Positron Jitter and Wakefield Effects in the SLC Injector Linac*

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ABSTRACT

The positron beam in the SLC injector linac is a high current ($7*10^{10}$particles /bunch), large transverse emittance ($\gamma\varepsilon$ = .01 m-rad) and long bunch length (~ 4 mm) beam. A large 5% positron intensity jitter was observed and correlated with the accelerating phase of the RF cavities in the positron source linac. For high transmission, the positron jitter must be reduced and strong wakefield effects cannot be ignored. A code was written to study causes of the positron jitter and wakefields in the SLC injector linac. The tracking results show that when the bunch lengths are 1.5, 2.1, 3.0, 4.0 mm, the injection apertures (leading to 30% loss) are 1.8, 1,6, 1.2, 1.0 sigma of transverse size at the beginning of the sector respectively. For the long bunches, the nominal 20% of beam size transverse pulse to pulse jitter causes an additional 3% loss. Also the bunch energy spread is more sensitive to the accelerating phase of the RF cavities.

I. INTRODUCTION

The SLC injector linac, named Sector-1, is about 100 meters in length. It consists of 5 12-meter disk loaded waveguide sections and 75 quadrupoles. 62 of the quadrupoles surround the RF sections. The quadrupoles form a strong focusing FODO array, and was designed to minimize beam size for optimal positron transmission. Its layout is shown in Figure 1. The electrons and positrons are accelerated simultaneously in Sector-1, from 210 Mev to 1.15 Gev before injection into the damping rings.

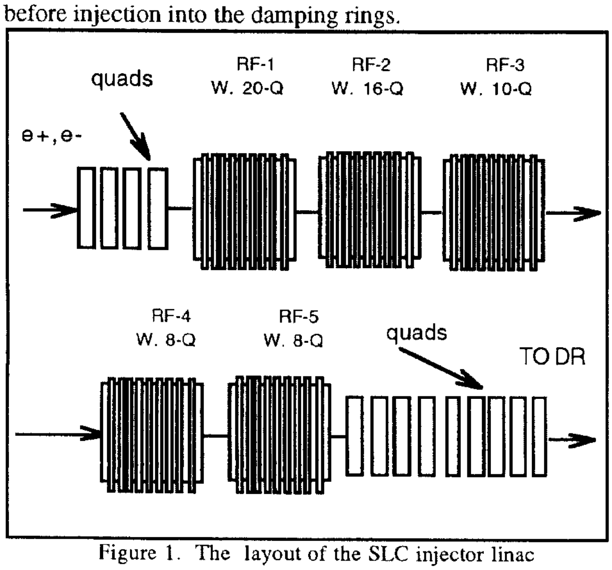

Figure 1. The layout of the SLC injector linac

A large positron intensity jitter (5%) is observed in the SLC. The jitter starts to grow in the middle of Sector-1. As seen in Figure 2, the jitter growth is correlated with the accelerating phases of the positron RF capture sections. Because the positron beam current is high (> $7*10^{10}$ particle/bunch), and the bunch length (~4mm) is much longer than the electron's, the wakefield is the probable cause of the jitter. In order to verify the above assumption, a code LI01_WAKE was written to study the positron jitter and wakefield effects in Sector-1 [1,2].

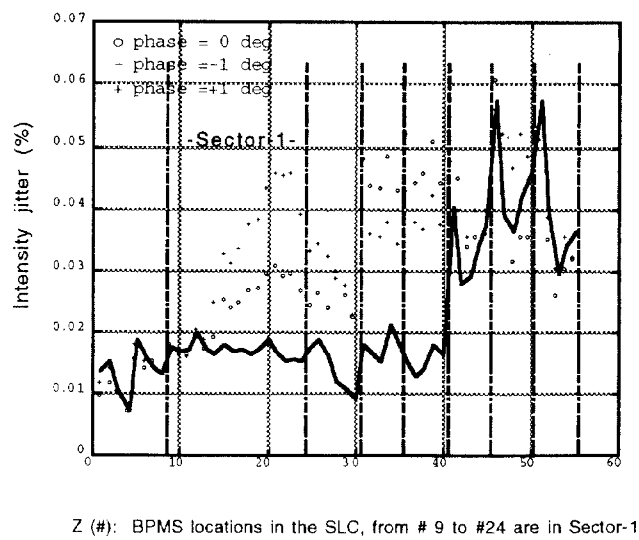

Figure 2. The positron intensity jitter vs BPM locations with different relative RF accelerating phase. "0.0" degree of the RF accelerating phase is given at the optimized value with minimum jitter.

II. SIMULATION PROGRAM

In LI01_WAKE, a gaussian shaped bunch is cut into 61 slices longitudinally. The particle number in each slice is determined so as to approach gaussian distribution, and the center of each slice is calculated from those particles. Calculations are done with positron bunch length of 1.5, 2.1, 3.0, 4.0 mm respectively. This is because it is not known. Figure 3 shows the fractions of beam in each slice for different bunch lengths. In the regions where the quadrupole field overlaps the linac RF field, the tracking particles are accelerated first, then wakefield effects are added, and the result is finally transported through the quadrupole field. Transverse wakefields are assumed to produce only transverse kicks, while longitudinal wakefield effects are limited to changes in the bunch's energy spread. We can simulate the beam transport through the sector with or without the wakefield effects. When the wakefield effects are included, we have the option of setting

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variours beam pipe apertures. For normal simulations, the aperture is set at 9.5mm, which is the RF structure inner radius. During the tracking, if a slice's transverse position is bigger than the aperture, the whole slice is considered to be lost. The RF accelerating phase is first optimized for minimum energy spread.

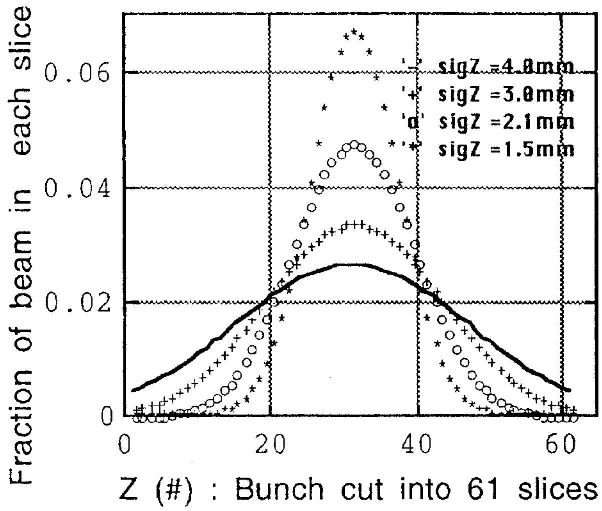

Figure 3. Percentage of number of particles in each slice.

III. TRACKING RESULTS

Figure 4 shows the beam trajectories for various positron intensities. In this plot, the bunch length is 4 mm, and the initial conditions are given as Y_0=0.0 mm, Y_0'= 1.0 mrad.

The different curves represent different beam intensities (number of particles/bunch). In the first 30 meters of Sector-1, the four trajectories are the same. After 30 meters, one can see the trajectories become quite different, and that the strong wakefield effects are dependent on the beam intensity. The beam loss starts in the middle of the sector when the beam intensity is $10*10^{10}$ particles per bunch.

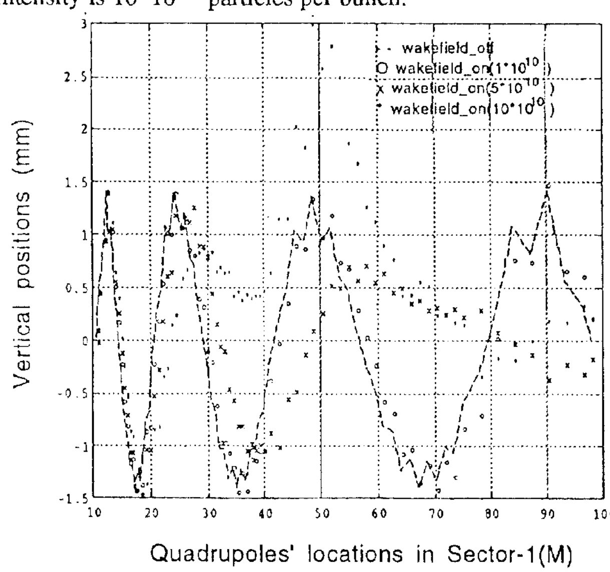

Figure 4. Simulated vertical trajectories in Sector-1.

The positron beam intensity is 7×10^{10} particles per bunch in the SLC injector linac in normal operation. We use this number in the following simulations. For different bunch lengths, we simulated distortions of the beam's transverse size caused by the wakefield effects. After the beam is transported through the Sector-1, the vertical offset of the bunch's tail becomes much larger than the head. The longer the bunch length, the larger the distortion. This is shown in Figure 5.

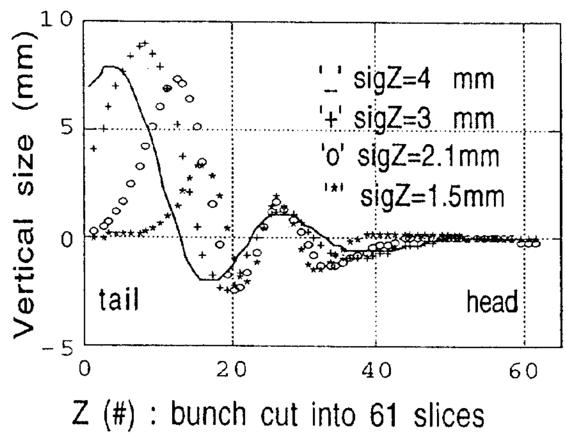

Figure 5. Simulated beam vertical size distortions at the end of the Sector-1.

When the positron intensity is 7×10^{10} particles per bunch, about 30% loss of the beam is lost in Sector-1. The injection aperture was found in the simulation by increasing the beam's initial displacement, until 30% of injected particles were lost in the Sector-1. The largest initial beam displacement is defined as the injection aperture. For different bunch lengths, the injection apertures are listed in table 1.

Table 1. Injection aperture versus bunch length

Bunch Length (mm)	Injection aperture/beam size
4.0	1.0 (3.0mm)
3.0	1.2 (3.6mm)
2.1	1.6 (4.8mm)
1.5	1.8 (5.4mm)

IV. COMPARISON BETWEEN SIMULATIONS AND MEASUREMENTS

In order to compare the simulation with the measurement data, we picked a typical orbit file from the SLC orbit record files. The injection conditions in the simulation were set up the same as that measured ones. A 20% jitter of beam size was added to the simulation injection conditions, since this much transverse jitter has been observed in the SLC. With the accelerating phases optimized, we checked where and how many particles were lost during the tracking. Table 2 lists the results. One can see that, for large bunch lengths, the energy spread is more sensitive to the accelerating phase, as is the particle loss.

Figure 6 shows how a measured orbit compares with the results from the tracking code. We simulated a 4 mm bunch beam through Sector-1 with and without the wakefield effects.

One can see that when the wakefield effects were not included, (marked 'wake_off') the beam trajectory is completely different from the measured orbit (marked 'measured'). With the wakefield on the measured trajectory is always in between the simulated trajectories. This is true, with or without the beam aperture limitations (marked 'aperture limit', 'no limit').

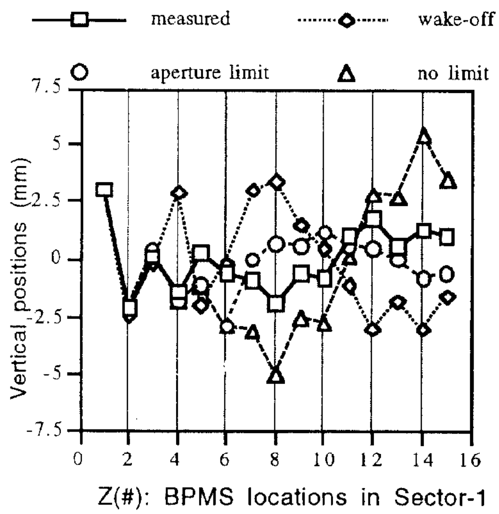

Figure 6. Simulation and measured results of beam trajectory versus BPMs.

Table 2. Tracking results. In which * indicates the optimized accelerating phases for each case.

bunch length (mm)	injected conditions (mm, mrad)	accelerate phase (degree)	# of loss $*10^{10}$	energy spread %	loss percent age %
4	3.0,-2.4	-2	1.990	1.270	28
		*-1	2.100	1.120	30
		0	2.100	1.150	30
	+20%	-2	2.320	0.860	33
		*-3	2.330	0.830	33
		-4	2.050	1.140	29
3	3.0, -2.4	0	1.790	0.930	26
		*-1	1.790	0.900	26
		-2	1.790	0.920	26
	+20%	1	2.040	0.810	29
		*0	2.040	0.780	29
		-1	1.720	1.000	25
2.1	3.0, -2.4	5	1.270	0.598	18
		*6	1.270	0.588	18
		7	1.270	0.614	18
	+20%	5	1.390	0.592	20
		*6	1.390	0.589	20
		7	1.390	0.620	20
1.5	3.0, -2.4	11	0.857	0.424	12
		*12	0.857	0.420	12
		13	0.857	0.440	12
	+20%	11	0.857	0.446	12
		*12	0.857	0.446	12
		13	0.857	0.446	12

VI. CONCLUSION

Our simulation study shows that the beam loss is related to RF accelerating phase and bunch length. The best match between the simulation and the measured beam trajectory indicates that the positron bunch length is about 4mm. Since there are a large number of quadrupoles in Sector-1, the misalignment of quadrupoles may affect the simulation results significantly. This effect is not included in our simulation. In order to achieve high transmission through Sector-1, the positron jitter must be reduced, because strong wakefield effects can not be ignored. For the 1994 SLC run, we have installed a new BPM and a pair of kickers. The kickers, (vertical and horizontal) will provide independent launch control for the positrons. More detailed studies are planned.

V. ACKNOWLEDGMENTS

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VII. REFERENCES

[1] J.T. Seeman , Observation of High Current Effects in High Energy Linear Accelerators (SLAC-PUB-5707, December 1991).

[2] K.L.F. Bane, Wakefield Effects in a Linear Collider (SLAC-PUB-4169 December 1986).