COMMISSIONING EXPERIENCE AND FIRST RESULTS FROM THE NEW SLS BEAM SIZE MONITOR*

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Abstract

In the context of the TIARA work package "SLS vertical emittance tuning" (SVET), an extremely small vertical beam size of 3.6 µm, corresponding to a vertical emittance of 0.9 pm, was verified using an optical monitor based on imaging of π-polarized light. Since the existing beam size monitor reached its limit of resolution, a new monitor beam line was designed and installed at the 08BD bending magnet of the Swiss Light Source (SLS) storage ring. Larger magnification and operation at shorter wavelength provide improved spatial resolution. Reflective optics enables convenient switching between different wavelengths. An optical table is located in a hutch outside the storage ring tunnel to provide access during operation. Movable obstacles in the beam path create interference patterns and thus provide redundancy of model based analysis of the images. In this paper we report on our commissioning experience and provide a comparison of the different measurement methods at different wavelengths.

INTRODUCTION

During the last years, a systematic coupling correction of the SLS [1] storage ring has been achieved in the context of the TIARA (Test Infrastructure and Accelerator Research Area) work package 6 [2, 3]. Several iterations of beam-assisted re-alignments of the storage ring magnets and vertical dispersion minimizations using model-based skew quadrupole corrections lead to a minimum vertical beam height of 3.6 ± 0.6 µm and a corresponding world record vertical emittance of 0.9 ± 0.4 pmrad [4]. So far, the vertical beam size has been determined with the existing BX09 π-polarization monitor, which has reached its resolution limit through this optimization campaign. Further minimization towards the so called quantum limit of the vertical emittance, which in case of SLS corresponds to 0.2 pmrad, required an improved design for a second beam size monitor, which was installed at the BX08 bending magnet during the 2013 SLS winter shut down.

WORKING PRINCIPLES AND RESOLUTION

For cross-checking of results, the new BX08 beam size monitor combines two complementary modes of operation. They both overcome the diffraction limitations for imaging of visible and UV synchrotron radiation (SR) by (a) direct imaging of the vertically polarized light according to the *π-polarization method* [5] and by (b) imaging the interference pattern of the vertically polarized SR from horizontal obstacles in the beam line according to the *interferometric method* [6]. While both measurement methods are capable of providing the required high spatial resolution of < 2 µm (rms) for SLS emittance optimization studies (at 266 nm wavelength), the π-polarization imaging allows for the additional detection and compensation for beam tilts, which makes it most suitable for supporting the nominal SLS user operation in the control room (0.13 % coupling at ~ 10 µm vertical beam size). The resolution limits of the two measurement principles applied in the new BX08 beam size monitor and the existing monitor at the BX09 bending magnet have been estimated with SRW (Synchrotron Radiation Workshop) [7] simulations for an interference fringe visibility of 2%. Figure 1 shows the corresponding resolution curves for the shortest transmitted SR wavelengths of 266 nm at new beam size monitor compared to 364 nm at the old monitor.

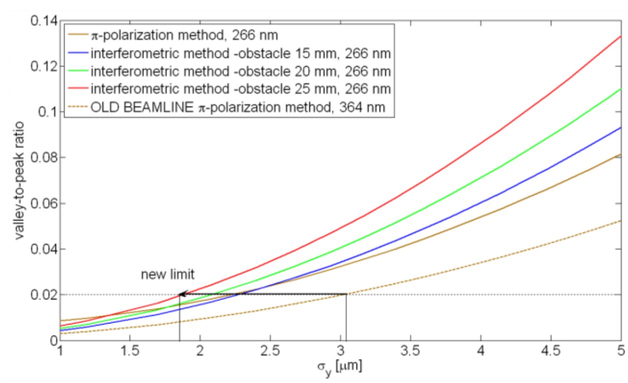

Figure 1: Simulated peak-to-valley ratios for different measurement methods at the old and new SLS beam size monitors for wavelengths of 266 nm (new monitor) and 364 nm (old monitor). The resolution limit has been set to a fringe (peak-to-valley ratio) visibility of 2%.

BX08 BEAM SIZE MONITOR DESIGN

The new BX08 beam size monitor has been designed to provide an increased vertical acceptance of ± 4.5 mrad to allow the imaging of the two vertically polarized SR lobes with 180° phase difference (π-polarization) in the visible to UV spectral range without obstruction. A water-cooled finger absorber of 4 mm height can be positioned in the beam line, such that the heat load on the downstream optical elements caused by the hard X-ray photons (with a much smaller opening angle ~ 1/γ) is minimized and corresponding distortions of the SR imaging is prevented.

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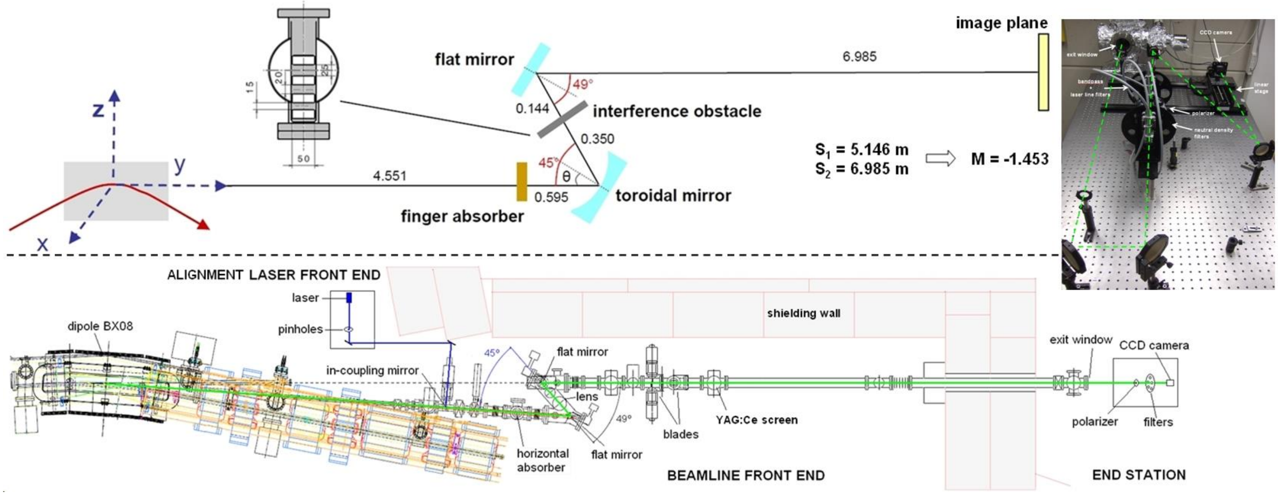

Figure 2: Optical layout (top) and CAD overview drawing (bottom) of the new SLS BX08 beam size monitor. The insert shows the present set-up in the optics hutch.

In the present (phase-1) configuration of the monitor, the SR beam is re-directed and focused into an optical hutch outside of the SLS shielding wall by two plane mirrors and a plano-convex fused silica lens. In the final (phase-2) configuration, which will be implemented during the SLS November 2013 shut down, the combination of the first SiC mirror and the lens will be replaced by a toroidal Si mirror, while the UV-enhanced, Al-coated fused silica second mirror remains unchanged. The surface quality of all optical elements has been defined through SRW simulations, resulting to a roughness of < 10 nm (rms) for the fused silica lens and 20 nm (rms) for the phase-1 and phase-2 mirrors. Imaging with a toroidal mirror allows the use of different and potentially shorter SR wavelengths without movement of the image plane (266 nm for the new BX08 monitor compared to 364 nm at the old BX09 monitor). The selected focal length of 3.045 m provides a magnification of -1.45, which results in an increased measurement precision of almost a factor of two compared to the existing BX09 monitor. Horizontal interference obstacles with different slit separations (15, 20 and 25 mm) can be moved in the beam to change quickly from the π-polarization to the interference method. In order to meet the stringent alignment tolerances of the beam line [8], both mirrors have been clamped to in-vacuum gimbal mounts, which allow a precise rotation of the mirrors without moving their centers. Pre-alignment and in-situ check of the beam path can be achieved with external alignment lasers and pinholes. Additional horizontal and vertical blades as well as a YAG:Ce screen can be moved in the SR beam in order to observe the footprint of the light and any possible obstructions before exiting the UHV system. On the optics table in the BX08 beam line hutch, a set of neutral density filters (30%, 10%, 3% or 1%) as well as bandpass and laser line filters (2 nm FWHM) can be moved into the beam. A Glan-Taylor polarizer can be rotated such that any residual horizontal polarization component of the SR is suppressed. The visible SR light is imaged to a Basler scA 1300-32gm CCD camera with 3.75 µm pixel size, while the UV radiation (266 nm) is imaged onto a PCO sensicam UV with 8 µm pixel size. Both cameras are mounted on a motorized translation stage for fine adjustment of the position of the image plane. Figure 2 gives a schematic overview of the monitor design (final configuration) and shows a CAD drawing of the beam line as well as the optics set-up in the beam line hutch.

BEAM LINE COMMISSIONING AND FIRST MEASUREMENTS

Careful laser alignment of the two plane mirrors and the plano-convex lens from the source direction (optics table in the SLS tunnel) and the beam line hutch allowed rapid commissioning of the beam size monitor with SR. This included the exact positioning of the finger absorber

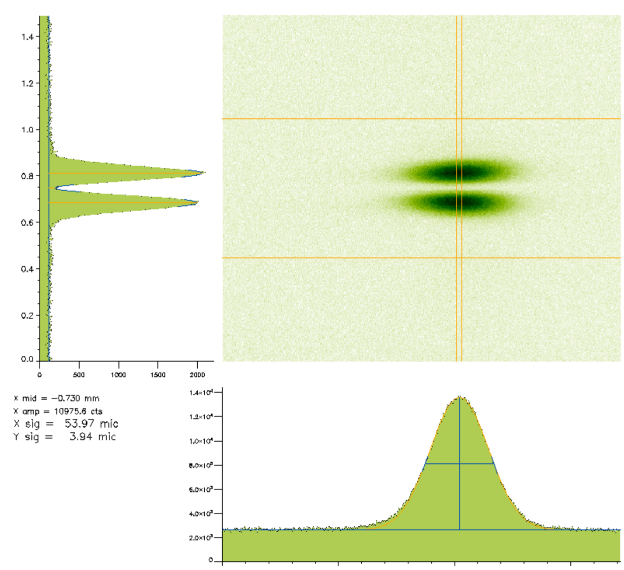

Figure 3: Screen shot of smallest vertical beam size of $\sigma_y \sim 4$ µm measured so far with the new SLS BX08 beam size monitor using the π-polarization imaging method.

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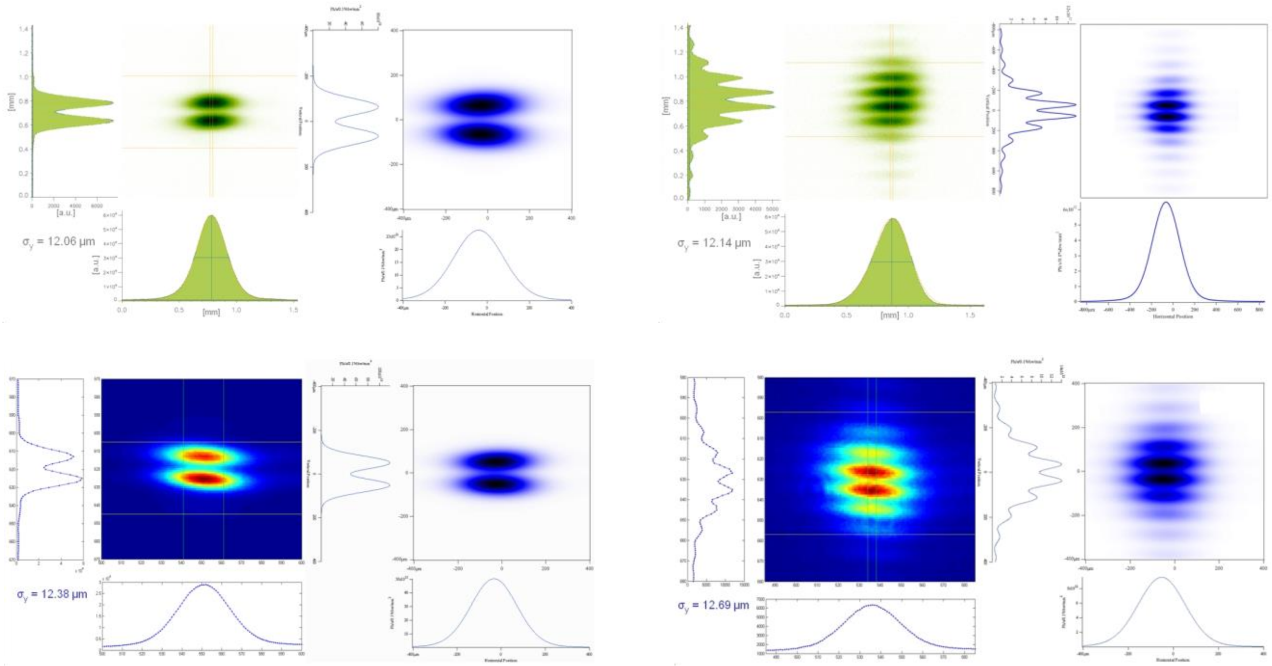

Figure 4: Beam size measurements and corresponding SRW simulations during nominal SLS user operation for SR wavelengths of 325 (top) and 266 nm (botton) using the π-polarization imaging (left) and interference methods (right).

for minimum heat load on the first mirror, the determination of the acceptance angles with the horizontal and vertical blades and the location of the image planes for the different SR wavelengths. The latter will not be necessary during phase-2, when the toroidal mirror will be installed as the focusing element.

Typical beam size measurements during nominal SLS user operation are shown in figure 4 for different SR wavelengths (325 nm and 266 nm) and for both complementary measurement methods using the π-polarization imaging and interference. During one of the TIARA WP6 emittance optimization runs, a minimal vertical beam size of 4 µm could be measured with the new BX08 monitor (see figure 3). The consistency of the results from both measurement methods of the new monitor has been cross-checked with the "old" BX09 beam size monitor. Figure 5 shows the comparisons of the vertical beam sizes, which were taken simultaneously.

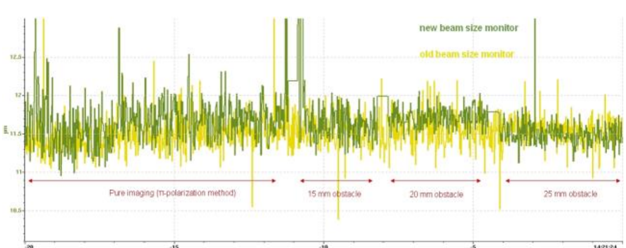

Figure 5: Comparison of vertical beam sizes measured with the old and the new monitor for both measurement methods: π-polarization imaging and interference.

OUTLOOK

During the SLS November 2013 shut down, a Si toroidal mirror will replace the lens as the focusing element of the new beam size monitor. This will ease operation at different SR wavelengths, since the location of the image plane in the optical beam line hutch will remain unchanged. Further vertical emittance optimizations are planned with this final beam monitor configuration.

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