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SLC Positron Source – Simulation and Performance*

Rainer Pitthan, Hans Braun,[a] J.E. Clendenin, S.D. Ecklund, R.H. Helm, A.V. Kulikov, A.C. Odian, G.X. Pei,[b] M.C. Ross, M.D. Woodley

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309

Abstract

Performance of the source was found to be in good general agreement with computer simulations with S-band acceleration, and where not,the simulations lead to identification of problems, in particular the underestimated impact of linac misalignments due to the 1989 Loma Prieta Earthquake.

Introduction

The overall design and performance of the SLC positron system has been described before[1]. Here, we describe mainly features which have changed since this review, due to the nature of SLC as a developmental accelerator, or due to external circumstances.

At present, the operation is as follows: electrons of 30 GeV are extracted at the 2-km point of the 3-km linac and focused on a moving tungsten-tantalum target [2]. Introduction of BNS damping [3], to counter unacceptable damping ring extraction kicker jitter, degraded the positron producing electron beam (scavenger beam) to the point where additional RF-control measures [4] had to be developed to keep the expected spot size on the target from growing beyond σ=0.6 mm, the optimal spot size for intensities of approximately $5\,10^{10}$ incident electrons.

Positrons (and electrons) from the target are captured by a magnetic focusing system. The essential parts are a 1.2 kGauss peak tapered solenoid field, a 55 kGauss peak pulsed magnetic field (flux concentrator) [5], and a 1.5 m long, high gradient, linac capture section. Positrons are then accelerated to ~200 MeV by three regular 3-m disk loaded wave guide sections. The flux concentrator, located 3 mm downstream of the target, is an important element in the system; it more than doubles the useful yield.

The 200 MeV positrons are transported back to the beginning of the main linac through a 2-km FODO lattice with some non-trivial properties [6] and through two 180°, 2.1 m wide, isochronous and achromatic turns [7]. Eventually the bunch is inserted into sector 1 (S01) of the main linac, accelerated to about 1.15 GeV, and brought via the south linac-to-ring transfer (SLTR) line to the south damping ring (SDR). Here ends the SLC positron source proper. In general we have excellent agreement in design and measured yield throughout the long, varied and complicated system up to sector 1. The area were design and performance do not agree, is the transmission through sector 1 and SLTR. The damping ring, with a transmission much below design, has different problems, described elsewhere [8]. Damping ring transmission has never been better than 70% and is sometimes below 50%, preventing the total yield in the final focus from reaching the value of 1, i.e., 1 positron for each electron.

In order to accept and transport the large-emittance, high-intensity, beams, sector 1 has been fitted with more than 70 quadrupoles, 20 alone in the first 12 m section, leaving little room for correctors or beam position monitors. Figure 1 shows the layout of beam components. Since electrons are co-accelerated with positrons within the same RF pulse, there is little possibility for steering the beams if the disk loaded wave guide structure is misaligned. The accelerator has to be more or less straight, how much so, we were taught by the 1989 Loma Prieta Earthquake. Tolerances which were originally 0.06 mm for the rms misalignment of the linac quadrupoles, had been relaxed to 0.1 mm.

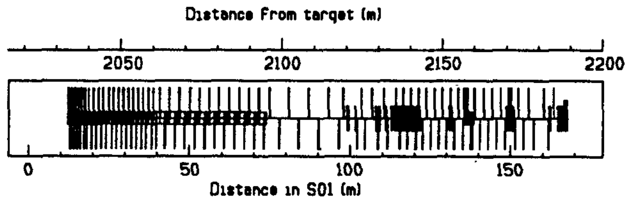

Figure 1. Layout of beam components in sector 1 and SLTR. Sector 1 ends at 100 m where SLTR starts. Quadrupoles are indicated by the lines which are either above (focussing) or below (defocussing) the horizontal axis. The only other elements indicated are accelerator sections (S01) and bend magnets (SLTR)

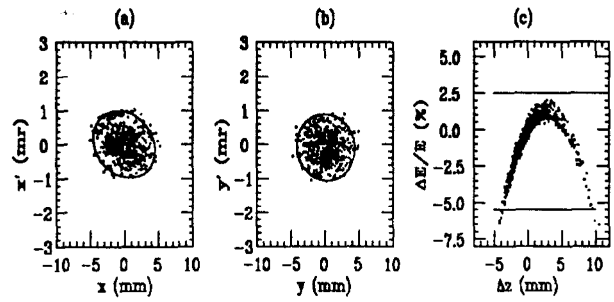

Figure 2. Six dimensional phase space from TURTLE at the end of sector 1.

Goals and tools

The main goal of our extensive program of simulation and experiment was to establish benchmarks at locations where beam characteristics could be measured well, and to use ray tracing to judge and predict the quality of the positron beam delivered to the SDR, to make sure that the beam was within the measured acceptance of the SDR.

Simulations were performed by generating positrons with EGS [9], tracking them through accelerator sections with solenoidal focussing with ETRANS [10], and then through the rest of the system with TURTLE [11]. TURTLE was modified to allow for realistic application of S-band acceleration.

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Figure 2 shows the six-dimensional phase space at the end of sector 1 from TURTLE for the aligned linac. Ellipses in (a) and (b) represent the stored damping ring acceptance (using TURTLE R_{12}'s and R_{34}'s). For the longitudinal part, (c), the horizontal line represents the $\pm 4\%$ measured energy acceptance of SLTR.

The linac S-band RF phase was 10° with respect to the center of the bunch, the phase resulting in best transmission (as evident from figure (2.c), where 3.3 mm correspond to 10°). The conclusion is that if everything is as designed, 75% of the beam at the end of sector 1 should be storable in the damping ring.

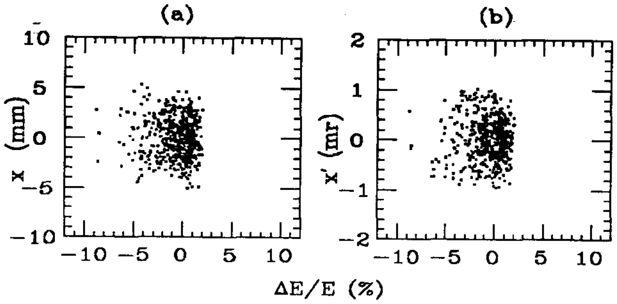

Figure 3. Filamentation plot for horizontal phase space at the end of sector 1. Same data as six dimensional phase space plot. Data for the vertical are similar.

Figure 3 addresses another important aspect of beam loss dynamics: is the outer part of phase space, if stripped off in S01, being re-populated in SLTR (filamentation)? There is indication of filamentation, otherwise the data should be contained in an ellipse, but only enough to partly re-populate the transverse phase space in SLTR, if cut in sector 1. In other words, since the transverse acceptance gets progressively smaller down the beam transport system, losses in sector 1 will to some extent reduce losses in SLTR, but no quantitative studies have been done.

Experiments

The characteristic most difficult to extract, and most worried about, was the positron bunch length, because bunch lengthening in the transport system, in particular the turns, will lead to additional energy spread during S-band acceleration in sector 1. Yield losses occur when these energy tails are being cut by the downstream system.

Experimental information on bunch length, and the performance of the turns, was obtained in several ways.

A direct measurement by means of a streak camera gave 3.5 mm, in agreement with calculations. That the 180° turns did not introduce spurious dispersion, and with it bunch lengthening, into the system, was ascertained by measuring the dispersion before and after the turns. And finally bunch length (gap) monitors verified the other measurements, but were of marginal accuracy, mainly due to the strong dependence of the signal on bunch intensity. Indirect, but most accurate, information comes from transverse profile measurements in areas with dispersion after acceleration to 1.15 GeV, when bunch length has produced energy spread. The measured beam profile in SLTR shown in figure 4 was taken before the earthquake, and implies σ_z no greater than the simulated and streak camera results. The profile monitor of figure 4 is located at a point with large dispersion; the complete agreement

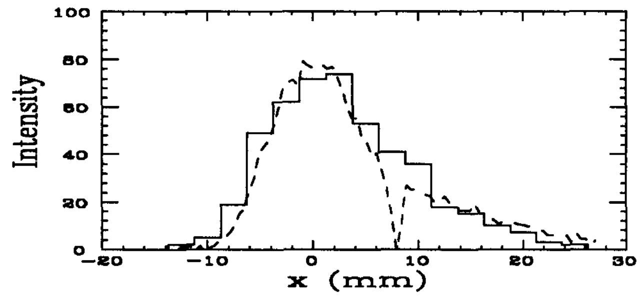

Figure 4. Horizontal beam profile in the SLTR where dispersion is large. Histogram: TURTLE; dashed curve: digitized profile screen measurement before earthquake. The dip in the dashed curve is due to the grid on the screen material.

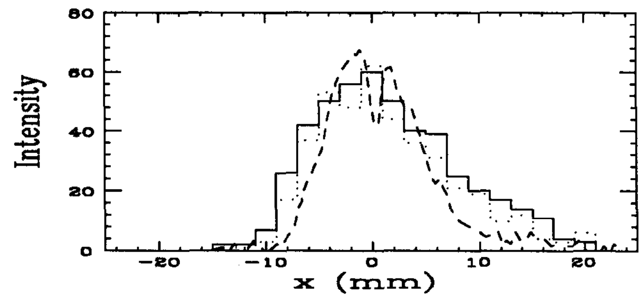

Figure 5. Horizontal beam profile in the SLTR, where dispersion is small. Histogram: TURTLE; dashed curve: digitized profile screen measurement after earthquake, before realignment. For dotted histogram, see text.

of the energy tail between 10 and 20 mm with TURTLE shows that the longitudinal phase space is at design specifications.

Figure 5 shows a beam profile at a point in the beam line dominated by betatron size, taken after the earthquake, before re-alignment. Still, at around 10 mm one can see the effect of the energy tail from sector 1 acceleration as will be discussed below. During this measurement (after earthquake, before realignment) beam losses in sector 1 were large (30% typically). Two TURTLE cases are shown in figure 5: the solid histogram corresponds to a well aligned case (0.1 mm rms for quadrupole misalignments) the dotted curve as calculated with the actual misalignments measured, but not corrected, after the earthquake. The latter case does not quantitatively agree with the experiment, but goes in the right direction. In view of the heavy losses in sector 1 during these measurements it is not surprising that the measured beam has a smaller size than the simulated one. More beam has been lost in sector 1 than would have been lost in SLTR up to this point due to re-population of phase space.

Figure 6 shows a recent (after re-alignment) profile measurement close to the end of the linac based on a wire scan. The horizontal beam profile looks similarly Gaussian and has the same good agreement between measurement and simulation. This plot shows that the transverse phase space of the positron beam more than 2 km after the target is exactly what it should be.

Since electrons and positrons go through the same beam line in sector 1, this type of measurement has only become possible with the recent development of

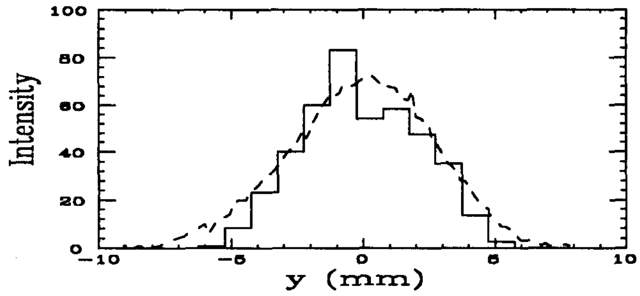

Figure 6. Vertical wire scan at the end of sector 1. Histogram: TURTLE (σ_y=2.57 mm); dashed curve: wire scan after sector 1 realignment (σ_y=2.60 mm).

wire scanners which survive the radiation environment of SLC [12], because with a screen one would loose the positron producing electron beam.

The bottom line in positron production must be the yield in the interaction point. Figure 7 shows the contribution of the positron source area discussed above. All yields were normalized to a value of 3.88 at the first toroid after the target. This isolates the comparison from fluctuations due to the energy of the incoming beam and its spot size on the target. The sharp drop of the dotted curve at the entrance to the first disk loaded wave guide in figure 7 is an artifact of the method used to simulate an orbit deviation of 2.5 mm (namely, shrinking the aperture from 9.5 mm to 7 mm). Halfway through sector 1, however, the dotted curve should correspond rather well to reality.

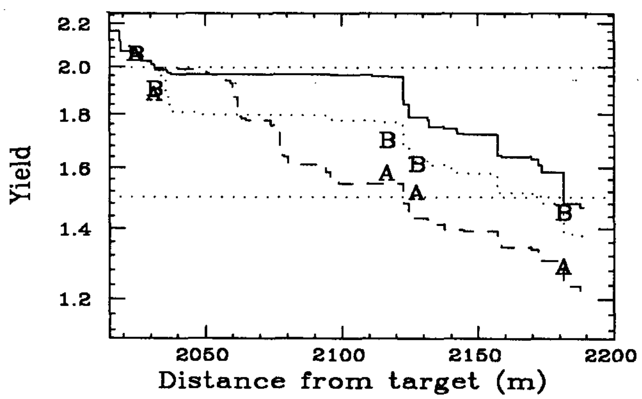

Figure 7. Yield in sector 1 and SLTR. Note the logarithmic scale. Large letters are toroid measurements: "A" - after earthquake, "B" - after re-alignment. Curves are TURTLE simulations: solid = aligned (1.5 mm orbit deviation); dotted = 2.5 mm orbit deviation; dashed = measured earthquake misalignment.

The alignment system of sector 1 is not well suited to reach accuracies of 0.1 mm (corresponding to 1.5 mm rms orbit deviation) with optical alignment. Beam based alignment [13] developed recently by switching off pairs of quadrupoles, and observing beam position changes downstream, indicates a misalignment level of 0.2 mm rms, which would correspond to approximately 2.5 mm orbit deviation, in agreement with figure 7.

Conclusions

The conclusions we draw are:
1. The earthquake resulted in a loss of appr. 20% positron yield during the following year, because the impact of the known misalignment was underestimated
2. At present the quadrupoles in sector 1 are aligned no better than 0.2 mm rms.
3. Aligning sector 1 to the design value of 0.1 mm should increase the number of positrons at the damping ring by 7% (figure 7).

(a) present address: Paul Scherrer Institut, CH-5232 Villigen, Switzerland;
(b) present address: Institute for High Energy Physics, Beijing, China.

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