© 1973 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

MONITORING THE BEAMS IN SPEAR WITH SYNCHROTRON LIGHT*

A. P. Sabersky

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Bringing the Synchrotron Light Out of the Ring

The SLAC storage ring, SPEAR, emits up to 150 kW per beam of synchrotron radiation. The power density on components inside the ring reaches 1 kW per cm^2, so transparent windows struck directly by the synchrotron radiation are out of the question. Only 5×10^{-4} of the total radiated power is visible light at 1.5 GeV. This power can be absorbed before the light passes through a window by having the radiation strike a metal mirror from which the visible light is reflected and in which the x-rays are absorbed.

We then face the problem of thermal deformation of the mirror. The x-ray power is concentrated in an angular cone of approximately 0.2 mrad width in the vertical plane, while the visible light has a divergence of 4 mrad. A slot in the mirror would pass the x-rays, and avoid most of the heating problems, but this is relatively impractical for a fixed mirror, since the vertical position of the beam is uncertain.

Mirror Deformations

A thermal-mechanical analysis[1] and experiments with electron beams show that deformation of a thick metal mirror surface is quite localized, for small-spot heating so there is only a small bad spot on the mirror surface.

A quality factor for different metals under dynamic deformation is

$$Q = k/(1+\nu)\,\alpha$$

where ν is the Poisson ratio, α is the coefficient of thermal-expansion, and k is the thermal-conductivity. The deformation is inversely proportional to the Q factor. Setting the Q for Cu = 1, the values for metals between 0°C and 400°C are

Be	= .44
Cu	= 1
Invar**	= .055

We also observed permanent deformations in mirror surfaces subjected to small spot heating. These effects were especially bad in copper mirrors, which we rejected for this reason. It seems that one must use metals which are very hard to avoid permanent deformation. Figure 1 shows permanent deformations in an Invar mirror subjected to spot power densities of ~500 watts/cm^2.

Mirror and Window

In order to reduce the power into the synchrotron light mirror, there is a watercooled vertical slit collimator with a width of 4 mm in front of the mirror. The collimator is the defining horizontal aperture of the optical system. The mirror is made of Invar, and has a polished, unplated surface 30 mm × 30 mm (Fig. 2). The mirror is clamped on to a watercooled mount, rather than having cooling tubes attached to it. This allows easy mirror changes and simplifies the manufacture of the mirror. After almost a year of SPEAR operation, with synchrotron light power into the mirror reaching 10 watts, there has been no degradation of the beam image due to permanent deformation, and no mirror darkening.

The window is polished, fused quartz which produces a wavefront distortion $<1/4\ \lambda$ at 6000 Å.

Alignment

The ideal central orbit of the storage ring lies in a plane perpendicular to the direction of gravity, so it is simple to align the optical axis of the instrument horizontally with bubble levels. There are stainless steel reflecting targets on the floor of the vacuum chamber just below the calculated position of the beam image. The target (Fig. 3) has two diffuse-finish segments which reflect light back towards a source, and a central polished ramp which reflects the light up and away from the source.

The line of sight passes through the center of the collimator in front of the Invar mirror and is centered on the dark space between the reflecting segments.

Although the pre-alignment techniques helped a great deal, it was still necessary to do a final touchup of alignment, with a stored beam, by remote control.

Television and Scanner System

The magnification of the optical system is 1. The objective lens is a two-element telescope achromat with a focal length of 1.22 m.

The central point of the beam seen through an aperture looking at the synchrotron light is the emission point. As the orbit moves transversely in a bending magnet (due to orbit distortions, etc.), the emission point moves axially.[2] One may calculate the angle of the line of emission points with respect to the axis of the optical system (Fig. 4). In SPEAR this angle is 10.2°. If the beam is imaged through a 1:1 magnification system and the axial motion Z is much less than the object to lens distance, ℓ, the image of the emission point will follow a line parallel to the line of emission points. The whole image-detecting system, including television and scanners, is mounted on a motor driven stage which is aligned so that it follows the image of the line of emission points. Once the optical system is properly aligned, the beam image is focused by centering it horizontally, thus setting the proper Z distance.

Optical Beam Splitters-Pellicles

Straight section space is always scarce, and the synchrotron light ports in SPEAR are expensive; therefore, there is only one optical port for each beam, and the light must be divided many ways. For beam splitters we use pellicles, commercially available devices,*** consisting of coated, thin plastic films stretched over flat frames. Pellicles are so thin that they cause no measurable distortion or displacement in the transmitted light beam, and have no chromatic aberration.

Television System

Ten percent of the light reaching the movable stage is reflected by a pellicle into the television system. For

*Work supported by the U. S. Atomic Energy Commission.

**Invar is a proprietary alloy approximately 36% Ni, 64% Fe.

***Made by National Photocolor Corporation, So. Norwalk, Connecticut and others.

attenuation of the light, there are three, separately actuated, thin, gelatin neutral-density filters, having transmissions of 10^{-1}, 10^{-2}, and 10^{-4}. Thus, there are seven steps of attenuation from 10^{-1} to 10^{-7}.

The beam image is refocused by an f/1.2 55 mm lens for the television vidicon. The illuminated dimension grid visible in Fig. 5 is optically added to the beam image with a pellicle (Fig. 6).

Scanning System

In order to produce an electronic signal which gives beam shape and dimensions, the beam image is scanned horizontally and vertically over stationary slits with an oscillating mirror. The scan is sinusoidal instead of linear, but this causes only small inaccuracies as long as the amplitude of the scan is greater than 2 times the width of the scanned image. Also, the electronic signal is displayed on an oscilloscope whose horizontal drive is a sinusoidal signal synchronized with the mirror.

The oscillating mirror assembly, the scanner, is a commercial device* often used for chopping light beams and for photometry. Figure 7 shows the scanner. The mirrors are 30 mm × 30 mm; the stiff wire supports act as torsional springs, and the mirrors oscillate torsionally at 100 Hz. The two mirrors oscillate 180° out of phase so that very little vibration is transmitted to the base. The oscillatory motion is picked up with a variable-reluctance system and a drive signal is fed in through a separate coil. A phase-locked loop drives the mirrors and is locked in on the pickup signal.[3] The time stability of this scanning system from one scan to another is better than 2 μsec in 10 msec. The accuracy of the measurements was limited by the stability of the phase-locked loop.

Both mirrors of the scanner are used, one for horizontal beam shape and the other for vertical. The light beam is split into two equal parts by a pellicle. One beam is reflected from one scanner mirror, then goes to a 1 mm vertical slit; this is the horizontal scanning slit. The other beam passes through a 90° image rotator (an arrangement of mirrors which is identical in action to a Dove prism), reflects from the second scanner mirror, then goes to a 0.1 mm slit. This is the vertical scanning slit. The vertical slit is rotatable in angle ±20° by remote control so that the axis of the slit can be aligned parallel to the horizontal axis of the beam image.

The light from each slit is collected by a lens, diffused and brought to a 10-stage photomultiplier, which produces the output signal.

In order to calibrate beam sizes derived from the scanned signals, it is necessary to measure the angular swing of the mirror. A separate optical calibration system is used on each mirror (Fig. 8). A lamp with a single, straight filament is the line source. The source is imaged with a lens, through the scanning mirror onto a calibration grid, which has a series of transparent slits parallel to the image of the line source. The distance from the mirror to the grid is the same as the distance from the mirror to the scanning slits. When the mirror scans, the photodiode gives out a train of pulses which correspond to distance scanned. These pulses can be electronically combined with the scanned beam signal (Fig. 9).

Bunch-Length Measurement

Bunch-length measurements are made with a vacuum photodiode looking at the intensity modulation of the synchrotron light. At the 1971 Conference, I reported[4] on a fast monitor which was to measure bunch length, and two of these devices were installed in SPEAR. Unfortunately, these devices failed because they were placed quite close to the circulating beam, and the strong radiofrequency fields of the beam penetrated the shielding of the monitor, causing excessive interference. We use a planar photodiode** with a photocathode diameter of 3 cm and a cathode-anode spacing of 6.35 mm, operated at 3 kV. The diode is mounted (Fig (Fig. 10) in the end of a section of 7.6 cm diameter coaxial transmission line. A bypass capacitor is made in the outer conductor by putting 0.1 mm of Mylar between two flanges. The high voltage circuit is completed with a piece of graphite-coated paper from the low voltage side of the outer conductor to tne center conductor.

The bunch length signal is transmitted back to the control room on 100 m of 5 cm diameter coaxial cable, where it is observed with a sampling oscilloscope (risetime = 90 ps). The time resolution of the system is estimated to be ~350 ps FWHM, and there is no measurable ringing or interference (Fig. 11).

Photometric Measurements

Photometric devices are used to measure circulating beam currents, and also as the most sensitive method of detecting stored beam.

A pellicle reflects out 10% of the light before the light reaches any other device, into the photometric system. Part of the light is diffused, and falls on a 3 cm diameter silicon photocell, which is operated with zero-bias and looks into a virtual short circuit.[5] The output current of each cell is read by a digital voltmeter, and calibrated against a dc current transformer. The system has a working accuracy of ±2%.

Part of the light goes to a 14-stage photomultiplier. This tube is sensitive enough so that one sees an injected electron bunch executing a single turn; this signal is very useful in the early stages of storing a beam. When the beam is spilling around the ring, there are false signals due to Cerenkov radiation in the photomultiplier window. The false signals have been suppressed by shielding the tubes with 5 cm of lead. There is a remote control shutter in front of the whole synchrotron light apparatus, and this is most useful in distinguishing false signals from real ones, in all devices.

Acknowledgement

I wish to acknowledge the unusual skills of Mr. R. Ricks, who designed and built most of the mechanisms in the synchrotron light system.

References

1. C. T. Hoard, Stanford Linear Accelerator Center, private communication.
2. A. P. Sabersky, "The geometry and optics of synchrotron radiation," to be submitted to Particle Accelerators.
3. A. P. Sabersky, "Phaselock onto an external resonant device," to be submitted to J. IEEE.
4. A. P. Sabersky, IEEE Trans. Nucl. Sci. NS-18, No. 3, 939 (1971).
5. P. G. Witherell and M. E. Faulhaber, Applied Optics 9, No. 1 (1970).

*Made by American Time Products-Bulova, Woodside, N. Y.

**ITT type FW-114.

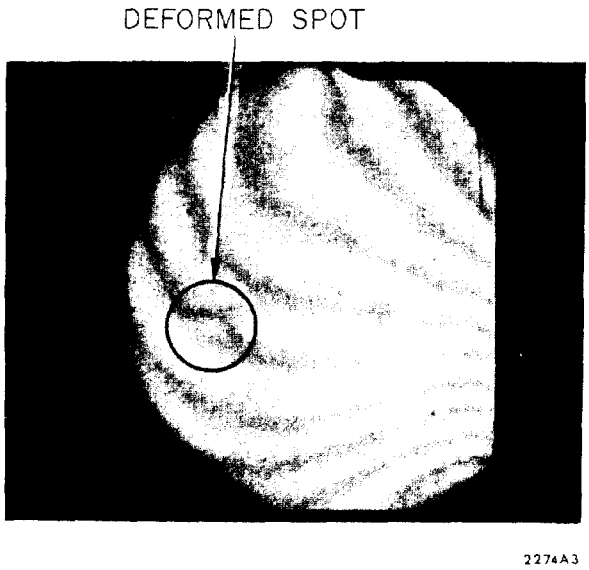


FIG. 1--Interferogram of permanent deformation in a thick Invar mirror which has been subjected to spot heating. $\lambda = 6328$ Å.

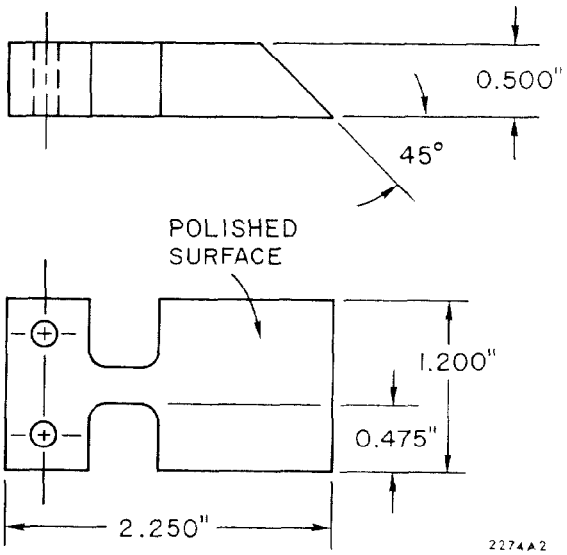


FIG. 2--Synchrotron light mirror. The neck between the mounting holes and the body of the mirror prevents the propagation of clamping stresses.

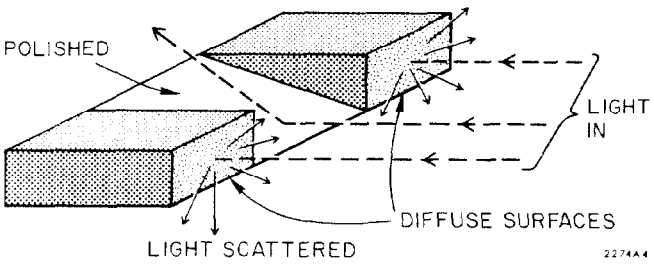


FIG. 3--Alignment target.

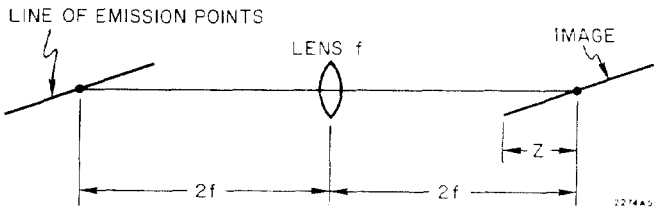


FIG. 4--Imaging system.

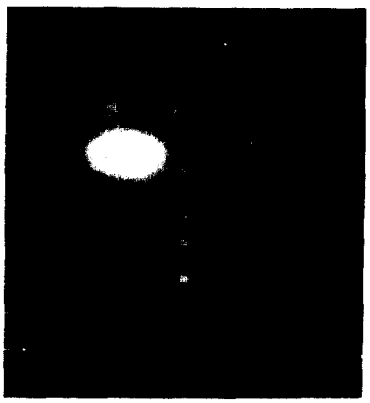


FIG. 5--Stored beams on the television screen.

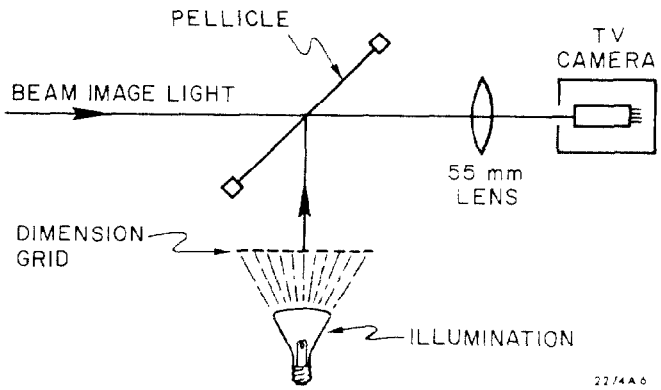


FIG. 6--Optical system for producing illuminated dimension grid.

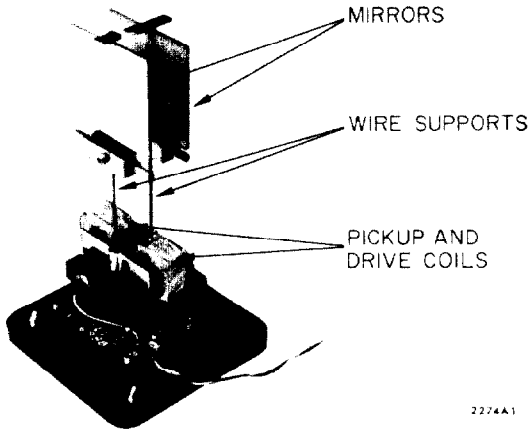


FIG. 7--Torsional scanner.

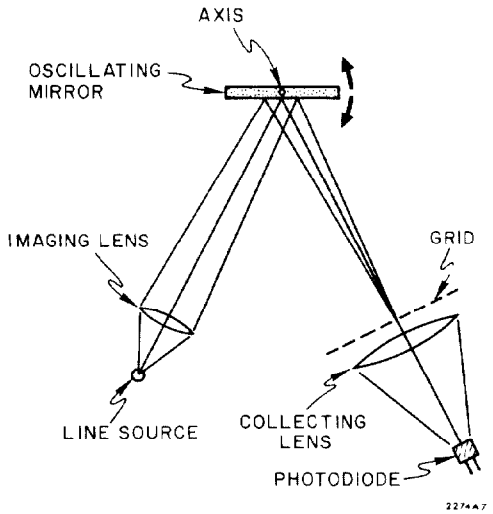


FIG. 8--Mirror calibrator optical system.

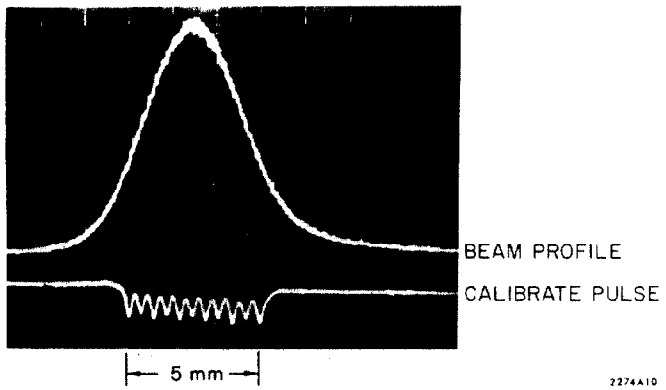


FIG. 9--Scanned horizontal beam profile and calibrator pulses.

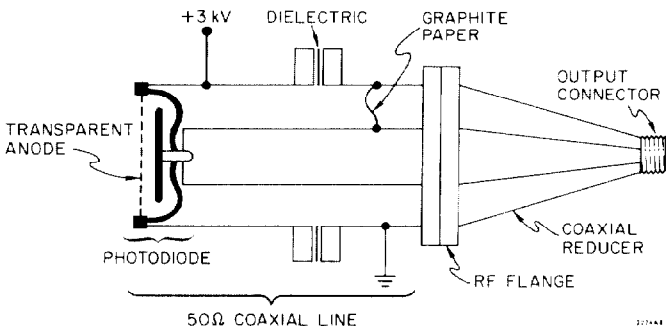


FIG. 10--Fast photodiode mount.

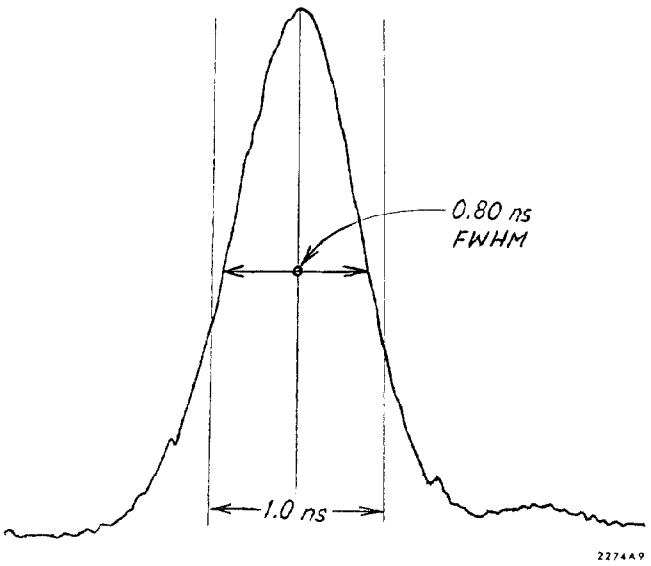


FIG. 11--A bunch length measurement plotted by an X-Y recorder.