BEAM SIZE MEASUREMENT AT SIAM PHOTON SOURCE STORAGE RING

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Abstract

Synchrotron radiation (SR) interferometer and direct imaging setups have been installed and subsequently utilized to investigate transverse beam profile at Siam Photon Source (SPS). Details of the optical setup as well as the beam sizes determined from the measurement will be presented. Comparison between the measured and theoretical values as established by linear optics calibration will be made and discussed. In order to demonstrate beam profiling capability of the interferometer and direct imaging systems, measurements with different operating parameters have been carried out and the results will be presented as well.

INTRODUCTION

Beam position stability of SPS storage ring has been improved as well as vertical beam emittance reduced, providing users with more stable and brighter synchrotron light. A new and improved beam profile monitor was installed to provide machine physicists with a tool to observe the improvement quantitatively. Both the transverse beam size, which is inversely proportional to the brilliance of the photon beam, and the time-dependent photon beam position, which reflects the beam position stability, have been investigated by this system.

Previously, the SPS beam profile monitoring system incorporated only direct imaging system, which is a conventional method for observing transverse beam profile and beam position. However, the resolution is limited due to diffraction effects [1]. In order to improve the precision of these measurements synchrotron radiation interferometers are at this time employed. The interferometer setup was originally developed to eliminate the diffraction effects in a low-emittance synchrotron storage ring, whose generated photon beam exhibits spatial coherency [1]. We also decided to move the setup from within the storage ring shielding wall to outside in the experimental area, which allows machine physicists to be able to perform several activities such as optical alignment, ND filter optimization, and slit separation determining, more conveniently. These activities are necessary to obtain good and reliable results. We found that this system is very helpful in our endeavour to reduce the beam size while maintaining reasonable beam lifetime.

It is worth mentioning that the measured results we obtained are in good agreement with theoretical results, which were obtained from the LOCO code [2].

This paper is organized such that the optical setup and the beam size determination are described in the next two sections, followed by a section presenting the results of the measurement. The beam size analysis is discussed in the penultimate section, and concluding remarks are presented in the final section.

OPTICAL SETUP

The setup utilizes visible synchrotron light from the bending magnet BM01. The horizontal opening angle is 17 mrad. A portion of this light is reflected into the setup inside a dark room by a water-cooled aluminium-coated mirror located inside the radiation shielding wall. The distance between the source point and the slit is 6.5 m. The schematic layout is shown in Figure 1. The first beam splitter reflects half of the light to the direct focusing imaging system, comprising only a single apochromatic lens, and transmits the remaining light to the interferometer systems.

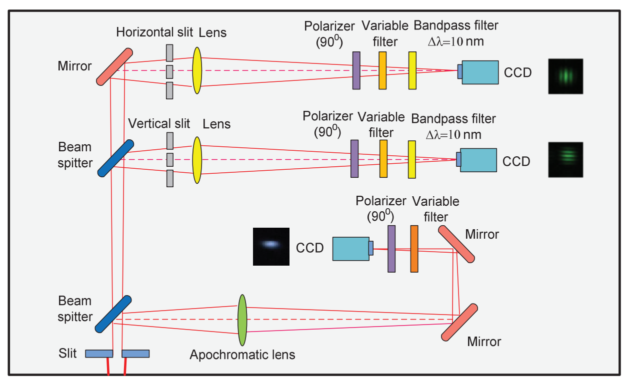

Figure1: Schematic layout of the beam profile monitoring system.

Direct Imaging System

To overcome chromatic aberration which has detrimental effect on the final resolution, an apochromatic lens, obtained from a telescope, is used for the direct focusing imaging system. Its focal length is 1370 mm. The light is then filtered by a 90° polarizer and variable neutral density filters, and recorded by a CCD camera. Each of the optical elements is carefully aligned in order to obtain a perfectly focused image.

Synchrotron Radiation Interferometer

As shown in Figure 1, the light passing through the first beam splitter is subsequently split into two branches for simultaneous measurements of horizontal and vertical beam sizes. These lights pass though double slits with 1 mm width to create the interference patterns. The pattern is then focused on a CCD camera by a 700 mm-focal length lens. A 550 mm wavelength bandpass filter with a bandwidth of 10 nm is inserted in front of the CCD camera to make the light quasi-monochromatic. The fringe contrast of interferogram can be optimized by adjusting the slit separation to minimize sensitivity to measurement error [3], [4].

BEAM SIZE DETERMINATION

To calculate the beam size and to find the beam center in both directions, the beam intensity image is first projected in the two directions and subsequently fitted using nonlinear Levenberg-Marquardt method. The computation is performed using the LabVIEW programming code. In the direct imaging system, the intensity distribution is analyzed by a Gaussian function:

$$f(x) = ae^{-\frac{(x-u)^2}{2\sigma^2}} + d \, , \tag{1}$$

where σ is the beam image size, u is the beam central position and d is the background level on the CCD camera.

The actual electron beam sizes can be determined from the CCD resolution and the magnification ratio of the optical setup as followed.

$$\sigma_{beam} = \sigma_{image} \times \left(\frac{CCDsize}{CCDpixel} \times \frac{1}{M} \right), \tag{2}$$

where M is the magnification ratio, which is determined by ratio of the image distance to the source distance. The pixel size of the CCD camera is 4.4×4.4 μ m^2.

In the interferometer system, the intensity distribution of each interference pattern measured with the CCD camera is fitted by:

$$I(y) = I_0 + I_1 \operatorname{sinc}^2(A(y - y_1))[1 + V\cos(B(y - y_2))], \tag{3}$$

where I_0 and I_1 are the background and pattern envelope intensities, respectively, A and B are frequencies, V is the visibility, and y_1 and y_2 are phase factors. All of these parameters are fitting variables. The beam size can then be obtained from

$$\sigma_{beam} = \frac{\lambda L}{\pi d}\sqrt{\frac{1}{2}\ln\left(\frac{1}{V}\right)}, \tag{4}$$

where λ is the wavelength, d is the double slit separation, and L is the distance from the CCD to the double slit.

MEASUREMENT RESULTS

Figure 2 shows both the measurement results from the direct imaging system as well as that from the interferometric setup. For the SR interferometers, the slit separations were set to give the visibility of 0.6, which is d=2 mm and d=3 mm for the horizontal and vertical directions, respectively. The beam sizes obtained from the synchrotron interferometer are 25% smaller than those from the direct imaging system.

The LOCO code was used to analyze the actual beam parameters. This method has been successfully employed to calibrate the actual storage ring optics and afterward restore the design optics. The optical parameters of the ring which have direct effect on the beam size such as betatron functions, dispersion functions, and coupling were obtained from the LOCO code and found to be in good agreement with measured values.

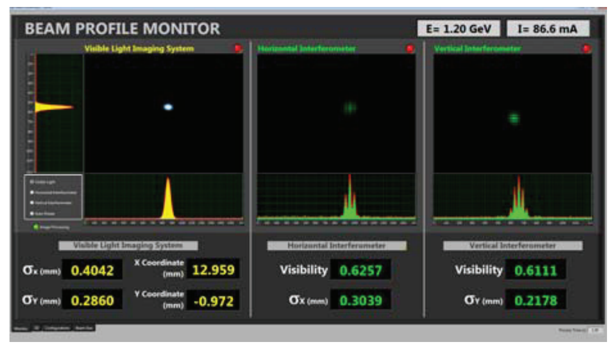

Figure 2: Real-time beam size monitoring panel. The leftmost panel shows the result from the direct imaging system. The two other panels show the results from the SR interferometers.

After the optical parameters have been established, equilibrium beam envelope was calculated by Ohmi's beam envelope formulae [5]. The beam emittances, as well as the beam sizes, are extracted from the envelope at every element in the model. These theoretical beam sizes are compared with the measured values from the beam profile monitoring system. This is summarized in Table 1. The beam sizes measured with the interferometer system are in good agreement with the predicted beam sizes, while there is a small discrepancy between the predicted beam size and the beam size measured with the direct imaging system. This discrepancy is most likely caused by the resolution of the imaging setup, which is generally limited by the diffraction effect.

Table 1: Predicted and measured beam size in normal storage ring operation.

Parameters	Horizontal	Vertical
$\sigma_{Calibration}$ [mm]	0.290	0.188
σ_{Direct} [mm]	0.378	0.250
$\sigma_{Interferomter}$ [mm]	0.281	0.185

The measured beam size and beam position are recorded every 5 seconds for routine monitoring as shown in Figure 3. They were found to be strongly correlated to the beam current. This is most likely due to the deformation of the first extracting mirror. In order to

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reduce this effect low beam current, ~50 mA, was used for the results shown in Table 1.

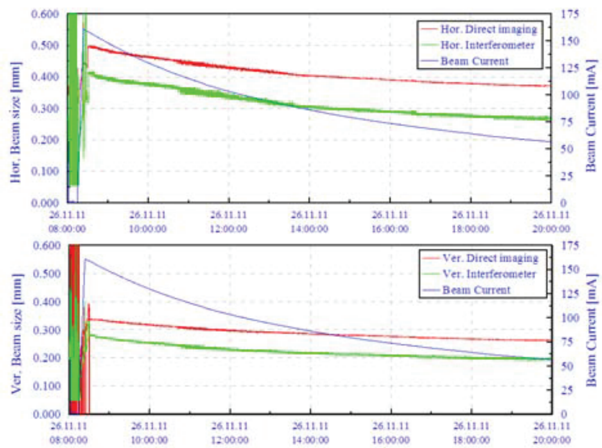

Figure 3: Measured beam sizes from direct imaging and interferometer systems as a function of beam current.

VERTICAL BEAM SIZE ANALYSIS

The capability of the beam profiling system was tested by varying the vertical electron beam size. By introducing vertical orbit distortion, vertical dispersion is introduced, altering the vertical beam size [6], [7]. Optics calibration was performed by using measured dispersion function and response matrix by the LOCO code after each successive orbit adjustment.

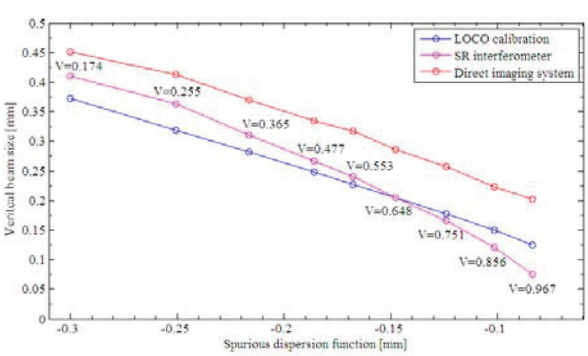

Figure 4: Vertical beam size variation as a function of spurious dispersion function.

Figure 4 shows the vertical beam sizes as determined by the LOCO calibration together with the measured values from the SR interferometer and the direct imaging system. The result shows that the spurious dispersion has a strong effect on the vertical beam size, as expected. As mentioned earlier, the beam size obtained with the interferometer is closer to the predicted value than that from the direct imaging system. However, the deviation becomes larger at higher and lower visibility. To minimize this error, the slit separation is chosen such that the visibility is in the range between 0.55 to 0.75.

Investigation has been carried out to find the optimum operation point of the storage ring, a compromise between the delivered photon flux density and the electron beam lifetime in the ring. This new beam profile monitoring system has proved to be an indispensable diagnostic tool for the machine people to accomplish this undertaking.

CONCLUSION

The new SPS transverse beam profile monitor were successfully set up, incorporating both direct imaging and SR interferometer techniques. The measured beam sizes obtained by interferometer are in good agreement with the predicted value with an error of 3% and 2% for the horizontal and vertical directions, respectively. The demonstration of the beam profiling capability has been performed, the results from which are necessary to determine the proper slit separation.

This beam profile monitoring system will be again used for the feasibility study of further reducing the beam size of the SPS storage ring.

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