Nuclear Instruments and Methods in Physics Research A 798 (2015) 127–134

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Operation of the CESR-TA vertical beam size monitor at $E_b = 4$ GeV

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ARTICLE INFO

Article history:
Received 15 July 2015
Accepted 16 July 2015
Available online 26 July 2015

Keywords:
Electron beam size
X-ray diffraction
Pinhole
Coded aperture
Synchrotron radiation
Electron storage ring

ABSTRACT

We describe operation of the CESR-TA vertical beam size monitor (xBSM) with $e^\pm$ beams with $E_b = 4$ GeV. The xBSM measures vertical beam size by imaging synchrotron radiation x-rays through an optical element onto a detector array of 32 InGaAs photodiodes with 50 μm pitch. The device has previously been successfully used to measure vertical beam sizes of 10–100 μm on a bunch-by-bunch, turn-by-turn basis at $e^\pm$ beam energies of ~2 GeV and source magnetic fields below 2.8 kG, for which the detector required calibration for incident x-rays of 1–5 keV. At $E_b = 4.0$ GeV and $B = 4.5$ kG, however, the incident synchrotron radiation spectrum extends to ~20 keV, requiring calibration of detector response in that regime. Such a calibration is described and then used to analyze data taken with several different thicknesses of filters in front of the detector. We obtain a relative precision of better than 4% on beam size measurement from 15 to 100 μm over several different ranges of x-ray energy, including both 1–12 keV and 6–17 keV. The response of an identical detector, but tilted vertically by 60° in order to increase magnification without a longer beamline, is measured and shown to improve x-ray detection above 4 keV without compromising sensitivity to beam size. We also investigate operation of a coded aperture using gold masking backed by synthetic diamond.

1. Introduction

The CESR-TA x-ray beam size monitor [1,2] (xBSM) images synchrotron radiation from a hard-bend magnet through a single- or multi-slit optical element onto a 32-strip photodiode detector [3] with 50 μm pitch and sub-ns response. A simplified schematic of the CESR-TA xBSM setup is shown in Fig. 1, and dimensions appear in Table 1. Separate installations exist for electrons and positrons. The hard-bend magnets have a bending radius of 31.1 m. The vertical beam size σ_b is extracted from a fit of the image for each bunch and turn to a set of unit-area templates; each template has convolved the point response function (`prf`) with Gaussian smearing for a particular beam size and magnification. Each such fit also yields a vertical beam position y_b and amplitude A_b. Ref. [1] describes our use of both single-slit (pinhole) and multi-slit optical elements, the latter of which are known as coded apertures, for $e^\pm$ beam energies of $E_b = 1.8$–2.6 GeV. In order to accurately predict the point response functions, in [1] we determined the detector's spectral response to x-rays up to about 5 keV. In [2], we gave a detailed description of the design and operation of two silicon-backed coded apertures.

Extending characterization of our detector's spectral response above 5 keV is useful for two reasons. First, a similar detector is an option for beam size measurement using x-rays from the SuperKEKB positron ($E_b = 4$ GeV) and electron ($E_b = 7$ GeV) beams. Second, a new, dedicated xBSM installation at CESR is being designed. Unlike the current setup, it will be able to operate in both CESR-TA (beam energies of ~2 GeV) and CHESS ($E_b = 5.3$–6.5 GeV) operating conditions. In both scenarios a substantial fraction of the x-ray spectrum will be above 5 keV, as is evident in Fig. 3 when comparing existing (B < 4.5 kG) and planned ($B = 4.5$ kG) installations. In Fig. 2, the response as determined in [1] is shown; note that the data acquired for $E_b = 1.8$–2.6 GeV could not distinguish between the possible response shown as curve #1 from that of curve #3.

The balance of this paper is organized as follows. First, in Section 2, the opening in the adjustable pinhole optical element for data acquired at $E_b = 4.0$ GeV is determined using techniques similar to those used in [1] for operation near $E_b = 2$ GeV. Second, Section 3 describes measurement of the detector spectral response using $E_b = 4.0$ GeV data, again using techniques previously described [1]. Third, in Section 4 we describe beam size measurements using several different x-ray ranges and a large range of beam sizes. Fourth, Section 5 reports on operation and calibration

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http://dx.doi.org/10.1016/j.nima.2015.07.028

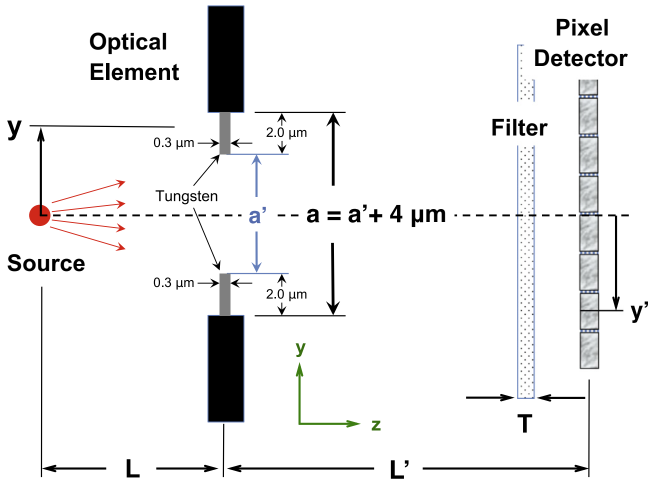

Fig. 1. Simplified schematic of xBSM layout (not to scale), shown with a model of the adjustable pinhole (PH) optical element. Dimensions appear in Table 1.

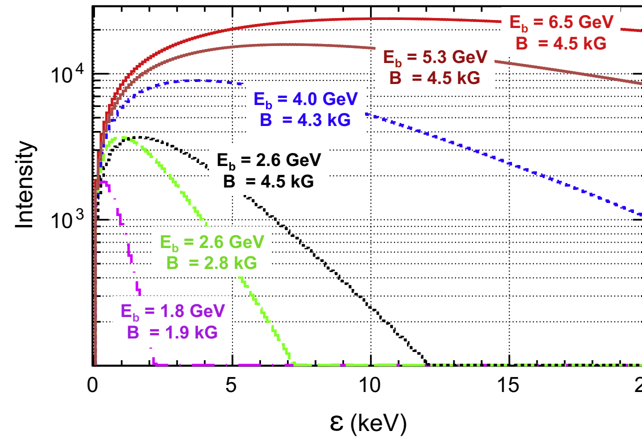

Fig. 3. Spectra of x-rays for several $e^{\pm}$ beam energy/magnetic field combinations, including a relative factor of ρ/γ (bend radius/(E_b/m_e)) to account for source length due to the $1/\gamma$ horizontal width of the synchrotron radiation searchlight. The curves labeled with magnetic fields below 4.5 kG correspond to the current xBSM configuration; the 4.5 kG curves correspond to a planned upgrade with a dedicated, fixed-field source magnet.

Table 1
Geometrical parameters defining the CESR-TA xBSM beamlines. Geometrical quantities are defined in Fig. 1. Distances assume the coded aperture optic; the pinhole optic is 25 mm closer to the source point and hence has a magnification value about 1% larger than shown. The uncertainties on L are from an optical survey. The uncertainties on L' are from the survey, CESR orbit, and the associated depth of field.

Parameter	e^- Beamline	e^+ Beamline
L	4356.5 ± 3.9 mm	4485.2 ± 4.0 mm
L'	10,621.1 ± 1.0 mm	10,011.7 ± 1.0 mm
$M \equiv L'/L$	2.4380 ± 0.0022	2.2322 ± 0.0020
a'	≈ 50–300 µm	Same as e^-
a	≈ 50–1000 µm	Same as e^-
$2\theta_{max} = a'/L$	11–69 µrad	11–67 µrad

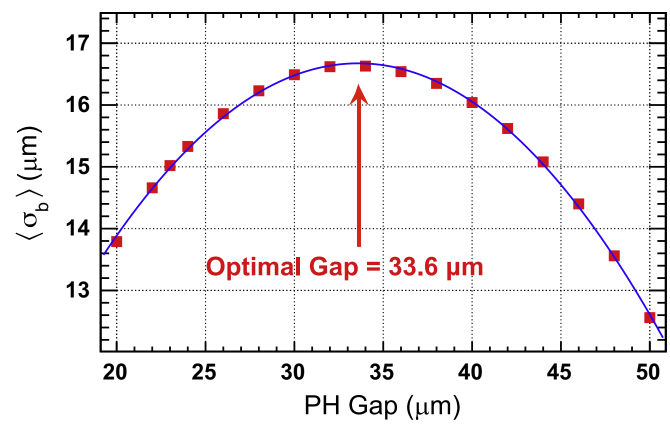

Fig. 4. Turn-averaged beam size $\langle\sigma_b\rangle$ for the same run at E_b=4.0 GeV based on prf's using the specified value of a' with a parabolic fit to the points superimposed.

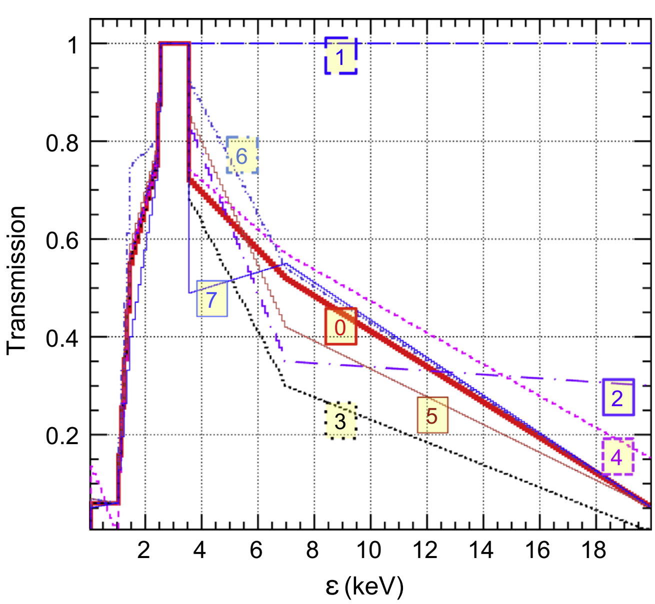

Fig. 2. Spectral response curves used to explore sensitivity of measured beam size to the detected x-ray spectrum. The thickest solid curve represents the nominal spectrum and is labeled as "0"; seven other alternative responses consistent with the data of [1] are also shown and labeled with numbers from 1 to 7.

of the detector after tilting it vertically by 60° with respect to the incident x-rays. Finally, Section 6 describes evaluation of a prototype for a diamond-backed coded aperture for use at SuperKEKB, and Section 7 summarizes our conclusions.

2. Size of pinhole opening

To determine the size of the gap in the adjustable pinhole (PH) used for our filter studies at E_b=4 GeV, we follow a procedure similar to that described in Section 5.3 of Ref. [1], and apply it to E_b=4 GeV data and the corresponding predicted synchrotron radiation spectrum. We need to determine, for the PH model shown in Fig. 1, gap size a' used for data acquired at E_b=4 GeV. We know the motor setting ($mset$=4.22), but need to determine its calibration to absolute distance.

The first step is to find the opening a' that our model predicts to result in the narrowest prf for an incident x-ray spectrum for magnet field strength B=0.43 T (which preserves the required bending radius at E_b=4.0 GeV). Each point in Fig. 4 corresponds to the beam size reconstructed from the same 1024-turn run using a prf made with a different value of a'. The narrowest