CESRTA X-RAY BEAM SIZE MONITOR OPERATION *

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Abstract

We report on the design and operation of the CesrTA x-ray beam size monitor (xBSM). The xBSM resolution must be sufficient to measure vertical beam sizes of order 10um by imaging 2-4keV synchrotron radiation photons onto a one-dimensional photodiode array. Instrumentation in the evacuated x-ray beam line includes upstream interchangeable optics elements (slits, coded apertures, and Fresnel zone plates), a monochromator and an InGaAs photodiode detector. The readout is a beam-synchronized FADC that is capable of parallel measurement of consecutive bunches with 4ns spacing. The xBSM has been used to measure beam sizes during the August 2009, November 2009, and April 2010 runs. Single turn measurements are fit to characteristic image shapes to extract beam sizes independent of position variations. The turn-averaged beam size provides feedback for low-emittance tuning.

INTRODUCTION

The International Linear Collider (ILC) will require low-emittance beams to meet the luminosity targets demanded by the goals of the experimental program. Damping rings will be employed to reduce the emittance. For efficient operation, long beam trains will be folded into the relatively small-circumference rings resulting in individual damping ring buckets populated with bunches at various stages in the damping. Monitoring the emittance will require measurements that are cleanly separated for adjacent bunches. In CesrTA, individual emittance measurements of closely spaced bunches are required to measure the dynamics of emittance growth. In the x-ray beam size monitor (xBSM), we use synchrotron radiation to measure the vertical bunch size and thereby vertical emittance. Separate xBSMs have been successfully commissioned in x-ray beam lines to measure the sizes of the electron and positrons. Most of the beam size measurements are made positron line while the electron line is used for readout development. The xBSM has been reported previously at IPAC09[1,2,3]. In this paper we discuss the design, recent operation, and upgrades of the xBSM.

x-RAY SOURCE AND OPTICS

The positron line xBSM is illustrated in figure 1. Synchrotron radiation x-rays are emitted in a dipole magnet to the right of the figure. Optical elements vertically focus an image of the beam onto the detector mounted in the enclosure. In the positron (electron) line, the optical element is located 4.36m (4.23m) from the x-ray source and 10.19m (10.67) from the detector; the magnification is 2.34 (2.52).

Three optical elements are available for 2GeV stored beam operation: a vertically limiting slit, a Fresnel Zone Plate (FZP), and a Coded Aperture (CA). These elements reside in the storage ring vacuum and can be selected and aligned remotely to meet the requirements of various measurements. At 2GeV, the typical power load on the optical element is of order 1 mW/mA; the optical elements are in contact with actively cooled copper supports to remove this heat.

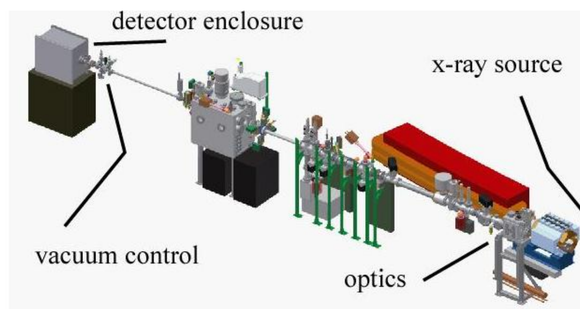

Figure 1: layout of the xBSM (positron line)

The FZP and CA are manufactured on a common silicon substrate. For the positron line, the patterns are cut into 0.7µm Au and are supported by a 2.5µm Si membrane. The FZP pattern has 120 transmitting rings in a diameter of 1200µm. The CA pattern has 8 transmitting elements with total dimensions 310µm in the imaging direction by 1200µm wide. For the electron line, the absorbing material is 4µm Ta and 0.02µm Ru. While the FZP pattern is identical, the CA is reduced in size to limit distortions due to angular misalignment of the CA to the beam plane. This CA pattern has 8 transmitting elements with total dimensions 155µm in the imaging direction by 500µm wide.

For 4GeV stored beam operation, there is a coded aperture designed for higher power in each line as well as the vertically limiting slit.

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DETECTOR

The detector, shown in figure 2, is a vertical array of 32 InGaAs diodes with pitch 50μm and horizontal width 400μm. The InGaAs layer is 3.5 μm thick, which absorbs 73% of photons at 2.5keV; there is a 160nm Si_3N_4 passivation layer. The time response of the detector is sub-nanosecond.

The detector is located in a rough vacuum (<0.5 torr) to reduce absorption. This volume is isolated from the storage ring volume by a thin (4μm) diamond window, which transmits 76% of x-rays at 2.5keV.

Readout of the detector is done in two ways. For alignment purposes and measurements which do not require isolation of bunches, the x-ray image can be scanned by moving a single diode through the image while recording the diode current. The resulting "slow scan" integrates many turns of the beam, thus removing statistical fluctuations but does not resolve turn-by-turn fluctuations.

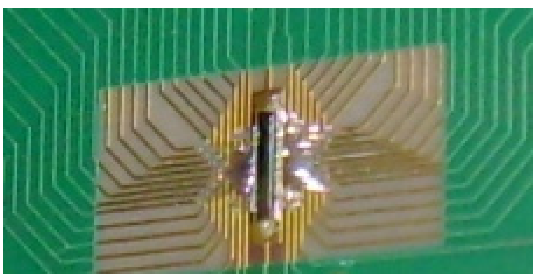

Figure 2: diode array

In a "fast scan" pulse heights from the 32 elements of the diode array are digitized, synchronous with the bunch crossing. The current electronics allows measurements with a 14ns repetition rate.

BEAM SIZE MEASUREMENTS

Images of the 2GeV beam, derived from fast scans of the 32 channel detector, are shown in figures 3, 4 and 5 for the three optical elements. The beam size was similar for the three cases.

The vertically limiting slit (image shown in figure 3) operates as a pin-hole lens. It is largely insensitive to the x-ray wavelength within the synchrotron radiation spectrum. The slit has been adjusted to be about 16μm in height which gives the minimum image width; a smaller slit height would cause the image to broaden due to diffraction while a larger sit height would cause the image to broaden due to transmission. While the pin-hole provides a simple peak, the image it is a convolution of the beam height and the slit height and thus cannot provide a useful measurement below a beam size of about 16μm. CesrTA is using this lens for current emittance measurements [4]. The distribution shown is a sum of 100 turns and includes a width component due to turn-by-turn motion of the beam of order 100μm (2 channels). To remove this motion from the measurement and extract the beam size from the data, the size is measured on individual turns and averaged.

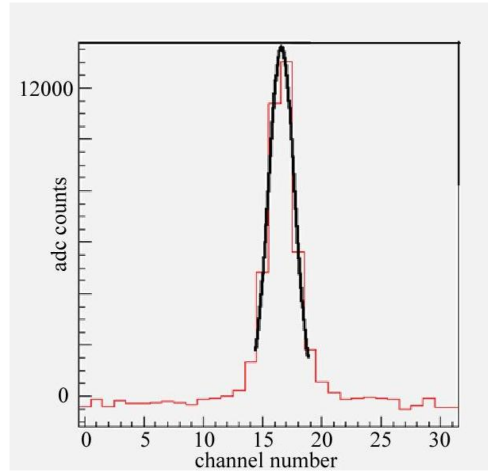

Figure 3: vertically limiting slit with Gaussian fit

The image of the Fresnel Zone Plate (shown in figure 4) is a diffraction pattern and sensitive to the x-ray wave length. The image shown is without the use of a monochromator. There is a central peak due to designing the x-ray beam and FZP to focus at the maximum of the x-ray wavelength distribution. The image has a broad underlying distribution of out-of-focus x-rays. Use of a monochromator eliminates the broad component but does not allow enough x-ray flux for useful turn-by-turn measurements. The central peak of the image shown provides useful beam size measurements to the smallest beam size. Development of a fitting procedure to extract this information is ongoing.

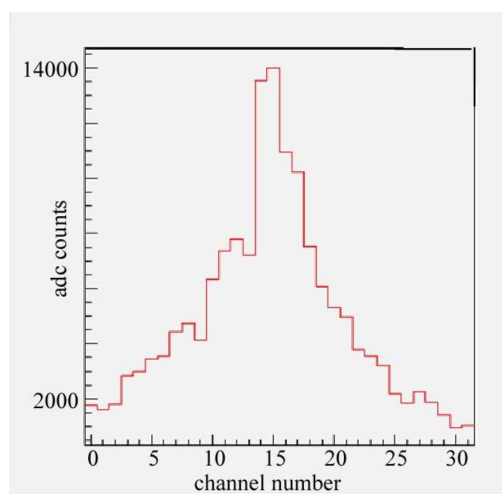

Figure 4: Fresnel Zone Plate

The image of the Coded Aperture (shown in figure 5) is a combination of transmission and diffraction resulting from the 8 slits ranging in size from 10 to 40μm (positron line). As in the case of the vertically limiting slit, the imaging is relatively insensitive to variations in the wavelength. The resolving power of the CA has been compared to that of the FZP, both without the use of a monochromator. Data was collected in "slow scans" for the two imaging devices, for two beam sizes. For each imaging device, the RMS of the difference between images from different beam sizes is an indication of the resolving power. The RMS difference for the CA was 1.7x greater than that of the FZP (for the same change in beam size and normalized for incident photon flux), indicating that the beam size resolving power of the CA is superior. In the future, we will develop the template based fitting procedure necessary to exploit the improved resolution. The CA is discussed in further detail elsewhere [5].

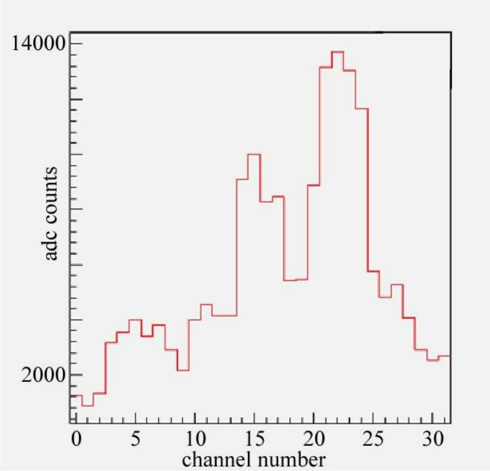

Figure 5: Coded Aperture

READOUT DEVELOPMENT

The current readout system was developed for 14ns bunch spacing. As shown in figure 6, the amplifier settling time, with optimized shaping, is sufficient for 14ns bunch spacing.

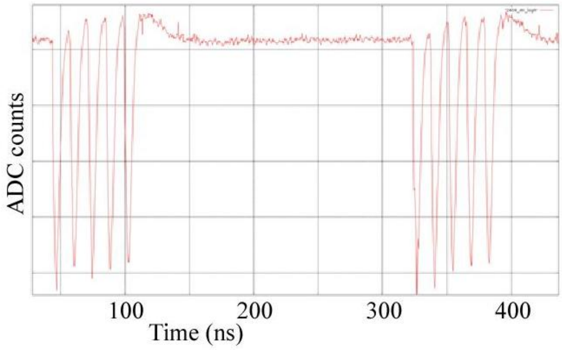

Figure 6: digitized waveform from current readout system. The display shows 5 bunches with 14ns separation in trains with 280ns separation.

To match the characteristics of the ILC damping ring design, CesrTA is being upgraded to operate with 4ns bunch spacing. A new readout for xBSM is being developed to operate with this bunch spacing. An additional limitation of the current readout system is that the fixed gain amplifiers limit the range in beam current that can be measured. The range is beam current is extended by placing a horizontally limiting slit in front of the detector. However, this introduces complications in alignment. The new readout system for the xBSM provides 32 parallel 250MHz digitizers. Variable gain amplifiers have a range of 24dB. Tests of the new system, figure 7, demonstrate the successful operation of the digitizers and the clean separation of 4ns spaced bunches.

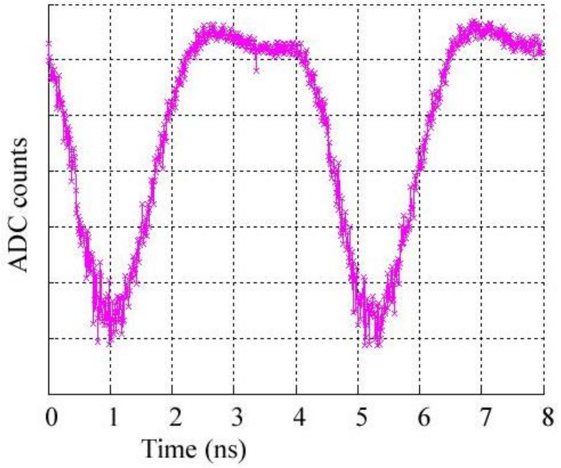

Figure 7: digitized waveform from fast preamplifiers and 4ns digitizer

SUMMARY AND FUTURE

The xBSM routinely provides positron beam size measurement support for low emittance tuning and dynamic emittance growth at CesrTA. The electron line is commissioned and operational with optics and detector. Future improvements includes the implementation of the 4ns readout instrumentation in both electron and positron lines. Development of advanced analysis procedures for the Fresnel Zone Plate and Coded Aperture will extend the measurement limit to 10 µm

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