Summary of Emittance Control in the SLC Linac*

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Emittance Goals

The SLC electron-positron collider requires micron size beams at the collision point in order to make maximum luminosity, which requires small beam emittances. These small emittances must be produced in the damping rings and accelerated down the linac without significant enlargement. The design (invariant) emittances $\gamma\varepsilon$ at the exit of the damping rings are 1.7 X 10^{-5} radian meters (r-m) both horizontally (x) and vertically (y). The allowed emittance at the exit of the linac is 3 X 10^{-5} r-m [1,2]. This report describes measurements of the beam emittance at various locations along the beam's trajectory and the techniques used to diagnose and correct errors.

Emittance Measurements

The emittances and Twiss parameters of the beams are measured using four wire scanners spaced over 1.5 π of betatron phase [3]. Each scanner contains three wires: x, y, and 45 degrees. The wires are moved through the stationary beams and signals are recorded every beam pulse. The signals are digitized and the reconstructed beam profile is fit to a gaussian distribution. Using the known quadrupole lattice between the scanners, the measured emittances and phase space parameters are calculated. A complete scan takes about one minute. The emittance resolution is about 0.3 X 10^{-5} r-m.

Emittance Results

Measurements of the emittances of the beams exiting the damping rings as a function of the storage time (Fig. 1) shows that the injected emittances are about three time larger than the design. Injection oscillations and betatron mismatches into the damping rings are the suspected causes of this enlargement. All measurements described here were taken with a long storage time (16.7 msec) to eliminate this problem. The damping ring must be coupled to make equal emittances in x and y. The adjustment of the ring tune to determine the best coupling is shown in Fig. 2. The ring to linac transport line shortens the bunch length using an RF compressor accelerator in combination with the energy dependent path length. The transport line is not an exact achromat so the induced energy spread causes some horizontal emittance growth. (See Fig. 3.) Much of this growth could be reduced with better tuning. With the compressor off, the emittances at the entrance to the linac are nearly unchanged up to a bunch intensity of 4 X 10^{10} e^- as shown in Fig. 4. With the compressor on (and large energy spread) the measured horizontal emittance at the linac entrance increases with intensity (Fig. 5) because of bunch lengthening with current in the damping ring.

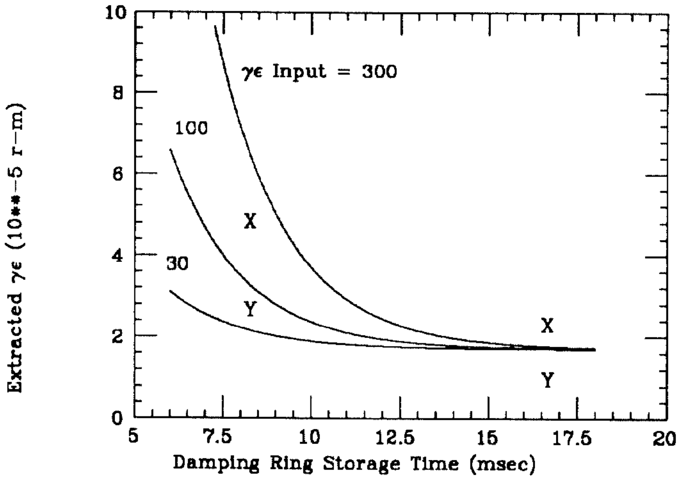

Fig. 1 Measured invariant emittances at the entrance to the linac (1.15 GeV) as a function of the storage time in the damping ring. X and Y refer to measured data and the curves to calculations. From these data, the initial damping ring emittance is about 100 X 10^{-5} radian meters or about three times the design value.

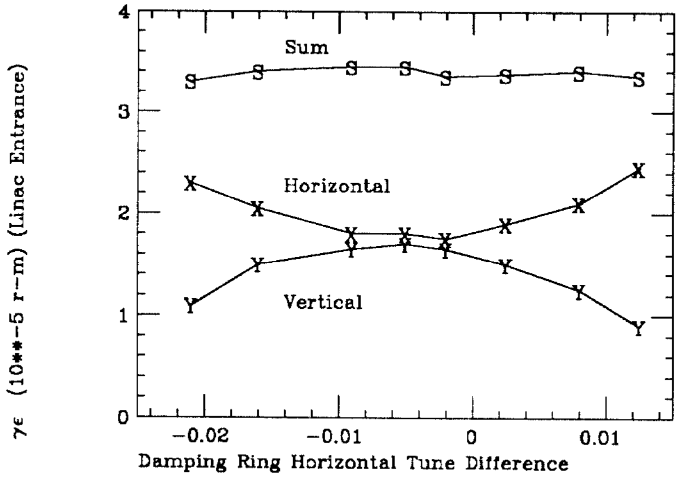

Fig. 2 Measured invariant emittances at the entrance to the linac (1.15 GeV) as a function of the horizontal tune of the electron damping ring. The goal is to couple the ring so that both the horizontal and vertical emittances are equal. The sum of the horizontal and vertical emittances is a constant as expected for storage rings.

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The beam launch parameters into the linac must be correct in order to avoid filamentation and wakefield effects downstream. The dispersion function in the ring-to-linac transport line must be adjusted so that it is properly cancelled in the linac as shown in Fig. 6. The dispersion can be adjusted to a few millimeters. The second-order optics of the tranport line must also be corrected through the use of sextupoles. Any betatron mismatches in the beam entering the linac are removed by adjustment of the matching quadrupoles in the transport lines which are located in a non-dispersive region. Dispersion matching can affect the betatron matching through non-orthogonalized variables which makes the tuning more difficult.

The beam in the linac has its trajectory corrected to about 120 μm rms to position monitors with resolutions of 25 μm and absolute positions of 80 μm. Quadrupoles have been aligned to about 100 μm. These errors in the placement of the position monitors and the quadrupoles in addition to those of the accelerating structures cause dispersive and transverse wakefields effects that increase the beam emittances in the linac. Inducing a betatron oscillation with the appropriate phase and amplitude has been shown to cancel to a large extent this

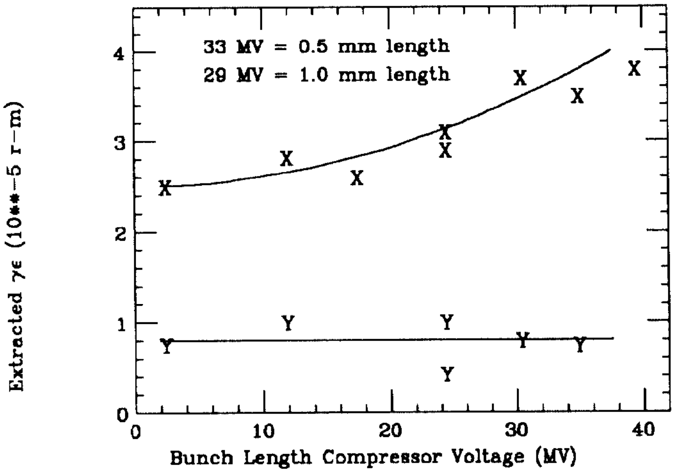

Fig. 3 Measured invariant emittances at the entrance to the linac (1.15 GeV) versus the RF voltage of the bunch length compressor in the ring-to-linac transport line. The horizontal emittance grows approximately quadratically with the energy spread introduced by the compressor. This increase in emittance at fixed current (2.5 X 10^{10}) indicates chromatic effects in the transport line where the horizontal dispersion is large. The vertical dispersion is small and the y emittance remains constant. The x and y emittances have different values here because the damping ring is not fully coupled.

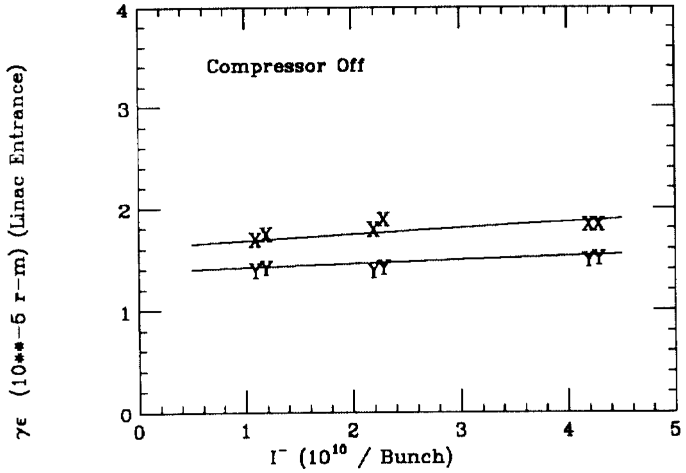

Fig. 4 Measured invariant emittances at the entrance to the linac (1.15 GeV) as a function of the beam intensity with the bunch length compressor off and a 16.7 msec storage time. The emittances increase slowly with current indicating that the damping ring, even with bunch lengthening, causes very little transverse emittance growth.

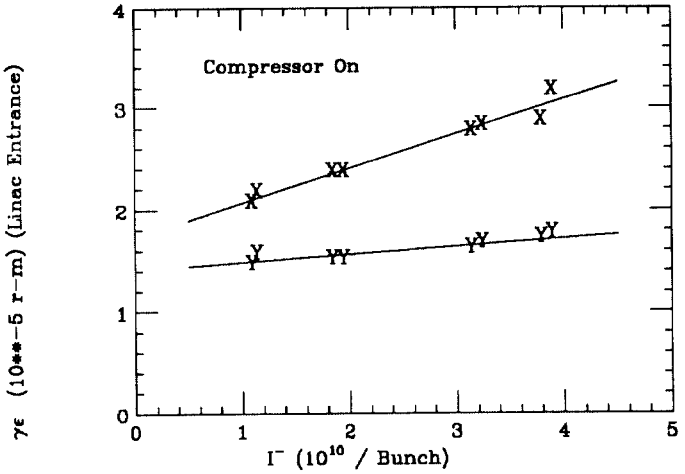

Fig. 5 Measured invariant emittances at the entrance to the linac (1.15 GeV) as a function of the beam intensity with the bunch length compressor on. Again, the vertical emittance remains constant but the horizontal grows. This growth is associated with the chromatic transport line and the onset of bunch lengthening in the damping ring at about 1 X 10^{10} electrons [4].

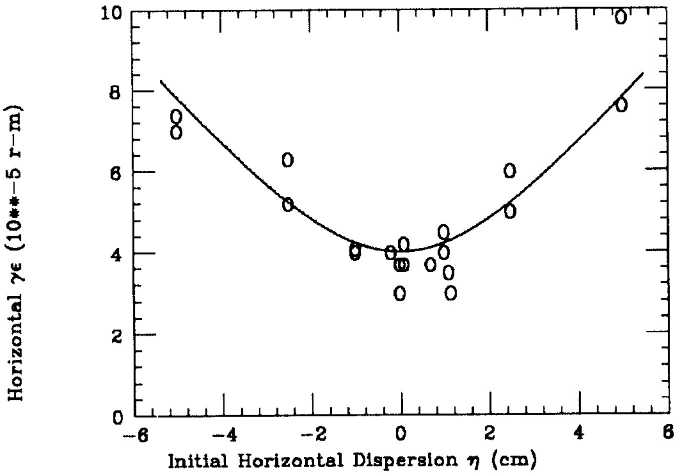

Fig. 6 Measured invariant horizontal emittance at the exit of the linac (47 GeV) as a function of the dispersion control setting at the entrance of the linac. The solid curve is a theoretical calculation of the expected growth due to filamentation of the dispersion assuming $\beta = 3$ m, $\alpha = 0$, and $\sigma_E/E = 1\%$. There is good agreement.

accumulation of errors. One such trajectory is shown in Fig. 7. This optimum trajectory needs correction every several hours. This technique was suggested in Ref. 5 and studied by a number of authors. Also, BNS damping has been used to reduce the effects of position and angle launch errors into the linac which cause wakefield emittance enlargement [6].

The best measured emittances as a function of current at 47 GeV is shown in Fig. 8. The emittances up to 3.5 X 10^{10} are equal to or below the allowed values at the end of the linac and have been obtained using all the methods discussed above. Excessive horizontal beam jitter above 4 X 10^{10} was the cause of the larger emittance.

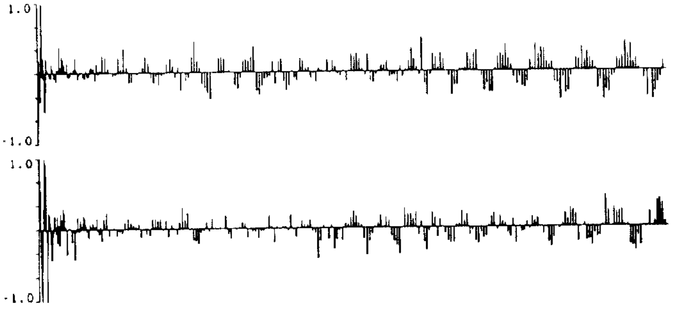

Fig. 7 Empirically determined linac trajectory along the 3 km linac which cancels the errors from the accumulation of dispersion and transverse wakefields errors at 3 X 10^{10} electrons. This oscillation lowered the horizontal emittance from 4.5 to 3.0 (X 10^{-5} r-m). This trajectory is not unique as other trajectories with similar oscillations can produce the same effect.

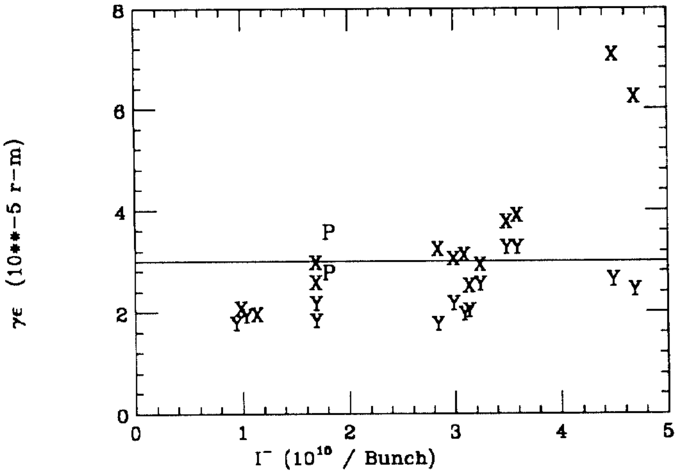

Fig. 8 Best measured invariant emittances at the exit of the linac (47 GeV) as a function of beam current. (The symbol P refers to positrons.) Emittances (x and y) at 1 X 10^{10} electrons have been measured at 2 X 10^{-5} r-m, which is 67% of the allowed value of 3 X 10^{-5} r-m. At 3 X 10^{10} electrons the allowed emittance values were obtained. Above about 4.0 X 10^{10} a strong launch jitter is produced from the damping ring system which causes larger emittances. Bunch lengthening (Fig. 5) and wakefields effects in the linac may also contribute. The jitter and wakefield effects are being studied.

A summary of the long term progress on emittance reduction in the SLC is shown in Fig. 9. Significant progress has been made, illustrated by the beam brightness (N / ε_x ε_y) which has increased by a factor of 350 over three years.

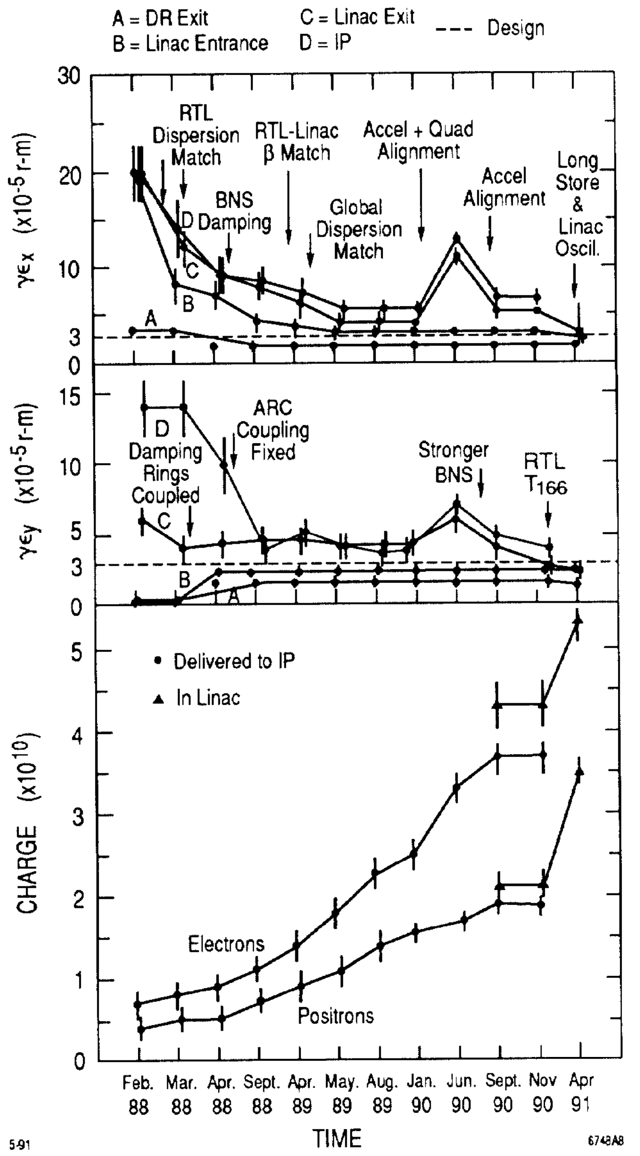

Fig. 9 History of the emittance reduction in the linac. The April 1991 emittances are for 3.5 X 10^{10} electrons.

References

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6) J. Seeman et al., SLAC-PUB-4968 (to be published).