OPTIMIZATION OF THE INTERFEROMETRY BEAM SIZE MONITOR IN PLS-II

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Abstract

Pohang Light Source-II (PLS-II) is recently upgraded to 3 GeV and the circumference, beam current, emittance of PLS-II storage ring are 281.82 m, 100 mA and 5.7 nm-rad, respectively. The storage ring includes an interferometry beam size monitor(BSM) system in 2B beam line. It consists of the quadrature slit, lens, 650 nm wave-length filter and CCD (charge-coupled device) camera. We will present the measurement results and the issues to optimize the beam size monitor system in the beam line.

INTRODUCTION

Pohang Light Source-II (PLS-II) is an upgrade project of the existing 2.5 GeV PLS. The circumference, beam current and energy of PLS-II storage ring are 281.82 m, 400 mA and 3 GeV, respectively [1]. The upgrade project of PLS-II includes emittance of 5.7 nm-rad and space for 20 insertion devices. The 3 GeV ring with two combined bendings in one cell is newly constructed in the existing tunnel. The SR (Synchrotron Radiation) interferometer was installed in 2B beam line. It is almost same with existing beam size monitor in PLS [2, 3]. The SR interferometry beam size monitor(BSM) is consists of four mirrors, quadrature slit, objective lens, polarized light filter, 650nm filter and CCD camera. The layout of the optical system of interferometry beam size monitor in PLS-II is shown in Fig. 1. The advantages of usage of the quad-slit is to reduce the cost and the distortion of synchrotron radiation due to the beam splitter. However, the quadrature slit has a problem to measure the accurate beam size with the small beam size such as the PLS-II machine. We present the problems caused by the quadrature slit and the beam size measurement result with double slit in PLS-II machine.

MEASUREMENT PRINCIPLE

The intensity of the interference pattern produced by the quadrature slit can be explained by following equation when the coupled effect between the horizontal and vertical was ignored, $I(x,y) = I_0 I_x(x) I_y(y)$. The horizontal and vertical interference pattern is given by Eq. 1 and 2.

$$I_x(x) = [\frac{\sin\left(\frac{\pi\omega_x}{\lambda R}x\right)}{\frac{\pi\omega_x}{\lambda R}}]^2[1+\gamma_x\cos\left(\frac{2\pi D_x}{\lambda R}x+\phi_x\right)] \quad (1)$$

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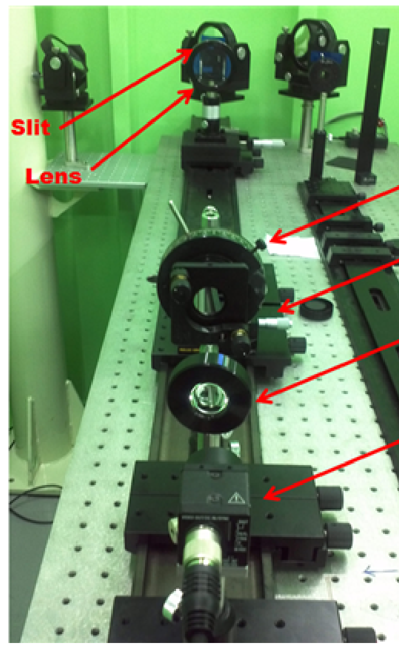

Figure 1: The layout of interferometry beam size monitor optical system.

$$I_y(y) = [\frac{\sin\left(\frac{\pi\omega_x}{\lambda R}x\right)}{\frac{\pi\omega_x}{\lambda R}}]^2[1+\gamma_x\cos\left(\frac{2\pi D_x}{\lambda R}x+\phi_x\right)] \quad (2)$$

where the λ is wave length of the synchrotron radiation, $\omega_x(\omega_y)$ is horizontal(vetical) slit size, $D_x(D_y)$ is the horizontal(vertical) slit separation, R is the distance from slit to CCD camera and $\gamma_x(\gamma_y)$ is the horizontal(vertical) visibility.

The beam size is estimated from the visibility of the interferogram, which indicates the complex degree of spatial coherence of the photons [4]. The relation between beam size and visibility given by the Eq. 3.

$$\sigma_x = \frac{\lambda}{\pi}\frac{s}{D}\sqrt{\frac{1}{2}\ln\frac{1}{\gamma}} \quad (3)$$

From the Eq. 3, the statistical error of the measurement, including the noise of the CCD camera, can be estimated. When the statistical error of the CCD camera is 1 4 %, the error of the beam size measurement is shown in Fig. 2.

As shown in Fig. 2, the effect of the statistical error of the CCD camera can be minimized when the visibility is about 0.6. Therefore, the visibility of the interferometry

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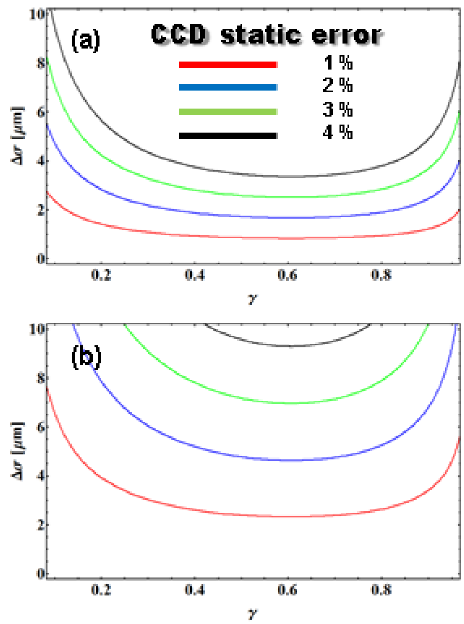

Figure 2: The beam size measurement error caused by the static error of CCD camera. (a) horizontal beam size (b) vertical beam size.

beam size monitor system in PLS-II was investigated as a function of the slit separation. More details about experiment are explained in next section.

EXPERIMENTAL

As recognized the multi-advantages of top-up mode operation for an advanced third generation light source, Pohang Light Source-II(PLS-II) was designed originally both for machine operation in decay mode and top-up mode. The upgrade project has completed in 2012 followed by 12 months construction and machine commissioning, and opened to user operation in decay mode since March 2012 [5]. During operation from March 2012 to July 2012, the maximum current of storage ring is limited to 100 mA due to the RF systems. Therefore, our experiments were performed in low-beam current. As shown in Fig. 1, the SR interferometry beam size monitor in PLS-III, which is installed in 2B beam line, is consists of four mirrors, quadrature slit, objective lens, polarized light filter, 650nm filter and CCD camera.

Tilt of the System

The tilts of the quadrature slit and CCD camera are one of the important source of the beam size measurement error. It could be checked by the intensity of the pattern at the each position in CCD camera. The intensity of the pattern as a function of the position in CCD camera is given in Fig. 3.

The tilt of the slit and CCD camera cause the tilt of the interference pattern. Hence, we can estimate the tilt of the hole system from the red line. The tilt of the interference

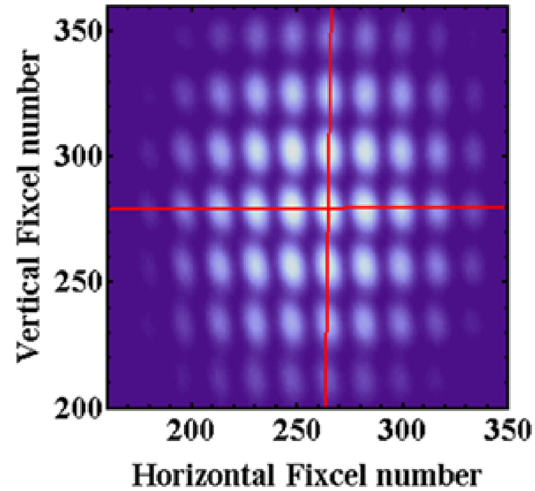

Figure 3: The interference pattern at the CCD camera. Red-line is produced by connecting the local maximum point in pattern.

pattern is up to 7 mrad($\sim 0.23\,^{\circ}$). Alignment of the component of the interferometry BSM is good enough to measure the very accurate beam size. It's also a ignorable value for data taking using projection method.

Linearity of CCD Camera

Due to the decay mode operation, the beam current is depend on the time. During the nominal operation, the beam current is 40 $\sim$ 100 mA. Hence, the test of linearity of the CCD camera in this beam current region is required. We performed the test by changing of the beam current in the ring. The maximum intensity of the interference pattern is measured in 40 $\sim$ 100 mA beam current that is shown in Fig. 4.

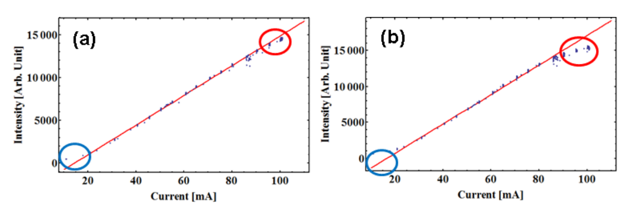

Figure 4: The linearity of the CCD camera. (a)Horizontal plane, (b) Vertical plane.

As shown in Fig. 4, the CCD camera only linear in beam current of 40 $\sim$ 80 mA. Especially, the vertical plane has a large non-linearity at around beam current of 80 mA. The CCD camera also has a negative offset. It's cause the measurement error of the local minimum point around the local maximum of the interference pattern. Based on this data, the beam size was calculated by using the fitting algorithm that is shown in Fig. 5.

The effect of the negative offset and non-linearity of the CCD camera was observed in beam size measurement. Especially, the effect of the negative offset cause the beam

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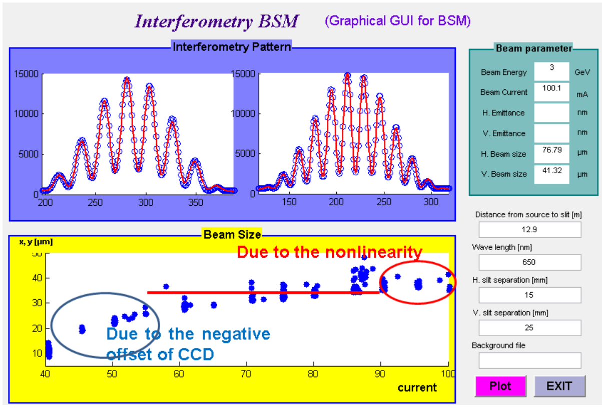

Figure 5: The linearity of the CCD camera. (a)Horizontal plane, (b) Vertical plane.

size measurement error of 5 $\sim$ 10 μm in the section of beam current of 40 $\sim$ 55 mA.

Unbalance Ratio

When the I_1 and I_2 are not equal, the effective visibility is calculated as

$$\gamma_{eff} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2} |\gamma| \tag{4}$$

where I_1 and I_2 are the intensities of the incident light for each slit [6]. In case of the double slit, the unbalance ratio between I_1 and I_2 is not so difficult to adjust over 0.9. For the quadrature slit, the adjustment of the unbalance ratio, however, is so difficult to adjust over 0.9. To estimate this effect, we performed the measurement of the visibility by changing the slit separation that is shown in Fig. 6.

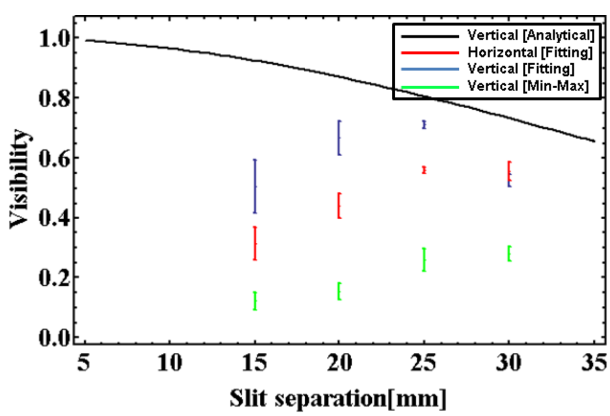

Figure 6: The visibility as a function of the vertical slit separation.

When we measure the visibility as a function of the slit separation on vertical direction, the horizontal visibility has the dependency. Also, the trend of the change of visibility is not corresponding to theory. It's caused by the unbalance ratio of the intensity of the incident light.

Double Slit

To adjust the unbalance ratio over 0.9, the double slit is adopted. By changing of the horizontal slit position, the unbalance ratio was adjusted over 0.9. After fixing the position of the slit, we performed the measurement of the visibility by changing the slit separation to measure the accurate beam size, that is shown in Fig. 6.

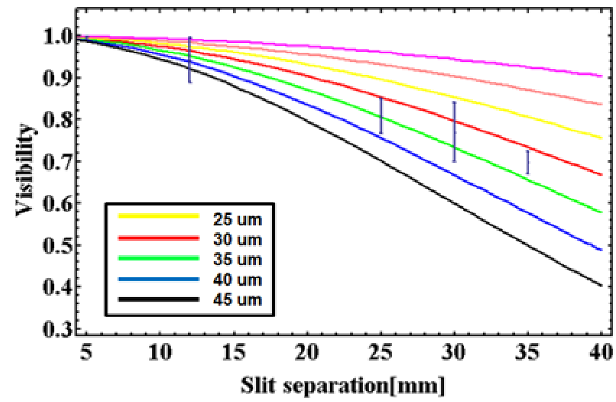

Figure 7: Effect of the unbalance ratio in quadrature slit.

As shown in Fig. 7, the trend of the changing of visibility as a function of vertical slit separation is well corresponding to theory. The vertical beam size in PLS-II is around 35 μm.

CONCLUSION

Many effects is related to the beam size measurement using SR interferometry beam size monitor with quadrature slit were investigated in PLS-II. From the linearity measurement, we found the negative offset camera and nonlinearity of the CCD. The CCD camera will be replaced to new one. Also, the quadrature slit has a serious problem to adjust the unbalance ration. It cause the large measurement error for the small beam size. As explained in experiment with double slit, the vertical beam size in PLS-II is around 35 μm.

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