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SLAC-PUB-874
March 1971

FAST BEAM MONITOR USING SYNCHROTRON LIGHT*

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Introduction

This paper describes a new type of fast beam-bunch monitor with a .1 ns risetime, useful for studying relativistic electron beams. The device is a coaxial vacuum photodiode looking directly at the whole spectrum of synchrotron light from relativistic electrons in a bending magnet.

Principle

The synchrotron light from a relativistic electron beam[1] causes copious electron emission when it strikes a metal surface, a fact well known to electron storage-ring designers. Fischer and Mack[2] have studied this effect at CEA, and, using their results, one may easily calculate the sensitivity of a photodiode using this type of photoemission. Using the parameters for the SLAC storage ring SPEAR[3] operating at 2 GeV ($E_c = 1.38$ keV) and comparing the total synchrotron light photosensitivity to the visible-light sensitivity of a fast vacuum photodiode using the visible portion of the same radiation, we find an approximate efficiency gain of 10. The efficiency of the monitor per degree of bend is calculated to be

$$E = \frac{I(\text{monitor})}{I(\text{beam})} = 6 \text{ percent/degree bend}$$

The precision of the time-information impressed on the synchrotron light is a factor. Assuming a line beam in a bending magnet and line emission of the radiation tangent to the chord formed, we may draw lines of equal time, isochrons, at which all photons emitted by a given electron will arrive at the same time (Fig. 1). For electron and positron beams of interest, the velocity of the particles may be considered to be c. A photocathode aligned with an isochron would give optimum timing information, but the finite opening angle of synchrotron light and finite size of the particle beam blur this perfect resolution. For the small phase space beams used at SLAC and for storage ring beams, this time blur is approximately .02 ns.

Photoemission is dependent on metal surface condition, and unless this can be carefully controlled, the photodiode cannot be considered a quantitative beam intensity monitor.

Construction

Electronic Considerations

For fast risetime applications, the photodiode should be matched as directly as possible to a high-frequency transmission line. The device operates directly in the vacuum of the accelerator or storage ring, so there must be a wideband vacuum window in the transmission line. To reduce the electron transit time from cathode to the anode, a high voltage bias must be applied with respect to the cathode, and a high-frequency isolating capacitor used to isolate the rest of the transmission line (Fig. 2).

End Structure

Ideally, the working end of the device should appear as a perfect open circuit to the rest of the transmission line, with no lumped capacitance or inductance. To reduce the transit time of photoemitted electrons, the anode should be close to the cathode, and this will produce high capacitance. Also, a simple squared-off end structure gives high-frequency ringing and distorted response. Useful structures have been found semi-empirically in this laboratory.

Thermal Problems

If the photodiode is to be used in a high-current device such as a storage ring, there will be a considerable amount of heat deposited in the photoemitter. This must be disposed of without introducing distortions or reflections. In the SPEAR photodiode, the heat is conducted through a solid center conductor outside the vacuum, where it is dissipated by natural air convection through a perforated coaxial line.

Coaxial Matching

To assure a simple, effective impedance match, the photodiode can be made to the dimensions of a standard coaxial line, and the signal taken out through commercially available high-frequency coaxial hardware.

Prototype

A prototype photodiode matched to 50 Ω line was constructed and tested in the beam switchyard of the Stanford Linear Accelerator.[4] Figure 3 shows a photograph of the device. Synchrotron radiation from a standard 3^o bending magnet was used. The prototype was built to the dimensions of EIA 1-5/8 in, 50 ohm, coaxial transmission line, inner conductor diameter, 1.69 cm, outer conductor diameter, 3.88 cm.

The accelerator was operating at 18 GeV, this giving a critical energy of 224 keV. The beam subbunches of SLAC are estimated to be 5^o phase width at 2856 MHz, approximately .005 ns long. Including the resolution blurring referred to, this gives a test-signal width of .020 ns. The SLAC beam knockout system[5] was in use, giving single subbunches separated by 50 ns within the 1.6 μs beam pulse. The main pulse repetition rate was 40 pps, and this was the sampling rate of the oscilloscope used to observe the fast pulses.

The oscilloscope was a Tektronix 564 with a type 3S2 sampling plug-in and a type S-2 sampling head, the combination having a measured risetime of .060 ns. The combined risetime of the photodiode structure and heliax connecting cable, 30 meters long, is estimated at .080 ns. The oscilloscope was synchronized to the accelerator radiofrequency and pulse repetition rate with high speed nuclear counting circuit modules. Observed short-term jitter was $\leq$ .020 ns.

Results

Figures 4 and 5 show the results displayed on a monitor oscilloscope. Figure 4 shows the risetime, approximated at .1 ns. The wiggles and ringing, shown more clearly in Fig. 5, are due to a combination of ringing within the structure of the device and pre- and post-accelerator bunches not completely suppressed by the beam knockout. Predicted efficiency was 4 percent; measured efficiency was 1 percent.

The disparity is probably due to the extrapolation of data in Fischer and Mack's[1] paper to very high critical energies.

Conclusion

High-frequency beam pickups generally suffer from mismatch problems due to structural limitations, and the further one must be from the beam, the worse these problems. A synchrotron light monitor is not a direct pickup, for the high-frequency information is modulated upon a much higher frequency subcarrier. Subcarrier demodulation by photoemission

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

(Submitted to the 1971 Particle Accelerator Conference, Chicago, Illinois, March 1-3, 1971.)

can be carried out in a well optimized structure far from the beam.

Fast photodiode pickups are thus very useful for storage rings, and the direct-emission type described is simpler than an arrangement of mirrors, windows and separate diodes. Also, it is more sensitive to begin with, and less liable to lose efficiency due to window or mirror darkening. Synchrotron light monitors can simply separate signals from two beams in counter-rotating electron-positron storage rings.

The engineering problems of designing a working monitor are straightforward, and the crudely built prototype described worked well.

References

1. R. P. Godwin, "Synchrotron radiation as a light source," Springer tracts in modern physics, Vol. 51.
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3. SPEAR Design Report, Stanford Linear Accelerator Center (August 1969).
4. R. B. Neal, ed., The Stanford Two-Mile Accelerator (W. A. Benjamin, New York, 1968), Chapters 17 and 18.
5. Ibid., pp. 256-259.

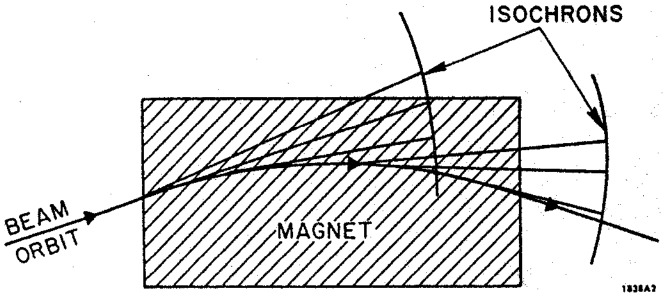

FIG. 1--Timing geometry for synchrotron radiation.

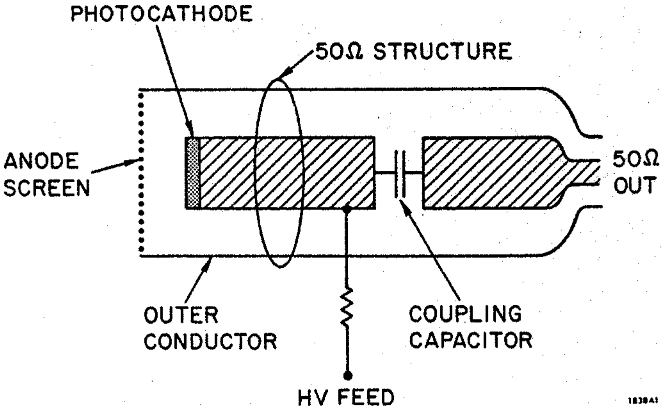

FIG. 2--Photodiode schematic.

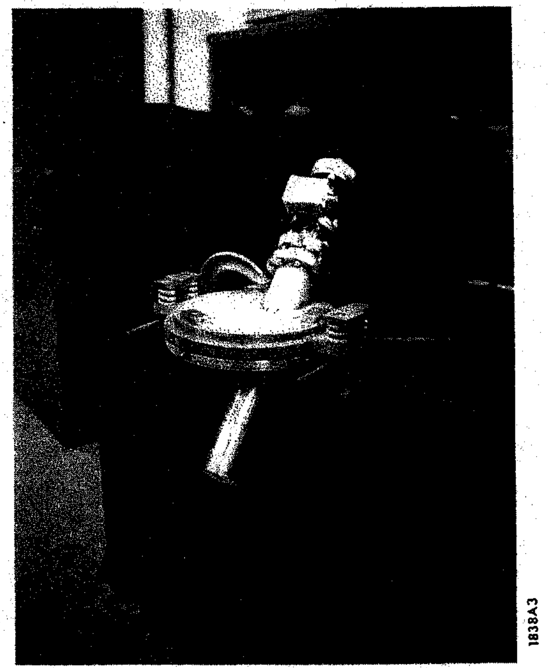

FIG. 3--Prototype monitor mounted in its vacuum flange.

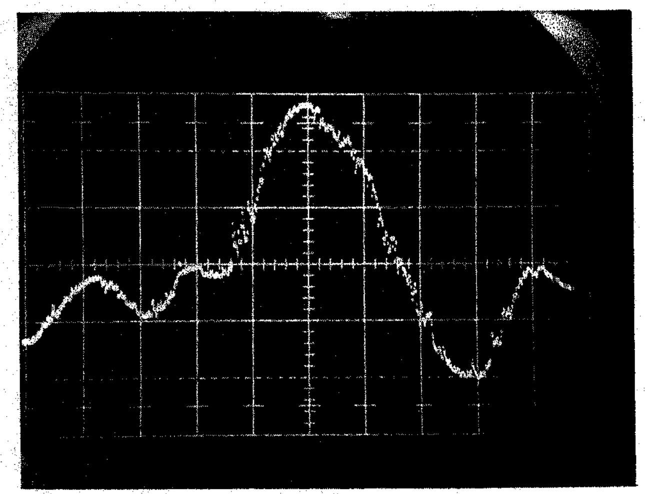

FIG. 4--Horizontal-.10 nsec/division. Vertical-50 mV/division.

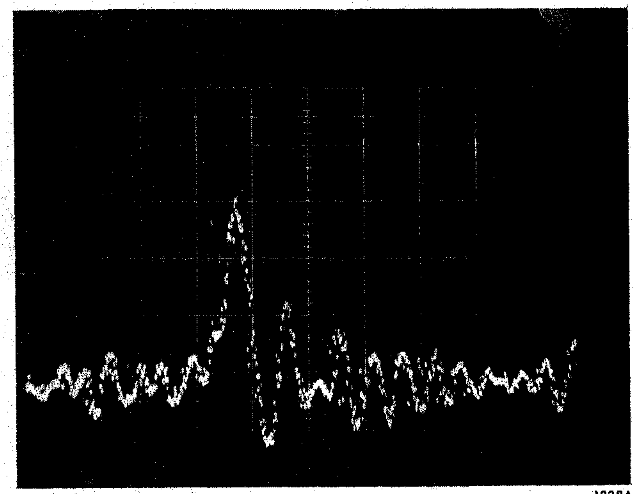

FIG. 5--Horizontal-.5 nsec/division. Vertical-50 mV/division.