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REAL TIME BUNCH LENGTH MEASUREMENTS IN THE SLC LINAC*

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ABSTRACT

The longitudinal charge distribution of bunches accelerated in the Stanford Linear Collider (SLC) linac will strongly affect the performance of the Collider. Bunch lengths are chosen in a balance between the deleterious effects of longitudinal and transverse wakefields. The former impacts on the beam energy spread whereas the latter is important to the transverse emittance. Two bunch length measurement ports have been installed in the SLC linac: one in the injector region and one after the emittance damping ring to linac reinjection point. These ports utilize a fused quartz Cerenkov radiator in conjunction with an electrooptic streak camera to permit real time monitoring of single s-band buckets with a resolution of several picoseconds. The design of the radiators and light collection optics is discussed with an emphasis on those issues important to high resolution. Experimental results are presented.

INTRODUCTION

The performance of the Stanford Linear Collider (SLC) is strongly affected by the transverse emittance and energy spread of beams delivered from the end of the linac into the bending arcs. A large transverse emittance leads directly to increased beam sizes at the Interaction Point (IP). Energy spread in the bunches can lead to bunch compression, as the beams travel through the arcs, which prevents luminosity enhancement from beam disruption during IP collisions. For SLC operation the transverse emittance (in both planes) should be $\gamma\epsilon_{x,y} \le 3 \times 10^{-5}$ m-rad and the energy spread within each bunch should be $\Delta E/E \le 0.5\%$. Bunch lengths are chosen by compromise to reduce the effects of longitundinal and transverse wakefields in the linac. For gaussian bunch shapes, longer bunch lengths result in less energy spread than short bunch lengths. When emittance growth due to transverse wakefields is considered, short bunch lengths are preferred. Present plans for SLC operation call for bunch lengths (of both positron and electron beams) of $\sigma_z = 1.5$ mm for acceleration after ejection from the damping rings. For efficient injection into the SLC emittance damping rings at beam energies of 1.21 GeV, beam energy spread is of principle concern. Therefore, the bunch length through this region has been chosen to be about $\sigma_z = 3$ mm.

Several Cerenkov radiation ports have been installed to permit observation of the bunch length[1,2,3] in the SLC. Each port consists of a thin fused quartz radiator, an optical transport system, and a mounting for an electrooptic streak camera. Beams traversing the quartz generate Cerenkov radiation which is directed toward the streak camera for analysis. The resolution of the combined Cerenkov radiator and streak camera system is about 2.4 ps FWHM, corresponding to a length resolution of 0.7 mm. A radiator has been installed in the injector region w[illegible] beams have an energy of about 50 MeV. A second port h[illegible] installed approximately 100 m downstream of the poin[illegible] which beams are reinjected into the linac from the damping rings. Beams at this point in the linac will have an energy of ab[illegible]ut 3 GeV.

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CERENKOV RADIATOR AND OPTICAL COLLECTION SYSTEM

For the SLC installation it was decided to employ a radiator of fused quartz, thereby avoiding the problems associated with introducing a gas cell into the beamline. Figure 1 illustrates the general features of th[illegible] bunch monitor system that has been developed for the SLC. A [illegible]isk of fused quartz is inserted into the beamline at the Cerenkov angle θ_c,

$$\theta_c = \cos^{-1}\left(\frac{1}{n(\lambda)\beta}\right) \qquad (1)$$

wherein $n(\lambda)$ is the optical index of refraction of the disk (at the wavelengths of interest) and β is the bunch velocity normalized to the vacuum speed of light. Cerenkov radiation is generated as the bunch traverses the disk. A slice of the light is transmitted through the radiator onto a front surface reflector whence it is directed from the beamline toward an electrooptic streak camera. Several lenses are placed in the optical path to image the radiator onto the aperture limiting iris of the streak camera system. The bunch intensity as a function of time appears on the scope face of the analyser electronics.

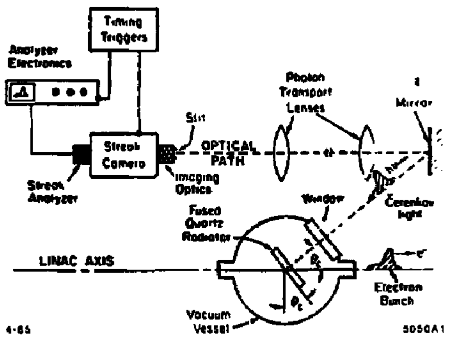

Fig. 1. A bunch monitor consists of a fused quartz radiator, mirrors and lenses comprising the optical path, and an electrooptic streak camera.

VUV grade fused quartz is used for the radiator. This quality material has the least amount of impurities which eventually darken in a radiation environment. A disk thickness of 1 mm is used; this is sufficiently long for adequate photon production while being significantly less than a radiation length so that potential thermal problems from beam energy deposition

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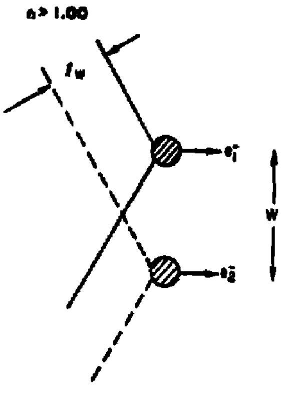

$$\Delta t_{size} = \frac{nW \sin\theta_c}{\beta c}$$

Fig. 2. The Cerenkov cone of e_2^-, displaced from e_1^- by w, is separated from the light cone of e_1^- giving rise to a temporal spread of Δt_{size}.

arrive at the analyzing plane in the streak tube. This transit time spread is given as[8]

$$\Delta t_{tr} = \frac{23.3}{E}(\Delta U)^{1/2}\text{ps} \qquad (5)$$

where E is the accelerating gradient in kV/cm at the photocathode in the streak tube; E = 20 kV/cm for the Hadland camera. ΔU is the initial spread in photoelectron energies expressed in eV. An upper bound for ΔU can be taken as the initial spread in incident photon energies. The range of incident photon energy is limited by the red cutoff of the S20 photocathode and either the highpass characteristics of the imaging light optics or from a lowpass filter specifically chosen for the purpose. For $3000Å < \lambda < 6000Å$, $\Delta t_{tr} = 0.84$ ps.

The finite size of the streak camera aperture image at the rear of the tube is effectively convoluted with the incident photon beam. This folding gives a minimum temporal width which is expressed as

$$\Delta t_{sl} = \frac{d}{v_{sweep}} \qquad (6)$$

wherein d is the slit image size and v_{sweep} is the speed at which the image in the streak tube is swept across the rear of the camera. The smallest value of Δt_{sl} occurs when d = the minimum image size as determined by the streak tube optics and when v_{sweep} is set for maximum. For the Hadland camera, $\Delta t_{sl} \geq 2$ ps.

Substitution of values into Eq. (3) results in $\Delta t_{res} = 2.4$ ps FWHM. This corresponds to a length resolution of 0.7 mm.

IMPLEMENTATION AT SLAC

As indicated previously, three streak camera ports have been installed. The streak camera is typically kept in the CID vault where it is used as a primary tool for tuning the bunch shape. It is desireable to place as much charge as possible into a single s-band bunch and to tune out satellites. Figure 3(a) is a photograph of a single bunch as seen on the streak in the quartz is avoided. The upstream surface of the radiator has been frosted so as to diffuse stray reflections which might appear at the streak camera after some delay from the primary signal. At optical wavelengths, θ_c is greater than the critical angle in the quartz so that radiation generated in a disk which was placed normal to the beam would experience total internal reflection and no light would be transmitted through the front of the disk. To circumvent this difficulty, the radiator is placed normal to the Cerenkov propagation vector, in one half-plane. The amount of light collected is limited by the aperture of the imaging optics; approximately 0.4% of the entire Cerenkov cone is focused onto the streak camera. This level is sufficient to enable bunches of several 10^8 particles per bunch to be analyzed at the highest camera sweep speed. The SLC bunches contain 5×10^{10} particles per bunch.

The streak camera chosen for the SLC is the Hadland Imacon 500.[4] This device has been fitted with quartz optics and an S20 photocathode. For single pulse analysis, the repetition rate must be kept below 20 Hz. Two trigger sources have been successfully employed for system operation. The signal from a gap monitor, placed upstream of the Cerenkov radiator, has been used to trigger the streak camera. More recently, timing pulses from the SLC timing system Programable Delay Units (PDU)[5] have been used.

SYSTEM RESOLUTION

The observed width of the analyzed bunch is related to the actual bunch width via

$$\Delta t_{ac} = (\Delta t_{bunch}^2 + \Delta t_{size}^2 + \Delta t_{tr}^2 + \Delta t_{sl}^2)^{1/2} \qquad (2)$$

where Δt_{bunch} is the actual bunch width, Δt_{size} is the width contribution arising from the finite transverse extent of the beam, Δt_{tr} is the transit time spread within the streak tube, and Δt_{sl} is the width due to the aperture limiting slit at the front end of the streak tube. The system resolution is given by Eq. (2) for the case of zero bunch length

$$\Delta t_{res} = (\Delta t_{size}^2 + \Delta t_{tr}^2 + \Delta t_{sl}^2)^{1/2}. \qquad (3)$$

As shown in Fig. 2 the bunch width causes an apparent increase in bunch duration. Photons emitted by a particle, e_2^-, displaced transversely from e_1^-, take a longer time to arrive at the streak camera even though both particles have the same longitudinal coordinate. For a bunch width of w

$$\Delta t_{size} = \frac{n(\lambda) w \sin(\theta_c)}{c} \qquad (4)$$

with c = the speed of light in a vacuum and the other values are defined as before. The apparent width of the beam as seen by the streak camera may be reduced with a field of view limiting slit. Through proper imaging, the slit of the streak camera itself can act as the stop. This technique is being used in the CID region where the large beam width would cause unacceptably large temporal broadening. For $w = 0.3$ mm, $\Delta t_{size} = 1$ ps.

Photoelectrons are emitted from the front of the streak tube with a range of initial energies and into a spread of angles. These distributions result in a range of times at which particles

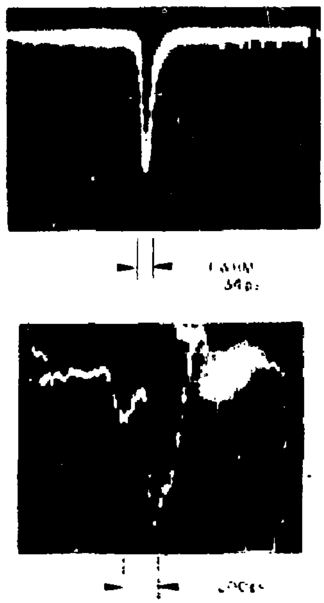

Fig. 3. Single s-band bunch as observed using (a) Cerenkov radiation and streak camera and (b) a gap monitor and sampling oscilloscope.

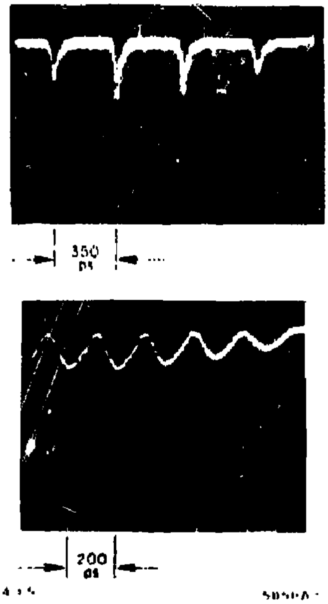

Fig. 4. Multibunch beam as viewed using (a) Cerenkov radiation and streak camera and (b) a gap monitor and sampling oscilloscope.

analyzer. No pre- or post-bunches are observed. Figure 3(b) is a photograph of a sampling scope display of the same beam as observed with a gap monitor situated just upstream of the streak radiator. Ringing of the gap monitor signal makes single bunch tuning difficult. Figure 4(a) is a view of the CID beam when the 178.5 MHz subharmonic bunchers have been turned off. This beam corresponds to what is presently being used to fill the PEP and SPEAR storage rings. The bunches appear at intervals of the linac s-band frequency, 350.1 ps spacing. Figure 4(b) is the same beam as viewed using the gap monitor and sampling scope technique. The differences in resolution between the two techniques, streak camera versus gap monitor, are clearly visible.

Besides being used to tune the injector, the streak camera system has been used to monitor the bunch shapes and numbers of bunches in beams that are deflected into the south ring and to observe the bunch shapes of damped beams. Reference 7 presents data acquired with the sector two installation. That data illustrates the shortening of the bunch length as the voltage in the damping ring RF compressor was turned on.

FUTURE PLANS

The streak camera-Cerenkov bunch monitor system has become an important tool for tuning those systems which affect the shape of particle bunches in the SLC. We are now considering the installation of extra ports in the positron production line and perhaps in the final focus region. Immediate plans for the bunch length monitoring ports call for further automation of the streak camera. At present, the streak camera must be manually adjusted for all operations. Once set up, the analyzed streak image can be viewed remotely with a TV camera which has been tied into the laboratory cable video system. Plans are being made to replace the streak analyzer with a remote viewing system which would connect directly to the SLC control computer. This would permit greater access to the bunch shape data for online analysis and control.

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