

# RECENT BEAM SIZE MEASUREMENT RESULT USING SYNCHROTRON RADIATION INTERFEROMETER IN TPS

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## Abstract

Taiwan Photon Source (TPS) was under commissioning operation in 2015. An optical diagnostic beam line was constructed in TPS 40th beam port for the diagnostics of the electron beam properties. A synchrotron radiation interferometer, one instrument of this diagnostic beam line, operates for monitoring the beam size. In the beginning, the interferogram of the vertical beam is usually distorted. We found the stray light affected the vertical interferogram obviously while the beam current was raised. This paper describes the problems we met and how to eliminate the stray light for better beam size estimation. In the normal course of events, TPS is driven in 300mA and the horizontal beam size is 56 $\mu$ m and the vertical beam size is 32 $\mu$ m. The beam current of TPS is maximumly driven to 518mA in June, 2016. This paper also presents the trend of beam size during current running up.

## INTRODUCTION

Taiwan Photon Source (TPS) was commissioned in 2015. The electron beam has stored in the storage ring of current 518 mA and energy 3 GeV in June 2016. The beam is operated at 300 mA for normal operation and the current is also rising up to 518mA for machine study.

To measure the transverse beam size, two monitors are adopted in TPS 40th beam port. One is an X-ray pinhole camera and the other is a synchrotron radiation interferometer (SRI). [1] The X-ray pinhole camera is installed in the vacuumed chamber inside the shielding wall. And the beam line is also extended to the experiment area by using several folding mirrors to transport light to pass through the shielding wall. The SRI is installed on an optical table in a hutch lab outside of shielding wall.

In this paper we present the recent beam size measurement result and the relation of measurement result between two beam size monitors. We also present the problems we met and our countermeasures.

## PRINCIPAL OF SYNCHROTRON RADIATION INTERFEROMETER

The synchrotron radiation interferometer, presented by Dr. T. Mitsuhashi in KEK, is widely applied to monitor beam size of synchrotron light sources [2,3,4]. The basic principle of a SR interferometer is to measure the profile of a small beam through the spatial coherence of light, and is known as the Van Citter-Zernike theorem. The distribution of intensity of the object is given by the Fourier transform of the complex degree of first-order spatial

coherence. The intensity of interferogram pattern,  $I$ , is shown as the function of position,  $y_1$ ,

$$I(y_1) = I_0 \left[ \text{sinc} \left( \frac{2\pi a}{\lambda R} y_1 \right) \right]^2 \left[ 1 + |\gamma(v)| \cos \frac{2\pi D}{\lambda R} y_1 + \varphi \right] \quad (1)$$

Where  $\lambda$  denotes the wavelength,  $R$  denotes the distance from the light source to the double slit, and  $D$  denotes the double slit separation, and  $a$  denotes half-height of slits.

The visibility  $\gamma$  is related to the complex degree of coherence.

$$\gamma = \left( \frac{2\sqrt{I_1 I_2}}{I_1 + I_2} \right) \left( \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \right) \quad (2)$$

The beam size is given by

$$\sigma_{beam} = \frac{\lambda R}{\pi D} \sqrt{\frac{1}{2} \ln \left( \frac{1}{\gamma} \right)} \quad (3)$$

According to the above equation (3), the beam size is observed by the visibility of the interferogram.

## MONITOR SYSTEM SETUP

The SRI beam-size monitor is installed at TPS 40th beam port. The beam line structure is shown as fig1. The radiation produced at the dipole magnet propagates 19.2 m to pass through the shielding wall.

The main error of the visible SR interferometer arises from the distortion of the mirror by the radiation power [5]. So the first mirror of the beam line is a cooled beryllium mirror, which was adopted to prevent distortion. After beryllium mirror, the light passes the extraction window and an aluminium reflection mirror, and then it transports through the shielding wall. In the outside of the shielding wall, two folding aluminium mirrors are used to connect the synchrotron light to the optical table in hutch. Synchrotron light is separated to three channels by two beam splitter. 50% light is delicate for SR interferometer and the other 50% light is for streak camera monitoring.

The SRI beam size monitoring system is constructed by a diffraction-limited high-quality lens for focusing; the focusing length of this lens is 2 m; the wavefront error is less than  $\frac{1}{10} \lambda$ . A polarizer and a band-pass filter are used to obtain quasi-monochromatic light. The centre wavelength of the bandpass filter is 500 nm with 10 nm bandwidth. An eyepiece is applied to magnify the

interferogram on CCD; Two CCDs are applied to observe the horizontal and vertical interferograms respectively. [6]

The distances from the source point to the horizontal and vertical double slits are 22 m and 22.5m respectively.

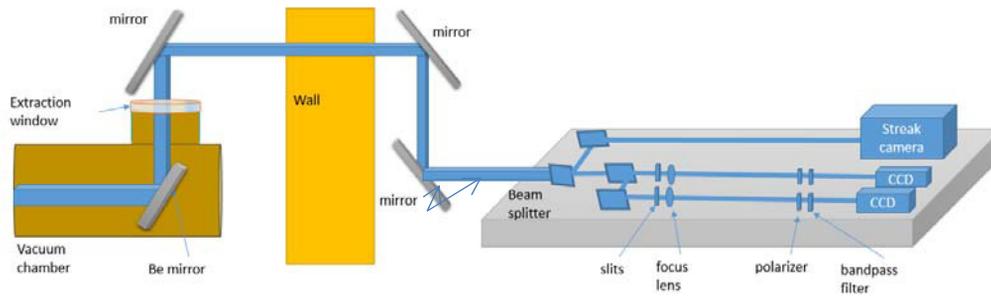


Figure 1: The optical architecture of monitors on optical table.

## TESTS AND RESULTS

### Stray light effect of vertical interferogram

The photons of the SR produce an interferogram after pass through a double slit, a focusing system, a band-pass filter, and a polarizer. By equation (3), the beam size of SRI is estimated from visibility of interference.

If the interferogram of beam is distorted, the beam size cannot be evaluated correctly. During the experiment, the interferogram pattern of the vertical direction is very sensitive to the position of the double slit; somewhere it becomes disordered, and the visibility fitting comes with huge error.

For high resolution, the half of the slit height of the double slit ( $a$ ) set as 0.5mm and slit separation ( $D$ ) set as 60mm at first. Since the slit separation is large, the spatial frequency of fringe of the interferogram is quite high, and the fringes are destroyed by background noise seriously, shown as fig2.

In order to find out the background noise, we change the vertical double slits to the horizontal channel. No matter horizontal slit at which channel, the pattern of horizontal interferogram is always intact. But the pattern of vertical interferogram is still fragmented. The stray light in background doesn't come from the optics.

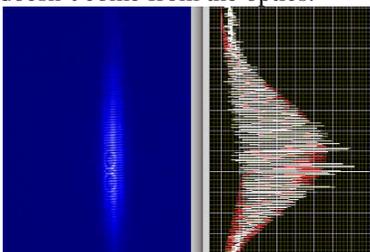


Figure 2: the vertical interferogram fringes and envelope of fringe are destroyed by stray light.

The ray trace is done for checking the optical system. The result is shown as fig3. Firstly we found the color band appears in the up and down edges of the synchrotron entrance light. The separated synchrotron lights passing through the slits of the double slit are also chromatic.

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Closing to the focus plane, an un-expected light spot point appears under the double slit light spot. The coming synchrotron light is not as parallel as designed light source.

The wide angle light is produced during light propagation and has the interference with the edge of vacuum pipe. The focus point of the edged light with wide angle is not same as the main point.

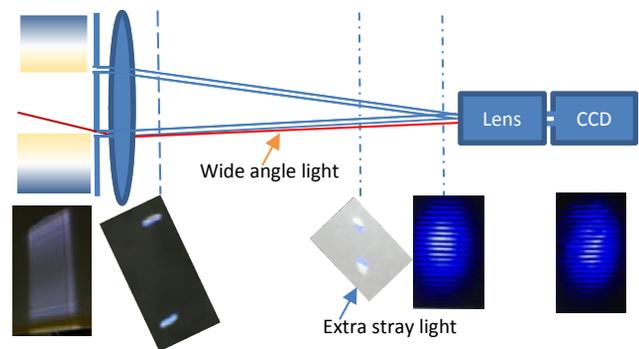


Figure3: The light distribution of ray tracing in different positions.

Several countermeasures are induced for stray light elimination. We change the vertical double slit to prevent stray light passing firstly. In order to find the most suitable coefficient of double slit, the vertical slit separation ( $D$ ) and half opening ( $a$ ) were tested with varied size. We enlarge the half opening ( $a$ ) of the vertical double slit to enhance the intensity of slit entrance light and the stray light noise level is declined. Not only increasing the SN ratio, the envelope width of the vertical interferogram is minimized when the half-height of slit opening is enlarged, shown as fig4. The magnification of eyepiece lens is increased to lower the spatial frequency of interference fringe on CCD. Eventually the half opening ( $a$ ) is chosen as 1.5 mm.

Then for eliminating the wide angle stray light, the vertical slit separations ( $D$ ) can't open too wide. The color band must be blocked for preventing entering the SRI monitor. When the slit separation was enlarged to 70 mm, the coherence of light source is poor and the interferogram is destroyed. By checking the entrance synchrotron light

which is reflected by an aluminium mirror, the width of white light without chromatic light is smaller than 50mm. The most suitable slit separation is less than 50mm. By reference to beam size error function, the recommend visibility is in the range of 0.2 to 0.8. [3] At 30um beam size level, the best separation value (D) is 40mm for system resolution compensation.

Finally, several stops were installed to decrease the stray light in the light path. The system stray light was totally blocked.

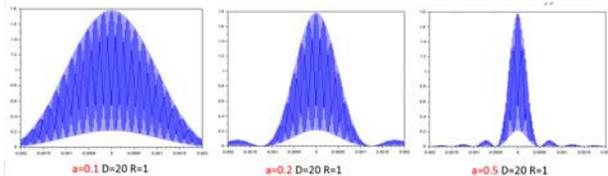


Figure 4: The interferogram variation by enlarging the half- height of the slit (a) of double slit.

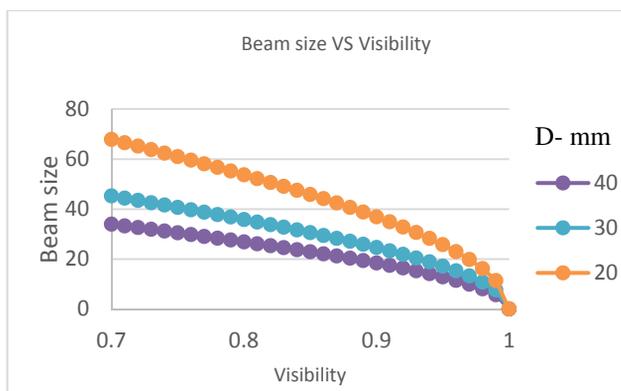


Figure 5: Beam size and visibility correlation for various double slit separation (D).

*Beam size variation for high current operation*

For a horizontal beam size monitor, the slit separation (D) is 20 mm and the half opening (a) is 0.5 mm. For a vertical beam size, the slit separation (D) is 50 mm and the half opening (a) is 1.5 mm. The horizontal beam size is 57.5µm and the vertical beam size is 35.8µm during 300mA operation.

The beam current of TPS is maximumly driven to 518mA in June, 2016. The trend of horizontal and vertical beam size during current run-up is shown as fig7 and fig 8. The measurement result of SRI has good correlation to X-ray pinhole camera.

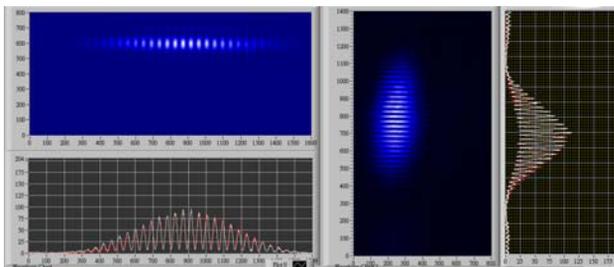


Figure 6: The horizontal and vertical interferogram image at normal operation 300mA.

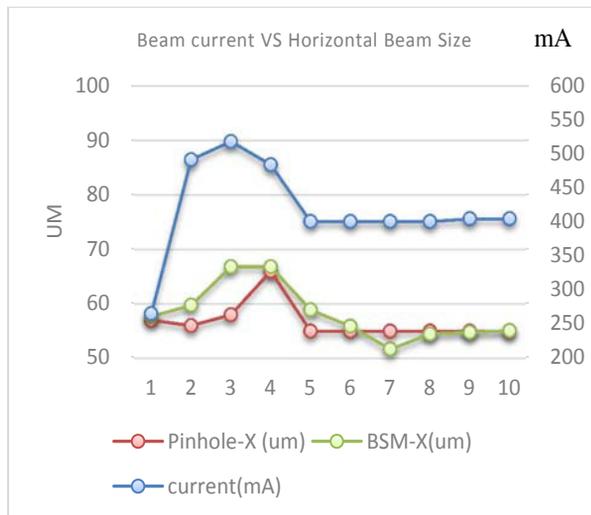


Figure 7: The horizontal beam size variation during various operation currents

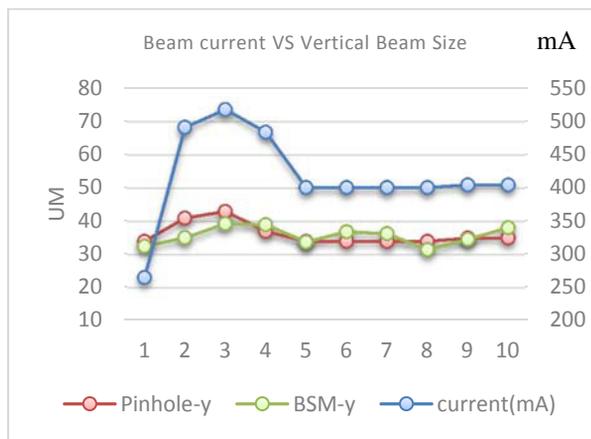


Figure 8: The vertical beam size variation during various operations current.

**CONCLUSION**

A SRI beam size monitor was installed and operated in NSRRC TPS from Sep, 2015. To minimize the measurement error of the vertical beam size, the stray light is eliminated by minimization the separation of the slit and enlarging the half-height of slit.

Since TPS starts operation, the SRI keeps monitoring the horizontal and the vertical beam sizes, the measurement result of SRI has good correlation to another instrument, pinhole camera. For improving the resolution, the intensity imbalance of the light path of the SR interferometer will be introduced to reduce the effect of the measurement error in the future.

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