STATUS OF THE NEW BEAM SIZE MONITOR AT SLS*

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Abstract

The Swiss Light Source (SLS) campaign on vertical emittance minimization and measurement required a beam size monitor with the ability to verify a sub-pm·rad vertical emittance. This corresponds to a beam height of less than 4 µm. Within the TIARA Work Package 'SLS Vertical Emittance Tuning' a new beam size monitor was designed and built. The monitor is based on the imaging of the π-polarized synchrotron radiation (SR) in the visible and UV spectral ranges. Besides imaging, the monitor provides interferometric methods using vertically or horizontally polarized SR. With these complementary methods the consistency of beam size measurements is verified. An intermediate configuration of the monitor beamline using a lens as the focusing element has been commissioned in 2013. With this setup a vertical beam size of 4.8 ± 0.5 µm, corresponding to a vertical emittance of 1.7 ± 0.4 pm·rad has been measured. During 2014 the monitor was commissioned in its final configuration with a toroidal mirror. The use of reflective optics allows wider bandwidth imaging and, thus, higher intensity.

INTRODUCTION

In 2008 a beam size monitor was built at SLS for the determination of the vertical beam emittance. This monitor uses the so-called *π-polarization method* [1] to determine the vertical beam size from vertically polarized (π-polarized) vis-UV synchrotron radiation (SR) imaged onto a CCD camera.

During an emittance minimization campaign supported by the TIARA work package 6 [2] a vertical beam size of 3.6 ± 0.6 µm, corresponding to a vertical emittance of 0.9 ± 0.4 pm, was measured using this beam size monitor, reaching its resolution limit [3]. The campaign included the design and construction of an improved second monitor. Besides the *π-polarization method* the new beam size monitor at SLS was designed to provide another measurement method: the creation of interference from either vertically or horizontally polarized (σ-polarized) SR with a horizontal obstacle. The vertical beam size is then deduced from the detected interference pattern. The availability of these complementary methods on the new beam size monitor enables the cross-checking of measurement results. A technique for beam size measurements using interference was already used at KEK with a double slit setup and σ-polarized SR [4].

The commissioning of the new monitor started in the beginning of 2013. A lens was used as the focusing element in this so-called intermediate configuration [5–7]. In dedicated low emittance machine shifts at the SLS a vertical beam size of 4.8 ± 0.5 µm was measured utilizing both available methods [8], see Figure 1.

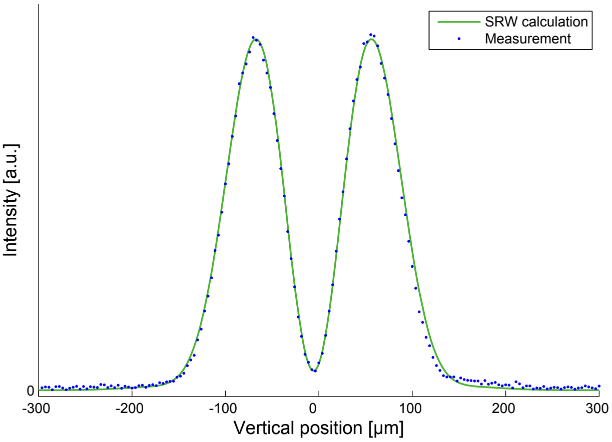

Figure 1: Vertical profile of π-polarized synchrotron radiation, imaged with the intermediate configuration using a lens (blue dots). SRW calculated profile for a vertical beam size of σ_y = 4.81 µm (green line).

The final monitor setup relies on a toroidal mirror as the focusing element. The preference of a toroidal mirror over a lens is due to the advantage of reflective optics to have a wavelength independent focal length. This enables a simpler change of the imaging wavelength in practice. Furthermore, the wavelength independence of the image plane allows us to use a wider wavelength band (10 nm FWHM instead of 1 nm) than with refractive optics and therefore nearly a factor 10 in light intensity. Due to a delay in manufacturing of this mirror the commissioning of the beamline in its final configuration started in January 2014. In this paper we will report on challenges during the commissioning and present first images of SR taken with the toroidal mirror.

BEAMLINE DESIGN

The beamline is designed to image the SR emitted by the electron beam in a bending magnet by a toroidal mirror onto the detector of a CCD camera. See Figure 2 for the beamline layout. A detailed description of the beamline is given in [6, 7].

The toroidal mirror is the first mirror in the *z-chamber* at 5.146 m of optical path length from the source point in the central bending magnet. See Table 1 for specifications of the mirror. The toroidal mirror is held by a *gimbal mount*,

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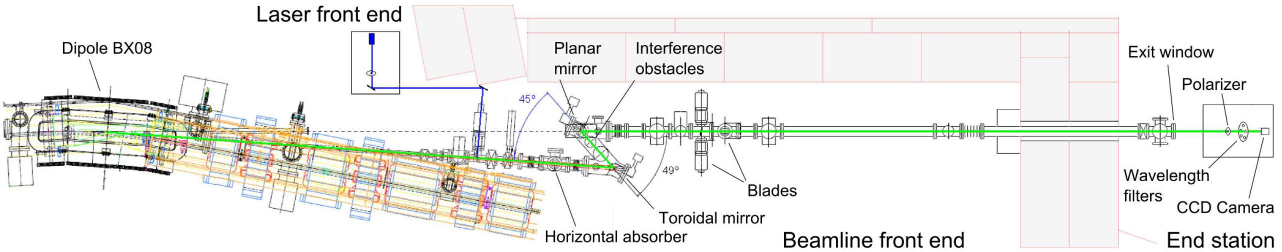

Figure 2: Layout of the new SLS diagnostic beamline (X08DA). Schematic of the end station.

a pivoted support that provides two rotational degrees of freedom for angular adjustment of the mirror. A planar mirror, also mounted on a *gimbal mount*, directs the SR to the CCD camera which is located outside the radiation shielding for better accessibility. The optical path length from the toroidal mirror to the image plane is 7.460 m. This results in a optical magnification of the beamline of −1.450.

Table 1: Toroidal Mirror Specifications

Material	Silicon
Size	76 mm x 76 mm
Surface quality (p-v)	$\lambda/30$ ($\lambda = 632.8$ nm)
Large radius	6592 mm
Small radius	5627 mm
Incident angle	22.5° (0.3927 rad)
Focal length (h/v)	3045 mm
Optical magnification	−1.450

For alignment purpose the beamline is equipped with lasers, situated at the laser front end on an optical table inside the SLS tunnel. The laser beams are guided through a pinhole and a window into the SR beamline. Via an incoupling mirror the laser beam is aligned coaxially to (but not simultaneously with) the SR and is guided over the optical elements to the camera for detection.

WORKING PRINCIPLE

When imaging π-polarized light the CCD camera detects the characteristic destructive interference pattern caused by the 180° phase difference of the two SR lobes. The intensity ratio between the valley in the mid plane and the peaks, the *valley-to-peak ratio*, depends on the source height i.e. the vertical electron beam size σ_y. We used SRW, the Synchrotron Radiation Workshop code [9, 10], which treats the phenomena of SR emission, propagation and focusing strictly within the framework of classical electrodynamics and wave optics, in order to derive the exact dependence of the *valley-to-peak ratio* and the vertical beam size. The code calculates the Fourier transform of the retarded potentials of the emitting relativistic electron. The fields are propagated along the beamline by applying the integral theorem of Helmholtz and Kirchhoff to this Fourier transform at each optical element.

The interferometric method of the beam size monitor is implemented when introducing one of the interference obstacles in the vicinity of the toroidal mirror into the path of the SR. The interferometric method does not rely solely on the characteristic phase difference in π-polarized light and, therefore, can also be applied using σ-polarized light which results in a variety of complementary methods. The theoretical calculation and analysis of the interference pattern and the deduction of the vertical electron beam size is done in the same manner as for π-polarized imaging.

In addition to the vertical beam size the horizontal beam size, being of the order of 60 µm, can be deduced from a Gaussian fit and SRW based calculations.

MIRROR ALIGNMENT

The correct positioning and alignment of the toroidal mirror is crucial for its imaging performance [2]. The installation of the toroidal mirror onto the *gimbal mount* inside the *z-chamber* was done with great care and assisted by the PSI alignment group. Two degrees of freedom, a tilt about the horizontal (T_x) and the vertical (T_y) mirror axis (but not a rotation about the surface normal (R)) , can be controlled remotely. See Figure 3 for a definition of the mirror axes.

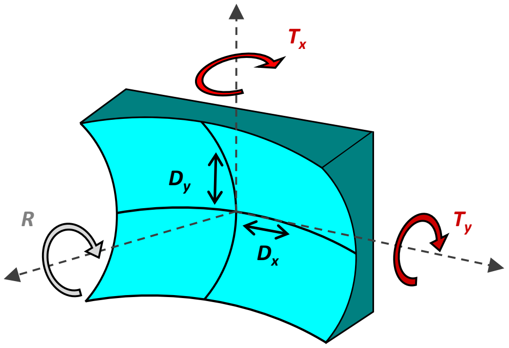

Figure 3: Sketch of a toroidal mirror. In our setup the rotations about the tilt axes T_x and T_y can be controlled remotely. A misalignment in rotation about the surface normal (R) or along the translations (D_x and D_y) must be excluded during mirror installation.

This allows an on line alignment using either a laser, coupled into the diagnostic beamline or SR. For the planar-convex lens formerly installed, the interference pattern from the reflections from both sides of the lens, known as *Newton's rings*, were of great use during the alignment and allowed us to estimate the deviation from perfect alignment. This effect is not present in case of the toroidal mirror configuration which makes the commissioning more challenging.

A useful guideline to find the correct horizontal tilt angle is to search for the intersection of the horizontal and vertical image planes. In that way a high precision for the horizontal tilt angle $T_x = 393 \pm 3$ mrad (corresponding to an incident angle of $45°/2$) has been reached and is required for proper imaging. Also a possible vertical deflection of the SR by the toroid must be minimized for distortion-free imaging. As a verification of the toroid's correct vertical tilt angle T_y the SR beam height and angle were measured with respect to the electron beam height, resulting in $T_y = 0.0 \pm 1.5$ mrad.

IMAGE QUALITY

Figure 4 shows the vertical profile of π-polarized SR, imaged at a wavelength of 325 nm. The image shows distortions in form of secondary maxima and a strong asymmetry around the mid plane. The source of this distortions is presently under investigation. For comparison, the vertical profile calculated with SRW based on a perfect alignment and perfect optical surfaces is included in the figure. We studied the effect of plausible misalignments and restrictions of the free aperture in SRW but could not reproduce the measurement results. However, the model implies perfect optical surfaces, whereas the optical elements in the beamline (the toroidal mirror in particular) can deviate from the ideal shape caused by manufacturing errors or due to high mechanical stress from improper installation.

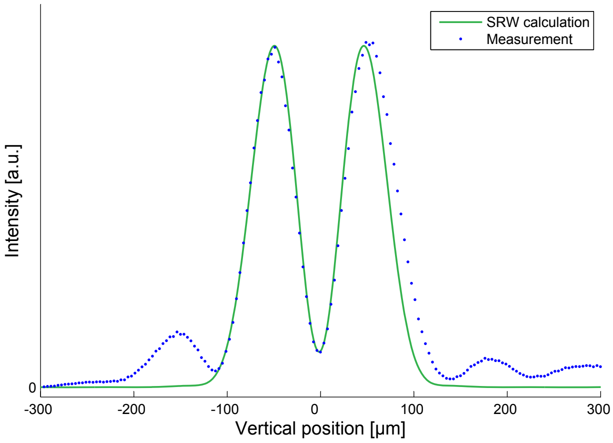

Figure 4: Vertical profile of π-polarized SR, imaged with the toroidal mirror (blue dots). SRW calculated profile for a vertical beam size $\sigma_y = 6.60$ µm (green line). The origin of the distortion of the measured profile is presently under investigation.

Material fatigue from UV irradiation and/or deposition of rest gas molecules have been observed on the Si exit windows of the SLS diagnostic beamlines. The flat mirror and the exit window of this beamline have been installed already in the beginning of the previous commissioning phase with the lens and might have suffered damage. However, imaging with light passing through the exit window at spots of little to no UV light exposure excluded this optical element to cause the image distortion.

Apart from image distortions the increase in light intensity due to a broader band of utilized wavelengths compared to imaging with the lens leads to a noticeable reduction of the relative pixel noise. This can be seen by direct comparison of Figures 1 and 4.

CONCLUSION & OUTLOOK

The new SLS diagnostic beamline is installed in its final configuration with a toroidal mirror. Although the mirror was thoroughly aligned the image quality is not yet satisfactory. During the next shutdown, scheduled for the end of June 2014, the beamline vacuum will be opened and a widespread investigation is planned. This includes remeasuring and correction of alignment, the free aperture and a quality inspection (and exchange when indicated) of the optical components.

The main advantages of the reflective optics setup have already become apparent: the same optical path is valid for all wavelengths and a motorized filter wheel enables an on line selection, typically 325, 405 and 532 nm. Also a broader wavelength band can be detected and due to the higher light intensity the signal-to-noise ratio is improved. This is expected to increase the accuracy of beam size measurements.

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