THE SYNCHROTRON RADIATION DIAGNOSTIC LINE AT SSRF*

J. Chen, Z.C. Chen, Y.B. Leng, G.Q. Huang, W.M. Zhou, K.R. Ye,
SINAP, Shanghai, 210200, China

Abstract

The synchrotron radiation photon beam line has been operated since 2009 at Shanghai Synchrotron Radiation Facility. There are two diagnostic beam lines of the storage ring behind bending magnet, which is employed conventional X-ray and visible imaging techniques. A synchrotron radiation (SR) interferometer using visible light region in order to measure the small transverse electron beam size (about 22μm), low emittance and a low coupling. A small off-axis mirror is set for the convenience of the observation. Wave front testing is used for interferometer to calibrate the deformation effect of optical components. An X-ray pin-hole camera is also employed in the diagnostics beamline of the ring to characterize beam. Typically the point spread function of the X-ray pinhole camera is calculated via analytical or numerical method. Those two methods check each other. As a result, the measurement with SR system has quite enough resolution of itself even though the absolute beam size acquired. This existed system suffices with dynamic problem for beam physics studies. It has been measured 2.8nm.rad in small emittance mode at SSRF.

GENERAL OVERVIEW

For SSRF 3.5Gev storage ring, the emittance is 3.9 (nm.rad). The Beam profile size, horizontal σx is 53μm and vertical σy is 22μm by the use of 1% vertical coupling. The monitor should be able to measure a small transverse beam dimension and motion.[1] So interferometer is one of better equipment to measure this order beam size. It is located at the 3^0 end of the $2^{\#}$ bending magnet of the first cell in the ring. A unique diagnostics line has been working. We also have imaged the beam profile at the SSRF using x-ray synchrotron radiation (XSR) at the $(0.8)^0$ end of same magnet, a selectable pinhole aperture. A unique synchroscan and dual-sweep features of visible streak camera has been used since 2009. Both transverse beam size and bunch length have been determined by this beamline.

The vertical opening angle of visible SR is roughly 3mrad. 4mrad opening will be available in the horizontal direction. The visible part of the synchrotron radiation is reflected by water-cooled Beryllium mirror. Using those two lines, we can characterize the electron beam size, phase-space ellipse and emittance. X-ray has been fetched directly from Al window. Synchrotron radiation monitor measures beam profile and beam size of the synchrotron radiation light source for performance optimization, routine operation check and various beam physics study. It is described those dedicated diagnostics beam lines, and measurement equipments such as SR interferometer, x-ray pinhole and streak camera etc. in this paper. There are the general design of the SRM, extraction mirror design, and measurement equipments. Using this monitor, we can characterize the electron beam size, phase-space ellipse and emittance. It will be shown some results also.

*Work supported by Shanghai Institute of Applied Physics

INSTRUCTION

The source point of SRM is bending magnet near injecting point. The synchrotron light is extracted by a water-cooled beryllium mirror. Then three mirrors guide the light to the dark room. The synchrotron light interferometers [2] [3] is set in the dark room and they measure horizontal and vertical beam sizes. Also a focusing system is applied to obtain the image of beam profile. The setup of all diagnostic beam line, it is include interferometer, x-ray pinhole camera and streak camera.

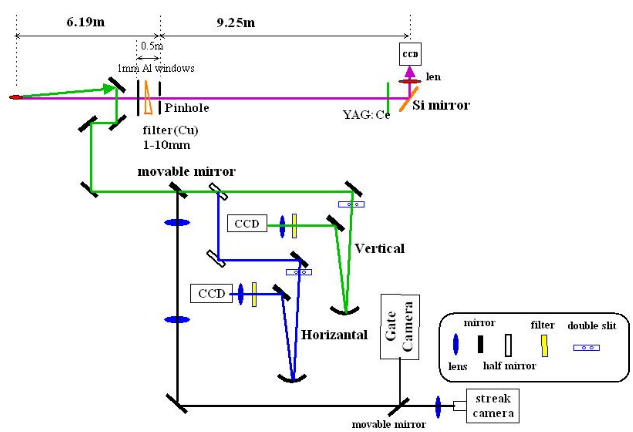


Figure 1: Schematic layout of the Optical Diagnostic Beamline viewed.

The basic layout and main components of the SSRF diagnostic beam line are shown in Fig. 1.

About this system detailed described is in the follows.

INTERFEROMETER & APPLICATION

The first mirror is set 9m apart from the source point, which reflects the visible light by 90° downward. Thermal distortion of the Be mirror for a given absorbed heat load by X-rays is simulated using the technique of finite-element analysis. We designed the mirror shape having a parabolic shape in the backside. Most of the X-ray will pass through the central thin part of the mirror.

The deformation of the mirror has been studied in detail in comparison with other materials. The result shows Be is best material for the extraction mirror.

ISBN 978-3-95450-119-9

Thermal Distortion Analyse

A thermal-mechanical analysis with electron beams show: the thermal distortion values for metals between 0^0C to 400^0C, these effects were especially good in Beryllium mirrors .The deformation of Be mirror is simulated by ANSYS and XOP for varying the shape, size, and diameter of cooling tube. We fixed outer-dimension of beryllium mirror is 80mm(wide), 60mm(high), 12mm(thickness). With the diameter of water-cooling tube will 8mm, the centric deformation of mirror surface results 3.9µm with inlet water temperature 26^0C. The highest temperature of mirror will be 56^0C.

Actually, the key point for interferometer design of the mirror is to make deformation smooth and symmetry about the centre of mirror. It isn't important for interferometer that 1 to 2 µm deformation of the mirror. The Calibration of interferometer has been done with ray trace technique. So, the beryllium mirror with two cooling tube which haves a parabolic shape in backside is applied in the SSRF. In the future, two parabolic shape Be mirrors in the backside, as shown in Fig. 2, can be employ extraction mirror on the way. One for daily monitors another one for interferometer measurement. The deformation will be getting small than one mirror. It will be install on beam line in the future.

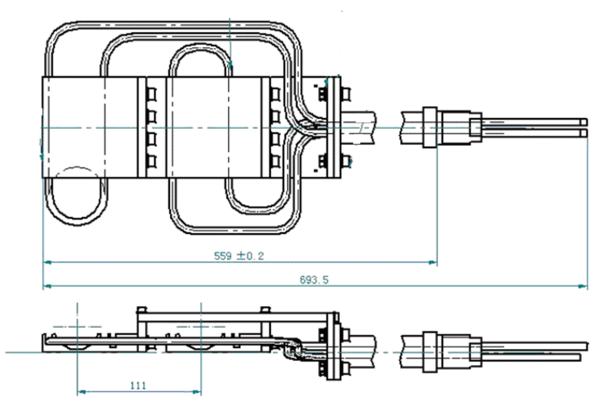


Figure 2: The construction of two Be mirrors.

Motor control can help us to select mirror. Small deformation place will be fetching light. The Point Grey Flea®2 is designed to have the form factor of similar industry standard analogy cameras to get interferometer pattern. Two Harsherian-type reflective SR interferometers are installed to measure the both of vertical and horizontal beam sizes. The double slit is set at 18 meter apart from source point. A focusing mirror, f=2000mm, is used as an objective mirror. A small off-axis diagonal mirror is set for the convenience of the observation. A band-pass filter, which has 50nm or 80nm bandwidth at 550nm, is used to limit the wavelength of input light. The σ-polarization of SR is selected by dichroic polarization filter. The arrangement of SR interferometers is shown in Fig. 3. A ray tracing method using a Hartman square mask is used to calibration of SR interferometer due to the first mirror deformation. [4]

The measuring interferogram is fitted by the intensity distribution of the form. The image analysis system works extracting the orthogonal profile, centre position, and least square fit to evaluate the beam sizes.

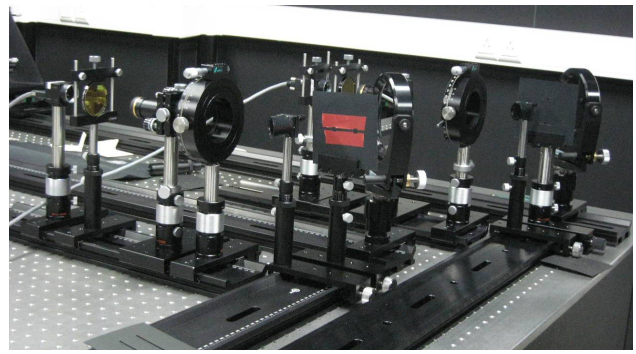


Figure 3: Arrangement of SR interferometers.

The 800Mb/s interface enables full frame rate and even more cameras on the same bus. The IEEE-1394b cable with jack screws allows a more secure connection to the camera. 12-bit A/D converter, Via external trigger, software trigger (on same bus), This equipment has been tested and found to comply with the limits for a Class A digital device, have good linearity It provide reasonable protection against harmful interference when the equipment is operated in experimental environment.

After all environments and system calibration, Interferometer is good enough for the measurement of a few µm small beam size.

Low Emittance Measurement

The very low effective emittance optics of SSRF is found out by the method of Multi-Objective Genetic Algorithm (MOGA). [5]

The main function of interferometer is to measure the beam profile size needed in the calculation of the emittance beam section size，calculated emittance from following formula (Eq.1),

$$\text{emittance}=\frac{6\pi(width^2-D^2(\frac{dp}{p})^2)}{B} \quad (1)$$

D the dispersion function

$\frac{dp}{p}$ momentum dispersion function

B beta function

Width beam width

So we can get emittance from beam size.

ISBN 978-3-95450-119-9

Table 1: Beam Parameters of the Low Emittance at SSRF

Parameter / unit	Mode A	Mode B
Tune (H, V)	23.313, 11.232	23.309, 11.238
Natural emittance / nm.rad	**3.4±0.2**	**2.9±0.2**
design emittance / nm.rad	**3.51**	**2.88**
Natural chromaticity (H, V)	-58, -17	-67, -23
Corrected chromaticity (H, V)	1.5, 1.0	2.0, 3.0
Momentum compaction factor	(4.1±0.2)×10-4	(4.2±0.2)×10-4
Synchrotron frequency	0.0073±0.0002	0.0074±0.0002
Coupling	0.4%	0.5%
Beam current / mA	210	210
Beam lifetime / hrs	16.5	15.0
Injection efficiency	>90%	~50%
RMS beta beatings (H, V)	0.6%, 0.7%	0.7%, 0.8%

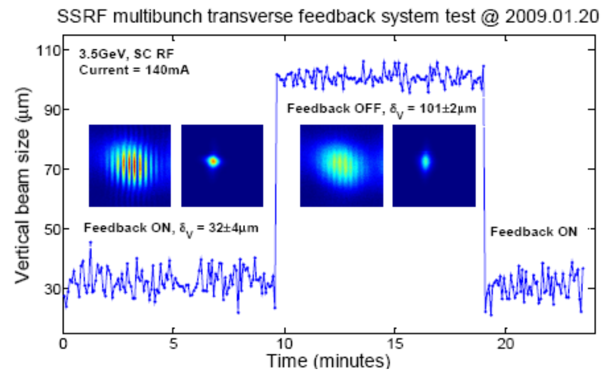
Interferometer is used to acquire beam size in order to determine the extent and study to get small the emittance at SSRF. The measured beam parameters in 2011 are summarized in Table 1. For mode A the design emittance is 3.51 nm.rad, measured natural emittance is 3.4±0.2. Also for mode B the design emittance is 2.88nm.rad, measured natural emittance is 2.9±0.2 , which shows a good agreement with theory.

It is useful to solve how much is the available lowest emittance and thus increase photon brightness.

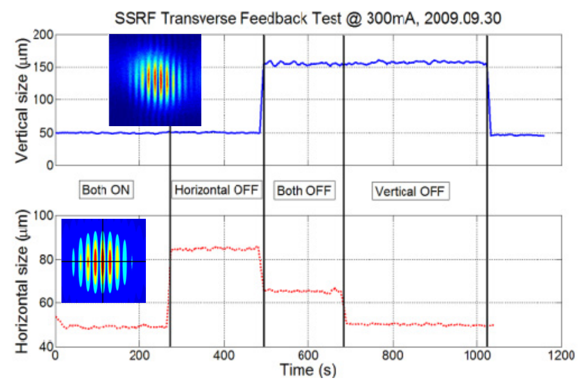
Adjusting Transverse Feedback

SSRF has been operated for users' experiments since May 2009. Transverse feedback system is useful to keep beam instability. The interferometer is used to watch the effect of transverse feedback system. The beam size measurement also used to adjust the transverse feedback system for SSRF storage ring. It is shown as in Fig. 4.

When beam current is getting higher than 40mA, the vertical beam size is getting large. If beam current changes from 40mA to 100mA, the vertical beam size will be getting larger from 35 um to more than 100 um. When the multi-bunch transverse feedback is work; the vertical beam size becomes smaller and stable. The observed beam size with transverse feedback is 35 um just same as in the low current. The variation is observed for x, y coupling parameters from those measurements. It is benefit for the adjustment phase of transverse feedback system.



(a)



(b)

Figure 4: (a) the interferograme and beam image variation for feedback on or off; (b) X and Y beam size variation for feedback on or off.

X-RAY PINHOLE IMAGING

Pinhole cameras provide a well known means to image the light of synchrotron radiation in the x-ray regime. The basic layout and components of the SSRF pinhole camera are shown in Fig. 1.

The X-ray beam from the bending magnet, alternatively the pinhole is installed after the aluminum window, which transmits only the high energy photons from vacuum to air. Putting the pinhole assembly outside the vacuum chamber simplifies design and maintain of the beamline but sacrifices achievable resolution.

The point spread function was found by summing over all wavelengths and was fitted with the Gaussian curve. The resultant rms width was used as the resolution of the system [6].

A pinhole array combined by two sets of tungsten slits, in horizontal and vertical directions, is placed behind the Al window, as close as possible from the source, 6.19 m in our case. The X-ray image of the pinhole camera was converted into a visible light image at peak wavelength of 530 nm with a YAG screen (thickness: 400 μm). The screen is placed at 9.25 m away from the pinhole, so that the image is magnified by a factor of 1.5 [7]. There are using a YAG/Ce crystal to convert the X-rays to visible light, A small Si mirror reflect image to CCD camera.

ISBN 978-3-95450-119-9

Then this is read out through an optical system and a CCD camera.

A block of 1mm-10mm variable wedge shaped copper is attenuator. It can move up and down by step motor to change attenuation values to select different energy X-ray.

A macro-lens 2.8/50 and a compact IEEE 1394 CCD camera get image from YAG screen scintillator. It has an 80-ns response time and be recorded by a CCD camera. An online video digitizer processes the data at a 30 Hz rate.

Fig. 5 shows the beam size comparison of calculation and measurements. It is obvious that the experimental data has good agreement with modelling data, which verifies the good usability and reliability of SSRF X-ray pinhole camera.

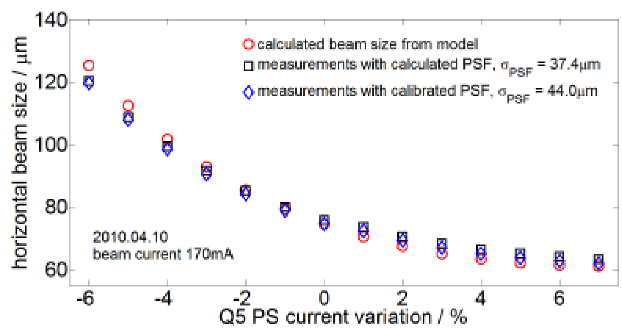


Figure 5: Comparison of calculated beam size and measured beam size.

The performance of the measurement of the transverse electron beam size is given by the width of the point spread function (PSF) of the X-ray pinhole camera. The contributions to the PSF width are the PSF of the pinhole itself due to diffraction, and the PSF of the X-ray camera. The widths of these two contributions add quadratically to the total resolution of the X-ray pinhole camera, in the approximation of a Gaussian PSF.

Let A is the aperture of a rectangular shaped pinhole. The contribution of the diffraction for a monochromatic photon beam of wavelength is given analytically by formula (Eq. 2).

$$S_{diff} = \frac{\sqrt{12}}{4\pi}\frac{\lambda d}{A} \tag{2}$$

A simple geometrical computation shows that S_{aper} can be expressed as formula (Eq. 3) [8],

$$S_{aper} = \frac{A}{\sqrt{12}}\frac{D+d}{d} \tag{3}$$

d is the distance from source point to pinhole.
D is the distance from pinhole to screen.

X-ray pinhole cameras are widely used due to simple setup and high practical reliability. Typically a pinhole based emittance monitor has a limited resolution of > 10 μm. Recent calculations taking into account the spectral distribution of the source and applying numerical methods to precisely evaluate the diffraction have shown that with the correct choice of pinhole size and magnification a better resolution can be achieved. Precise calculation or calibration of the point spread function of the whole system is required in this case [9].

By varying the beam size S at the source point and measuring image size $\sum$, the practical Ssys can be derived from Eq.4 using least-square fitting method.

$$\Sigma = \left[(s\frac{D}{d})^2 + S_{sys} \right]^{1/2} \tag{4}$$

A new beam based calibration method had been developed in the SSRF storage ring.

The high level physical application environment has been set up and done the online test of device control using MatLab and middle layer with the SSRF centre database.

STREAK CAMERA

Bunch length measurements is performed with a streak camera (HAMAMATSU C5680) that uses a scan streaking of 125MHz (1/4 RF) and also dual time streaking is available. As shown in Fig. 1. The attainable phase stability is good: less than 2ps, and a bunch separation of 2 ns, while the revolution frequency is 694 KHz. The synchroscan unit operates at 125 MHz allowing the bunch train to be analysed bunch-by-bunch, even bunches on one sweep and odd bunches on the return sweep. The temporal resolution of the synchroscan unit is less than 2ps which will allow an individual bunches to be resolved clearly and analyzed.

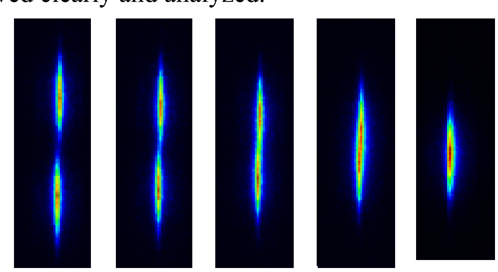


Figure 6: The drifting between bunches while beam injection.

Fig. 6 shows the drifting of bunch to bunch when beam injection in 10 seconds. Streak camera represents the temporal profile of the light impulse. Diagnostic beam line receives visible SR from a standard dipole magnet. Bunch length measurements are made by imaging the source onto the input slit of a dual-axis Hamamatsu C5680 streak camera. It will be benefit to study beam instability, combining with the analysis of another diagnostics monitors.

DATA ACQUISITION AND CONTROL

Application software is located at workstation /Unix and PC/Linux control console, supporting commercial software Matlab and LabVIEW.

PXI IOC software can be separated into two parts. The first part is LabVIEW low level application, which is developed in house, to complete raw data acquisition and

ISBN 978-3-95450-119-9

signal processing. The second part is the Shared Memory IOCcore and SM LabVIEW library, which is developed and maintained by SNS/ORNL, to implement the interface between low level LabVIEW application and EPICS CA server.

A LabVIEW and shared memory IOC core technique-based application has been developed to control the camera and communicate with the control system through EPICS CA protocol. The x and y position of the CCD, and the x and y position and angles of the pinhole array can be remotely adjusted. On the optical path, second and third mirror also can control for synchrotron radiation light fetch.

The timing card (Event receiver) is a standard VME bus module used by many laboratories, which driver package is supported by EPICS community. It has been worked for streak camera trigger control.

CONCLUSIONS

Preliminary commissioning of the SRM is performed; the glass window has been used to overcome the effect of air flow. The linearity between electron beam intensity and radiation image intensity in such system is good. Accompany with neutral density filter. The dynamic range can be extended to 10^3 and with excellent linearity.

The SR monitors measure the beam size, and bunch length etc. Beam size of electron in storage ring has been achieved. The transverse RMS beam sizes in both horizontal and vertical direction are measured in the rage of a few mA to 200mA by synchrotron radiation interferometer successfully. The results of vertical beam size measurement for beam regulation. When beam current is 200mA, using a wave length λ = 550nm, with acquired data 600 times, the observed horizontal beam size is 52.3±0.4um and it is good agreed with designed value. The observed vertical beam size is 34.3±0.4um, and it is stable with transverse feedback system. From this observed vertical beam size, eminttance coupling is 1.2%.

The very effective emittance 2.9±0.2nm.rad of SSRF was found, when coupling is 0.5%, by SR interferometers to measure the beam sizes.

The X-ray pinhole camera is an imaging system to obtain a profile of electron beam normally and its point spread function has been calculated via analytical or numerical method. Interferometer and x-ray pinhole camera, those two methods check each other in the operating.

ACKNOWLEDGEMENTS

The authors would like to thank everyone who contributed to this design through discussions and suggestions. In particular， we appreciate T. Mitsuhashi supports and advices for the constructing this system. The authors express thanks for discussing with physical group colleagues. The support provided by the Technical Services Division in particular the colleagues in the mechanical, vacuum, alignment and control groups.

REFERENCES

[1] T. Mitsuhashi, "Beam Profile and Size Measurement by SR Interferometer" in Beam measurement, Ed. by S.Kurokawa, et al., P399-427, World Scientific (1999)

[2] T. Mitsuhashi, "Measure of Small Transverse Beam Size Using Interferometer" DIPAC 2001, P26-30.

[3] Y. Yamamotoa, I. Sakaib, T. Mitsuhashic, D. Amanod, H. Iwasaki, "Interferometric measurement of the beam size in the compact storage ring," Nucl. Instr. and Meth, A467–468 (2001) P921–924

[4] K.R.Ye, Y.B.Leng, J.Chden, etc., "Synchrotron Radiation Monitor and Mirror at SSRF," Proceedings of DIPAC09, P381-383 Basel, Switzerland

[5] S. Q. Tian, B. C. Jiang, M. Z. Zhang, J. Chen, and et al, "Design and commissioning of the very low emittance optics in the SSRF storage ring," IPAC 2012

[6] Preliminary Design of Pinhole Camera for NSLS-II Project, BNL-82324-2009-CP

[7] Leng Yong-Bin *et al.,* "The beam-based calibration of an X-ray pinhole camera at SSRF, "2012 *Chinese Phys. C* 36 80

[8] P. Elleaume, C. Fortgang, C. Penel, et al., "Measuring beam sizes and ultra-small electron emittances using an X-ray pinhole camera," J. Synchrotron Rad. 2 (1995)

[9] C. A. Thomas and G. Rehm, "Pinhole camera resolution and emittance measurement"

ISBN 978-3-95450-119-9