RENOVATION OF SR MONITOR AND MEASUREMENT OF EMITTANCE AT THE PHOTON FACTORY

Yuhji HAYASHI, Toshitada HORI and Toshiyuki MITSUHASHI*[1]

Department of Physics, Faculty of Science, Hiroshima University,
*High Energy Accelerator Research Organization, Oho, Tsukuba, Ibaraki, 305-0801 Japan

Abstract

The SR monitor system at the BL21 was renovated to measure the emittance of electron beam at the Photon Factory after the upgrade. SR-extraction mirror system, optical relay system, measuring optics are newly installed in diagnostics beamline BL21. The thermal deformation of SR-extraction mirror is measured by ray tracing method. The beam size is measured by the use of SR interferometer. The energy spread of the electron beam is also measured trough bunch length measurement via streak camera. The emittance is evaluated from the results of beam size and energy spread. The result of emittance is 38.7nmrad, and it agreed with designed value in 10%.

1. INTRODUCTION

We have upgraded the Photon Factory (PF) to install four new-straight section for the short gap undulator and to increase the length of existing straight sections [1]. Monitoring the beam profile, beam size, bunch length based on using the synchrotron radiation (SR Monitor) will improve greatly the efficiency of the operation of new scheme of the PF. We have four SR monitors at BL5, BL27, BL21, and beam transport line. The SR monitors set in BL5, and BL27 are mainly used for machine studies [2][3][4] and optical monitor developments [5][6][7][8]. The SR monitor set in BL21 is using as the daily monitoring. In this time, we renovate SR monitor at the BL21 to measure the electron beam emittance of the new scheme of PF. At the same time, to measure the performance of SR-extraction mirror, the Hartmann squire array mask is installed just after the extraction mirror to perform the ray tracing based on Hartmann method. This Hartmann squire array mask is also used for a calibration of SR interferometer. After the calibration of SRI, we measure a current dependence of beam size. The energy spread of the beam is also measured through bunch length measurement by streak camera. Combining results of beam size measurement and energy spread measurement, we evaluate emittance of the beam.

2. RENOVATION OF SR MONITOR AT BL21

2-1 Replacement of SR extraction system

Ordinary-used SR extraction system in the beam diagnostics beamline BL21 has a water-cooled cooper mirror. This cooper mirror was seriously damaged by long time irradiation of SR. We replaced this mirror system by new mirror system which has a water-cooled beryllium mirror. A schematic drawing of the beryllium mirror and its photograph are shown in Fig.1.

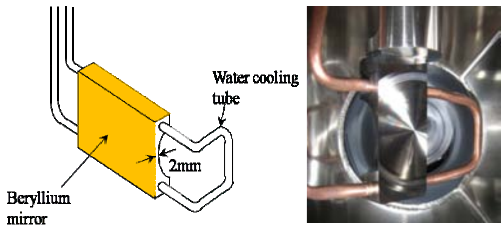


Fig. 1: schematic drawing of water-cooled beryllium mirror and its photograph.

In the previous SR extraction system, we used a commercially-available glass window for the separation of vacuum to the air. Optical quality of this glass window is very worth, and we use a metal O-ring sealed glass widow which has a transparent wavefront error less than λ/10 [9] in the new system.

2-2. Thermal deformation of the beryllium mirror

The thermal deformation of beryllium mirror due to strong irradiation of X-ray component of SR is one of serious problem in the SR monitor. We measure the thermal deformation of beryllium mirror by ray tracing method based on Hartmann method [10]. A schematic drawing of set up of ray tracing method is shown in Fig. 2. A 10 x 10 squire-array mask is set just after the mirror to sample the rays. The diameter of hole is 1mm, and separation between the holes is 5mm.

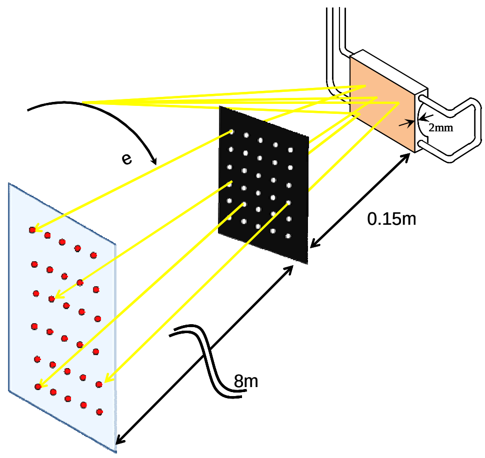
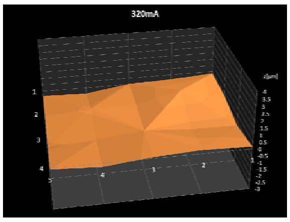


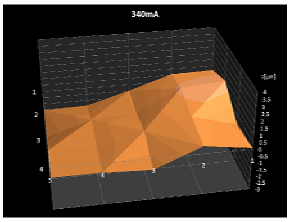
Fig. 2: Schematic drawing of set up of ray tracing measurement.

[1] Toshiyuki.mitsuhashi@kek.jp

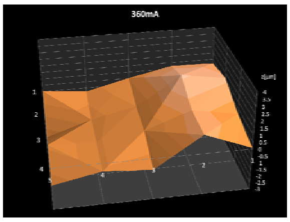
We used the SR as a light source of ray tracing. The propagations of rays are observed by a screen which set 8m downstream from the squire mask. We measured current dependence of mirror shape at several ring current. The initial shape of the mirror was deformed by irradiation of SR. Since current dependence of deformation was rather smaller than this initial deformation of mirror shape, we measured changes between the mirror shapes at higher ring current and mirror shape at 300mA. The results of mirror shape changes in the higher ring current are shown in Fig. 3.



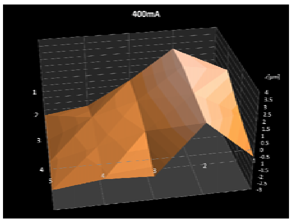
320mA



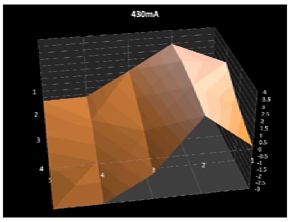
340mA



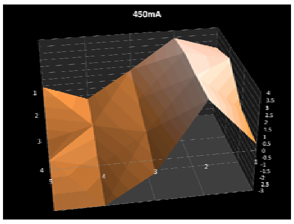
360mA



400mA



430mA



450mA

Fig. 3: The results of mirror shape changes in the higher ring current from the mirror shape at 300mA.

The mirror was deformed by 6μm by the ring current increase from 320mA to 450mA. This deformation is more than 10 times larger than average wavelength of visible SR, and we cannot do any quantitative beam size measurement by the SR monitor without any correction of these deformations.

2. Qualitative observation of beam profile by a focusing system

We have installed a focusing system to observe a qualitative image of the electron beam. To reduce the effects of thermal deformation of beryllium mirror as mentioned in upper, we limited entrance aperture of the objective lens of focusing system by a squire-aperture mask. A typical image of the beam is shown in Fig. 4.

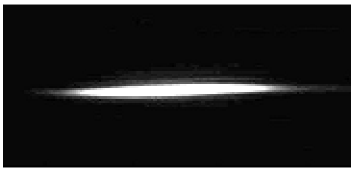


Fig. 4: Qualitative image of the electron beam observed by a focusing system.

3. Quantitative measurement of beam size and its current dependence by SR interferometer

A Quantitative measurement of the electron beam size is performed by using the SR interferometer [6]. For horizontal direction, the SR interferometer having retro-focus optics [11] was used to measure a large beam size. Since the actual separation of double slit will change due to thermal deformation of beryllium mirror, we mast correct this effect. The intrinsic separation of double slit when no deformation of the beryllium mirror is measured by ray tracing using a one hole of squire array mask [6][10] of the Hartmann ray-tracing system. Results of intrinsic separation of double slit in both of horizontal and vertical direction are shown in Fig. 5.

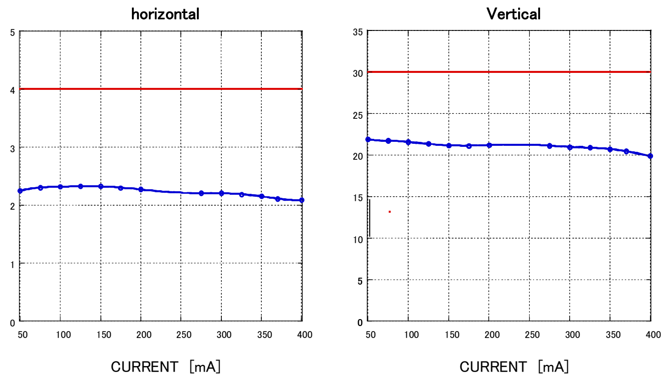


Fig. 5: Results of intrinsic separation of double slit in both of horizontal and vertical direction.

In these measurements, the actual separations of double slits are 4mm in horizontal and 30mm in vertical. Since the magnification of retro-focus optics in the horizontal SR interferometer is set 2, the actual separation of double slit is about twice of intrinsic separation. Rather a large difference between actual and intrinsic separation in vertical direction is due to permanent deformation of beryllium mirror. Current dependences of intrinsic separations due to change of the mirror shape are also observed. By using measured intrinsic separations of double slit, we measured current dependence of beam sizes in horizontal and vertical directions in the current region from 50mA to 400mA. Results of current dependence of beam sizes before and after this correction are shown in Fig. 6. In the vertical direction, current dependence of the beam size is small. In the horizontal direction, the beam size is almost constant from 50mA to 270mA, but sudden jump of beam size is observed around 270mA. The beam size in beam current larger than 270mA is about 20% larger than its size in lower than 270mA.

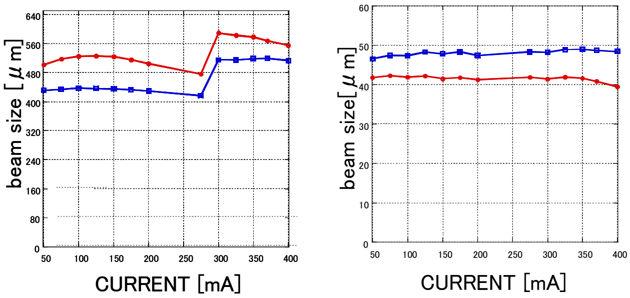
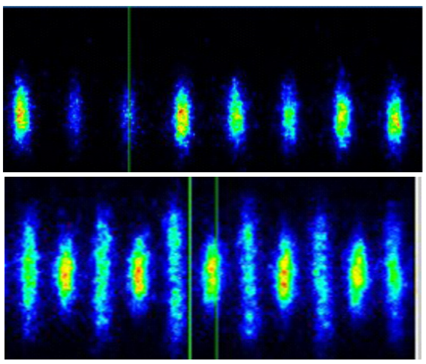


Fig. 6: Results of current dependence of beam sizes. Red line denotes beam size evaluated using actual separation of double slit. Blue line denotes beam size evaluated using intrinsic separation of double slit.

4. Measurement of energy spread of the electron beam

To investigate beam size jump in horizontal direction around 270mA, we have measured energy spread of the electron beam via bunch length measurement by using streak camera. Since the dispersion function is not zero at the source point of BL21, the information of energy spread is also necessary to evaluate the emittance of the electron beam. Results of longitudinal beam profile measured lower than 270mA and upper than 270mA is shown in Fig. 7.



(a)

(b)

Fig. 7: Longitudinal beam profile measured below 270mA (a) and upper 270mA (b).

Result of bunch length lower than 270mA is 33psec. Upper than 270mA, the bunch length measurement results are 40ps in shorter one and 60psec in longer one. Relationship between bunch length and energy spread is given by following equation.

$$\sigma_\tau = T_0 \sqrt{\frac{\alpha E_0}{2\pi h e V_{rf} \sin\phi_s}} \left(\frac{\Delta E}{E} \right).$$

The result of energy spread evaluated by using this equation is shown in Fig. 7 (a). The energy spread evaluated from the result of horizontal beam size by using the designed emittance is also shown in Fig. 7 (a). The ratio between energy spread evaluated from beam size and it from bunch length is shown in Fig 7 (b). These two results are agreed within 10%.

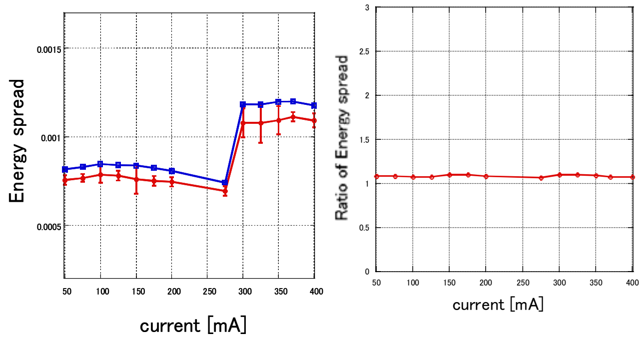


Fig. 7: (a): The result of energy spread. Red line denotes energy spread evaluated from bunch length. Blue line denotes energy spread evaluated from beam size. (b): Ratio between energy spread evaluated from beam size and it from bunch length.

4. Evaluation of electron beam emittance

Since the ratio between two results of energy spread is almost constant in measured range of beam current, we can conclude increase of horizontal beam size upper than 270mA is due to increase of energy spread. Small current dependence of horizontal beam size as shown in Fig. 6 is also can explain by current dependence of energy spread. From these evidences, we can conclude emittance of the electron beam has almost no current dependence. The result of emittance and coupling are summarized in table 1 with designed values.

Table 1 The result of emittance and coupling with designed values.

	σ_x [μm]	σ_y [μm]	ε_x [nmrad]	ε_y [nmrad]	Coupling(%)
Measurement result	416±5	48±1	38.7±1.3	0.244±0.001	0.63±0.11%
designed	413	59.4	35.5	0.355	1%

The result of emittance is agreed with designed value in 10%.

REFERENCES

[1] T. Honda, et al. Proc. PAC05, p.2678 (2005).
[2] S. Sakanaka, Y. Kobayashi, T. Mitsuhashi and T. Obina, Jan. J. Appl. Phys., Vol.42, p.1757 (2003).
[3] A. Ueda and T. Mitsuhashi, Proc. PAC05, p.2717 (2005).
[4] S,Sakanak, T. Obuna and T. Mitsuhashi Proc. EPAC08, p.1269(2008).
[5] T. Mitsuhashi and M. Tadano, Proc.EPAC02, p.1936 (2002).
[6] T. Mitsuhashi , Proceedings of BIW04 (2004).
[7] T. Mitsuhashi, Proc. DIPAC05, p.7 (2005).
[8] T. Mitsuhashi and M. Tadano, Proc. PAC07, p.3368 (2007).
[9] T. Mitsuhashi and K. Kanazawa, Proc. 13th Sym. on Accel. Sci. and Tec., p387(2001).
[10] T. Mitsuhashi and M. Tadano, Proc. APAC01, p.704 (2001).
[11] J.W. Flanagan H. Hukuma, S. Hiramatsu and T. Mitsuhashi, PAC05, p.3150 (2005).