BEAM MEASUREMENT WITH SYNCHROTRON RADIATION FOR BEPCII STORAGE RING

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Abstract

The detail of Synchrotron Light Monitor for BEPCII storage ring is introduced. The Synchrotron Light Monitor measures both transverse beam profiles and longitudinal bunch length. Transverse profiles are measured by visible light imaging and spatial interferometer, and longitudinal bunch length is measured by streak camera and two photon intensity interferometer.

INTRODUCTION

BEPCII could be running as two modes: the SR mode for BSRF (Beijing Synchrotron Radiation Facility); the CLD mode for BESIII (Beijing Spectrometer III). The main parameters of the two modes of BEPCII are listed in Table 1.

Table 1: Main Parameters of BEPCII

Modes	SR	CLD
Energy (Gev)	2.5	1.89
Max Current (mA)	250	980
Horizontal beam size (μm)	720	850
Vertical beam size (μm)	150	120-250

The beam size measurement of BEPCII comprises two methods as: the visible synchrotron light imaging and spatial interferometer, and the bunch length measurement comprises two methods as: streak camera and intensity interferometer. Both of them will be discussed in detail in follow.

BEAM SIZE MEASUREMENT

The Synchrotron Light Imaging beam profile monitor

The outline of the imaging method is shown in Fig. 1. The optics of the method likes the telescope optics system. Lens 1 used for accumulating light and compresses it, while lens 2 for the magnifying and focusing light to the CCD. The wavelength used for imaging is 450±10nm; and Glan-Taylor prism is used for polarizer to select out the σ-polarized component of synchrotron light. An adjustable aperture is used for reducing astigmatism. The image measured by the visible light imaging method is shown in Fig. 2. By projecting the image horizontally and vertically, and fitting them by Gaussian function, the Gaussian type beam size in image σ_p could be maintained. To calculate the real beam size σ_m, the magnification M of the total system is required:

$$\sigma_m = \sigma_p * M \tag{1}$$

We measured M by local bump electron beam some distance ΔB and record the image movement ΔI on CCD, than we get the M by

$$M = \Delta B / \Delta I \tag{2}$$

The beam size can be get from formula (1) and (2). However, this beam size is not the exact beam size because of diffraction. To get the exact beam size σ, the point spread function (PSF) is required. One way to get PSF is approximate calculation by the aperture size and the distance from the aperture to the CCD. The other way is to measure it by the method shown in ref [1]. In our case, both of the two methods get the same result as 130 micron. This size is considerable for the vertical beam size. Since we have the PSF, the real beam size can be calculated as

$$\sigma = \sqrt{\sigma_m^2 - PSF^2} \tag{3}$$

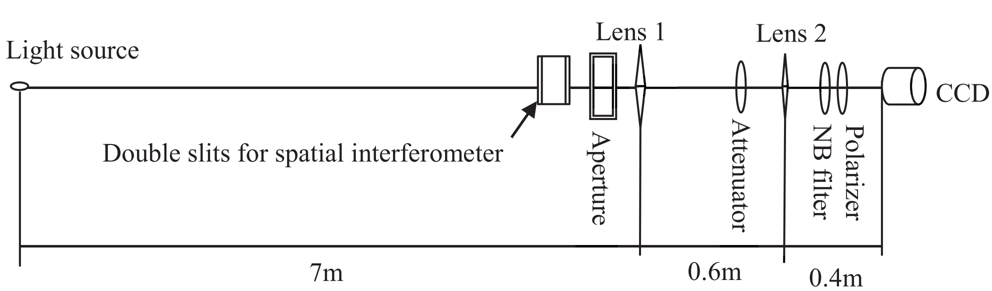

Figure 1: The outline of visible light imaging measurement and magnification measurement. F1 and F2 are focus length of the lens 1 and lens 2.

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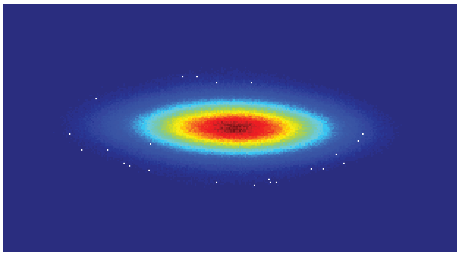

Figure 2: Image taken by synchrotron light imaging method.

Spatial Interferometer Vertical Beam Size Measurement

The principle of spatial interferometry beam size measurement method is illustrated in ref [2], which could be described simply as followed: the spatial coherence degree of the observation plane is the normalized Fourier transformation of the intensity distribution of the light source. The spatial coherence degree distribution could be measured by the double slits interference. The spatial coherence degree equals the visibility of the interference fringe when the light intensity at each slit equals. After deduction, the intensity distribution function of light source as spatial coherence degree could be described as formula (4), here we assume the light intensity at each slit the same:

$$I(y) = 2I_0 \sin c^2(\frac{2\pi a}{\lambda L_1} y)(1 + \gamma \cdot \cos(\frac{2\pi d}{\lambda L_1} y)) \quad (4)$$

I_0 is the light intensity at slits, a is the width of the single slit; L_1 is the distance between light source and double slit; λ is the wavelength of SR used; d is the distance between double slits. γ is the spatial coherence degree, which equals the visibility when the light intensity at each slit equals. This method gives the Gaussian type beam size as followed formulas. Formula (5 is suitable for real time monitor when keeps the d constant, while formula (6) is suitable for precisely measurement, which requires changing the value of d and getting the Gaussian distribution of γ with it.

$$\sigma_y = \frac{\lambda L_1}{\pi d}\sqrt{\frac{1}{2}\ln\frac{1}{\gamma}} \quad (5)$$

$$\sigma_y = \frac{\lambda L_1}{2\pi\sigma_\gamma} \cdot \quad (6)$$

σ_y is the Gaussian beam size to measure; σ_γ is the Gaussian width of γ (The Fourier transformation of Gaussian function is also a Gaussian function). For the vertical beam size of BEPCII as shown in Table 1, the spatial interferometer works but not horizontal one, because the size is too large to view visibility of the interference fringes in our case. The experiment setup is just like Fig. 1, when add a double slit before the first lens. Figure 3 shows a schedule view of the interference fringes measured in SLM of BEPCII. The precisely measurement and its Gaussian fitting result is shown in Fig. 4.

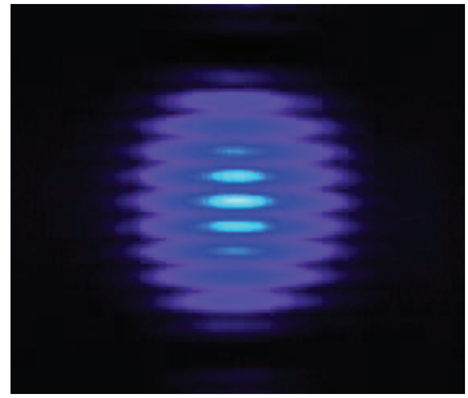

Figure 3: The image of spatial interferometer fringes.

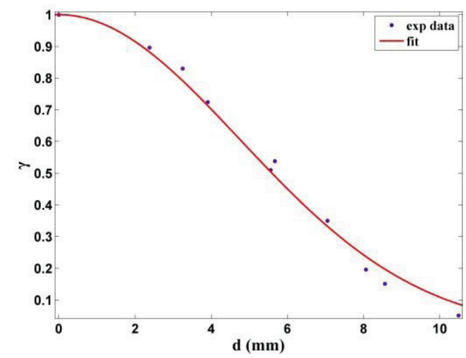

Figure 4: The Gaussian fit of γ vs. d.

Measurement Results

All the above experiment results are summed up in Table 2:

Table 2: The Beam Size Measurement Result of SLM at CLD mode (μm)

	Imaging	Spatial interferometer
Vertical	179±20	165±5
Horizontal	832±40	----

As we can see that the measurement results of visible synchrotron light imaging method shows the most direct image of the real beam profile, and precise horizontal beam size measurement, however, the precision of the vertical beam size measurement is limited by the diffraction effect. The vertical spatial interferometer method maintains precisely measurement result. The two method work together to satisfy the beam profile measurement needs of BEPCII.

BUNCH LENGTH MEASUREMENT

Streak Camera Bunch Length Measurement

For bunch length measurement, typical measurement instrumentation is streak camera. The streak camera of Hamamatsu C5680 was used to measure the bunch length of BEPCII storage ring as usual. The resolution of C5680 is 2ps. The typical measurement result is shown as Fig.5 and Fig.6.

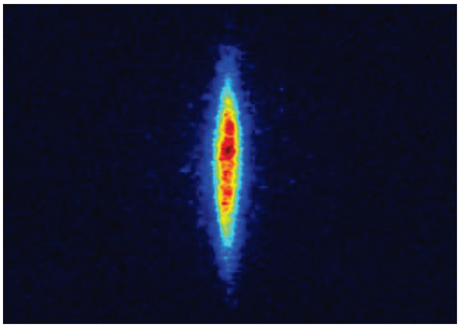

Figure 5: Image of bunch length measurement with streak camera.

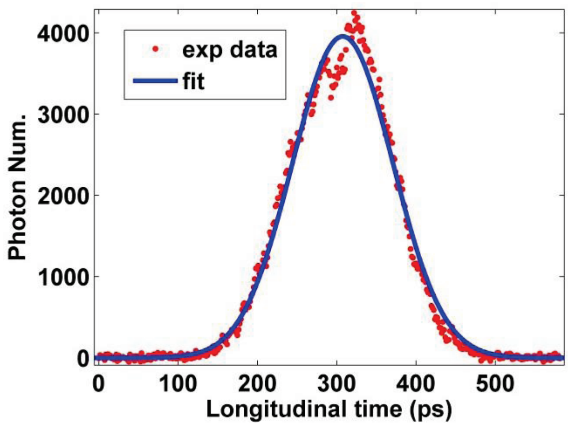

Figure 6: Fit curve of bunch image by streak camera.

Intensity Interferometer Bunch Length Measurement

The principle of two photon intensity interferometer is illustrated as ref [3], [4], [5]. The intensity interfere is also called Hanbury Brown and Twiss effect (HBT). For BEPCII, the layout of intensity interferometer is shown as Fig.7. The incident synchrotron light is collimated by lens. An aperture is used to increase spatial coherence degree. After passing throw polarization prism, a grating monochromator is used to obtain light as bandwidth of 0.1nm at 542nm. The Output light from monochromator splits to two part, and both of them be reflected by mirrors, but one mirror is movable by stepping monitor. Another cube splitter is used to interfere. At last, the two light beams are detected by two PMTs (rise time about 2ns). Signal from PMTs come to SR400 two channels gated photon counter. (Minimum gated width is 5ns).

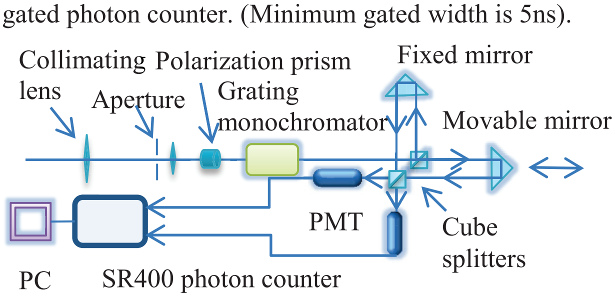

Figure 7: Layout of Intensity interferometer.

The coincident count rate between the two detectors is measured by SR400. Theoretical coincident count rate is:

$$CC(\delta\tau) = K\sigma_p^2\left(1+\frac{\tau^*}{\sigma_p}\left(1-\frac{1}{2}\exp\left(-\frac{\delta\tau^2}{4\sigma_p^2}\right)\right)\right) \quad (7)$$

Where

$$\frac{1}{\tau^{*2}} = \frac{1}{\sigma_p^2} + \frac{1}{\tau_c^2} \quad (8)$$

Here, we assume light purse as Gaussian type. K is proportional constant. $\delta\tau$ is delay time by the movable mirror, σ_p is Gaussian width of the purse. τ_c is coherence time of synchrotron light. The *CC* pre-measurement result of BEPCII is shown as Fig.8, from which we can see dip in the centre.

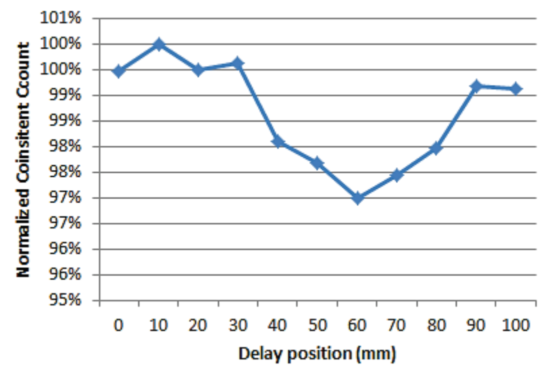

Figure 8: Pre-measurement result of two photon intensity interferometer.

CONCLUSION

For transverse beam size of BEPCII, the visible light imaging is suitable for real time beam profile monitor, and horizontal beam size measurement, but vertical beam size should be measured by spatial interferometry method. For longitudinal bunch length, streak camera works well, and intensity interferometer seems work, but needs more precise experiments.

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