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Dual-Axis Streak Camera**

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# Commissioning of the Advanced Light Source Dual-Axis Streak Camera\*

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## Abstract

A dual-axis streak camera, Hamamatsu model C5680, has been installed on the Advanced Light Source photon-diagnostics beam-line to investigate electron-beam parameters. During its commissioning process, the camera has been used to measure single-bunch length vs. current, relative bunch charge in adjacent RF buckets, and bunch-phase stability.

In this paper we describe the visible-light branch of the diagnostics beam-line, the streak-camera installation, and the timing electronics. We will show graphical results of beam measurements taken during a variety of accelerator conditions.

## 1 THE SOURCE OF LIGHT

The Advanced Light Source (ALS) is a 1-2 GeV, third-generation synchrotron light source which has been in operation since 1992. One bend magnet beam-line [1] off the storage ring is devoted to beam diagnostics. Silicon mirrors deflect the visible portion of the photon beam to an optical bench. Recently a Hamamatsu streak camera system was installed to view the visible light and provide temporal information on the electron beam bunches.

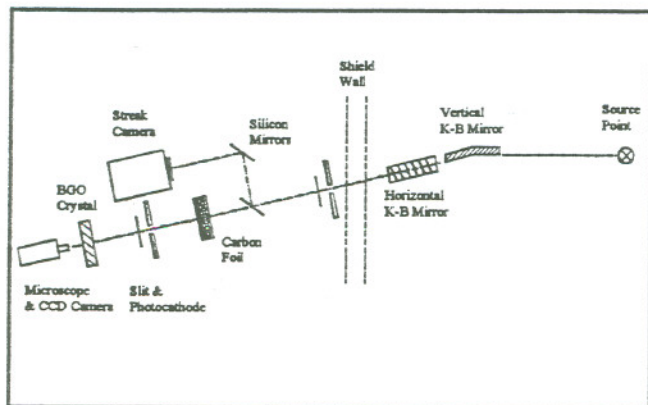


Figure 1. Schematic of diagnostics beam-line.

## 2 THE CAMERA SYSTEM

The streak camera and optical hardware are installed on a small optical bench above the beam line. The camera system consists of a Hamamatsu C5680 streak camera fitted with an M5679 dual time base extender unit and an M5675 synchroscan unit. The streak tube S20 photo cathode operates over wavelengths from visible to UV. The camera output is RS-170 video. The camera input optics (A1974) have an effective  $f$  number of 1.2, a magnification of 1:1, and spectral transmittance from 400 to 900 nm. Other accessories include an M5676 fast single sweep unit, an M5677 slow single sweep unit, a C1097 trigger delay unit, and a C4547 streak trigger unit. All measurements for this paper were taken with the synchroscan unit.

### 2.1 Camera Synchronization

The synchroscan module deflects the streak tube beam with RF sine waves on the deflection plates. At the ALS the synchroscan frequency is 124.9 MHz ( $\frac{1}{4}$  the cavity RF) which falls between the manufacturer's range of 75 to 165 MHz. The ALS synchroscan RF is derived from the storage ring RF master oscillator. In order to minimize timing jitter the RF is filtered in a cavity ( $Q = 1000$ ) before being divided by four. The ring orbit clock (SROC, 1.523 MHz) is re-synchronized with the RF at the beam line racks. System jitter measured with an Tektronix 11801B sampling oscilloscope is less than 4 ps rms.

The synchroscan module is driven continuously. The maximum triggering rate for the dual axis module is 10 Hz. Triggers for this unit are derived from the C4547 streak trigger unit which reduces the SROC trigger to 10 Hz. A Stanford Research DG535 delay generator is used to delay the dual-axis triggers to permit measurement of a desired bunch or series of bunches.

The longest sweep range for the synchroscan module is 1.4 ns, approximately  $\frac{1}{6}$  of the 124.9 MHz sine wave duration. The fastest sweep range is 150 ps. The dual sweep axis module time range is from 100 ns to 100 ms.

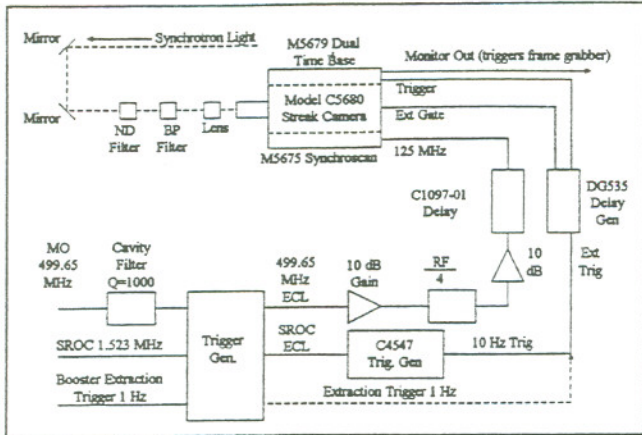


Figure 2. Streak camera block diagram.

### 3 MEASUREMENTS

#### 3.1 Bunch Length

Single bunches ranging from 1 to 20 mA average current were circulated in the ALS. Fig. 3 shows the measured rms bunch length and the shift in synchronous phase as the bunch current was increased. To determine phase shift two bunches were stored at any time. One bunch was weak and taken as the phase reference as current in the other bunch was increased.

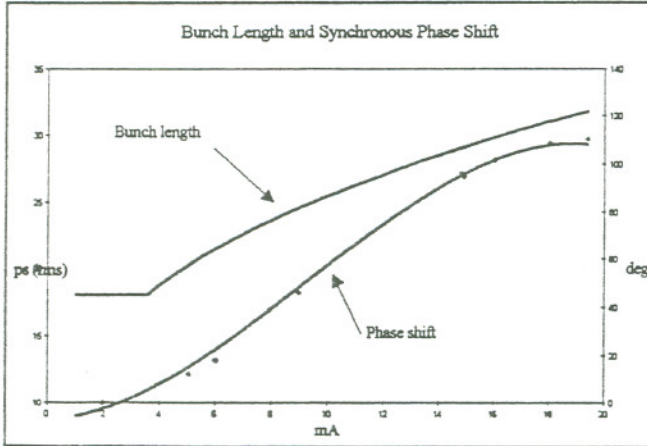


Figure 3. Single bunch length and shift in synchronous phase. The bunch length curve is fitted to experimental data. The phase shift curve is a polynomial fit to data shown.

#### 3.2 Beam Damping

The ALS has bunch-by-bunch damping systems to suppress longitudinal and transverse coupled-bunch instabilities. The dramatic effect of longitudinal damping is seen in the following two figures.

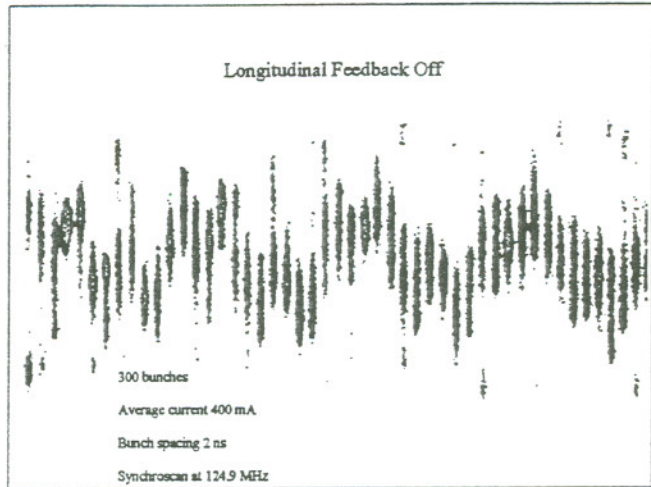


Figure 4. Damping off. Vert. = 1 ns. Horiz. = 200 ns. Bunch spacing = 2 ns. Every other bunch is shown.

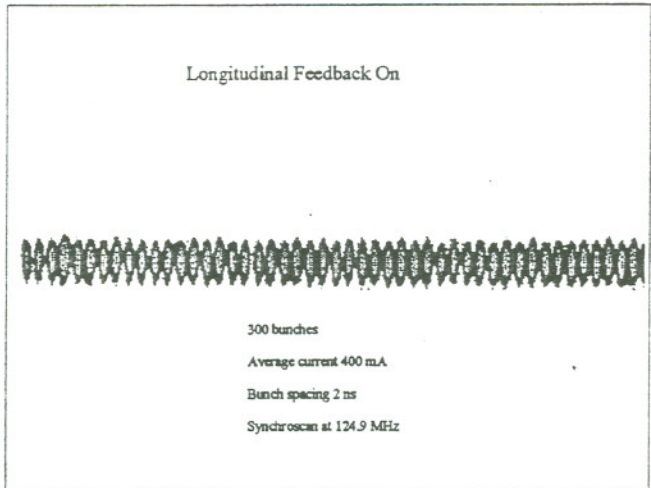


Figure 5 Damping on. Vert. = 1 ns; Horiz. = 200 ns. Bunch spacing = 2 ns. Every other bunch is shown.

#### 3.3 Camera Resolution and Dispersion

Accurate measurements of electron bunch length require good focus of the synchrotron light spot on the streak tube photocathode and understanding of chromatic dispersion in optical elements and space charge effects in the streak tube. For our bunch length measurements we achieved a vertical spot size of 4.3 channels, which, on the 600 ps streak range, yields time resolution of 5.4 ps. (On the fastest range, 150 ps, this focus yields 1.3 ps resolution.) The factory reports chromatic dispersion of 0.05 ps per nm at 620 nm in the A1974 input optics. At 488 nm where our measurements were made we take the dispersion to be about 0.1 ps per nm. With the shortest bunches we measured 13 ps reduction in FWHM by placing a 488 nm bandpass filter with 10 nm bandwidth in the optical path. Measurements of space charge effects were attempted over

five decades of light intensity without a bandpass filter. We observed a 10% increase in FWHM of a 50 ps bunch as neutral density filters were removed and the microchannel plate intensifier (MCP) gain was decreased from its maximum value. These measurements were made during a production run at 1.9 GeV with 300 bunches and damping systems working. It is thought that bunch length remained constant during the measurements. It is worth noting that repeated measurements at fixed settings resulted in about 10% changes in FWHM. Clearly, many more measurements must be made to fully characterize our streak camera system.

### 3.4 Potential Well Distortion

The effects of potential well distortion in the bunch profile are apparent above 2 mA. This is due primarily to inductive and resistive broadband impedance in the storage ring vacuum chamber.

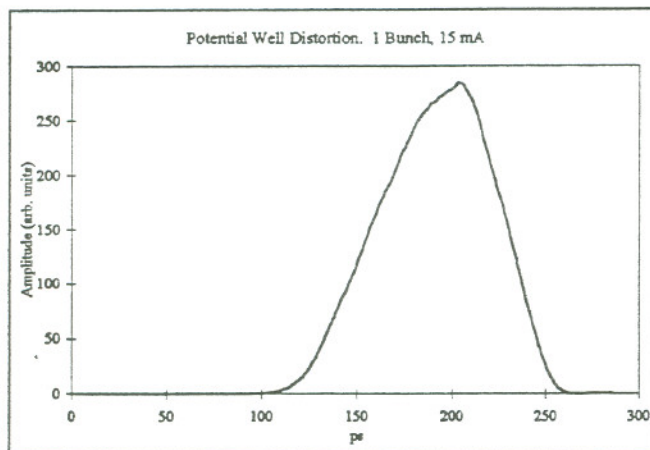


Figure 6. High current bunch showing distortion.

### 3.5 Bunch Purity

The ALS injector electron gun is modulated at 124.9 MHz providing bunches at 8 ns intervals. The gun may be gated to provide a single bunch. If the gun timing is not adjusted properly a weak bunch may be accelerated and corrupt the purity of the desired single bunch. Also improper settings of gun bias allow dark current to be accelerated in the linac. Charge from a single bunch in the storage ring may migrate to a following RF bucket 2 ns away. Attempts were made to measure single bunch purity in the storage ring with the streak camera.

Of the three sweep modules the synchroscan module offers the highest dynamic range for light intensity measurement. Because the camera sweeps at the same rate as electron gun modulation it is easy to see another bunch 8 ns away. By adjusting MCP gain and light intensity for

maximum performance, one may examine a streak image on a log plot and see another bunch weaker by a factor of about 1000. For this measurement the dual axis scan is used. Finding a weak bunch 2 ns away is more difficult. The camera is adjusted for optimum performance with the strong bunch using single axis scanning. Then the 124.9 MHz RF is adjusted in phase exactly 2 ns. This has the effect of gating the streak tube although the strong light is still striking the photocathode. Again, a dynamic range of about 1000 to 1 is obtained. To satisfy ALS single-bunch users we will require a better bunch purity measurement technique. Components of a single-photon counting system have been obtained for more rigorous measurements. This system is not yet operational. In addition, we will require a method to knock out unwanted bunches when they are detected.

## 4 CONCLUSION

The streak camera has proven to be a very powerful tool for examination of the ALS electron beam temporal characteristics. Recently the camera has been used to study non-linear longitudinal dynamics in the presence of cavity RF phase modulation [2].

## 5 ACKNOWLEDGEMENT

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- [1] R. Keller, T. Renner, D. Massoletti, 'Electron Beam Diagnostics Using Synchrotron Radiation at the Advanced Light Source', Proceedings of the 7<sup>th</sup> Beam Instrumentation Workshop, Argonne National Laboratory May 1996, Published in AIP Conference Proceedings No. 390, pp 240
- [2] J. Byrd, et. al. 'Nonlinear Longitudinal Dynamics Studies at the ALS' these proceedings.