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15 July 2013

The research leading to these results has received funding from the European Commission under the FP7-INFRASTRUCTURES-2010-1/INFRA-2010-2.2.11 project TIARA (CNI-PP). Grant agreement no 261905.

This work is part of TIARA Work Package **6: SVET R&D Infrastructure**.

THE NEW SLS BEAM SIZE MONITOR, FIRST RESULTS*

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Abstract

An extremely small vertical beam size of 3.6 μm, corresponding to a vertical emittance of 0.9 pm, only about five times bigger than the quantum limit, has been achieved at the storage ring of the Swiss Light Source (SLS). The measurement was performed by means of a beam size monitor based on the imaging of the vertically polarized synchrotron radiation in the visible and UV spectral ranges. However, the resolution limit of the monitor was reached during the last measurement campaign and prevented further emittance minimization. In the context of the work package SLS Vertical Emittance Tuning of the TIARA collaboration, a new improved monitor was built. It provides larger magnification, an increase of resolution and enables two complementary methods of measurement: imaging and interferometry. In this paper we present the design, installation, commissioning, performance studies and first results obtained with the new monitor.

WORKING PRINCIPLE AND MONITOR DESIGN

In 2008 a beam size monitor was build 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 images formed from vertically polarized vis-UV synchrotron radiation (SR) on a CCD camera. During 2012, in the context of the emittance minimization campaign supported by the TIARA work package 6 [2], a vertical beam size of 3.6 ± 0.6 μm, corresponding to the worldwide smallest vertical emittance in a storage ring, 0.9 ± 0.4 pm, was measured at SLS [3] with the use of that monitor. However, the resolution limit of the monitor was also reached during this campaign. Thus, to further continue the emittance minimization program the construction of an improved second monitor was necessary.

The new beam size monitor at SLS provides two complementary measurement methods: the pure imaging of the vertically polarized light (π-*polarization method*) and the imaging of the interference of the vertically polarized light with a horizontal obstacle. The latter is known as *interferometric method* and has already been used at KEK [4]. Both methods follow the van Cittert-Zernike theorem [5], based on the fact that from the measurement of the partial spatial coherence of the synchrotron light the size of the light source, that is the electron beam, can be inferred. The availability of both methods on the new beam size monitor enables cross-checking of the results and extends the measurement range.

A sketch of the new beam size monitor is presented in Figure 1. The source point of the beamline is the central bending magnet of sector 8 (BX08) of SLS. The emitted SR in the X-ray range, which has a small vertical opening angle ($\sim 1/\gamma$) and contains most of the energy, is absorbed by a water cooled horizontal *finger absorber* (4 mm height) in order to avoid heat-load induced distortion of the first optical element. Furthermore, the beamline has been designed in a zigzag shape to ensure that neither remanent X-ray SR nor bremsstrahlung from beam electron scattering on residual gas atoms can reach the optical table in the beamline hutch, outside of the SLS shielding wall. Also the horizontally polarized light on the range vis-UV, heavily concentrated in the mid-plane, is partly obstructed by the finger absorber. Vertically polarized light in the range of vis-UV, distributed in two lobes with a phase difference of 180°, travels almost non-obstructed along the beamline.

While the final implementation of the monitor (to be upgraded in November 2013) will use a toroidal mirror as a focusing element, the present set-up uses a plano-convex fused silica (FS) lens. The surface accuracies of the lens surfaces are 3 nm and 8 nm (rms). The lens is placed in between a first flat SiC mirror, that should be able to withstand some low intensity direct SR without distortion, and a second flat UV enhanced Al-coated FS mirror. The mirrors have a surface accuracy of 31 nm and 21 nm peak to valley, respectively. Both are mounted over *gimbal mounts*, pivoted supports with two rotational degrees of freedom. The toroidal mirror will be made of Si and will have a surface accuracy of 21 nm peak to valley. It will replace the first mirror (and the lens) and provide for easier shifts of detection wavelengths. Apart from these high accuracy optical elements, the beamline is also equipped with horizontal and vertical blades to determine the acceptance angle of the light, and with a diagnostic element consisting of a YAG screen, that can be introduced into the light path to inspect the footprint of the SR several meters before the image plane in order to check for possible obstructions in the beamline.

The beamline ends with a FS exit window at an optical table. Contrary to the old SLS beam size monitor, the optical table of the new monitor is located in an experimental hutch, outside of the SLS storage ring tunnel. Thus, it is accessible for maintenance at any time also during machine operation. External to the vacuum a series of optical elements filter the beam before it is measured; neutral density filters can be selected to lower the transmission down to 30%, 10%, 3% or 1%, a Glan-Taylor polarizer can be re-

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* Work partially funded by the European Commission under the FP7-INFRASTRUCTURES-2010-1/INFRA-2010-2.2.11 project TIARA (CNI-PP). Grant agreement no 261905

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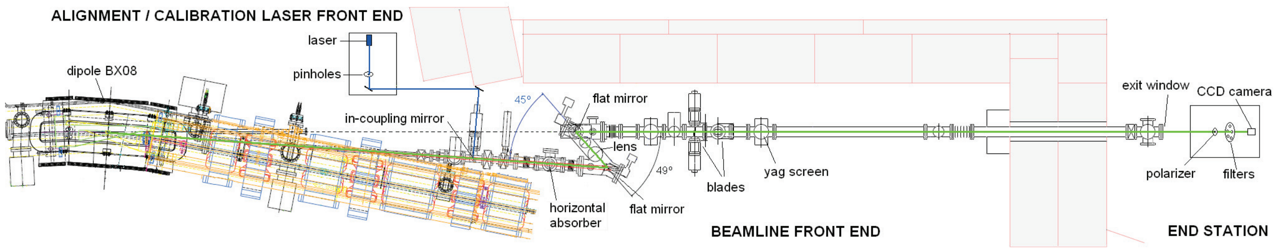

Figure 1: Layout of the X08DA beamline, laser front end and end station are schematic.

motely rotated to eliminate non-vertically polarized light, and a combination of bandpass and laser-line filters can be included to narrow the selected wavelength down to 2nm FWHM. The two lobes of vertically polarized light are finally imaged onto a CCD camera (Basler scA1300-32gm, pixel size 3.75 μm) located at the image plane of the lens. The CCD camera is mounted over a remotely controlled linear translator in order to finely adjust its position to that of the image plane. Overall the beamline of the new monitor is $\sim$6 m longer and provides images with larger magnification ratio, 1.97 vs 0.84 for a 364 nm wavelength. This fact, together with the use of a CCD camera with smaller pixel size, 3.75μm vs 4.65 μm, implies an increase of the measurement precision.

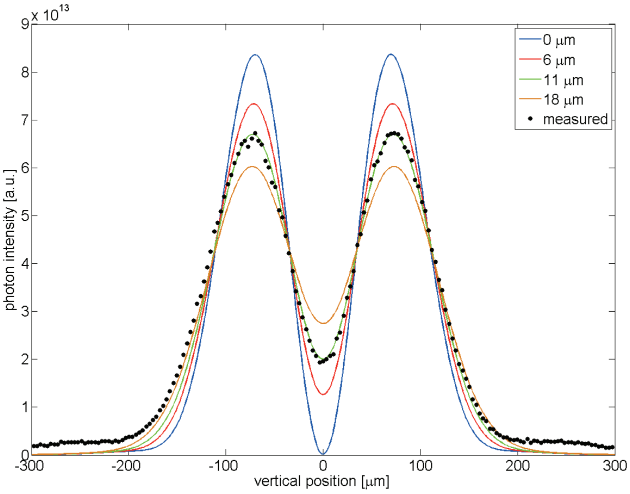

Figure 2: Measured (dots) and calculated (solid lines) vertical image profiles for different beam sizes. The measured valley-to-peak ratio leads to the conclusion that the corresponding beam height is 11 μm.

The image at the CCD camera shows the characteristic destructive interference pattern caused by the 180° phase difference of the two vertical SR lobes. The ratio of the intensity between the lobes (valley) and the maximum intensity of the lobes (peak) is defined as the *valley-to-peak ratio*, which depends on the vertical source size (vertical height of the electron beam, σ_y), as shown in figure 2. A look-up table based on theoretical calculations using the SRW (Synchrotron Radiation Workshop) code [7], as the ones shown in figure 3, is then used to convert the valley-to-peak ratio to σ_y. The horizontal beam size (or beam width, σ_x) can be inferred from the horizontal projection of the vertically polarized light and SRW simulations.

In the vicinity of the lens, three horizontal obstacles of different heights, 15, 20 and 25 mm, may be inserted in the light path, blocking 3, 4 or 5 mrad of the central vertical SR distribution, respectively. This turns the π-polarization method into an interferometric method, and the measurement results can be cross-checked with both methods. As indicated in Fig. 3, we expect (at best) to resolve a 2% valley-to-peak ratio with the new monitor. By detection at 266 nm instead of 364 nm, we might now detect a σ_y of around 2 μm, with both methods. The interferometric method has the advantage of a slightly larger valley-to-peak ratio, while the π-polarization method may detect possible beam rotations.

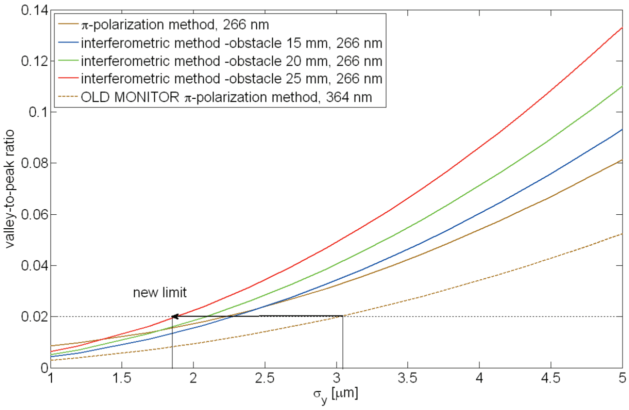

Figure 3: Calculated valley-to-peak ratios for different wavelengths and measurement methods as a function of the vertical beam size.

An optical table with three lasers of wavelengths 405 nm, 532 nm and 694 nm is located in the SLS tunnel. An additional laser of wavelength 266 nm will also be installed there starting June. These lasers are used for alignment of the beamline optics and for calibration of the monitor by means of imaging quality tests. At the same distance as the SR source point from the BX08 bending magnet, a set of pinholes, with diameters between 1 μm and 200 μm, can be inserted in the laser beam path to be imaged with the beamline optics. To this end the laser is coupled through

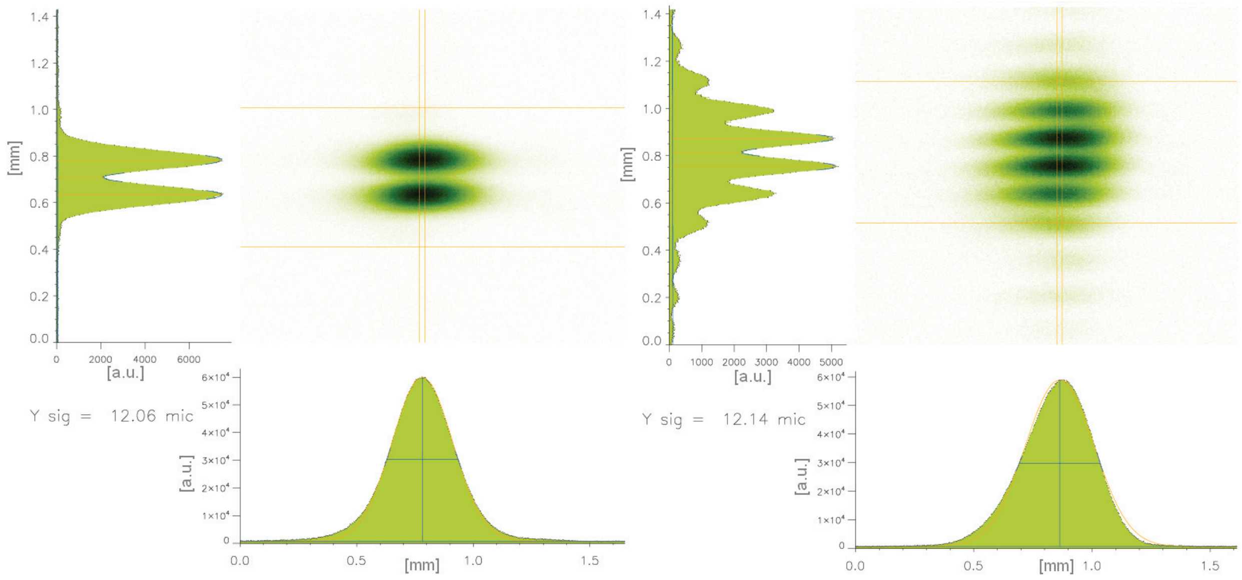

Figure 4: Images on the CCD camera and corresponding projections and fits for the π-polarization (left) and the interferometric (right) methods.

a window into the beamline, where an in-coupling mirror reflects the laser along the same path as the SR until the CCD camera, as shown in figure 1.

COMMISSIONING AND FIRST BEAM SIZE MEASUREMENTS

The new beam size monitor was installed and comissioned during the regular winter shutdown at SLS. The alignment of all optical elements inside the beamline front end was realized with the use of two coaxial lasers; one located in the end station, pointing upstream along the beam line, and the other one at the laser front end, coupled into the beam line pointing downstream.

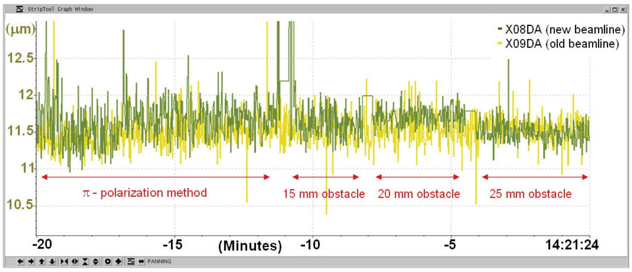

Figure 5: Comparison of the vertical beam sizes measured simultaneously on the old beam size monitor and on the new one. The measurements on the new beam size monitor have been done with the π-polarization and the interferometric measurement methods using different obstacle sizes.

At the end of January synchrotron radiation was imaged on the CCD camera in the measurement station for the first time. Two screenshots from the graphical interface that reads the CCD camera are shown in figure 4 for the π-polarization and the interferometric methods. Further commissioning included the optimization of the position of the finger absorber in order to minimize the heat load on the first mirror, and the calibration of the movable horizontal and vertical blades that determine the acceptance angles. Also the calibration of the interference obstacles was realized resulting in consistent beam size measurements for the different methods and obstacle sizes, as shown in figure 5. Furthermore, a careful angular alignment of the polarizer and the CCD camera, with a maximum roll error of 2.4 mrad to the bending plane of the dipole magnet was achieved.

REFERENCES

[1] Å. Andersson et al, "Determination of a small vertical electron beam profile and emittance at the Swiss Light Source", Nucl. Instrum. Meth. A **591**, 437 (2008).

[2] For more information on the TIARA work package 6 see: http://www.eu-tiara.eu/rtd/index.php?id=42

[3] M. Aiba et al, "Ultra low vertical emittance at SLS through systematic and random optimization", Nucl. Instrum. Meth. A, in press.

[4] T. Mitsuhashi, "Measurement of small transverse beam size using interferometry", DIPAC 2001, ESRF, France.

[5] P.H. van Cittert, "Phisica", 1, 201(1934). See also M. Born and E. Wolf, "Principles of Optic", chapter 10, Pergamon press (1980).

[6] N. Milas et al, "Specifications for the new SLS beam size monitor", TIARA/WP6:SVET mid-term report, 2012.

[7] O. Chubar and P. Elleaume,"Accurate And Efficient Computation Of Synchrotron Radiation In The Near Field Region", proc. of the EPAC98 Conference (1998).