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ENERGY MATCHING OF 1.2 GEV POSITRON BEAM TO THE SLC DAMPING RING*

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Abstract Positrons collected at the SLC positron source are transported over a 2-km path at 220 MeV to be reinjected into the linac for acceleration to 1.2 GeV, the energy of the emittance damping ring. Since the positron bunch length is a significant fraction of a cycle of the linac-accelerating RF, the energy spread at 1.2 GeV is considerably larger than the acceptance of the linac-to-ring (LTR) transport system. Making use of the large pathlength difference at the beginning of the LTR due to this energy spread, a standard SLAC 3-m accelerating section has been installed in the LTR to match the longitudinal phase space of the positron beam to the acceptance of the damping ring. The design of the matching system is described, and a comparison of operating results with simulations is presented.

INTRODUCTION

The positron source for the Stanford Linear Collider (SLC) was designed to produce within the acceptance of the positron damping ring (DR) in excess of two positrons for every high-energy electron hitting the production area of the positron target.[1] During the initial commissioning of the source,[2] the maximum yield (ratio of positrons at a given location to electrons hitting the positron production target) at the interaction region was only about 0.5, with typical values being in the region of 0.35 e^+/e^-. In Fall 1988, the SLC underwent a major upgrade to improve the overall performance of the collider. For the positron source, the improvements included an increase in the RF capture accelerating gradient from 18 to 40 MeV/m, installation of an energy-matching RF accelerating section in the LTR, and an extensive study of the beam optics to permit the magnet system to be run at model values.

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These improvements have doubled the yield of positrons at the interaction region, with typical (maximum) values now at 0.7 (0.9) e^+/e^- at 60 Hz. In what follows, the design and performance of the energy matching section in the LTR is described.

A sketch of the SLC is shown in Fig. 1. The transport line between the 1-GeV linac and the e^+ DR was designed with an energy acceptance of ±1.6%. Originally this was to be the defining energy acceptance of the DR, but the dynamic energy acceptance of the DR has been measured to be more like ±1%. In principle, as will be shown, this acceptance should be adequate, but, in fact, it is smaller than the actual energy spread of the beam. Consequently, as much as a factor of 2 was being lost in charge between the 1-GeV linac and the DR.

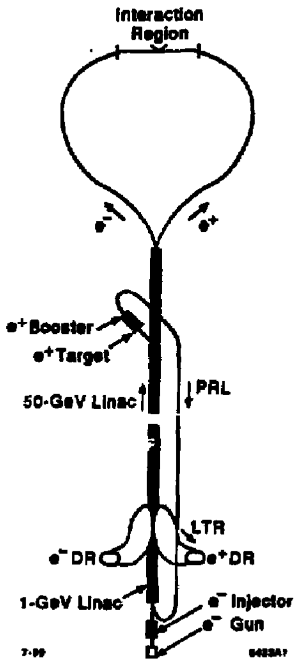

FIGURE 1 Sketch of the SLC; PRL is the 220 MeV positron return line, DR is the damping ring, and LTR is the linac-to-ring transport system. The electron bunch destined for the positron production target is extracted from the main linac at the two-thirds point (30–33 GeV).

DESCRIPTION OF THE BEAM

At the end of the 1-GeV linac, the energy spread in the positron beam is dominated by the $\cos(2\pi\Delta z/\lambda)$ term introduced by the accelerating RF, where Δz is

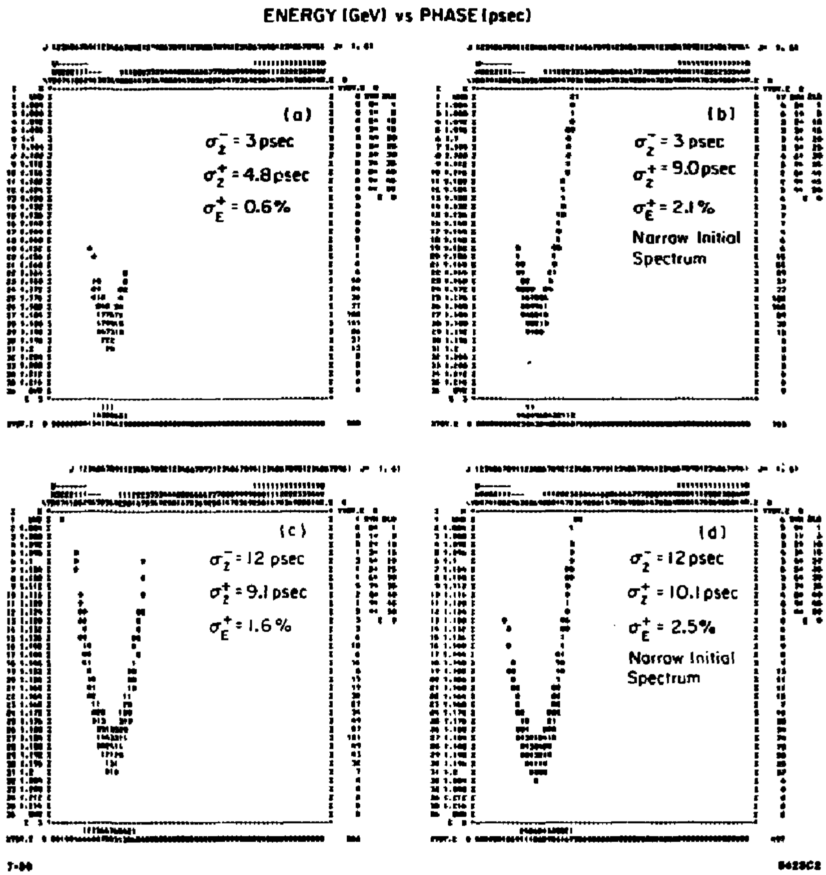

FIGURE 2 ETRANS scatter plot of energy (in GeV) vs. phase (in psec) at the end of the 1-GeV linac for the conditions indicated. The initial number of electrons hitting the target is 200. The scale for the plotting symbols is on the right. For (a) and (c), the beam is centered on the crest of the source RF, whereas for (b) and (d), the source RF is adjusted for a narrow energy spectrum. The value of σ_z^- assumed in the initial conditions and the rms half-width of the energy, σ_E^+, and of the phase, σ_z^+, for each scatter plot is indicated.

the positron beam bunch length. To simulate this beam, a ray tracing program, ETRANS,[3] is used at SLAC. ETRANS is designed to track the positrons generated at the production target by EGS[4] through the solenoidal and accelerating fields of the source region. ETRANS does not include the effects of space charge, wakefields, or a F0D0 lattice. However, with relatively minor adjustments for the overall effect of the 2-km F0D0 lattice used to transport the beam from the source to the DR, one can add the 1-GeV linac to the simulation in order to study the beam in the LTR transport line. The unknowns for the simulation are primarily the bunch length of the electron beam hitting the positron target and, to a lesser extent, the energy spectrum of the 220-MeV positron beam. The electron bunch length is nominally $\sigma_z^- = 3$ psec, but under some circumstances, could be as large as 12 psec. The energy spectrum of the low-energy positrons is determined by the RF phase of the positron source capture and booster accelerating sections. The two conditions of RF phase discussed here are: first, with the beam centered on the RF crest; and second, with the beam ahead of the crest to produce the narrowest possible spectrum. A scatter plot of the beam at the end of the 1-GeV linac is shown in Fig. 2 for these four conditions. These and the scatter plots that follow are for an initial ensemble of positrons generated by EGS for 200 electrons incident on the positron production target. The computed yields are summarized in Table I. Notice that the yield within a hard energy cut of ±1% is the same for $\sigma_z^- = 3$ psec regardless of the source spectrum.

TABLE I Computer simulation results.

Source Spectrum	σ_z^- (psec)	Yield (e^+/e^-) After Energy Cut		
		Without Compressor ($\Delta E = \pm 1\%$)	With Compressor ($\Delta E = \pm 2.5\%$)	Improvement
Centered	3	2.7	2.9	7%
on RF crest	12	1.7	2.5	47%
With narrow	3	2.7	3.2	19%
spectrum	12	1.5	2.1	40%

The measured bunch length at the end of the 1-GeV linac for the condition of a narrow source spectrum is $\sigma_z^+ = 10.1 \pm 3.5$ psec. This is consistent with the rms half-widths shown in Figs. 2(b), (c) and (d), but not (a). The source spectrum is generally adjusted to be narrow, so it is likely that σ_z^- is at least somewhat greater than 3 psec. A direct measure of σ_z^- using a spectrometer composed of a profile monitor in the transport line between the 50-GeV linac and the e^+ target yields $\sigma_z^- = 4 \pm 1$ psec.

The energy spread at the end of the 1-GeV linac is readily measured with a profile monitor early in the LTR. If one ignores a long low-energy tail, the energy distribution is fairly Gaussian, with an rms half-width of $\sigma_E^+ = 0.8 \pm 0.1\%$. The low-energy tail beyond the ±2.5% energy acceptance of the newly modified LTR contains up to 30% of the total charge. The computer simulations shown in Fig. 2 also indicate a low-energy tail. The simulated tails are considerably larger when the source RF is adjusted for a narrow energy spectrum. The percentage of charge in the low-energy tail outside a ±2.5% energy spread is 9% in the case of Fig. 2(b), and 15% in the case of Fig. 2(d). By contrast, it is only 0% and 5% in the case of Figs. 2(a) and 2(c), respectively. Why the measured charge in the low-energy tail is greater than that predicted is not known.

Matching the energy spread in the positron beam to the acceptance of the DR by using an energy compressor in the LTR allows one both to make use of the extra charge that can be transported to the end of the 1-GeV linac by the technique of adjusting the source RF phase for a narrow energy spectrum, and also to capture any positrons within a rather large energy range that happen to make it to the LTR for any reason.

DESIGN OF THE ENERGY COMPRESSOR

The LTR beta function and dispersion are shown in Fig. 3. The principal bends are in the horizontal plane. The measured and design emittances of the beam are $10^5\gamma\epsilon = 150 \pm 50$ and 250 m, respectively, so that it is clear that the horizontal beam size in the first 25 m of the LTR is dominated by dispersion. Given this geometry and noting that the path length difference (dL/dp/p) after the 120-m point is a constant 9.2 mm/%, it is apparent that a strong energy-phase correlation is developed in the beam early in the LTR; i.e., $\Delta s = R_{56}\delta$, where Δs is the shift in phase of a particle having a fractional energy deviation of δ from the centroid energy. That an RF accelerating section installed in this area is sufficient to compress the positron beam energy spread to within ±1% is shown below.

If the RF phase in the compressor section is adjusted so that the particles with the centroid energy, E_0, pass through the zero crossing, then the no-load energy gain required is given by

$$E_{comp} = \frac{\delta E_o}{\sin\left(\frac{2\pi}{\lambda} R_{56}\delta\right)} \quad .$$

For $\lambda = 105$ mm and $E_0 = 1.2$ GeV, one finds that the required accelerating energy

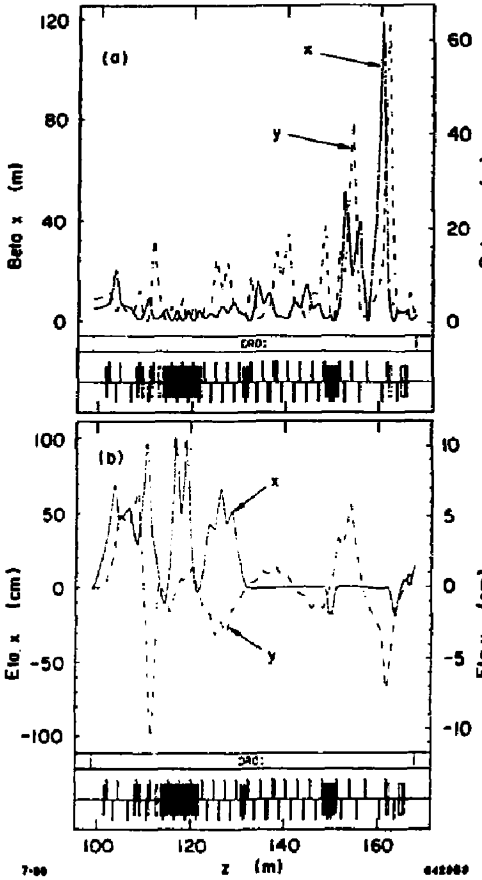

FIGURE 3 Beta and dispersion functions of the linac-to-ring transport system. The horizontal (vertical) scale is on the left (right). The principal bending plane is the horizontal. The origin for the abscissa scale, $z = 0$ m, is at the beginning of the 100-m, 1-GeV linac. The lower scale indicates the z-location of focusing quadrupoles (tall half-tick marks pointing up), defocusing quadrupoles (tall half-tick marks pointing down), and bends (shorter full-tick marks). The 3-m RF section for energy compression is installed beginning at $z = 135$ m.

is $E_{comp} = 22$ MeV.

The R_{56} matrix element can be applied to the bunch populations of Fig. 2. The results for the case of a narrow source spectrum are shown in Fig. 4 for a beam at the entrance and exit to the compressor section. In each case, the compressor energy is 22 MeV and the compressor RF phase is adjusted to maximize the number

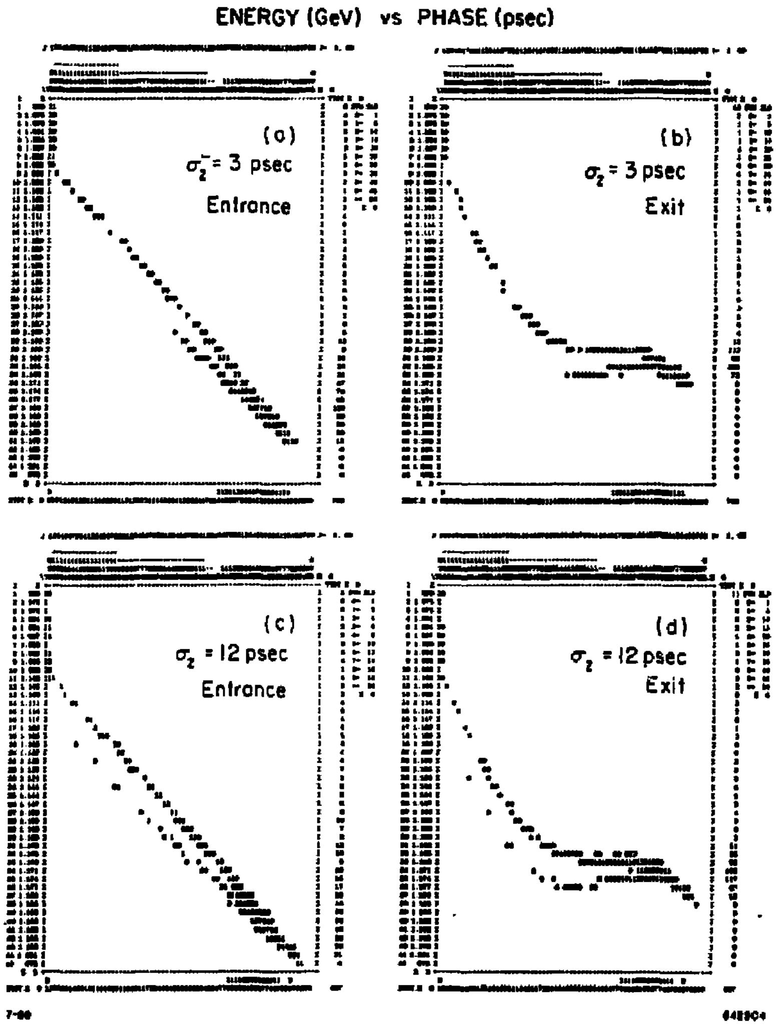

FIGURE 4 ETRANS scatter plot of energy (in GeV) vs. phase (in psec). The RF phase of the source is adjusted for the beam to have a narrow energy spectrum. The four plots are as follows: (a) and (c) are at the entrance of the energy compressor section, while (b) and (d) are at the exit; (a) and (b) are for $\sigma_z^- = 3$ psec, while (c) and (d) are for 12 psec. The source spectrum is adjusted for the beam to have a narrow energy spectrum.

of particles within a ±1% energy cut at the end of the LTR. The expected yields are shown in Table I. The increase in yield for the various conditions tabulated varies from almost no increase to a maximum increase of 47%. These yields all assume an energy acceptance upstream of the compressor of ±2.5%, and downstream, ±1%.

EXPERIMENTAL RESULTS

A standard SLAC 3-m accelerating section has been installed in an LTR straight area at $z = 135$ m. It is powered by a 5045 klystron installed at the modulator station that formerly powered the now-decomissioned girder 1–7 of the 1-GeV linac. The required S-band power in MV is given by

$$P = \frac{1}{f}(E_{comp}/10)^2 \quad ,$$

where f is the power transmission through the rectangular waveguide run from the klystron to the accelerating section. Since about 89 m of rectangular waveguide at 0.02 dB/m attenuation were required, $f = 0.67$ and therefore $P = 7.5$ MW. The 5045 klystron, which runs at about 60 MV when saturated, was especially chosen for its stable running at low power.

As stated earlier, the LTR energy acceptance had been designed for ±1.6%. It is only at the DR septum that the effective aperture is reduced to ±1%. Upstream of the energy compressor, the effective aperture had to be opened to at least ±2.5%. This required a new design for several magnets, including three short horizontal bending magnets that in the new design utilize permendur pole pieces.[5] Several additional components, such as correctors, beam position monitors, and vacuum chambers, also had to be replaced. The new energy acceptance has been confirmed experimentally.

The positron beam was initially run through the new LTR with the energy compressor turned off. The previous 40–50% loss of intensity between the end of the 1-GeV linac and the beginning of the LTR just downstream of the recently removed ±1.6% energy aperture is now reduced to a 30% loss. The remaining loss is associated with the long low-energy tail, as previously mentioned. The transmission through the LTR itself now appears to be essentially 100%. (The transmission through the old LTR after the ±1.6% energy defining aperture had not been carefully measured, but was high.)

With the compressor RF off, the transmission from the LTR through the DR is about 65%. Turning on the RF increases that transmission by about 10%, which corresponds to the increased charge that can now be transported to the compressor by a newly increased aperture of the beginning of the LTR. Most of the 30% loss after the compressor occurs after the beam is stored in the DR and during extraction from the DR. This indicates the DR parameters may not have been optimized.

CONCLUSIONS

Overall, the energy matching in the LTR is presently contributing a 10% increase in the yield of the positron beam accelerated to the interaction region. Another 10-20% should be achievable. Along with other improvements, the yield of positrons out of the DR has more than doubled in the past year to typical (maximum) values of 0.7 (0.9) e^+/e^- at the present machine repetition rate of 60 Hz.

The present stationary target, limited to 2.4×10^{10} e^-/pulse at 60 Hz and even less at 120 Hz, will be repaced sometime after September 1989, with a moving target designed for in excess of 5×10^{10} e^-/pulse at 120 Hz.

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