SLAC-PUB-5135
January 1990
(I)

A PRECISION SYNCHROTRON RADIATION DETECTOR USING PHOSPHORESCENT SCREENS*

C. K. Jung, J. Butler,° M. Lateur, J. Nash, J. Tinsman, and G. Wormser°°
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

M. Levi and F. Rouse
Lawrence Berkeley Laboratory, Berkeley, CA 94720

Abstract

A precision detector to measure synchrotron radiation beam positions has been designed and installed as part of beam energy spectrometers at the Stanford Linear Collider (SLC). The distance between pairs of synchrotron radiation beams is measured absolutely to better than 28 μm on a pulse-to-pulse basis. This contributes less than 5 MeV to the error in the measurement of SLC beam energies (approximately 50 GeV). A system of high-resolution video cameras viewing precisely aligned fiducial wire arrays overlaying phosphorescent screens has achieved this accuracy.

INTRODUCTION

A detector has been designed and installed to monitor positions of beams of synchrotron radiation. In our application we measure within 28 μm the absolute separation ($\approx$27 cm) between two beams of synchrotron radiation. A system of video cameras viewing phosphorescent targets has been designed for this purpose and is in operation.

The synchrotron radiation detector described here is part of energy spectrometers [1] shown in Fig. 1 for the precision measurement of SLC beam energies. Two dipole magnets, one upstream and one downstream of the spectrometer magnet, generate a pair of swaths of synchrotron radiation whose separation is inversely proportional to the SLC beam energy. The quadrupole doublet focuses the beam at the plane of the synchrotron light monitors. The synchrotron beams are several hundred microns wide in the direction of separation and a centimeter or more long (depending on collimation). The critical frequency of the synchrotron radiation is $\hbar\omega_c \approx 3$ MeV, which implies that the beams interact with target materials dominantly via Compton scattering and the atomic photoelectric effect.

The phosphorescent screen monitors (PSMs) detect the visible light emitted from the phosphor materials when struck by synchrotron photons [2]. Each synchrotron beam is viewed by its own phosphorescent screen and video camera. An arrangement of fiducial wires overlaying the screens permits absolute position calibration.

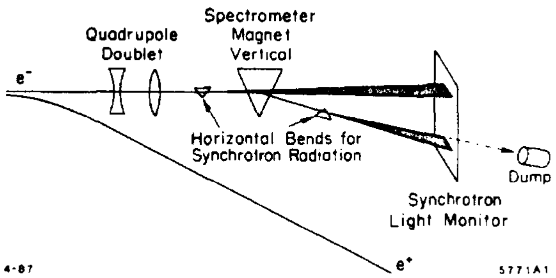

Fig. 1: Conceptual design of the extraction line spectrometer.

The video images of the synchrotron swaths are digitally recorded and readout rates of up to the maximum SLC design repetition rate of 180 Hz have been achieved. The data is recorded on the data tapes of the MARK II detector presently installed at the SLC. Data is collected on a pulse-to-pulse basis and recorded for beam crossings producing MARK II triggers. The data is also made available to the SLC control room independent of the MARK II data acquisition system.

PSMs as part of the SLC energy spectrometers are now providing precise measurements of beam energies which is crucial for the determination of the mass and the width of the Z particle produced at SLC [3]. Separations of pairs of synchrotron stripes are measured absolutely within 28 μm which contributes less than 5 MeV to the error in the measurement of SLC beam energies (approximately 50 GeV). The contributions to this net systematic error has been carefully studied.

DESCRIPTION OF THE PHOSPHORESCENT SCREEN MONITORS

The PSM shown in Fig. 2 consists of two identical target and video camera systems which monitor simultaneously a pair of synchrotron radiation beams. An Invar (iron-nickel alloy with low thermal expansion coefficient) support structure holds both targets and fixes the distance between them. An independent support structure holds the video camera systems, mirrors, and illumination lights. The whole system is mounted on a base plate which is, in turn, aligned with respect to the beam line.

---

* Work supported by Department of Energy contracts DE-AC03-76SF00515, DE-AC03-76SF00098, and DE-AM03-76SF00010.

° Present address: Fermilab, Batavia, IL 60510.

°° Present address: LAL-Orsay, 91405 France.

Presented at the IEEE Nuclear Science Symposium,
San Francisco, CA, January 15-19, 1990;
and submitted to Nuclear Instruments and Methods.

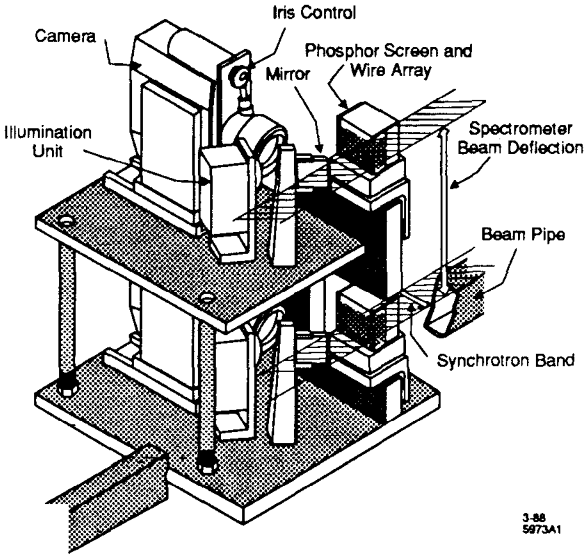

Fig. 2: An isometric view of the PSM together with the SLC beam pipe and the swaths of synchrotron radiation.

Each target consists of a phosphor screen and an array of fiducial wires. The 50 by 46 mm phosphor screens are custom made. The phosphor material, Gd_2:SO_2:Tb, emits visible green light when struck by synchrotron radiation. The phosphor is deposited on a thin (0.037 inch) aluminum substrate. The screens are easily replaced without disturbing the alignment of the fiducial wires.

The fiducial wires for absolute position calibration are the most critical part of the target assembly. Inconel wires of 100 μm diameter are strung a few hundred microns above the screen surface. The nominal center-to-center spacing between the wires are 500 μm. A "bar code pattern is encoded in the fiducial wire array by selectively removing some of the wires which provides an unambiguous recognition of each wire. The two wire arrays were precisely aligned with respect to each other and then measured with a precision optical system. The position of each wire is recorded to an accuracy of 5 μm yielding an overall accuracy of 8 μm on the absolute distance between the two wire frames.

Mirrors are used to enable placement of the cameras and lenses out of the path of the synchrotron radiation. The mirrors are made from an aluminum coating on a Zerodur substrate.

The camera system used is as follows. A high-quality optical lens (Nikon 35 mm, F = 1.4) is used in conjunction with an RCA Ultricon video camera. Small projection lamps with light diffusers are used to illuminate the fiducial wire arrays during calibration. The cameras were aligned with respect to the wire arrays to an accuracy of 20 mrad. Much of the electronics of the video cameras are removed from the camera and relocated further from the beam line and shielded in order to minimize radiation damage effects.

The camera images are digitally recorded as follows. The fiducial wires and the synchrotron stripe which runs parallel to them are viewed by the video cameras. The video frame is then digitized and compressed into a one-dimensional array (perpendicular to the wire direction) before readout by using a DSP Technology 2030/4101 signal averager. Readout rates of up to the maximum SLC design repetition rate of 180 Hz have been achieved. The data is recorded on the data tapes of the MARK II detector presently installed at the SLC. Data is collected on a pulse-to-pulse basis and recorded for beam crossings producing MARK II triggers.

The SLC extraction line synchrotron beams were first observed (with an SLC electron beam intensity of 2×10^9 $e^\pm$/pulse) on the PSMs in February 1988. Since then the monitors have been routinely collecting data. To date there have been no serious operational problems except some radiation damage of components such as camera lenses which need to be replaced once in a while.

PHOSPHORESCENT SCREEN PERFORMANCE

The PSMs measure absolutely the separation between the pairs of synchrotron radiation beams with a systematic error of less than 28 μm. The contributions to this net systematic error are given in Table 1 and are discussed below.

Table 1: Systematic Errors

Source of Error	Size of Error
Fiducial wire positions	8 μm
Pixel image location calibration	14 μm
Uniformity of response	14 μm
Parallax error	9 μm
Centroid finding	16 μm
Total error	28 μm

Careful attention has been given to the precise measurement of the fiducial wires. The individual wires and the spacing between the two arrays were measured on precision optical comparators to an absolute accuracy of better than 8 μm. Thermal effects are not expected to compromise the fiducial wire geometry at this level.

A calibration procedure determines the correspondence between camera pixels and the positions (relative to neighboring fiducial wires) viewed on the phosphorescent screens. Calibration data are collected with the target assemblies illuminated with diffuse light from a lamp. Fifty consecutive video frames are summed up for each of three different illumination settings. Figure 3 shows a sample digitized one-dimensional calibration image. The fiducial wires produce the valleys seen in the figure. Note the pattern of occasional missing fiducial wires that uniquely

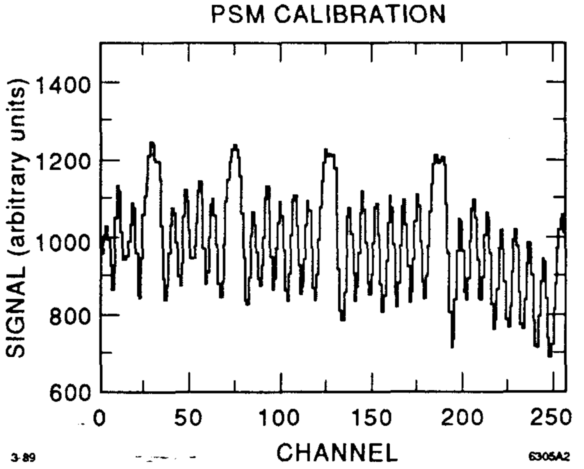

Fig. 3: PSM calibration data.

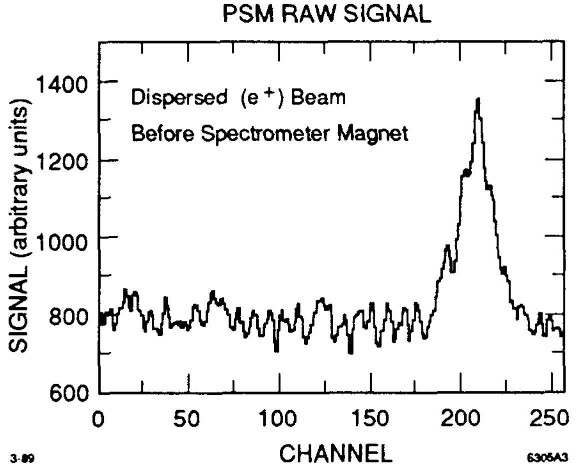

Fig. 4: Raw beam profile from the PSM.

identify the portion of the target assembly being viewed. As each pixel is relatively close to an image of a fiducial wire, global optical distortions do not introduce significant calibration errors. An upper limit to the errors associated with this calibration of pixel positions is obtained by comparing the known wire spacings with the spacings in pixels of the wire images in the camera. Assuming no optical distortions and fitting the magnification, the agreement between actual and observed fiducial wire geometry implies a 10 μm error in determining pixel locations. Adding quadratically the calibration errors from both screens gives the second entry in Table 1.

Nonuniformities in the overall response of the phosphorescent screen system are estimated to contribute less than 14 μm to the measurement of the separation between the pairs of synchrotron beams. Nonuniformities in response can arise from three sources: variations in the screen light output as a function of position on the screen; gain or saturation effects in the video cameras; and shadowing due to the fiducial wires.

The uniformity in response of the phosphorescent material and video cameras as a function of position has been tested by viewing the same synchrotron stripe at two different locations on the screen. The two stripe positions determined from physically distinct areas of the phosphorescent screen are found to correlate very well, even when the synchrotron radiation beam is swept across the screen. From many measurement of this type it is clear that nonuniformities in the phosphorescent material or gain variations in the video cameras do not contribute a significant systematic error. In addition, remote control of the camera lens iris maintains the video camera within the linear region of its response for any beam intensity.

The fiducial wire array shadows 20% of the light emitted by the synchrotron stripes. A uniformly spaced array would not cause an apparent centroid shift for the typical beams of 750 to 1500 μm width (FWHM). However, the missing wire elements in the bar code pattern can cause an apparent centroid shift. A calculated average error of 14 μm on the determination of the distance between the two stripe centroids is assumed here due to this effect. In practice, corrections can be applied to fully eliminate this source of systematic error.

An additional source of systematic error arises from the parallax error due to the viewing angle of the video cameras. The cameras are aligned (to 20 mrad) to view the screens at normal incidence, the short depth of field requires this condition. Since the fiducial wires are a few hundred microns above the surface of the screens a slight viewing angle will skew the apparent position of the wires. This parallax error is estimated to contribute no more than 9 μm.

A Gaussian fit is used to determine the centroids of the synchrotron stripes. Good fits are obtained indicating that the stripe profiles are approximately Gaussian in shape. Code is available using other algorithms for centroid fitting including weighted averaging and correlation techniques. These different centroid finding algorithms give similar results. At an electron or positron beam intensity of 1×10^{10} particles per pulse a significant error of 16 μm arises from signal/noise considerations. Since this error is statistical in nature, this error is much reduced at higher beam intensities or when combined in a running average.

Combining the various systematic errors in quadrature, the net systematic error in the measured separation of the pairs of synchrotron stripes is estimated to be less than 28 μm.

Figure 4 shows raw data including a peak from a beam of synchrotron radiation. Calibration data is used to subtract signals not due to the synchrotron beam. The corrected data, such as those seen in Fig. 5, is fit to a Gaussian. In this way, the position and width of the synchrotron beams are measured.

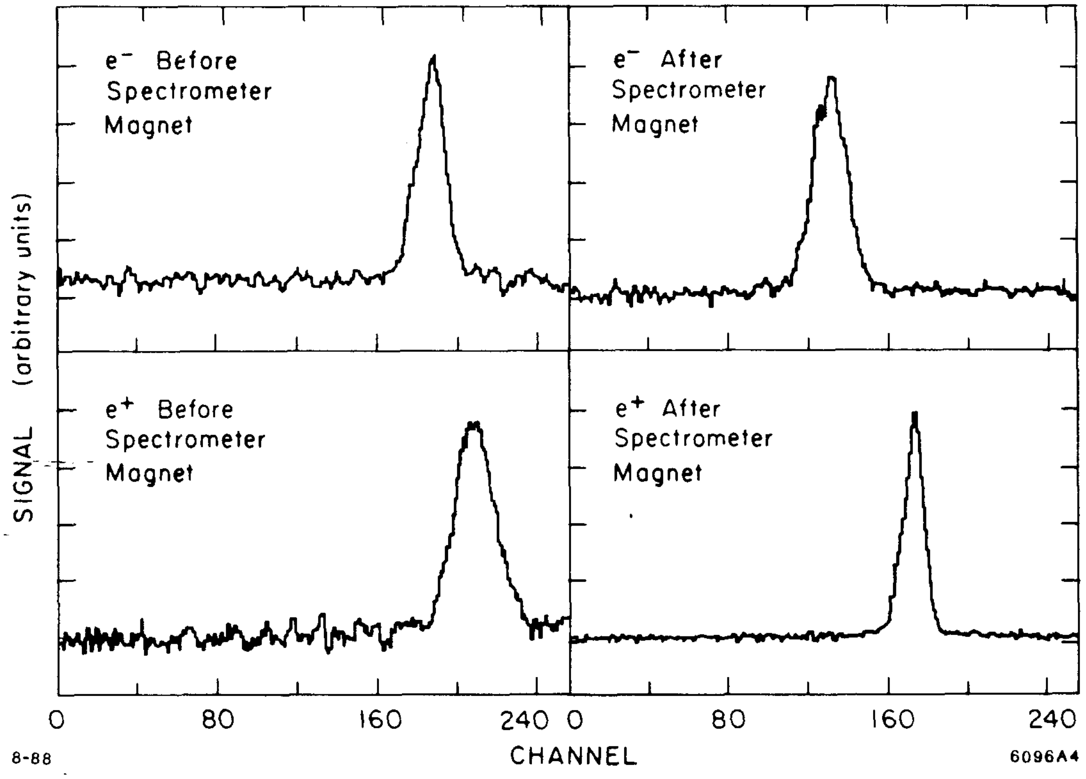

Fig. 5: Corrected data for both screens of both electron and positron spectrometers.

CONCLUSIONS

PSMs are now providing precise measurements of positions of synchrotron radiation beams. Separations of pairs of synchrotron stripes are measured absolutely within 28 μm on a pulse-to-pulse basis. This contributes less than 5 MeV to the error in the measurement of SLC beam energies (approximately 50 GeV). These detectors are part of the SLC energy spectrometers.

ACKNOWLEDGMENTS

The work described in this paper would not have been possible without the contributions of numerous people. M. Ross and J. Seeman are thanked for sharing their valuable expertise on phosphorescent screens technique. V. Lee and J. Tsai deserve credit for their fine work on the design and assembly of the PSMs.

REFERENCES

[1] J. Kent *et al.*, SLAC-PUB-4922 (1989); M. Levi, J. Nash and S. Watson, Nucl. Instrum. Methods **A281**, 265 (1989).

[2] A particularly useful precedent is described in J. Seeman *et al.*, SLAC-PUB-3945 (April 1986), published in proceedings LINAC86, 441.

[3] MARK II Collaboration, G. S. Abrams *et al.*, Phys. Rev. Lett. **63**, 1558 (1989); Phys. Rev. Lett. **63**, 2173 (1989).