STATUS OF A DOUBLE SLIT INTERFEROMETER FOR TRANSVERSE BEAM SIZE MEASUREMENTS AT BESSY II*

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Abstract

The upgrade of the BESSY II storage ring to BESSY VSR [1] demands additional beam diagnostics for machine commissioning and development. Especially bunch resolved measurements are needed. Currently, transverse beam size measurements are done with X-ray pinhole monitor systems, which cannot provide bunch resolved information. Alternative methods to measure the transverse beam size using synchrotron radiation in the visible spectrum are interferometric techniques, which could also be upgraded to bunch resolved systems. For that purpose a double slit interferometer has been constructed. Commissioning of the system has started and experimental results are discussed and compared with the existing pinhole system.

INTRODUCTION

In operation since 1998 BESSY II [1] is a third generation light source located in Berlin Adlershof from the Helmholtz-Zentrum Berlin (HZB). The electron storage ring operates at an energy of 1.7 GeV optimized for soft X-rays. There is also a dedicated low-α optics for shorter pulses than in standard user optics, offered only a few weeks per year. The planned upgrade of BESSY II to the **V**ariable pulse length **S**torage **R**ing BESSY VSR [1, 2] tries to combine those aspects, to provide intense short pulses as well as high average photon flux simultaneously.

With regard to BESSY VSR it is necessary to upgrade the machine diagnostics. Because of the different bunch types in terms of current, bunch length and transverse beam size, bunch resolved diagnostics is needed for the commissioning and development of BESSY VSR. On the other side non-invasive diagnostic techniques ensuring long term quality and stability of user operation.

This contribution focuses on measuring the transversal source sizes. At BESSY II two pinhole systems are in operation to image the source point directly [3]. Because of the diffraction limit X-ray radiation at 16 keV is used. For BESSY VSR further techniques are required, especially systems using visible light are of interest, because they could be upgraded easily to a bunch resolved system. One well understood and efficient method is the double slit interferometry [4]. While using visible light, this method can measure small transversal sizes down to a few µm and provides the possibility of bunch resolved measurements with gating techniques.

INTERFEROMETER THEORY

Interferometry methods using synchrotron radiation to measure the transversal beam size have been installed at a number of storage rings. The theory is introduced in [4] and shortly outlined in the following. The interference pattern at the detector plane for a double slit interferometer can be seen in the right panel of Fig. 2 and is given by

$$I(x) = (I_1 + I_2)\,\mathrm{sinc}^2\left(\frac{\pi a}{\lambda f}x\right)\left[1 + V\cos\left(\frac{2\pi d}{\lambda f}x + \psi\right)\right], \tag{1}$$

where x is the position at the detector, a the full single slit width, d the full slit distance, f the distance between the lens and the detector screen, λ the wavelength, ψ the photon phase, I_1 and I_2 the intensity at the slits and V denotes the visibility. The visibility of an interferogram fringe is then defined by the maximum intensity peak I_{max} and the local minimum intensity I_{min} next to the peak:

$$V = \frac{I_{\mathrm{max}} - I_{\mathrm{min}}}{I_{\mathrm{max}} + I_{\mathrm{min}}} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}|\gamma|, \tag{2}$$

where γ is the complex degree of coherence. So, in case of same light intensities at the two slits the complex degree of coherence is equal to the visibility.

The complex degree of coherence is given by the van Cittert-Zernike theorem:

$$\gamma = \int \mathrm{d}x\, f(x)\exp\left(-i\frac{2\pi d}{\lambda L}x\right), \tag{3}$$

where L denotes the distance between the source and the double slit and $f(x)$ is the shape of the source. It states that γ is given by a Fourier transform of the intensity distribution of the source object. This means that the visibility in an interference pattern of a point source is 1 and gets smaller for an extended source, e. g. the contrast in the interference pattern gets worse [4].

For measurements shown in this contribution it is furthermore assumed to observe only Gaussian beams, possible intensity imbalances between or at the two slits are neglected and depth of field effects are not considered. For a Gaussian beam profile Eq. (3) simplifies and the visibility equals γ:

$$V = |\gamma| = \exp\left[-2\left(\frac{\pi\sigma_x d}{\lambda L}\right)^2\right], \tag{4}$$

where σ_x is the rms width of the beam. Therefore the beam size

$$\sigma_x = \frac{\lambda L}{\pi d}\sqrt{\frac{1}{2}\ln\left(\frac{1}{V}\right)}, \tag{5}$$

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can be measured by fitting the interference fringe to obtain the complex degree of coherence.

SETUP

At BESSY II the radiation of a dipole in a high-β segment is used for various diagnostic systems. Figure 1 shows schematically the SR interferometer setup at the diagnostic beamline. The light is guided vertically out of plane of the storage ring bunker, allowing operation while beam shutters are closed.

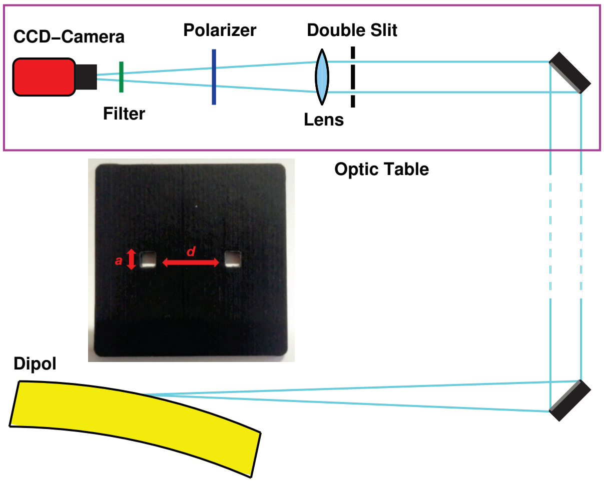


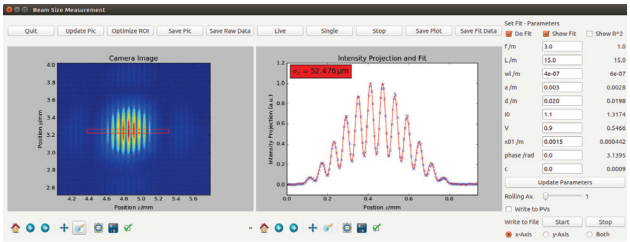
Figure 1: Sketch of the double slit interferometer at the diagnostics beamline and picture of the double slit.

On the optic table the source point is imaged with a lens onto a CCD-Camera and a double slit or other diffraction obstacles can be illuminated with the synchrotron radiation to get a diffraction pattern. In addition the light passes through a polarisation filter and a bandpass filter to obtain an interference pattern from a monochromatic, polarized ray.

COMMISSIONING

Preparation

For the beam size measurements a python-tool was developed, which uses the EPICS environment of BESSY II. A screenshot of the application is shown in Fig. 2. It shows a camera image and the interference fringe data from the region of interest, which is fitted. With this tool online measurements and data archiving is possible.



Set Fit - Parameters

☑ Do Fit ☑ Show Fit ☐ Show R^2

f /m	3.0	1.0
L /m	15.0	15.0
wl /m	4e-07	6e-07
a /m	0.003	0.0028
d /m	0.020	0.0198
I0	1.1	1.3174
V	0.9	0.5466
x01 /m	0.0015	0.000442
phase /rad	0.0	3.1395
c	0.0	0.0009

Rolling Av. 1

☐ Write to PVs

Write to File

● x-Axis ○ y-Axis ○ Both

Figure 2: Screenshot of the python tool for online analysis.

In the first step the free parameters of the interferometric beam size monitor need to be defined. The area illuminated with synchrotron light on the table has a diameter of approximately 30 mm to 35 mm and the distance to the source point is (16.1 ± 0.4) m. On the other hand the interesting region for the beam size we want to be able to measure is in the range from 30 µm to about 150 µm. To illustrate this, the visibility is plotted against the beam size for different slit separations in Fig. 3 at a wavelength of 550 nm, according to Eq. (4). Combined with the region for the visibility where the error of the beam size is minimized, in this case a slit separation of 15 mm to 20 mm is optimal.

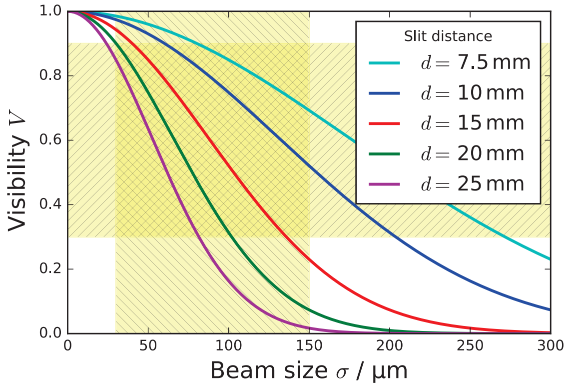


Figure 3: Visibility vs. the beam size for various slit separations at wavelength of 550 nm, see. Eq. (4). The shaded area illustrates the interesting region for BESSY II beam sizes and the visibility region for minimal errors, respectively.

The double slits where printed with a 3D printer, with a anti reflection coating, for various slit separations from 7.5 to 25 mm with a fabrication error of 0.1 mm. The slit widths and heights are 3 mm for each slit. The CCD camera used for imaging is a Prosilica GT1920 from Allied Vision. The camera dark current noise was measured to be 1 %.

Experimental Results

The first test was to measure the beam size with the interferometer over a wider range and compare it with the two pinhole systems, PINH3 and PINH9. Parameters of the systems can be found in Tab. 1. We controlled vertical beam size with a noise excitation producing a static blow up. The slit separation was set to 15 mm, and the wavelength chosen to 550 nm. The measurement of the noise amplitude scan for the vertical beam size measured with double slit interferometer and pinhole systems is shown in Fig. 4.

Table 1: Parameters of the source points of the interferometer and the pinhole systems in standard user mode.

	PINH3	**Interferometer**	**PINH9**
Position s / m	35.04	35.07	125.03
hor. β-function / m	0.396	0.390	0.463
ver. β-function / m	21.1	21.1	22.5
hor. dispersion / m	0.0083	0.0104	0.0098

The results from the PINH9 system and the double slit interferometer are in good agreement for beam sizes below 70 µm, while there is a difference to the PINH3 data, which

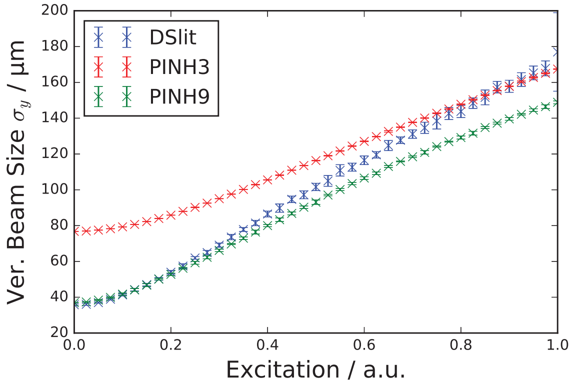


Figure 4: Measured vertical beam sizes with the interferometer and the pinhole systems while scanning the excitation.

does not seem to perform very well for smaller beam sizes. For larger beam sizes the beam sizes of the interferometer and PINH3 match. It is also visible that the interferometer has a higher noise due to some vibration in the beamline.

Moreover we tested the behavior of the visibility according to Eq. (4) as a function of the slit separation and the wavelength. The measurements are shown in Fig. 5. One measurement series with variable slit separation was done in standard user mode at a wavelength of 400 nm, while the other was done by changing the wavelength of the bandpass filter in low-α mode with a slit separation of 10 mm. Both measurement were done for the horizontal beam size with σ-polarized light.

The results from the two measurement and the values from *elegant* tracking and model are shown in Tab. 2. For uncertainties of the measured values only the contribution from the fit, ΔL and Δd are considered, further possible contributions from intensity imbalances at the slits, bandwidth of the filters (10 nm) and lens aberration are not. In addition the incoherent depth of field effect for the horizontal beam size [5] is neglected. BESSY II has a relatively small bending radius of 4.35 m, but the effect might be significant for smaller beam sizes.

In comparison to the *elegant* model the value from the measurement in standard user mode is 7 % larger, the value from the low-α measurement 22 %. A possible source for the deviation could be a distortion of the extraction mirror. This leads to different effects depending on intensity, position, polarisation and wavelength, especially in the vertical direction and is subject of further investigation.

CONCLUSION

We successfully designed and installed a interferometric beam size monitor. First results for the measured beam sizes show reasonable agreement with the models. As described above the measurement needs to be improved further concerning the setup and the error estimation, but in general a future upgrade of the system with fast ICCD camera or photodiode array for bunch resolved measurements is possible.

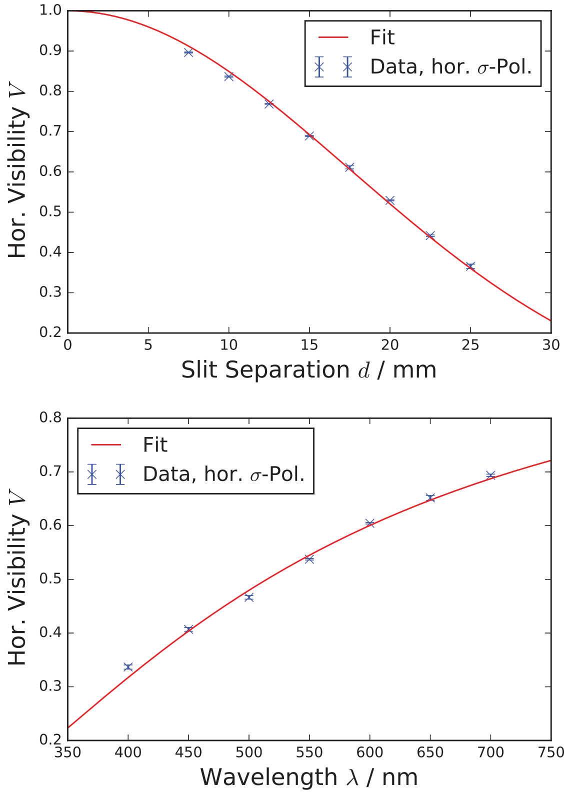


Figure 5: Visibility measured as a function of the slit separation (standard user mode, top) and of the wavelength (low-α mode, bottom). The red line shows the fit according to Eq. (4).

Table 2: Beam sizes from measurements and models. The error of the pinhole measurements is dominated by the diffraction limit and is about 11 µm.

σ_x/µm	**PINH3**	**Interferometer**	**PINH9**
Std. user	74	58.5 ± 1.4	60
low-α	177	155.2 ± 3.7	143
Model std. user	54.9	54.6	59.4
Model low-α	132.5	127.6	133.0
σ_y/µm (meas. Fig. 4, no excitation)	76.8	35.8 ± 0.9	37.0

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