THE TWO METHODS FOR BEAM PROFILE MEASUREMENT OF BEPC II STORAGE RING

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Abstract

The two methods used for real time beam profile measurement at the BEPCⅡ Storage Ring, visible synchrotron light imaging and spatial interferometry, will be introduced in detail, including the magnification calibration, point spread function (PSF) measurement, image restoration and spatial coherence measurement. The measurement results were compared with each other and agree well.

INTRODUCTION

BEPCⅡ can be operated in either of two modes: SR mode for the BSRF (Beijing Synchrotron Radiation Facility); and CLD (collider) mode for BESⅢ (Beijing Spectrometer Ⅲ). The SR mode is run with smaller emittance and coupling coefficient to get high quality synchrotron light, and the CLD mode is run with larger emittance and flexible coupling coefficient to achieve high luminosity. The main parameters of the two modes of BEPCⅡ are listed in Table 1.

Table 1: Main Parameters of BEPCⅡ

Mode	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 SLM (Synchrotron Light monitor) of BEPC Ⅱ comprises two methods to measure the beam size: visible synchrotron light imaging and spatial interferometry [1]. Both will be discussed in detail in this paper.

EXPERIMENT

The Visible Synchrotron Light Imaging Method

The outline of the imaging method is shown in Fig. 1. The optics of the method is similar to a telescope optical system. Lens 1 is used for collecting light and concentrating it, while Lens 2 is used for magnifying and focusing the light on the CCD. The wavelength used is 450±10 nm; a Glan-Taylor prism is used as a 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 the profile with a Gaussian function, the Gaussian beam size in pixels, σ_p, can be measured. To calculate the actual beam size σ, the magnification M of the total system is required:

$$\sigma = \sigma_p * M \qquad (1)$$

We measured M with a simulated light source and a straight-edge (shown in Fig. 1). First, the straight-edge was used to block part of the source, and was moved along the optical axis until the edge image contrast was maximized, as shown in Fig. 3. Next, the straight-edge was moved horizontally and vertically, recording the distance moved at the object position, ΔO, and the distance moved in the image plane, ΔI, from which we get the magnification:

$$M = \Delta O / \Delta I \qquad (2)$$

From Formulas (1) and (2) we get the beam size. However, the imaging resolution is limited by diffraction effects, and one way to compensate for this effect is by image reconstruction via deconvolution of the Point Spread Function (PSF).

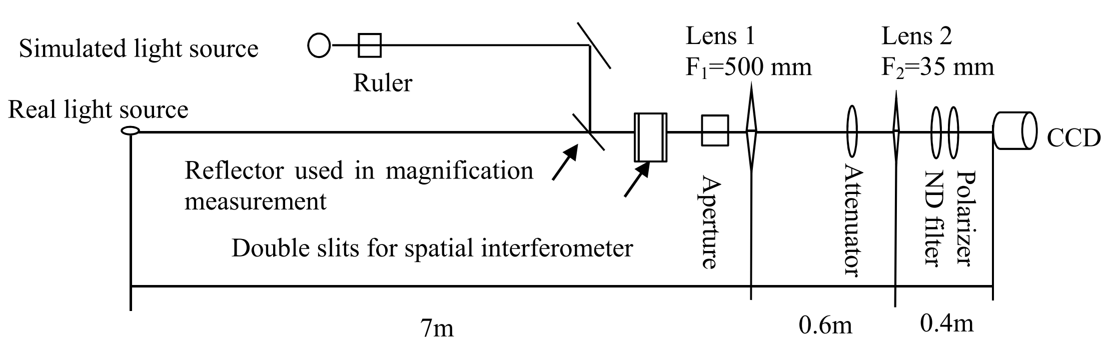

Figure 1: Layout of visible light imaging and magnification measurements. F1 and F2 are focal lengths of Lens 1 and Lens 2, respectively.

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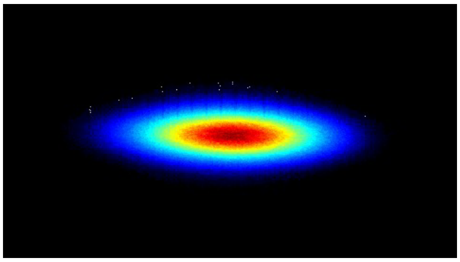

Figure 2: Image taken by synchrotron light imaging method.

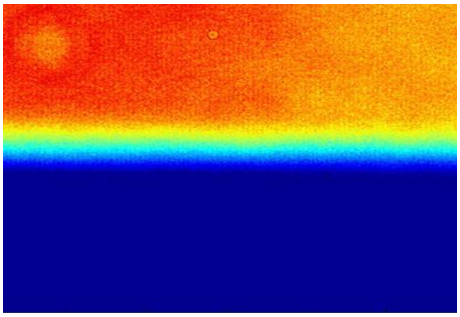

Figure 3: Straight-edge image of the magnification-measurement system.

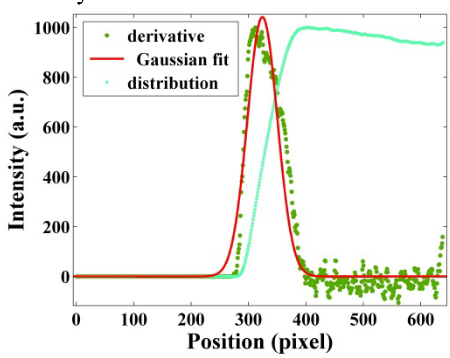

Figure 4: The straight-edge image intensity distribution, its derivative and the Gaussian PSF fitting.

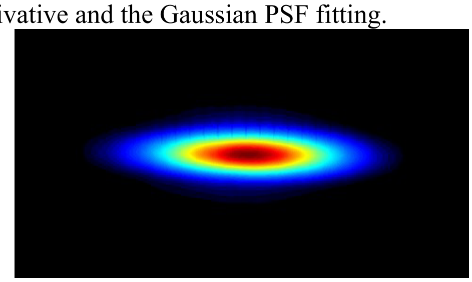

Figure 5: The reconstructed image by deconvolution.

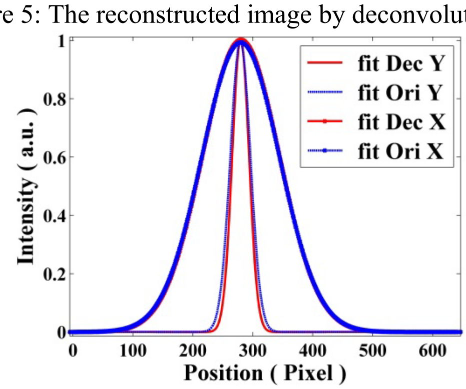

Figure 6: Gaussian fit before or after deconvolution: σ_{px} from *91.4* to *90.5* pixels; σ_{py} from *23.6* to *19.7* pixels.

PSF Measurement and Deconvolution

Fig. 3 shows the image of the straight-edge in the object plane, the same one used in the magnification measurement, by which the PSF could be calculated using the method in Ref. [2]. The principle can be described simply as follows: the derivative of the straight-edge image intensity distribution is the PSF of the system. The PSF can be approximated as Gaussian in shape. Fig. 4 shows the straight-edge image intensity distribution and its derivative, and the PSF fitting curves. The fitted Gaussian width of the PSF is 13 pixels. With the PSF, the measured beam image in Fig. 2 can be reconstructed by deconvolution. We used the Wiener deconvolution method to do that [2]. The result is shown in Figs. 5 and 6, from which we can tell that the real vertical beam size is be a little smaller than the one directly measured, while the horizontal beam size almost the same. For this reason, another precise beam size measurement method is required to calibrate the vertical beam size; that method is the spatial interferometer [1].

Spatial Interferometer Vertical Beam Size Measurement

The principle of spatial interferometry beam size measurement is described in Ref [1], and can be summarized as followed: the degree of spatial coherence measured in the observation plane is the normalized Fourier transformation of the intensity distribution of the light source. The spatial coherence distribution can be measured by double-slit interference. The degree of spatial coherence equals the visibility of the interference fringe when the light intensity at each slit is equal. The interference pattern can be written as shown in Formula (3), where we assume that the light intensity at each slit is the same:

$$I(y) = 2I_0 \sin c^2\left(\frac{2\pi a}{\lambda L_1} y\right)\left(1 + \gamma \cdot \cos\left(\frac{2\pi d}{\lambda L_1} y\right)\right) \quad (3)$$

Here, I_0 is the light intensity at each slit, 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 the two slits, and γ is the degree of spatial coherence (visibility). The visibility gives the Gaussian type beam size using the following formulas. Formula (4) is suitable for real-time monitoring with d kept constant, while formula (5) is suitable for precise measurement, which requires recording the values of γ at different value of d.

$$\sigma_y = \frac{\lambda L_1}{\pi d}\sqrt{\frac{1}{2}\ln\frac{1}{\gamma}} \quad (4)$$

$$\sigma_y = \frac{\lambda L_1}{2\pi\sigma_\gamma} \quad (5)$$

Here, σ_y is the Gaussian beam size to be measured, and σ_γ is the Gaussian width of γ. (The Fourier transformation of

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a Gaussian function is also a Gaussian function, so the distribution of γ vs. d is Gaussian). For the vertical beam size at BEPCⅡ shown in Table 1, the spatial interferometer works only in the vertical direction, because the size in the horizontal direction is too large to measure the visibility of the interference fringes in our case. The experimental setup is like that of Fig. 1, with a double slit added before the first lens. Fig. 7 shows a view of the interference fringes measured with the SLM of BEPCⅡ. The precise measurement and its Gaussian fitting result are shown in Fig. 8.

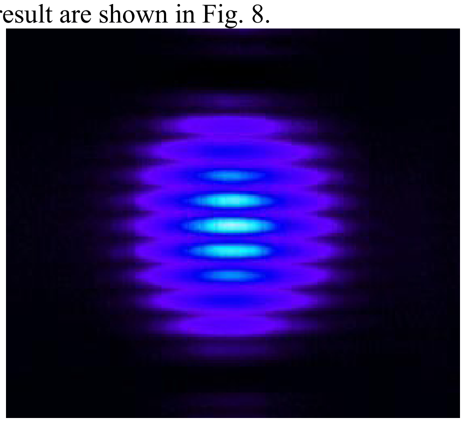

Figure 7: Image of spatial interferometer fringes.

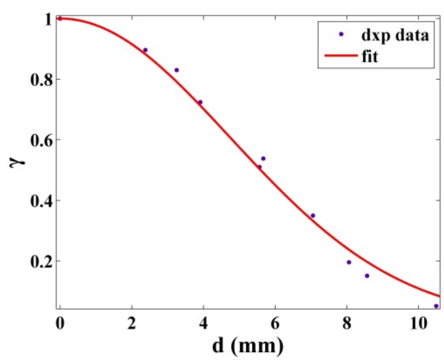

Figure 8: Gaussian fit of γ vs. d .

RESULTS

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

Table 2: Beam Size Measurement Result using SLM in CLD mode (μm)

	Imaging	Deconvolved image	Spatial interferometer
Vertical	215±20	179	165±5
Horizontal	840±40	832	----

In these results, the measurement using the visible synchrotron light imaging method shows the most direct image of the real beam profile. Precise horizontal beam size measurement is possible as is, however, the precision of the vertical beam size measurement is limited by the diffraction effect. After image reconstruction by PSF deconvolution, the measurement precision is improved. The vertical spatial interferometer method provides a more precise and stable measurement result than the imaging method. The two methods work together to satisfy the beam profile measurement needs of BEPCⅡ.

CONCLUSION

For the beam size of BEPCⅡ, the visible light imaging is suitable for real-time beam profile monitoring, but the vertical beam size measurement result is limited by the effect of diffraction. There are two ways to resolve this effect. Firstly, the image measured can be reconstructed by PSF deconvolution, but the process is too time-consuming. On the other hand, the vertical beam size can be calibrated by other measurement methods, such as the spatial interferometry beam size measurement method, which avoids the diffraction effect, though this measurement has its disadvantages, such as losing the position information, a slow calculation process, and being only suitable for beam sizes of tens to hundreds of microns.

ACKNOWLEDGMENT

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[2] S.W. Smith, *The scientist and engineer's guide to digital* signal *processing*, (California Technical Pub, 1997): 423–450.