DESIGN AND EXPECTED PERFORMANCE OF THE NEW SLS BEAM SIZE MONITOR*

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Abstract

The vertical emittance minimization campaign at SLS, realized in the context of the TIARA WP6, has already achieved the world's smallest vertical beam size of 3.6 µm, corresponding to a vertical emittance of 0.9 pm, in a synchrotron light source. The minimum value reached for the vertical emittance is only about five times larger than the quantum limit of 0.2 pm. However, the resolution limit of the present SLS emittance monitor has also been reached during this campaign, thus, to further continue the emittance minimization program the construction of an improved second monitor is necessary. In this paper we present the design and studies on the performance of this new monitor based on the image formation method using vertically polarized synchrotron radiation in the visible and UV spectral ranges. This new monitor includes an additional feature, providing the possibility of performing full interferometric measurement by the use of a set of vertical obstacles that can be driven on the light path. Simulations results are used to investigate the possible sources of errors and their effects on imaging and the determination of the beam height. We also present the expected performance, in terms of emittance accuracy and precision, and discuss possible limitations of this new monitor design.

MOTIVATION

The main objective of the TIARA (Test Infrastructure and Accelerator Research Area) work package 6 [1, 2] is the achievement and control of ultra-low vertical emittances. This is of large interest for present and future storage ring based light sources in order to utilize small period / gap undulators, which provide higher photon energies, and for the design of damping rings for future linear colliders to obtain their desired high luminosities. In this context, a vertical emittance tuning and optimization program has been launched at the Swiss Light Source (SLS) at Paul Scherrer Institut (PSI) in Villigen, Switzerland [3]. The main activities include (a) the suppression of betatron coupling and vertical dispersion by beam-assisted realignment of the storage ring magnets and the subsequent application of correction schemes using skew quadrupoles, (b) the measurement of small vertical beam sizes by means of a high resolution beam profile monitor and (c) the determination of intra beam scattering contributions to the emittance.

SLS Vertical Emittance Minimization

In case of ideal flat storage ring lattices, extremely low vertical equilibrium emittances can be obtained, which are only limited by the direct recoil of the emitted photons [4]. For SLS this so called quantum limit of the vertical emittance is at 0.2 pmrad. In reality, however, magnet errors and alignment tolerances (typically in the order of few tens of µms) as well as beam position measurement errors lead to betatron coupling and vertical dispersion causing a subsequent emittance growth to several pmrad or even tens of pmrad. Thus, as a first step towards emittance minimization, a beam-assisted re-alignment of the SLS storage ring magnets (lattice) was carried out in April 2011, leading to a substantial reduction of the rms vertical corrector kick from initially ~ 130 µrad to ~ 50 µrad. On the wa to a systematic vertical dispersion correction, the BPM roll errors were determined and regarded as “fake” vertical dispersion contributions, when the model-based dispersive skew quadrupole correction was applied. As a result, the spurious vertical dispersion could be reduced by using the 12 dispersive skew quadrupoles to < 1.3 mm rms. In a final step, a SVD model-based betatron coupling correction was performed with the 24 non-dispersive skew quadrupoles, which reduced the coupling part of the orbit response matrix by almost a factor of 2.5. Several iterations of this procedure including a final random optimization lead to a vertical beam height of 3.6 ± 0.6 µm and a corresponding vertical emittance of 0.9 ± 0.4 pmrad [5]. Figure 1 shows this final “random walk” optimization of the SLS vertical beam height, measured with the existing π-polarization monitor [6], which reached its resolution limit during this emittance minimization campaign.

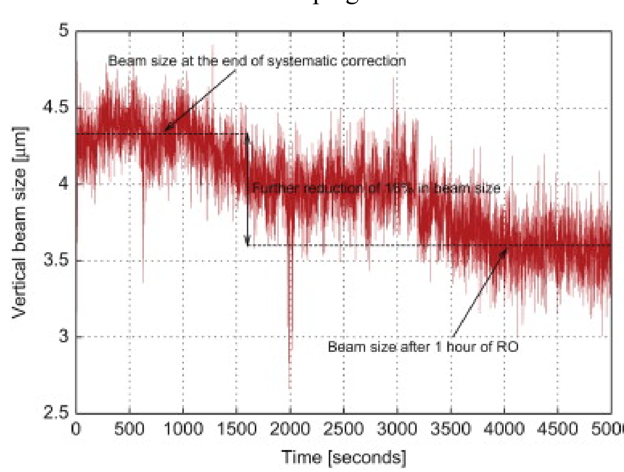

Figure 1: Random optimization of the SLS vertical beam height. The resolution limit of the existing π-polarization monitor has been reached at 3.6 ± 0.6 µm.

*The presented work has received funding from the European Commission under FP-7-INFRASTRUCTURES-2010-1/INFRA-2010-2.2.11 project TIARA (CNI-PP). Grant agreement no. 261905.

ISBN 978-3-95450-119-9

THE NEW SLS BEAM SIZE MONITOR

The new beam size monitor at SLS will provide two different modes of operation: (a) the imaging of the vertically polarized synchrotron radiation (SR) with the so called *π-polarization method* [7] and (b) the interference of the vertically polarized synchrotron radiation with the so called *interferometric method* [8].

Working Principles and Monitor Design

Both, the *π-polarization* and the *interferometric method*, allow the use of visible or ultra-violet SR for the determination of beam sizes well below 10 µm.

In a π-polarization mode of operation, the two lobes of the vertically polarized SR from the BX08 bending magnet of the SLS storage ring are imaged onto a CCD camera (Basler scA1300-32gm) at the end of the beam line. In order to avoid damage of the optical elements and heat-load induced distortion of the image, the hard X-ray part of the synchrotron radiation, which has a small vertical opening angle (~ 1/γ) and contains most of the energy, is absorbed by a water cooled horizontal "finger" absorber (4 mm height) without obstructing the well separated vertical lobes of the SR. In case of the new SLS beam size monitor, the imaging of the π-polarized components will be achieved by a toroidal mirror, generating the characteristic destructive interference pattern, caused by the 180° phase difference of the two vertical SR lobes. The resulting peak-to-valley ratio can be related to the source size (vertical beam height). In addition to the beam height and width, the π-polarization method reveals also information about the local vertical dispersion by determining the tilt of the image.

The interferometric method will be implemented on the same beam line by introducing a double slit in the path of the synchrotron radiation. The working principle of this method follows the *van Cittert-Zernike theorem* [9] and is based on the fact that the measurement of the spatial coherence of synchrotron light in the vis-UV region is related to the beam size.

A sketch of the new monitor is presented in Figure 2, and more details on the design can be found in [10]. The main characteristics and improvements of the new monitor in respect to the existing one are:

- the beam line ends outside of the SLS storage ring tunnel, thus being accessible at any time - also during machine operation
- the larger magnification ratio of M = -1.45 increases the measurement precision of almost a factor two
- the use of the toroidal mirror as a focusing element provides a free selection of the SR wavelength without moving the image plane
- the potential use of shorter wavelengths (e.g. 266 nm) enables an increase of the resolution to smaller beam sizes
- two measurement methods – π-polarization and interferometric – enable cross-checking of results and extended measurement ranges
- calibration and alignment with the use of a laser setup provides an online performance check of the monitor

Expected Performance

The simulations of the SR propagation along the new beam size monitor have been performed using the SRW (Synchrotron Radiation Workshop) code [11].

The π-polarization monitor resolution has been studied for three different wavelengths (266, 340 and 498 nm). Figure 3 shows the expected increase of the monitor sensitivity for shorter wavelengths as the slope of the peak-to-valley curve becomes steeper. Although the proximity of the two lobes in the image plane increases at shorter wavelengths as well, this will not limit the

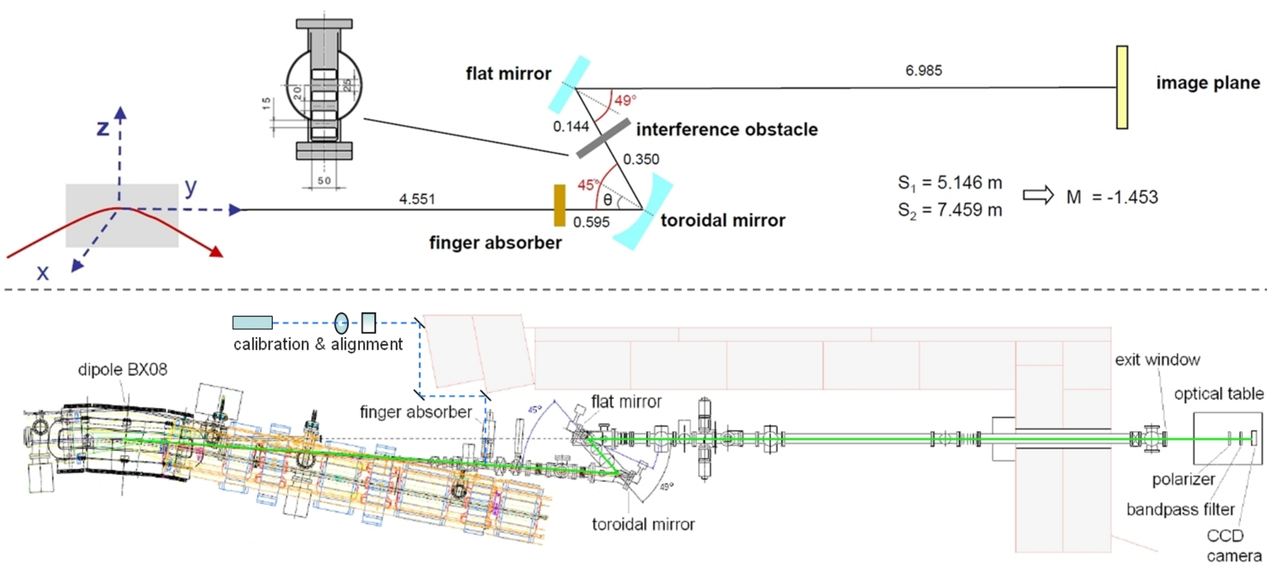

Figure 2: Schematic design of the new SLS beam size monitor applying the π-polarization and interferometric methods (top). Layout of the X08DA beam line – calibration and alignment set-up and imaging station are schematic (bottom).

ISBN 978-3-95450-119-9

performance, since the smaller pixel size of 3.75 μm of the Basler CCD camera and the enlarged magnification of the new monitor compensate for this effect.

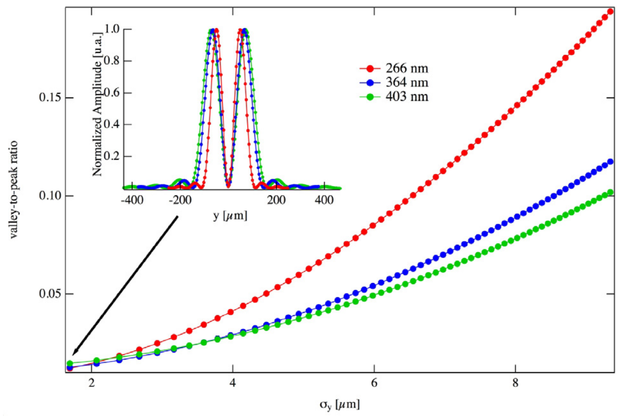

Figure 3: SRW simulation of peak-to-valley resolution for the π-polarization method and for different wavelengths.

The sensitivity of the π-polarization method to beam height changes is well matched to the nominal user operation mode of the SLS with a vertical beam size of ~ 10 μm at 0.13 % coupling. In case of further emittance minimization studies in the SLS storage ring, the interfometeric method will be applied, providing superior resolution of < 2 μm as shown in Fig. 4.

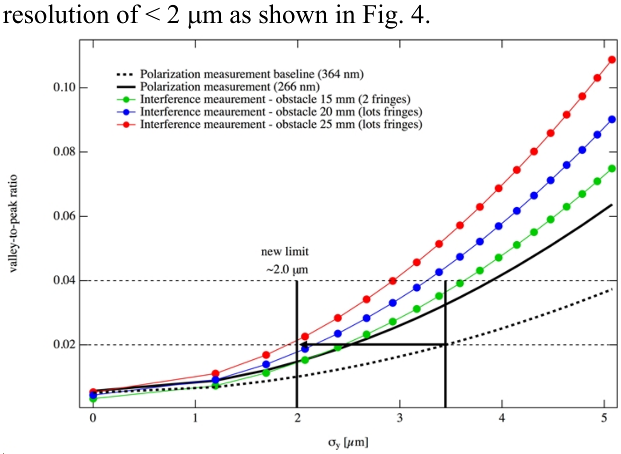

Figure 4: SRW simulation of the fringe visibility for the interferometric beam size measurement method as a function of slit separations (15, 20, 25 mm). The π-polarization method is shown as a reference.

Tolerance Studies

The toroidal mirror is the most critical component of the new beam size monitor concerning surface quality, offsets and misalignments. Mirror imperfections were modelled according to [12] and simulated with SRW, resulting in specifications for the mirror fabrication in terms of slope errors < 0.2 arcsec, roughness of λ/30 (at 633 nm) and waviness from the polishing procedure to be allowed in vertical or radial directions. The toroidal mirror will be mounted in a gimbal mount, a pivoted support which allows for the rotation of the mirror around the horizontal and vertical axes, while keeping its centre fixed. In order to define the constraints on mechanical alignment necessary to utilize the monitor at its full resolving power of < 2 μm, all possible misalignments of the toroidal mirror from its ideal position have been included in the SRW simulations. The results show that horizontal and vertical offsets of up to ± 50 μm are not affecting the determination of the vertical beam size. A vertical tilt, however, turns out to be quite critical and results in an overestimation of the beam size from the valley-to-peak ratio of 11%, 100% or even 270% for tilts of ± 1, ± 3 or ± 5 mrad respectively. In order to avoid such overestimation of the beam size due to vertical tilts, the gimbal mount will be adjusted by using a laser-based alignment and calibration set-up until a symmetric interference pattern is observed at the CCD camera. Horizontal tilts of the same amount as above, will lead to an underestimation of the beam size in the order of 6%, 33% and 46% in case of decreasing incident angles of the light on the toroidal mirror. Increasing horizontal incident angles lead to a less critical overestimation of the beam size by 4%, 6% and 10%. These effects will be compensated by adjusting the gimbal mount of the toroidal mirror until the distance between the two peaks is minimal. Finally, rotation around the normal axis of the toroidal mirror by ± 1, ± 3 or ± 5 mrad results in beam size overestimations of 1.5%, 17% or 49%.

REFERENCES

[1] For more information on TIARA, see: http://www.eu-tiara.eu/

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

[3] For more information on SLS, see: http://www.psi.ch/sls/

[4] T. O. Raubenheimer, "Tolerances to Limit the Vertical Emittance in Future Storage Rings", SLAC-PUB-4937, Aug.1991.

[5] M. Aiba M. Böge, N. Milas and A. Streun, "Ultra low vertical emittance at SLS through systematic and random optimization", NIM A 694 (2012) 133.

[6] Å. Andersson, M. Böge, A. Lüdeke, V. Schlott and A. Streun, "Determination of a small vertical electron beam profile and emittance at the Swiss Light Source", NIM A 591 (2008) 437.

[7] O.V. Chubar, "Resolution Improvements in Beam Profile Measurements with Synchrotron Light", IEEE Particle Accelerator Conference, Washington, 1993, p. 2510.

[8] T. Mitsuhashi, "Measurement of small transverse beam size using interferometry", DIPAC 2001, Grenoble, p. 26.

[9] P.H.van Cittert, Phisica, 1, 201(1934) and also see M. Born and E. Wolf, "Principles of Optics", chapter 10, P491, Pergamon press. (1980).

[10] TIARA/ WP6 Report "Specifications for the new SLS beam size monitor".

[11] O. Chubar and P. Elleaume, "Accurate and efficient computation of synchrotron radiation in the near field region", proc. EPAC98 (1998) 1177.

[12] M. Sanchez del Rio and A. Marcelli., "Waviness Effects in Ray-Tracing of Real Optical Surfaces", NIM A 319 (1992) p. 170.

ISBN 978-3-95450-119-9