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E-line: A new crystal collimator beam line for source size measurements at CHESS

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Abstract

A new X-ray beam line has been constructed at cornell high energy synchrotron source (CHESS) to measure the vertical and horizontal source size of the positron particle beam. The cornell laboratory of elementary particle physics (LEPP) operates the storage ring (CESR) for X-ray generation for the CHESS user community by circulating electrons and their antimatter counterpart positrons in counter-rotating beams. As the laboratory reduces the emittances of particle beams to increase X-ray brilliance, there has been an increasing need for diagnostic tools to measure and monitor source size. A beam line front end that accesses the positron synchrotron light has been fitted with an experimental chamber and apparatus of compact design capable of horizontal and vertical source size measurement using the "crystal collimator" technique, and an additional setup for vertical beam position monitoring using a luminescence-based X-ray video beam position monitoring system. The crystal collimators each consist of two Si(2 2 0) crystals in a dispersive (+,+) arrangement that diffract X-rays to a fluorescent material coated on a view port observed with a CCD camera. Measurements of the positron vertical beam size using the crystal collimation method at E-line are compared with measurements of visible synchrotron light at a remotely located dedicated port on the storage ring.

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Keywords: Beam size; Synchrotron X-rays

1. Introduction

After work was done to verify the feasibility of measuring beam sizes with a crystal collimator [1–3], it was proposed that the Cornell High Energy Synchrotron Source (CHESS) E-line might be suitable as a dedicated beam line for these types of measurements for the positron beam. We decided to use crystal reflections with a Bragg angle of 22.5° in order to produce a 90° change in beam direction after the two dispersive reflections (see Fig. 1). Si(2 2 0) reflections were chosen so the energy would be 8.44 keV, the Darwin width 4.89 arcsec, and structure factor about 69. This choice gave the geometry required and selected an energy near the bend magnet critical energy of 10.3 keV for particle beam energy 5.3 GeV.

1.1. Initial testing of the E-line vertical source size measurement

To examine the accuracy of the measurements obtained from the E-line apparatus, comparisons were made between E-line and a dedicated pinhole setup that monitors the visible synchrotron light.

From the LEPP synch light measurement removing the system resolution:

$$\sigma_{\mathrm{LEPP(true)}} = \sqrt{(280\ \mu\mathrm{m})^2 - (130\ \mu\mathrm{m})^2} = 248\ \mu\mathrm{m}$$
$$\Rightarrow 584\ \mu\mathrm{m}\ \text{Full Width at Half Maximum (FWHM)}.$$

The source sizes at alternate locations along the storage ring are related to this by the beta functions at the locations:

$$\mathrm{FWHM_E} = \sqrt{\frac{\beta_{\mathrm{E}}}{\beta_{\mathrm{LEPP}}}}\mathrm{FWHM_{LEPP}} = \sqrt{\frac{16.3}{10.8}} \times 584\ \mu\mathrm{m} \Rightarrow 717\ \mu\mathrm{m}.$$

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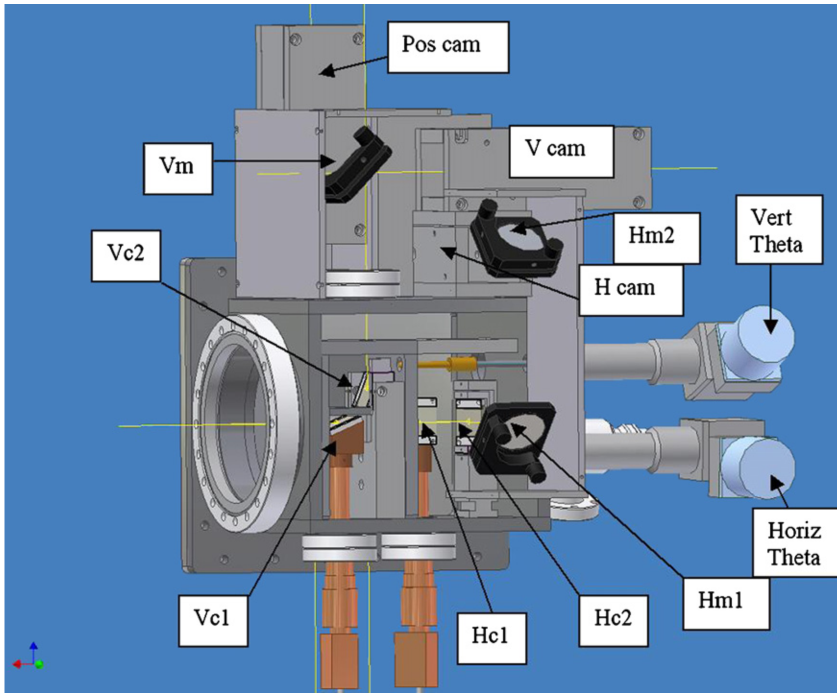

Fig. 1. The E-line components. The cutout figure above shows the two sets of Si(2 2 0) crystals that are used to measure the vertical (Vc1 and Vc2) and horizontal (Hc1 and Hc2) source size. The second crystal for the two setups is tuned to diffraction conditions with the stepping motors on the right (Vert Theta and Horiz Theta). The doubly diffracted beams impact fluorescent screens on $2\frac{3}{4}$in. flanges which are viewed by CCD cameras (V cam and H cam) through the mirrors (Vm and Hm1 and Hm2) mounted on manual gimble mounts.

At E-line, after removing the spatial resolution of 178 microns FWHM (derived from the crystal angular acceptance and distance from source) and optical resolution of 120 microns FWHM (determined by a knife edge and erfc measurement), a size of 705 microns FWHM was obtained. This was in good agreement with the calculated size.

1.2. Operation of the vertical source size measurement

Shortly after the above tests were conducted, work was done to reduce the vertical beam size for CHESS running. This resulted in the vertical beam size at CHESS E-line being reduced to a measured sigma of 189 μm (or 445 μm FWHM). Accelerator machine studies were conducted that demonstrated that further beam size reduction could be obtained and measured on E-line by optimizing the horizontal to vertical coupling and that E-line had very good sensitivity to these changes (see Figs. 2 and 3). The LEPP Synch light monitor was not able to resolve the changes at these smaller vertical beam sizes at the time. However, particle beam lifetimes suffered at the reduced beam size, presumably due to the Touschek effect, and thus we were not able to take full advantage of the smallest beam size for normal CHESS operations. Subsequently, after many months of beam processing through regular operations the vacuum and particle beam lifetime had improved to the point that in April 2007, we reduced the positron vertical beam source size to a measured value of 290 μm FWHM at E-line, which resulted in a factor of 2 increase in intensity on the beam lines that image the source through optics. Further improvement may be accomplished in the future with a top-off mode of operation being developed that would effectively give infinite particle beam lifetime, even with a further reduced beam size, by frequent low current injections in operating conditions.

1.3. Operation of the horizontal source size measurement

Once the horizontal portion was operational, the E-line horizontal beam size was measured to be 4.07 mm FWHM with Centroid. Calculating from the following operating lattice design parameters:

$\beta_x = 16.56, \quad \eta_x = 1.316, \quad \Delta E/E = 6.6e-4,$
$\text{Emitt.}_{\text{Horiz.}} = 1311\ \text{nm rad}.$

The calculated size would be

$$1000 \times \left((\beta_x \times \text{Emitt.}_{\text{Horiz.}}) + \eta_x^2 \times \left(\frac{\Delta E}{E}\right)^2 \right)^{1/2}$$
$$= 1.71\ \text{mm} \times \sigma (\text{or}\ \ 4.03\ \text{mm FWHM}).$$

This is in good agreement with the measured values obtained from E-line.

2. General operations

The vertical beam size measurements at E-line were recently used to increase the brightness of the synchrotron