FAST ENERGY SPECTRUM AND TRANSVERSE BEAM PROFILE MONITORING AND FEEDBACK SYSTEMS FOR THE SLC LINAC*

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ABSTRACT

Fast energy spectrum and transverse beam profile monitoring systems have been tested at the SLC. The signals for each system are derived from digitizations of images on phosphor screens. Individual beam bunch images are digitized in the case of the transverse profile system and synchrotron radiation images produced by wiggler magnets for the energy spectrum. Measurements are taken at two-second intervals. Feedback elements have been installed for future use and consist of RF phase shifters to control energy spectrum and dipole correctors to control the beam launch into the linac affecting the transverse beam profile. Details of these systems, including hardware, timing, data acquisition, data reduction, measurement accuracy, and operational experience will be presented.

OVERVIEW

Figure 1 provides an overview of the transverse beam profile, and energy spread monitoring and feedback systems. The monitor elements of both systems are located at the end of the linac where the energy spread and the resonant blow-up of the transverse beam size are most pronounced. Signals from the monitors are collected via CAMAC and processed by a single Intel 80/30 microcomputer with a 80386 CPU. The computer then communicates via a dedicated link with feedback elements at the start of the linac which can adjust the energy spread and beam profile. This system is imbedded in the standard SLC Control Program, which allows for communication with the the rest of the SLC via the host VAX 8810.

ENERGY SPREAD MONITORING AND FEEDBACK SYSTEM

The beam bunches in the SLC linac experience longitudinal wakefield effects which lower the energy of the particles in the tail of the bunch relative to the head. The magnitude of this wakefield induced energy spread depends critically on the bunch length and intensity (number of e^+ or e^- per bunch). To control this effect, the approximately 1.5-mm-long beam bunches can be accelerated off the peak of the 2856 MHz RF in the linac, thus causing a difference in the accelerating field between the head and the tail of the bunch.

The energy spread measurement is made independently on the e^+ and e^- bunches in an area of large dispersion, $\eta = 70.0 \pm 2.0$ mm, after they have passed through the splitter magnet 50B1 just past the end of the linac, shown in Fig. 2. The dispersion is calculated from the lattice model. The energy spectrum of each bunch is extracted from the equation $\sigma_x = \eta\sigma_E/E$ where σ_x is the lateral width of the vertical swaths of X-rays generated as they pass through wiggler magnets, shown schematically in Fig. 3. The X-rays impinge upon $Gd_2O_2S : Tb$ phosphor screens (separately for e^+ and e^-) and the resulting images are viewed

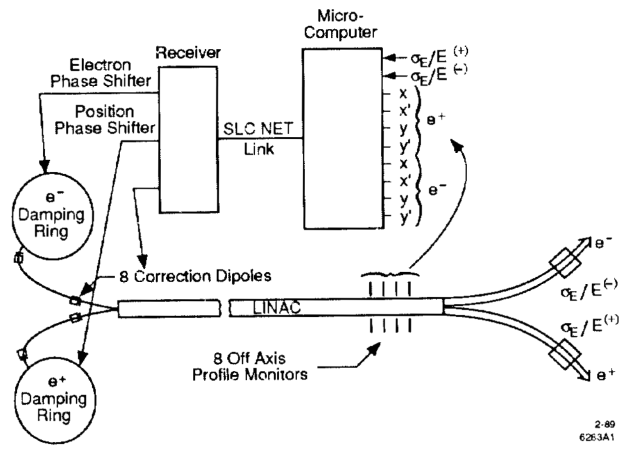

Fig. 1. Overview of the transverse beam profile and energy spread monitoring and feedback systems.

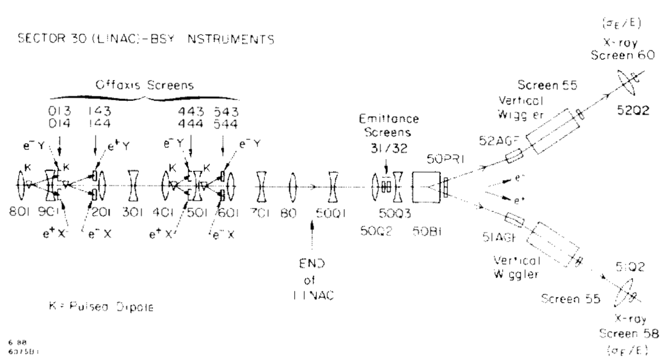

Fig. 2. Linac Sector 30 and Beam Switch Yard Instruments showing locations of beam profile and energy spread monitors.

by ultracon TV cameras. These cameras have been shown to have a linear response to the intensity of the image. The camera images are digitized by commercial transient waveform digitizers which are triggered by the SLC timing system and synchronized to the beam passage. The camera's vertical sweep is synchronized in the same way. The digitized field is 128 × 32 pixels covering a ± 3% region in energy horizontally. The digitizers are interfaced to summing units which construct projections onto the horizontal of the digitized images in real time. This eliminates the need for making the projection in software, thus saving time. The 32 vertical pixels cover the top one-third of the camera field making the projection available in the summing

* Work supported by Department of Energy contracts, DE-AC03-81ER40050 (CIT), DE-AC03-76SF00515 (LBL), DE-AC03-76SF00010 (UCSC), DE-AC03-76SF00098 (SLAC).

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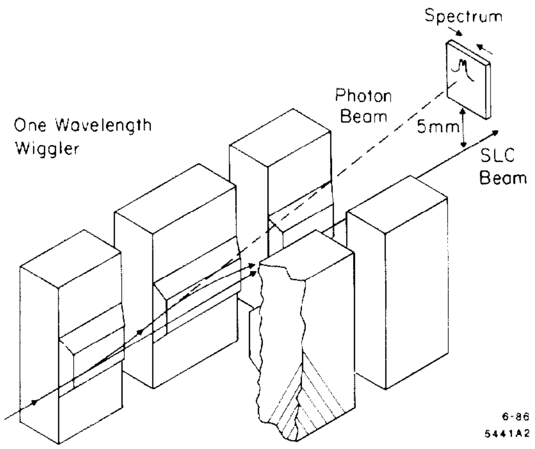

Fig. 3. Schematic of the X-ray Wiggler system used to measure σ_E/E.

memory after the same fraction of the camera's 60 Hz vertical sweep time. These digitized images are then collected by the microcomputer which extracts the energy spreads and relative energies of the bunches from the projections as follows: First, a stored background image is subtracted from the X-ray image forming the signal. The backgrounds are taken with the beams off as the persistence of the phosphor screens causes a permanent image for SLC rates above 60 Hz. Next, the peak of the signal is found and the width σ_x is computed after the tails have been truncated at the 5% of peak level. This peak finding and truncation was found to be necessary when monitoring SLC beams due to fluctuations in background light levels and shifts in camera and digitizer levels. The energy spread of the beams is then found from this width σ_x and the dispersion η from the linac model. The relative energies are derived from the location of the signal mean values. A single measurement of the e^- energy spectrum is shown in Fig. 4. A series of measurements are shown in Fig. 5 where the width is seen to jitter at the 0.03% level.

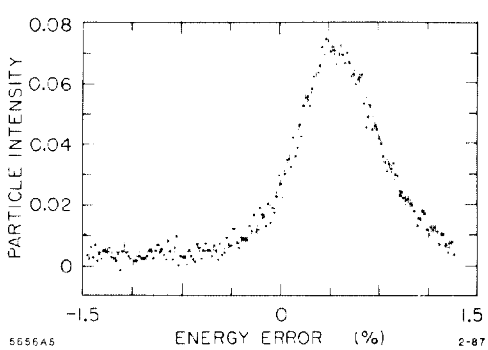

Fig. 4. Typical measurement of the energy spectrum for an individual bunch using the X-ray Wiggler (with the beam off background distribution subtracted). The energy is measured relative to 47 GeV.

To date, this system has been used exclusively as a monitor and has not yet been employed for feedback. In the future, the feedback process will be carried out by sending new settings to RF phase shifters located in each of the damping rings. This will set the phase with respect to the Linac 2856 Mhz RF independently for e^+ and e^- bunches. The communication between the microcomputer and phase shifters is carried out on a dedicated channel of the SLCNET link. The values of the phases needed to correct (minimize) the current measurements of σ_E/E will be determined based on a calibration of the RF phase shifters in the given SLC running configuration. This calibration will be controlled by the microcomputer and will consist of stepping the electron and positron damping ring phases over a range sufficient to observe a minimum in energy spread. The microcomputer will then move the phases to the minimum. A calibration from an earlier hardware configuration is shown in Fig. 6. In this figure the overall linac phase was used instead of the e^- damping ring phase. Much of the feedback hardware and a development version of the calibration code is in place and has been tested.

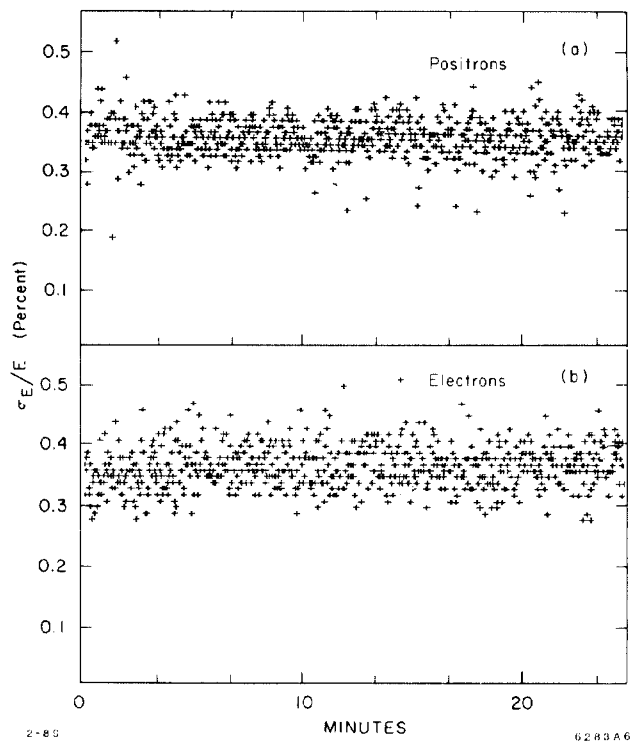

Fig. 5. Energy spread of the linac as a funtion of time without feedback. Measurements are made at 0.5 Hz.

TRANSVERSE BEAM PROFILE MONITORING AND FEEDBACK SYSTEM

A bunch executing a betratron oscillation in the linac will be subject to transverse wakefield effects. This results in the resonant buildup of non-Gaussian transverse tails. The magnitude of the wakefields depends on the bunch length and intensity, and on the size of the betatron oscillation.

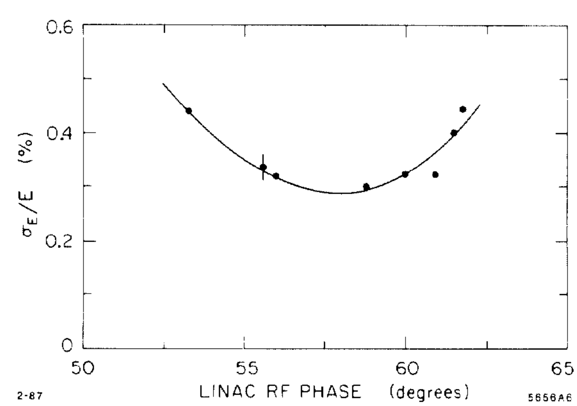

Fig. 6. Measurement of the bunch energy spread, σ_E/E, as a function of the RF phase of the Linac.

The measurement process is started when the beams are kicked off axis onto phosphor screens as shown in Fig. 7. A total of eight screens are used in this system, four for electrons and four for positrons, shown schematically in Fig. 2. Screens measuring the same quantity (*e.g.*, e^+ X) are separated by 90° in the betatron phase. The screens are tilted at a 45° angle to the beam axis to amplify the projection being measured. The four kicker magnets are pulsed sequentially at a 0.5 Hz rate, providing x,x′, y,y′ measurements for e^+ and e^- over an eight second interval. The images of the transverse beam profiles left on the screens are viewed by ultracon TV cameras. The camera outputs are multiplexed in pairs (following the kicker magnet pulse sequence) to transient waveform flash ADCs as in the energy spread system, but without the summing units. Thus the microcomputer is programmed to make a projection as it collects the data from the digitizers. The digitized field is 32 × 128 pixels, with the projection onto the 128 bins covering 3 mm of the screen. The read out and projection of the digitized image takes 100 ms. The width of the signal is then found as in the energy spread system with a typical measurement shown in Fig. 8.

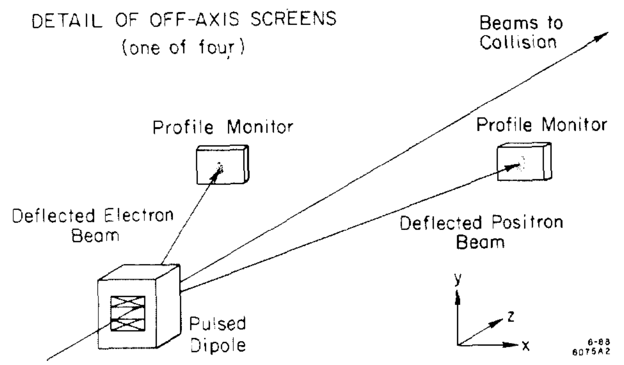

Fig. 7. Detail of one of four sets of off-axis profile monitors used in the transverse beam profile monitoring system.

As with the energy spread system the potential for closed-loop feedback exists, but has not been used to date. Four bipolar air core dipoles of maximum strenghth (2.2 Gm) are located in the positron damping ring to linac transport line and four in the electron line, each controling one of the launch variables x,x′, y,y′. Because of space restrictions, the dipoles in a given plane partially mix position and angular variables. The feedback process will be based on a calibration of these magnets where the effect on the beam profile of stepping each dipole through its range will be observed on the profile monitors and stored for reference. The microcomputer can then send new settings to the magnets to correct distortions if later observed. The communication from the microcomputer to the magnets is again carried out on the SLCNET link.

DATA STORAGE AND INTERFACE WITH THE SLC

During each 0.5 Hz cycle, the current energy spreads and profile moments are stored in a ring buffer on the microcomputer. The contents of the ring buffer can be transfered to the VAX host computer and displayed as a funtion of time to look for changes in the quantities over a 24-minute period (see Fig. 5). In addition, a current set of measurements is collected every four minutes by the SLC control program and stored in the SLC Database. Also stored are the present settings of the active feedback control elements (magnets and phase shifters) so that their configuation can easily be recovered. As an example, Fig. 9 shows the electron spot size at one of the profile monitors over a 24-hour period. The peak to peak variation is about a factor of two, representing the linac condition in September 1988.

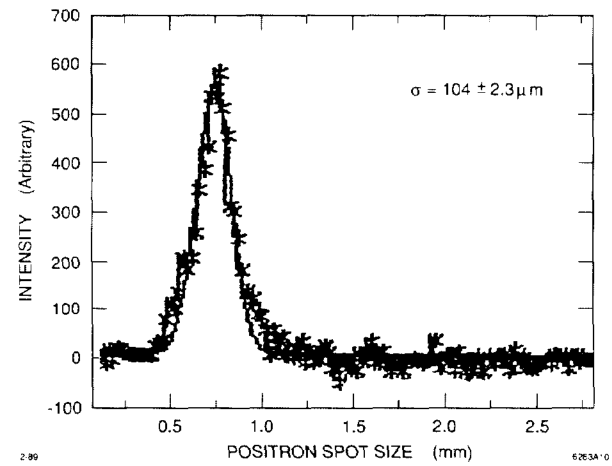

Fig. 8. Projection of a digitized positron beam profile with width $\sigma_x = 104 \pm 2.3$ μm (statistical error only).

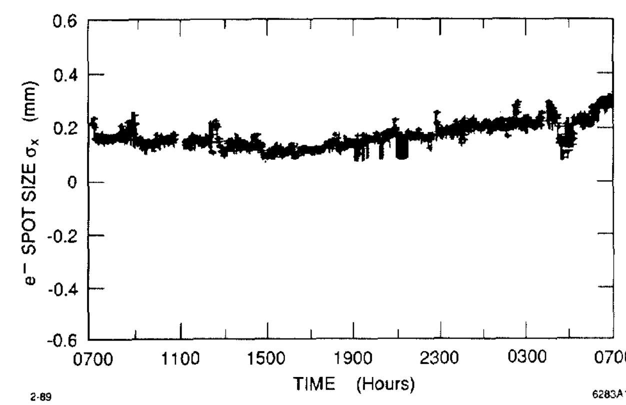

Fig. 9. Measurements of the electron spot size (width σ_x of projection) taken at four-minute intervals over a 24-hour period.

OPERATIONAL EXPERIENCE

The energy spread and transverse beam profile systems successfully monitored SLC beams during the 1988 run. Both loops are monitored similtaneously by the microcomputer at a 0.5 Hz rate, yielding a measurement of σ_E/E and the moments of one of the profiles (x,x′, y,y′) for both e^+ and e^-. A maximum rate of 4 Hz has been achived with the addition of summing units in the energy spread system and the upgrade of the microcomputer from a 8086 system to 80386. Time was also saved by storing backgrounds for the profile monitors rather than taking them anew each pulse.

Further studies are now underway to improve signal-to-noise and overall stability and reliability during 1989 physics runs. Plans are also in the works to use the transverse beam profile system to calculate the beam emittance.

ACKNOWLEDGMENTS

Thanks are extended to the many people at SLAC who have helped with the linac commissioning. Special thanks are due to the Operations Group, the Software Group, and to Instrumentation and Control. Thanks are also extended to the SLAC Publications Department who kindly helped prepare this document.