SLAC-PUB-5068
LBL-27753
September 1989
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EXPERIMENTAL BEAM DYNAMICS AND STABILITY IN THE SLC LINAC*

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Abstract The SLC linac must produce stable high energy, low emittance beams to make maximum luminosity. The incoming beam conditions must be correct and stable. The trajectories of the two beams must be controlled to about 100 μm. The energy and energy spectrum of each beam are controlled to a few parts per thousand. The beam transverse dimensions are measured to be about 100 μm at the end of the linac. The online monitoring, feedback, and control of these conditions are discussed. Automatic controls with time scales of pulse-to-pulse through a few minutes are used.

ENERGY AND ENERGY SPECTRUM

The precision measurements of the properties of the Z^0 require careful control of both the central value of each bunch's energy E and energy spectrum σ_E within each bunch. E must be held constant at the IP to within 50 MeV, and σ_E/E is required to be 0.3% (to avoid large losses in the $\pm 0.5\%$ momentum-defining slits and to avoid chromatic enlargement at the Final Focus).

The energy spectrum system has been described previously.[1] Just downstream of the dipole magnet 50B1 (which separates the e^+/e^- bunches to the S/N Arc), vertical wiggler magnets cause synchrotron radiation stripes with widths σ_x, related to the energy spectrum by $\sigma_x = \eta\, \sigma_E/E$, where η is the dispersion, calculated and measured to be 70 $\pm$ 2 mm.

Presented at the XIV International Conference on High Energy Accelerators, Tsukuba, Japan, August 22–26, 1989.

★ **Work supported by Department of Energy contracts DE–AC03–76SF00515 (SLAC) and DE–AC03–76SF00098 (LBL).**

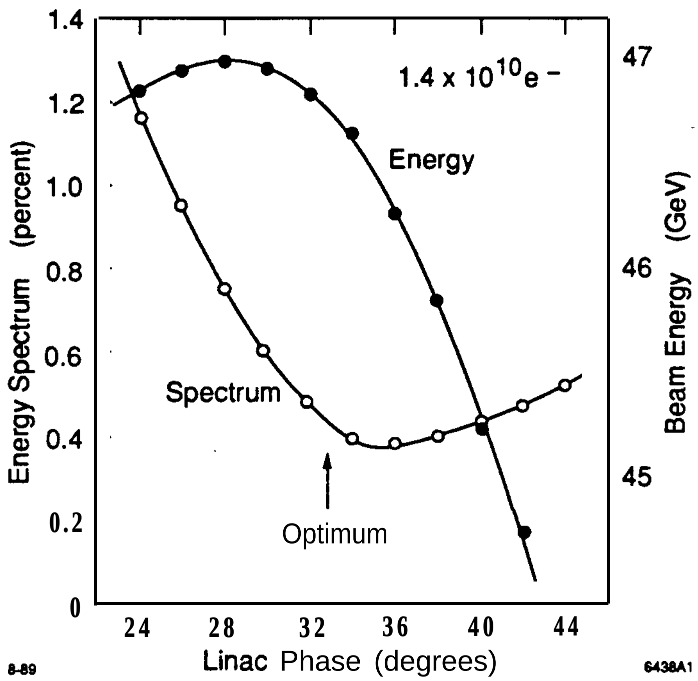

FIGURE 1 Energy and energy spectrum for an e^- beam as a function of the linac phase.

The energy spectrum is a function of the phase of the S-band accelerator, since the head and tail of the 0.75-mm-long SLC beam experience different fields. Figure 1 shows the observed energy spectrum of the linac as the phase is varied; agreement with theory is good. Routine measurements of σ_E are made every two seconds.

The e^+/e^- bunch energies are also measured using Beam Position Monitors (BPMs) positioned upstream and downstream of the splitter 50B1. A pulse-to-pulse energy measurement is shown in Fig. 2 as a function of time. The rms jitter is $\approx$ 30 MeV, consistent with the BPM position resolution.

The stability of the SLC requires that changes in the energy and energy spectrum be controlled. Near the end of the 3 km linac, two of the last sectors (out of 30) have their RF klystron phases adjusted to provide energy control for electrons.[2] Their phases are such that

$$4B = -4A \tag{1}$$

to maintain the energy spectrum, and

$$\delta E = 2E_0(1 - \cos\phi_A) \tag{2}$$

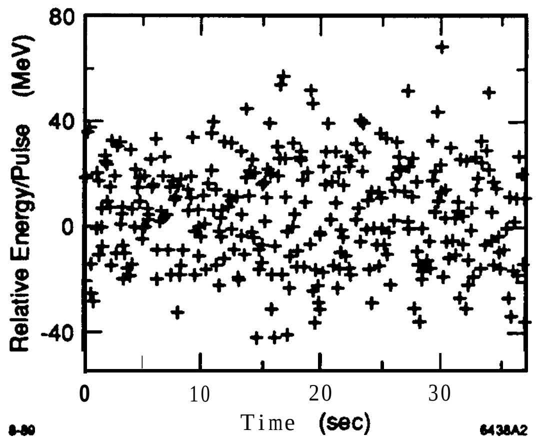

FIGURE 2 Energy of the e^- beam measured pulse to pulse.

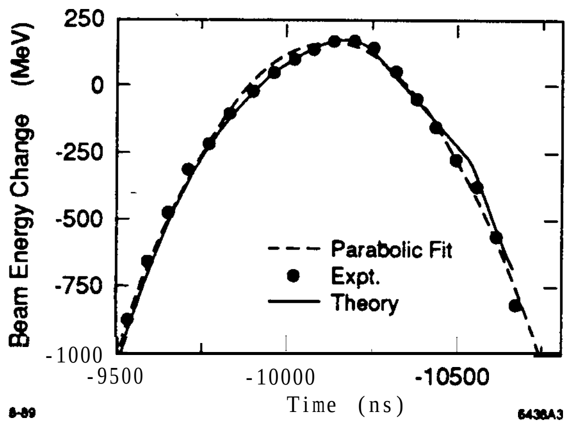

FIGURE 3 Measured SLED waveform compared with predictions.

for energy control. E_0 is the energy that each sector would impart to the beam at the peak of the S-band cycle and δE is the observed deviation of E from nominal. Figure 1 shows the measured e^- energy as a function of the linac phase. Due to beam loading (longitudinal wakefield) effects, the minimal observed σ_E/E occurs about four degrees higher than the phase of maximal E for 2 x 10^{10} particles. The operating point (labeled the optimum) is chosen to minimize the loss of particles in the energy collimating system.

The e^+ energy is usually stabilized by the e^- feedback, but sometimes requires an independent adjustment. For this purpose, the timing of the SLED waveform[3] is varied to adjust the relative e^+/e^- energies. Figure 3 shows the measured SLED curve compared with the modeled curve (we recall here that the e^- bunch in the linac arrives 59 nsec later than the e^+ on this waveform).

The procedure for setting up, or re-initializing, the e^+ and e^- energy and energy spectra is as follows. First, the electron damping ring phase is adjusted to give the desired e^- σ_E/E. Then, ϕ_A, ϕ_B are adjusted to fix the e^- energy. The e^- E feedback loop is turned on. The adjustment of the positron damping ring phase is used to set σ_E/E for e^+. Finally, the timing for the SLED waveform is varied (with the positron RF phase as a vernier) to set the e^+ energy.

STEERING IN THE LINAC

The excitation of transverse wakefields, as well as the possible introduction of momentum-position correlations (residual η), requires stringent limits on the allowed beam excursions from the central trajectory. Steering in the FODO linac lattice of the SLC uses separate horizontal and vertical dipole magnets associated with the BPMs in the center of each quadrupole. A crucial element in the convergence of the auto-steering procedure is the accurate determination of the betatron phase advance down the linac. Inaccuracies in the estimated klystron amplitudes lead to errors in the phase advance. A technique devised to hasten the convergence is a diagnostic tool using a dipole kick of known magnitude and a measurement of the difference trajectory resulting from the kick. Energy mismeasurement is readily apparent and straightforwardly corrected. The Linac Energy Management (LEM) program uses careful accounting of the energy gain along the linac in order to scale the lattice accurately, so that e^+/e^- simultaneous steering typically converges within two or three iterations when the linac is subdivided into four sections.

Figure 4 shows the X and Y trajectories of the e^- beam, relative to a reference trajectory acquired some 40 minutes earlier (a "difference" orbit). A horizontal (X) betatron oscillation of ≈ 0.1 mm amplitude is evident. Present understanding ascribes this oscillation to an instability in the damping ring extraction kicker and a changing energy profile.

BACKGROUND SUPPRESSION

The background illuminating the MARK II detector at the IP is sensitive to the beam size, and also to its non-Gaussian tails. The control of these beam sizes and tails has been mostly successful, but some work remains.[4,5]

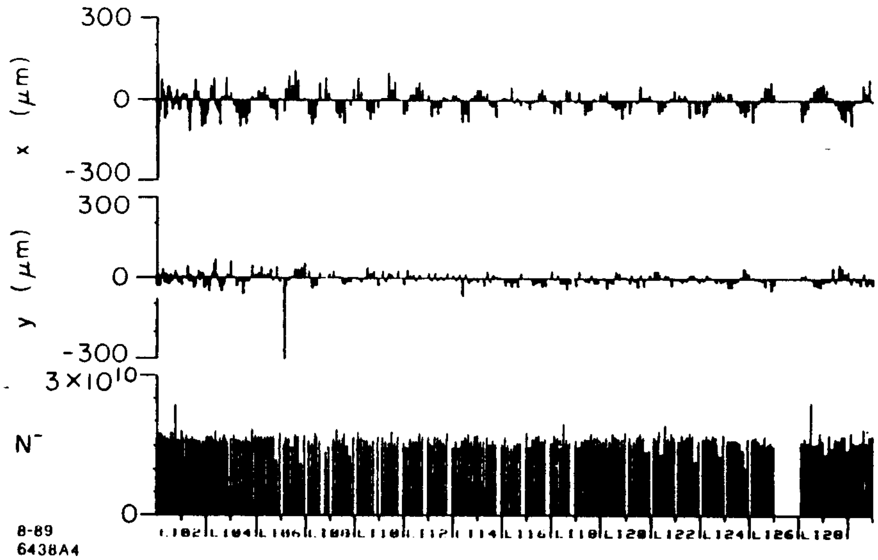

FIGURE 4 Difference orbit for an e^- beam along the 30 sector (LI02–LI30) SLC linac. Shown are the horizontal (X) and vertical (Y) excursions, and the beam intensity (in particles/pulse) TMIT.

The approach we have adopted to eliminate the effect of these tails on MARK II background is to force the beams through narrow -collimators. By careful placement of the collimator jaws along the beam, and careful steering through the jaws, we have been able to control these tails. The feedback system to keep the e^+ and e^- beams centered in the collimators uses a microcomputer to derive the settings for a set of eight dipole magnets (4X and $4Y$), based on measurements of a set of four BPMs (X and Y). The basic mathematics takes the form $\delta\theta_i = T_{ij}\ \delta x_j$, mapping the BPM deviations δx_j onto the corrector deflections $\theta_i' = \theta_i + \delta\theta_i$. T_{ij} is the transfer matrix that is readily calculated from the linac lattice; alternatively, T_{ij} can be determined experimentally in a calibration that systematically moves each of the θ_i over a fixed range and fits to the observed δx_j. In practice, this latter method is used, since lattice errors can cause significant convergence problems, and even oscillations can occur if T_{ij} is sufficiently inaccurate. The initial response to the feedback system is shown in Fig. 5. The loop gain is typically set small enough so that stability is assured; the penalty here is that several seconds are required for beam restoration after large excursions. The short-term stability achieved is typically $\pm 50\ \mu$m.

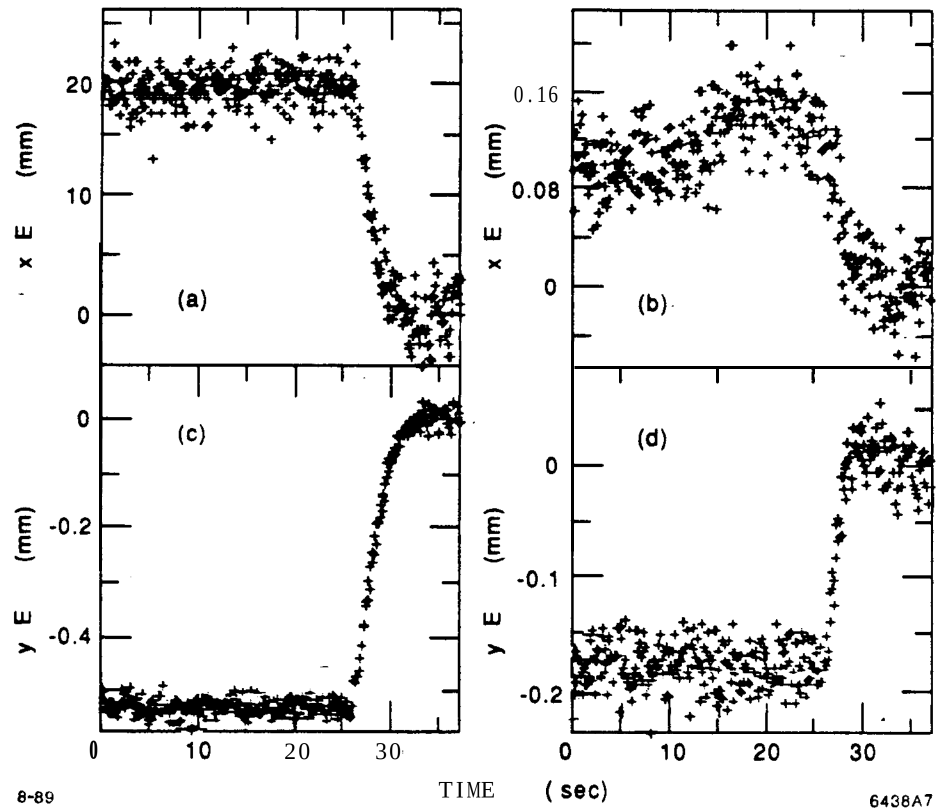

FIGURE 5 Position response of the e^+ and e^- beams as a function of time. The feedback loop upstream of the linac collimators in LI30 is turned on at t = 21 sec.

REFERENCES

1. E. J. Soderstrom et al., Proc. of the Particle Accelerator Conf., Chicago, IL, 1989; SLAC-PUB-4896 (1989).
2. G. S. Abrams et al., "Fast Energy and Energy Spectrum Feedback in the SLC Linac," Proc. of the IEEE Particle Accelerator Conf., Washington, DC, 1987, p. 1258.
3. M. A. Allen et al., Proc. of the 1986 Linear Accelerator Conf., Stanford, CA, p. 39; SLAC-REP ORT-303 (1986).
4. J. T. Seeman, "Beam Dynamics Verification in Linacs of Linear Colliders," SLAC-PUB-4752 (1989).
5. J. T. Seeman et al., "Observation and Control of Emittance in the SLC Linac," XIV Int.' Conf. on High Energy Accelerators, Tsukuba; SLAC-PUB4889 (1989).