/2 $\beta\lambda$, 673 to 1000 MeV)

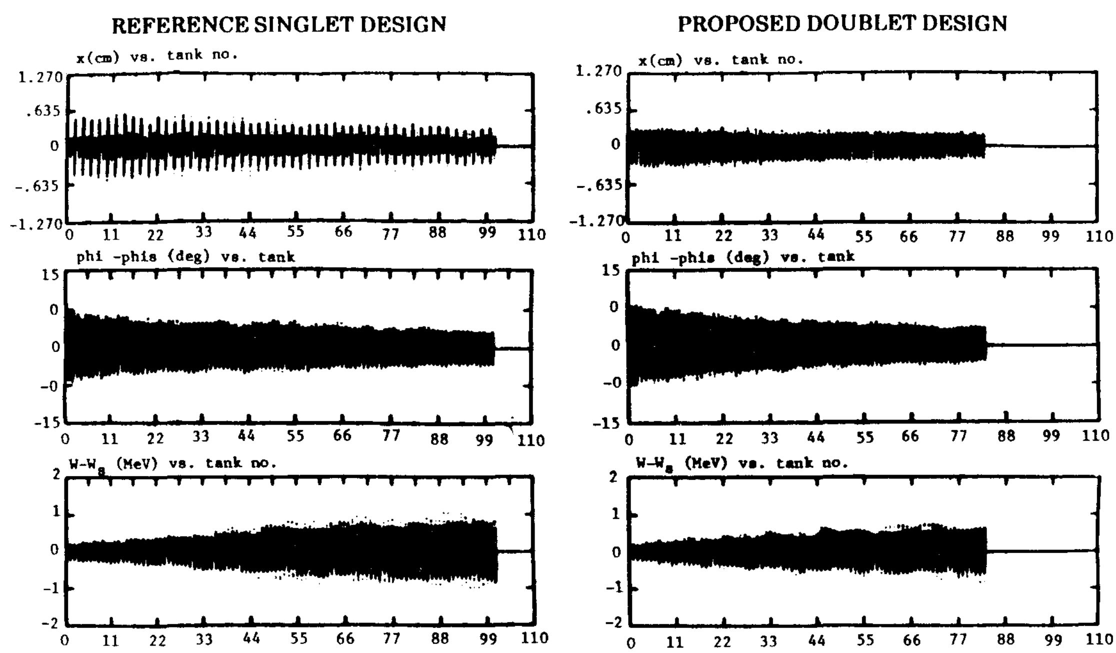

Fig. 2. Plots of beam size, phase and energy spread as a function of tank number along two proposed linacs.

does the singlet CCL, the doublet provides a smoother transverse envelope transition.

We determined that ramping the accelerating gradient cell-by-cell over two tanks is not adiabatic on the beam, but is gentle enough to provide a smooth longitudinal transition for the beam. To study how independently of current the beam could be matched from the DTL into the doublet CCL, we used TRACE 3-D[5] to simulate a matching region consisting of the last few DTL cells, an electromagnetic quadrupole, a five-cell buncher cavity (1284-MHz), an electromagnetic quadrupole doublet (with

TABLE 2
Input and Output Emittances from Simulation for the 1284-MHz CCL Examples using a Uniform Input Distribution

	Singlet Example	Doublet Example
70 MeV ε_t	0.0185 π·cm·mrad	0.0185 π·cm·mrad
600 MeV ε_t	0.022 π·cm·mrad	0.020 π·cm·mrad
70 MeV ε_L	0.305 π-deg-MeV	0.305 π-deg-MeV
600 MeV ε_L	0.335 π-deg-MeV	0.315 π-deg-MeV
Emittance Growth ε_t	18%	5.5%
Emittance Growth ε_L	10%	3.5%
Current (mA)	75	75
Transmission	100%	100%

TABLE 3
Comparison of the Structure Parameter for the Two Design Examples. Both are at 1284-MHz for 70-600 MeV Energy Gain

	Singlet	Doublet
E_oT	6.5 MV/m	6.5 MV/m
Phase advance/period	70°	70°
Length of the CCL	120 m	130 m
Tank geometry	20 cells/tank	24 cells/tank
# of tanks	66	54
# of modules	11	9
# of cells	1320	1296
# of bridge couplers	55	45
Bore radius	1.27 cm	1.0 cm

gradients independently adjustable), a second buncher cavity, another independently adjustable doublet, and the first three accelerating tanks of the CCL. This matching region is shown in Fig. 4. The buncher voltages provide two knobs for longitudinal matching, and the one single quadrupole and two doublet quadrupoles provide five knobs for transverse matching. The beam was rms matched, for a current of 25-mA at 428-MHz, from the DTL output to tank 3 of the CCL for various ramp rates (no ramping, and 0.1-6.5 MV/m to 1.3- 6.5 MV/m) in the first two CCL tanks. The matching section parameters were then held constant as the DTL beam current was varied from 50% to 150% of the nominal 25-mA value. Twiss parameters resulting from this matching section were nearly the same as those wanted by CCL Tank 3. The matching section is largely current independent. Although not ramping any tanks of the doublet CCL gave good current independence, the non-ramped matching section exhibited rapid rf phase envelope size changes throughout the matching section. Additionally, the field gradient required in one of the bunchers was prohibitively high (7.2 MV/m).; using 10-cell bunchers would allow operation at lower gradients. The longitudinal transition of the beam occurs most smoothly when the ramp rate is from 1.3 MV/m to 6.5 MV/m over two CCL tanks (see

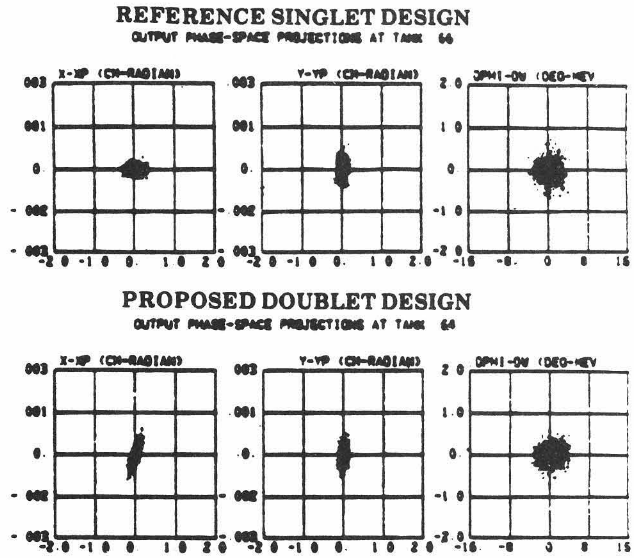

Fig. 3. Output phase-space plots at 600 MeV for the reference singlet design and the proposed doublet design.

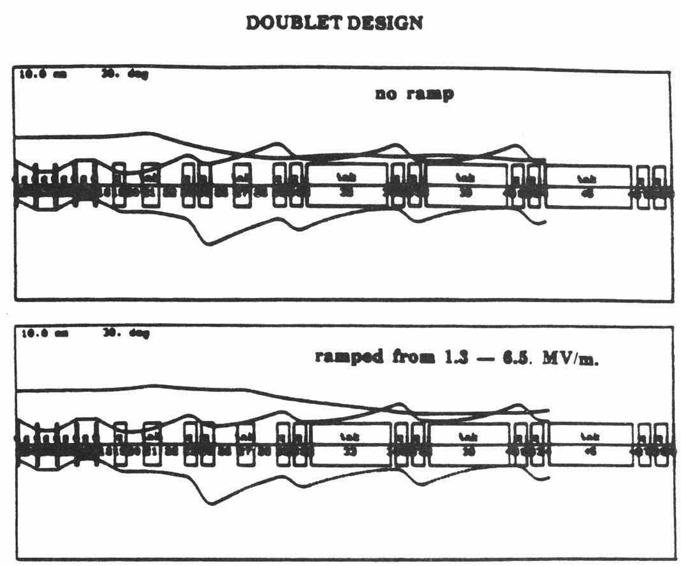

Fig. 4. Beam envelopes through the matching region for both the unramped and ramped doublet design examples. A smoother longitudinal transition is observed for the ramped case.

Fig. 4), thus achieving a nearly current-independent match. This matching section also performs very well for the singlet CCL.

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