FAST ENERGY AND ENERGY SPECTRUM FEEDBACK IN THE SLC LINAC

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Abstract

The energies and energy spectra of the positron and electron beams emerging from the SLC Linac must be carefully maintained so that the beams can be transported through the Arcs to the Final Focus without phase space dilution and also to specify the collision energy. A fast feedback system has been designed and constructed to control these parameters. The energies and energy spectra are measured nondestructively using position monitors and synchrotron radiation width monitors. The controls consist of RF phases in the Damping Rings, SLED timing, and RF amplitude. Theoretical aspects of the feedback process, algorithms, and operational experience are discussed.

Introduction

The energy of the Stanford Linear Collider (SLC) is determined by the acceleration of electrons and positrons in the 3 kilometer SLAC Linac. The desired energy stability is ±0.1% (50 MeV at full beam energy), while the required energy spread (of a single pulse) is 0.2%. These parameters are required to reduce dispersive effects in the Arcs and Final Focus and to specify the interaction energy.

The required stability will be achieved using a feedback system schematically depicted in Fig. 1. The electron and positron energies $E^{\pm}$ and energy spreads $\Delta E/E$ are measured on a pulse-to-pulse basis at the interface between the end of the Linac and the beginning of the North and South Arcs. A microcomputer analyzes these measurements and computes control settings for upstream correctors to guide the next pulse through the Linac. Error handling, stability and convergence monitoring, and possible operator intervention are performed via the standard SLC control system[1] architecture using the host VAX 11/780.

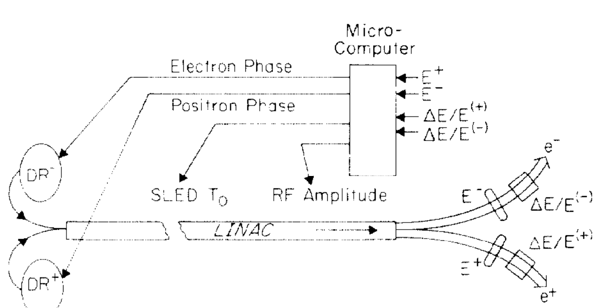

Fig. 1. Overview of the energy jitter/energy spread feedback system.

Monitor and Control Systems

Figure 2a illustrates the constituents of the monitoring/control system. The central element in this system is the Intel 86/30 microcomputer which communicates with the monitoring hardware, the control hardware, and the host VAX. It handles calibration, data acquisition and reduction, error handling and control functions. The VAX is used to poll the micro to monitor continually the feedback processes as well as to study in detail the pulse-to-pulse deviations and corrections.

The basic measurements are performed in a dispersive region ($\eta \approx 70$ mm) just downstream at the end of the Linac (whose primary function is to steer electrons (positrons) into the North (South) Arc). The beam energy is determined by the charge centroids measured by a set of (strip-line) beam position modules (BPMs). The position of this centroid in the horizontal plane is determined both by the launch conditions (x and x') into the Arcs and by an energy change in the beam. The microcomputer unravels these effects using the three BPM readings and calculates the beam energy shift. This provides the monitoring signal for the energy stability feedback.

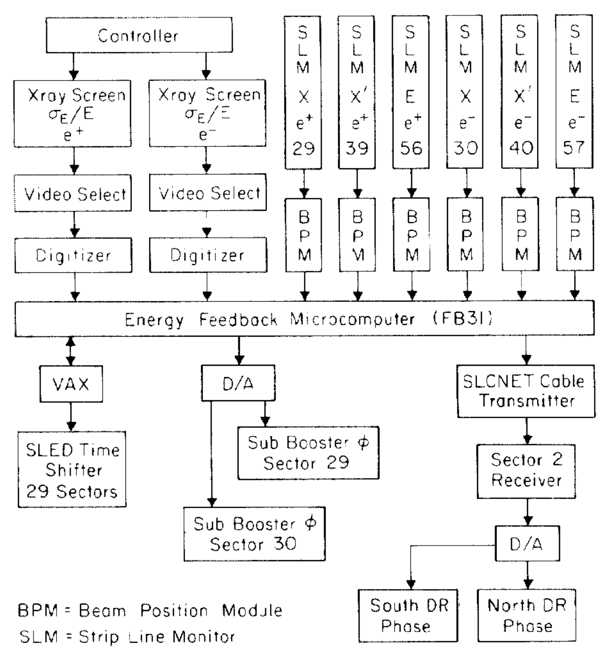

Fig. 2. Monitor and control elements of the energy jitter/energy spread feedback system.

The beam energy spectra (separately for e^- and e^+) are measured via the Wiggler configuration[2] illustrated in Fig. 3. The beam undulates in the vertical dimension, emitting X-rays in a vertical swath whose lateral extent measures the energy spectrum of the beam. The X-rays are detected by their impact on a phosphorescent screen; the light emitted by the screen is picked up by a TV camera and then digitized to abstract the width (in energy) of the beam. A typical measurement of $\Delta E/E$ is shown in Fig. 4.

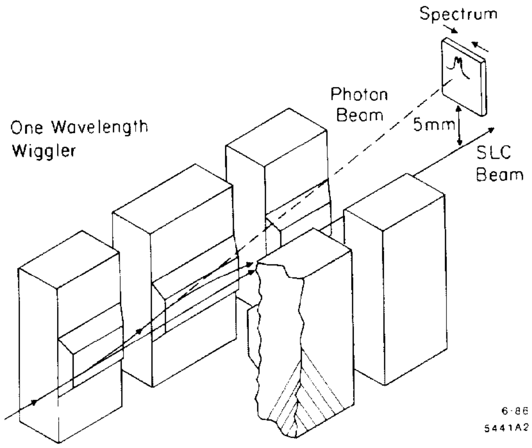

Fig. 3. Schematic of the X-ray Wiggler system used to measure σ_E/E in the Arcs.

The technique to vary reliably the Linac energy on a pulse-to-pulse basis is illustrated in Fig. 5. Here the control variable is the RF phase of one (arbitrary) klystron (with $\approx$ 250 MeV peak accelerating energy); the beam energy displays the expected sinusoidal behavior. As shown in Fig. 2, the design for the energy feedback system will utilize sub-booster phases for klystrons at the end of the Linac. As a simple phasing also affects the energy spread of the beam, two separate phases are varied so as to buck each other, causing the energy to vary with minimal effect on the energy spread.

An illustration of the variation of the energy width as a function of phase is given in Fig. 6. While the position of zero phase is arbitrary, the appearance of a minimum in the spread as well as an approximately parabolic form as a function of phase are features expected quite generally. As shown in Fig. 2, two separate phases will be involved for e^- and e^+; we plan to use the phase of the North and South Damping Rings (DR), $\psi^{\pm}_{DR}$, as independent control variables.

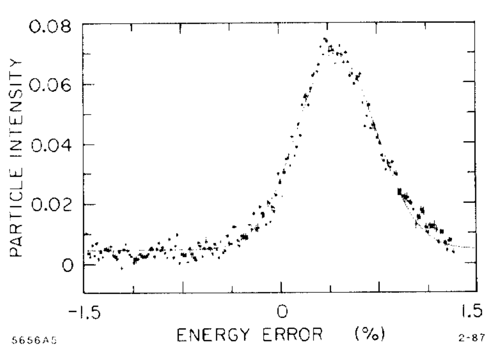

Fig. 4. Typical measurement of the energy spectrum for an individual bunch using the X-ray Wigglers (with the beam-off background distribution subtracted). The energy is measured relative to 47 GeV.

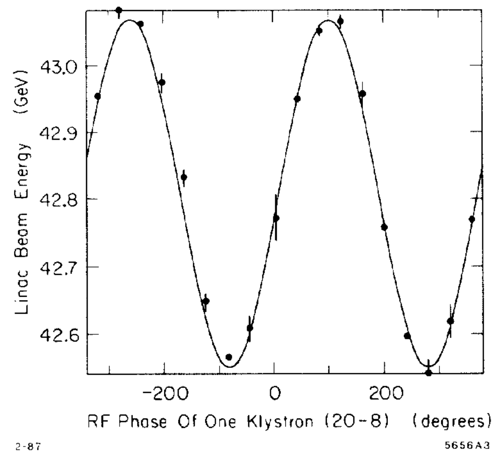

Fig. 5. Measured Linac beam energy as a function of the RF phase of an individual klystron.

Finally, we note that only one control variable is specified above for the energy feedback (the Sector 29/30 sub-booster phase). An independent control is required so that the e^- and e^+ energies are separately variable: we choose the control variable to be the position of the positrons on the SLED timing curve[3] (the electrons are then constrained to follow 60 nsec later). This position in time can only be varied by the VAX, as each of the 29 Linac Sectors must change in lock-step; however, the host architecture prevents the feedback microcomputer from addressing the individual Sector microcomputers except through the VAX. Thus this part of the control loop will be exercised at a slower rate than the part directly controlled by the feedback microcomputer.

The Feedback Process

To date the energy and energy spread feedback processes have not been turned over to closed loop control. Even so, considerable experience and understanding have been achieved. As shown in Fig. 7b, the energy jitter pulse-to-pulse is measured to be $\approx$ 0.1%. However, on the scale of tens of seconds excursions 2–3 times this jitter are common, as illustrated in Fig. 7a. We understand these slow energy variations as arising from (unavoidable) klystron faults.

If E is the average energy gain of one of the 29 Linac Sectors (each of which is 100 m long with 8 klystrons), typically about 2 GeV, the energy gain in the Linac, E_{Linac}, is

$$E_{Linac} = 27 \times E + 2E\cos\phi,$$

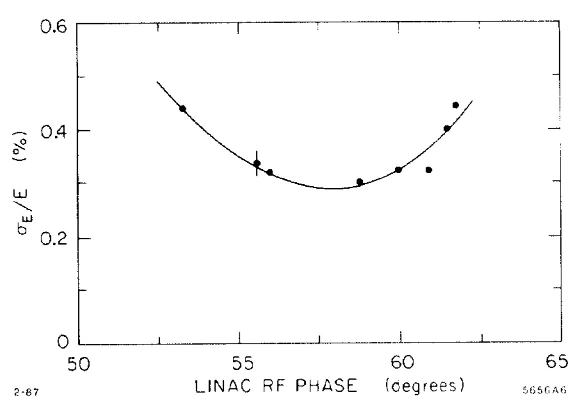

Fig. 6. Measurement of the bunch energy spread, σ_E/E, as a function of the RF phase of the Linac.

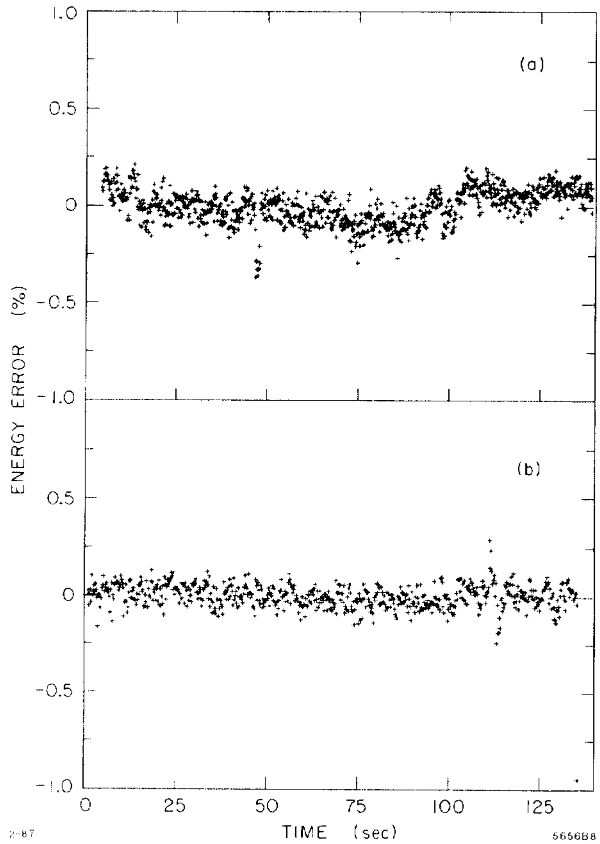

Fig. 7. Measurements of the pulse-to-pulse energy jitter of the Linac as a function of time without feedback.

where ϕ is the phase of the next to last Sector (29) and $-\phi$ is the phase of the last Sector. The positron energy gain is

$$E^+ = E_0 + E_{Linac} \cos \psi^+_{DR} \times \mathrm{SLED}(t^+).$$

Here SLED(t^+) is the energy function[3] describing the relative energy gain as a function of the position of the positrons in time on the SLED curve; E_0 is the energy of the beam in the Damping Ring, typically 1.15 GeV. The energy gain for electrons is

$$E^- = E_0 + E_{Linac} \cos \psi^-_{DR} \times \mathrm{SLED}(t^+ + 58.8 \text{ nsec}),$$

since the electrons follow at a fixed time after the positrons down the Linac. Hence by varying ϕ and t^+ and taking advantage of the non-linearity of the SLED curve, we may independently vary E^+ and E^-. The energy spectra of the two beams are controlled by adjusting $\psi^\pm_{DR}$ to place the bunches appropriately on the RF wave form such that longitudinal wakefields and the cosine curvature of the RF field roughly cancel (to yield a small energy spread). Aside from routine problems involving robustness of the monitoring/control processes, no difficulties have been encountered in implementing the energy feedback process.

In contrast, study of the energy width as a function of beam intensity has revealed some complexities. The bunch length as measured[4] by a streak camera in the Linac increases with beam intensity, and the measured energy spread of the beam similarly increases (see below). The energy spread increase is not inconsistent with that expected for the observed bunch lengthening, which occurs in the Damping Ring system.

Another complication arises from unexpected rapid changes in the width for changes in the overall Linac phase as small

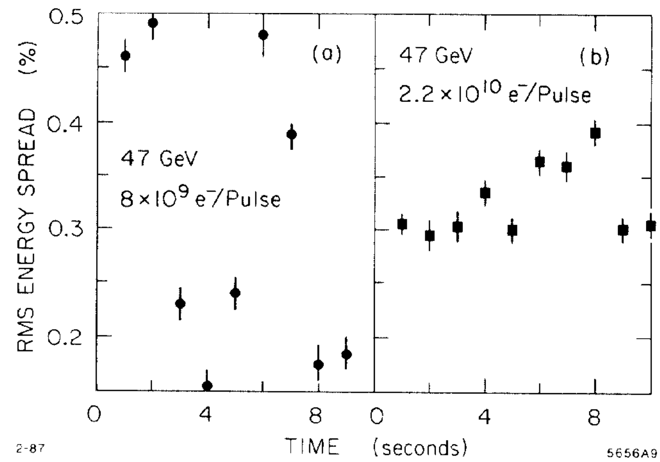

Fig. 8. Measurement of the energy width, σ_E/E, as a function of time for two different Linac intensities.

as 1–2°. Model calculations using wakefield simulations suggest minima in the energy width that do not change appreciably for 5–10° variations in phase. We presently believe that the narrow energy widths currently measured may be due to cancellation effects of the true energy spread in the beam with energy-position correlations in the dispersive region of the Arcs.

In Fig. 8 we show the measured energy width for individual pulses at two different beam intensities as a function of time. The large widths observed in Fig. 8a correspond to time periods when individual klystrons were in the process of cycling, giving rise to an unstable beam. The data in Fig. 8b indicate both the level of reproducibility when klystrons are stable and the overall increase in width when beam current increased.

With both energy and energy spectrum systems behaving reasonably close to design goals, it is planned to turn on these feedback systems in closed loop form soon.

Acknowledgments

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[4] R. Stiening, "The Status of SLC," invited talk at this Conference.