BEAM PROFILE MONITER BY ADAPTICE OPTICS

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Abstract

A beam profile monitor by the use of adaptive optics system was constructed and tested for the design study of SR monitor for B-factory. The Shack-Hartmann wavefront sensor was designed and constructed for a measurement of wavefront error caused by a deformation of an extraction mirror for visible synchrotron radiation. An adaptive optics system was designed by the use of a deformable mirror having 31 actuators. The performance of the monitor was tested at Photon Factory. The wavefront error was corrected better than λ/5 in rms. The observed blurred image of the beam was well corrected.

1 INTRODUCTION

The beam profile monitor based on an imaging of the synchrotron radiation (SR) is generally used as a diagnostics of the high energy circular accelerator [1]. The monitor gives a visible beam profile which will greatly improve the efficiency of commissioning and operation of the accelerator. In this monitor, the visible SR beam is extracted by a mirror from the circular accelerator, then the SR beam guided into a focusing system to making an image of stored electron beam. Since the SR beam has high power (often more than 10 W/mrad) and broad band spectrum (visible light to hard X-rays), the mirror will be deformed by a thermal expansion caused by absorption of X-rays in the spectrum. The deformation of the mirror introduce a wavefront error (often more than few λ (λ=633 nm)) and it makes a blurred beam image. To observe quasi-diffraction limited image of the beam, we designed and constructed an adaptive optics system[2] to correct this wavefront error. The monitor was applied to measure a beam sizes in the new high brilliant configuration of Photon Factory.

2 DESIGN OF ADAPTIVE OPTICS SYSTEM FOR THE COMPENSATION OF WAVEFRONT ERROR

2.1 Design of the adaptive optics system

We designed the adaptive optics system to compensate a wavefront error caused by the deformation of extraction mirror. The wavefront error is transferred on the deformable mirror using a relay lens system (1:2) and compensated by deformable mirror. A schematic drawing of designed adaptive optics system for the monitor is shown in Fig. 1. The wavefront error caused by extraction mirror is watched by one Shack-Hartmann wavefront sensor [3]. The wavefront error caused deformable mirror is also watched by second Shack-Hartmann wavefront sensor. We use a deformable mirror CILAS BIM31 which is a "bimorph" type mirror having 31 electrodes in the behind of the mirror surface. After the wavefront correction, SR beam will pass through a band pass filter (500nm+/-5nm) and polarisation filter (choose σ component), then it focused by a doublet lens. The image of the beam was observed with a CCD camera.

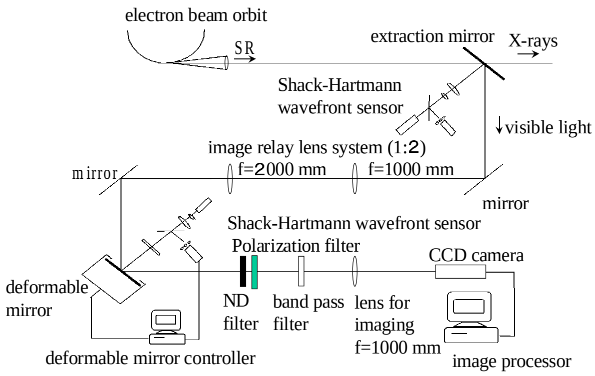

Fig. 1 A schematic drawing of adaptive optics system for the monitor

2.2 Wavefront sensing

We designed and constructed the Shack-Hartmann wavefront sensor to measure a wavefront error caused by the deformation of extraction mirror[4]. The outline of the Shack-Hartmann wavefront sensor is shown in Fig.2. The sensor consists a multi-lens array , two image relay lens systems and a CCD camera. The wavefront error caused by a deformation of the extraction mirror is transferred on the multi-lens array by an image relay lens system (20:1) and transferred wavefront error is sampled by each lenslet. In the focal plane of the multi-lens array, the image spot of each lenslet is shifted by a quantity proportional to the local slope of the wavefront. Then the image plane of the multi-lens array is again transferred on the CCD camera by an image relay lens system (1:1), and measure the position of the image spot. We can measure the rms. spot displacement by 1/10 of the pixel, then the corresponding sensitivity is λ/20 (λ=633 nm).

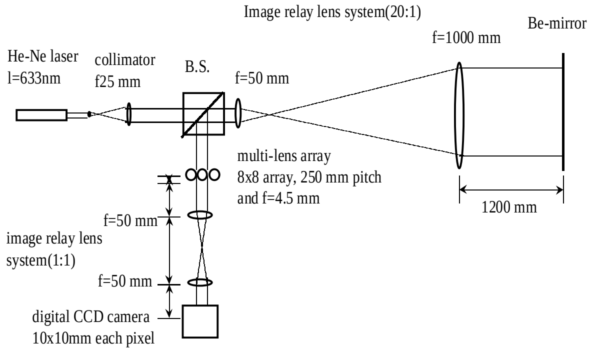

Fig.2 Outline of the Shack-Hartmann wavefront sensor for the SR extraction mirror.

3 BEAM PROFILE MEASUREMENT BY ADAPTIVE OPTICS SYSTEM AT PHOTON FACTORY

The monitor was applied to measure the beam profile in the high brilliant configuration at Photon Factory. An estimated natural emittance will be 30nmrad. The correction of wavefront distortion was performed at the stored beam currents 12.6mA and 92mA. The control of the deformable mirror is performed by a linear control system. The wavefront error is one time expanded into the Zernik's circular polynomials[5]to obtain the Zernike's aberration coefficients [5]. Then this wavefront represented by Zernike's aberration coefficients is assumed to a wavefront which is given by linear combination of response functions of each channel of the deformable mirror. Since the real wavefront given by the simultaneous excitation of the actuators is not linear, we measure the constructed wavefront again and make a feedback loop to obtain sufficient small wavefront errors. Remaining peak to valley and rms. wavefront errors during the feedback are shown in figures 3 and 4.

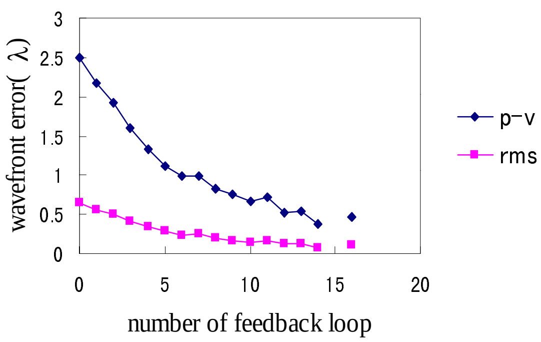

Fig.3 Remaining peak to valley and rms. wavefront errors during the feedback at 12.6mA.

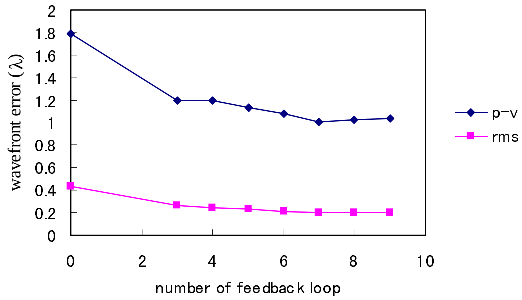

Fig.4 Remaining peak to valley and rms. wavefront errors during the feedback at 92mA.

The remaining wavefront errors reduced to less than λ/5 in rms. after the 5 to 8 feedback loops. Since the Rayliegh's criterion of diffraction limited optics is λ/4, we can observe quasi-diffraction limited image after wavefront correction. The statuses of wavefronts before and after corrections at the ring current 92mA are shown in Fig. 5. In this figure, remaining wavefront error is also shown.

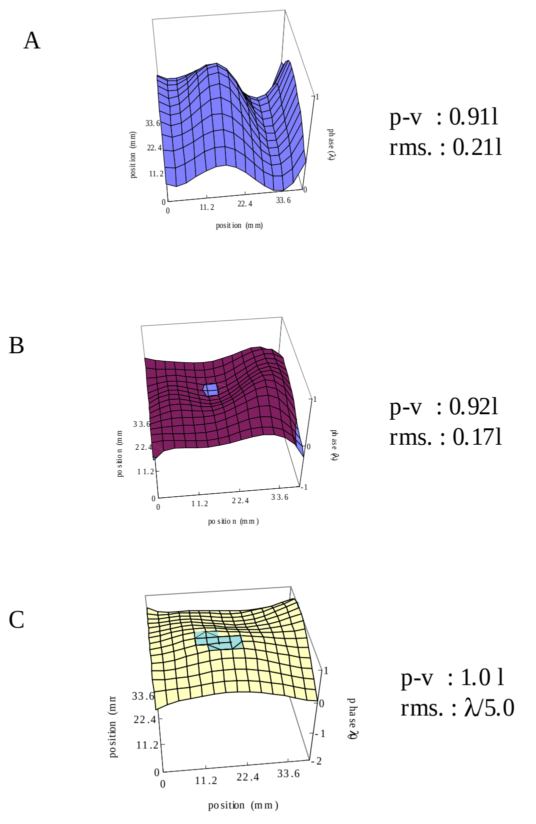

Fig.5. Results of wavefront correction at beam current 92mA. A: wavefront by SR extraction mirror, B: wavefront by deformable mirror, C: summation of A and B.

The results of observed image of the beams are shown in figures 6 and 7.

uncorrected image σ_x=430µm σ_y=240µm corrected image σ_x=255µm σ_y=139µm

remaining wavefront error p-v : λ/2.7, rms. : λ/12.5

Fig.6 Observed beam image at beam current 12.6mA.

uncorrected image σ_x=250µm σ_y=237µm corrected image σ_x=254µm σ_y=139µm

remaining wavefront error p-v : λ/2.7, rms. : λ/5.0

Fig.7 Observed beam image at beam current 92mA.

From these figures, the images of beam were well corrected.

4 HORIZONTAL BEAM SIZE MEASUREMENT BY MEANS OF DIFFRACTION CORRECTION

Since the adaptive optics system gives us a quasi-diffraction limited image of the beam, we can make a correction of diffraction effect in the horizontal beam size measurement. In the horizontal plane, entrance pupil was illuminated uniformly by the SR, we can calculate the diffraction patterns of each conditions to apply the remaining wavefront error to entrance pupil of the focusing system. Results of this calculation for horizontal sizes of diffraction peak are 89.2µm for 12.6mA and 89.3µm for 92mA respectively. The results of horizontal beam sizes after diffraction correction are listed in Table 1. The estimated horizontal beam size under the beam emittance 29nmrad is also listed in Table 1.

Table 1 Results of horizontal beam size

	12.6mA	92.0mA
observed beam size	430µm	250µm
with wavefront correction	255µm	254µm
with diffraction correction	238µm	237µm
estimated beam size	237µm	237µm

In the vertical plane, intensity distribution of the SR is not uniform, it is rather difficult to calculate the expected diffraction pattern. The vertical beam profile and the size can measure by the use of SR interferometer [6],[7].

5 CONCLUSIONS

A beam profile monitor by the use of adaptive optics system was constructed. SR monitor for B-factory. The Shack-Hartmann wavefront sensor was designed and constructed for a measurement of wavefront error in the precision less than λ/20. The performance of the monitor was tested at Photon Factory. The wavefront error was corrected better than λ/5 in rms. The observed blurred image of the beam was well corrected. The results of measured beam sizes are good agree with the estimated beam sizes those are evaluated from the beam emittance 29nmrad. The developed adaptive system will be applied to the SR monitor for B-factory.

6 ACKNOWLEDGMENTS

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7 REFERENCES

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