A CONSTRUCTION OF OPTICAL BEAM PROFILE MONITOR FOR HIGH BRILLIANCE CONFIGURATION OF THE PHOTON FACTORY

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Abstract

A beam profile monitor by means of an imaging the visible synchrotron light was designed and constructed for the high brilliance configuration of the Photon Factory. The monitor consists of an extraction Be-mirror for the SR beam and a diffraction-limited focusing system. A deformation of the Be-mirror is watched by a Fizeau-type interferometer. Performance of the monitor was tested at BL27 optical laboratory of the Photon Factory operated with 1GeV. The Fourier optical analysis of the system has been done by the use of result of aberration analysis of the surface deformation of the Be-mirror. The correction of this effect is also described.

1 INTRODUCTION

The beam profile monitor based on an imaging of the synchrotron radiation will give a visible beam profile, which greatly improves the efficiency of the commissioning of the new high brilliance configuration of the Photon Factory[1]. In this configuration , the beam emittance is designed to 27nmrad in horizontal. An expected beam size will be σ_x : 352µm,σ_y : 74µm. To measure the such a small beam size, we design a beam profile monitor by means of imaging the visible SR beam. The image of the beam will be blurred by not only diffraction effect but also an aberration introduced by the extraction. A strong power of the SR beam deforms the extraction mirror. We present a design of the optical beam profile measurement system for high brilliant configuration of the Photon Factory and a correction of blurred image in this paper.

2 EXTRACTION OF THE VISIBLE SR AND MEASUREMENT OF THE DEFORMATION OF BE-MIRROR

The extraction mirror must withstand the maximum angular power of the synchrotron lights given in Table 1. Because of small absorption of X-rays, water-cooled Be-mirror was constructed as a extraction mirror for the visible SR beam. A effective area of the mirror is 50 mm x 50 mm. The thermal design of the mirror was optimized by computer code ANSYS. The outline of the Be-mirror is shown in Figure 1.

Table 1 Parameters of the bending magnet angular power of the SR light and beam sizes.

Bending radius	8.66m
Dipole filed	0.96T
Angular power of SR	13.2W/mrad at 350mA
Beam size (135deg lattice)	σ_x : 352µm,σ_y : 74µm

Even the small absorption of the X-rays, a thermal deformation of the optical flatness of the mirror can exceed the tolerance of the diffraction-limited optics such as Rayleigh's criterion(about the wave front error larger than l/8λ).

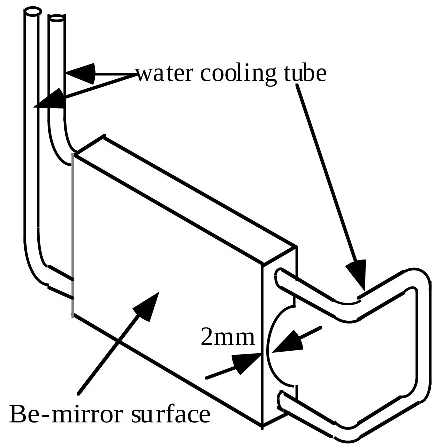

Figure1 Design of the Be-mirror.

The mirror deformation is also caused by the mechanical stress of mounting and cooling water. The initial quality of the surface flatness of the Be-mirror was l/4λ (λ=630nm). After a 150˚C baking, the mirror surface was deformed permanently. The surface flatness is always watched by a Fizeau-type interferometer within a precision of 1/20λ. A result of interferometry of the mirror surface without SR beam irradiation is shown in Fig.2. The Be-mirror was deformed to cylindrical way in the horizontal about 2.36µm peak to valley.

The vacuum chamber for the Be-mirror has two vacuum-tight optical windows, one is for extracting the visible SR beam and other is for the interferometer. The window systems consist of two optical flats those place in series. The optical flats are made of BK7 and SF11, those having a surface quality of l/10λ (λ=630nm). The first window separates ultra-high vacuum of the ring and next high vacuum room(10^{-6}Pa). The second window separates the high vacuum room and the atmospheric environment.

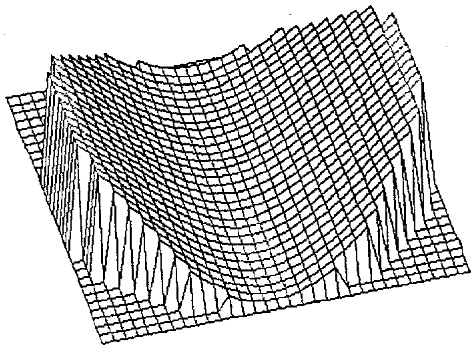

Figure 2. Surface deformation caused by 150˚ C baking. The side length of three dimensional plot is 50mm

3 FOCUSING SYSTEM

The optical image of the beam is produce by a diffraction limited focusing system placed in the experimental room under the accelerator tunnel. The focusing system consists a doublet lens MELLES GRIOT LAO366 having a diameter of 80mm and focusing length of 1000mm which optimized to the wave length of 546.1nm and a magnification lens system. The residual geometrical aberration by the lens is negligible small and image will be diffraction limited near by on axis. A quadrant slit is applied just in front of the focusing lens to define the entrance aperture. A band pass filter having a band width of 10 nm is applied for obtaining quasi-monochromatic lay at 550nm. The transverse conjugate ratio of the objective lens is arranged to 0.148. An amplitude transmittance of the entrance pupil is modified by a vertical angular intensity distribution of the SR. To create a simple generalized pupil function, an apodization for the entrance pupil of the system is applied for the entrance people of the lens.

4 FOURIER OPTICAL ANALYSIS OF THE FOCUSING SYSTEM INCLUDING ABERRATION OF THE BE-MIRROR

The finite aperture of the entrance pupil of the focusing system produce a diffraction. With the Fresnel approximation of the diffraction theory and the paraxial lens transfer function, the point spread function (PSF) of the system is a Fourier transform of the generalized pupil function of the system[2]. A wave front error caused by a deformation of the Be-mirror treated by means of wave front aberration in these approximation. A Zernike's aberration coefficients are evaluated from the surface deformation of the mirror as shown in Figure 2 by the least squire fitting of the complete Zernike's power series. The result of first 8 terms of the Zernike's aberration coefficients are listed in table 2. The discrepancy between the Zernike surface and observed surface is less than l/100λ. Because of the mirror was deformed to cylindrical way, the aberration coefficient of the fourth term (astigmatism) of Zernike's power series is large.

Table 2 First 8 terms of the Zernike aberration coefficients of surface deformation of the Be mirror.

tip of wave front	C1= 0 .0
tilt of wave front	C2= 0.0
shift from diffraction focus	C3=0.949
astigmatism	C4=2.012, C5=0.148
third order coma	C6=0.070, C7=-0.079
third order spherical	C8=-0.093

Because of the mirror was deformed to cylindrical way, the aberration coefficient of the fourth term C4 (astigmatism) of Zernike's power series is large.

To obtain the PSF at the balanced astigmatism point, the propagation of the wave front error is calculated by a computer code ZEMAX by the use of these aberration coefficients. A result of the PSF is shown in Fig.3. The rms widths of the central peak of the PSF are 11μm in vertical and 12.0 μm in horizontal. The image of the beam is given by a convolution of the PSF and the geometrical image.

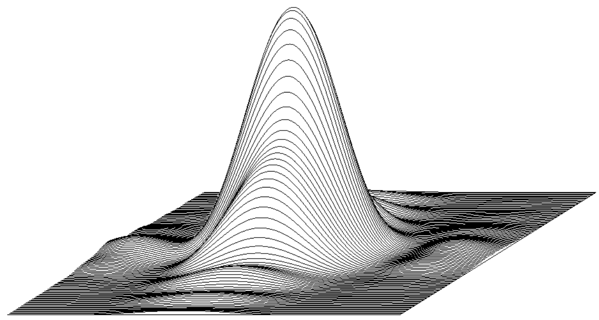

Figure 3 The PSF at the balanced astigmatism point. The side length of the 3-dimensional plots is 108μm.

5 MEASUREMENT OF THE BEAM PROFILE AND DECONVOLUTION OF PSF

We measured a beam profile in the present Photon Factory operated with the ring energy of 1GeV. With the 1 GeV operation of the ring, estimated natural emittance will be 20.7 nmrad and it is almost same value as in the high brilliant configuration. To avoid further deformation of the mirror by heat of the SR beam, the beam profile was measured at the stored current of 1mA. The focus of the system was carefully adjusted at the balanced astigmatism point. A CCD TM7/4915 and image processor LBA100A of Spiricon company was used to observe the beam image.

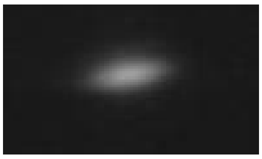

Fig.4 A beam image of the Photon Factory. The ring energy is 1GeV and the beam current is 1mA.

The rms beam sizes from the beam image are 96.5 μm in the vertical and 280μm in the horizontal. The raw image of the beam as shown in Fig.4 is given by a convolution of the PSF (Fig.3) and the geometrical image. Considering the conjugation ratio of 0.148, the rms width of the PSF is almost same size as in the beam size. Therefore, to observe the original beam size, it is necessary to deconvolute the raw image by the PSF. Recently, deconvolution technique (restoration of the image) is currently used in the astronomical observation[3]. In the present time, a Wiener inverse filter [4] was applied. In the spatial frequency domain, the convolution integral is represented by

$$G(u,v)=H(u,v)F(u,v) + N(u,v) \qquad (1)$$

where G denotes a two dimensional Fourier transform of blurred image, H is thought of as a inverse filter (two dimensional Fourier transform of PSF) , F is a two dimensional Fourier transform of original image, and N is as a two dimensional Fourier transform of noise term in the image. The Wiener inverse filter H_W in equation (1) is given by

$$H_w(u,v) = \frac{H^*(u,v)}{|H(u,v)|^2 + \frac{\phi_n(u,v)}{\phi_f(u,v)}} \qquad (2)$$

where the asterix indicates the complex conjugate of H. ϕ_n is the power spectra of the noise and ϕ_f is the power spectra of the signal. In the present time, the raw image was taken at the balances astigmatism point, we neglect asymmetric components of the obtained PSF as shown in Fig.3, and use a Gaussian approximation as the PSF. To perform the deconvolution process, we use the computer code Hidden Image which has the maximum entropy deconvolution method. A result of the deconvolution is shown in Fig.5. The rms beam sizes from this beam profile are 49.2 μm in the vertical and 206μm in the horizontal. By the use of measured values of β function, The emittance at 1GeV operation of the ring are 0.13 nmrad in the vertical and 22 nmrad in the horizontal.

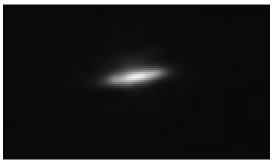

Fig. 5 Beam profile after deconvolution process, scale is same as in Fig.4.

6 CONCLUSIONS

A beam profile monitor for the high brilliant configuration of the Photon Factory was designed and constructed. A Be-mirror was applied as a extraction mirror of The visible SR beam. We have analyzed aberration of the focusing system including the deformation of the Be-mirror in the Fourier optical manner, and obtained a PSF at balanced astigmatism point. We measured a beam profile of the Photon Factory with a ring energy of 1GeV at the balanced astigmatism point of the focusing system. By the use of obtained PSF and beam profile image, we applied the image restoration method. After the image restoration process, we obtained a beam emittances 0.13 nmrad in the vertical and 22 nmrad in the the horizontal. We conclude; 1. the present system has a enough performance to measure the small enittamce in the high brilliant configuration of the Photon Factory; 2. the image restoration technique with measured PSF as used in the astronomical observation is very useful tool not only to eliminate the aberration of the focusing system but also obtaining the geometrical image.

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