EMITTANCE DIAGNOSTICS AT THE MAX IV 3 GeV STORAGE RING

J. Breunlin*, Å. Andersson, MAX IV Laboratory, Lund University, Sweden

Abstract

With the MAX IV project in Lund, Sweden, an ultralow emittance storage ring light source is going into user operation in 2016. Due to its multibend achromat lattice design the 3 GeV storage ring reaches a horizontal emittance lower than 330 pm rad. Emittance diagnostics will involve two diagnostic beamlines to image the electron beam with infrared and ultraviolet synchrotron radiation from bending dipoles. Placed in locations of different optic functions the beamlines will provide experimental access to both horizontal and vertical emittance and to beam energy spread. Since bunch lengthening with harmonic cavities is essential for machine performance, time resolved measurements with synchrotron radiation for individual longitudinal bunch distributions are of special interest as well.

INTRODUCTION

Visible and near UV synchrotron radiation (SR) can be used to resolve vertical beam sizes at the few µm scale. This has been shown by imaging with π-polarized SR [1] and with the *obstacle diffractometer method* [2] at the Swiss Light source. The MAX IV diagnostic beamlines provide diffraction obstacles as well as double-slits for a direct experimental comparison of the double-slit interferometer [3, 4] and the obstacle diffractometer technique.

Due to the low horizontal emittance the horizontal beam size is 20 to 30 µm at the beamline locations in the MAX IV 3 GeV ring. To resolve such low beam sizes a technique based on imaging with a wide horizontal opening angle and at wavelength in the near IR will be applied.

At present one diagnostic beamline (matching dipole 1 in achromat 20) is under commissioning while the other (unit cell dipole 5 in achromat 2) is delayed due to a mechanical problem with one vacuum chamber. We present the achromat 20 beamline design, measured images of SR in comparison to results from theoretical models and a first estimate of the vertical beam size and emittance.

BEAMLINE DESIGN

The diagnostic beamline images SR from a bending magnet onto a CCD camera. See Fig. 1 for a schematic beamline layout. The bending magnet is the first matching dipole in achromat 20 of the MAX IV 3 GeV storage ring with a dipole field that increases from zero to 0.53 T within the observable range of the beamline (18.5 mrad or 490 mm along the dipole), see Fig. 2.

A thin water-cooled absorber, covering a vertical opening angle of 1.9 mrad, protects the beamline optics from powerful x-ray SR. At low beam currents (<3 mA) this absorber is retractable to allow unaltered imaging of SR. The first

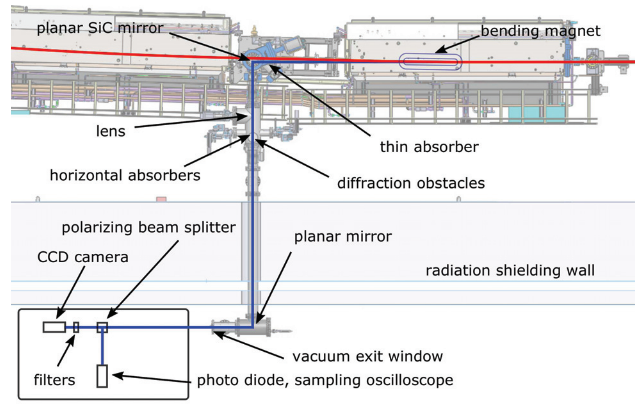

Figure 1: Schematic beamline layout. The electron beam path is indicated in red, the SR path is shown in blue. The distance from the center of the bending magnet to the planar SiC mirror is 1.85 m.

planar mirror, made of silicon carbide, is chamfered and installed in proximity to the electron beam (~1 mm from the electron beam pipe with 20 mm diameter). A second planar mirror outside the radiation shielding wall is required for radiation concerns. The lens (fused silica) is planar-convex with one spherical surface and a diameter of 76 mm. It is placed 2.45 m from the dipole center and images with an optical magnification of −2.18 at a wavelength of 488 nm.

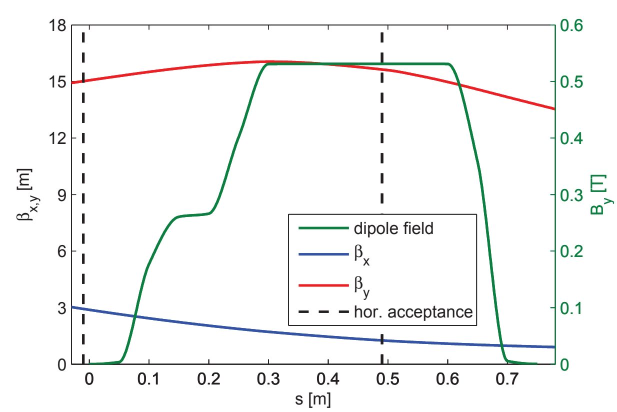

Figure 2: Design beta functions and dipole field strength in the matching dipole. The dashed lines mark the maximum horizontal angular acceptance of the diagnostic beamline.

Two movable horizontal absorbers installed close to the lens define the horizontal opening angle. The vertical acceptance angle of the beamline is limited by the vacuum chamber in the dipole and is ±4.5 mrad. A variety of diffraction obstacles and double-slits can be inserted close to the lens to generate vertical diffraction in a controlled fashion. Special attention has been turned to a solid beamline design

* jonas.breunlin@maxiv.lu.se

to avoid image blurring from mechanical vibrations during long exposure times.

The beamline front-end outside the radiation shielding holds an optical table with a polarizing beam splitter (Glan-Taylor prism), wavelength filters and the CCD camera. By using the ordinary ray from the polarizer time resolved measurements of SR with a sampling oscilloscope or a photodiode can be done simultaneously to SR imaging.

MODELING THE BEAMLINE

Images of the electron beam with SR in the IR-vis-UV range are highly dominated by effects inherent to SR emission and diffraction. These effects are theoretically predictable and it is thus possible to derive both the horizontal and vertical electron beam sizes from imaged SR. The theoretical calculations were done in the Synchrotron Radiation Workshop (SRW) [5, 6]. SRW is based on near-field calculations and preserves all phase information of the SR witch is emitted by the ultra-relativistic electron beam along its curved trajectory in the bending magnet. The SRW model of our beamline contains the varying bending magnet field as well as relevant optics such as apertures and the lens.

VERTICAL BEAM SIZE MEASUREMENTS

Vertical intensity profiles of imaged π-polarized SR offers vertical beam size resolution by evaluating the intensity ratio of maxima and minima in the diffraction pattern, see [1]. Such a profile is shown in Fig. 3 for an imaging wavelength of 488 nm at 1 nm bandwidth. Since in the present state

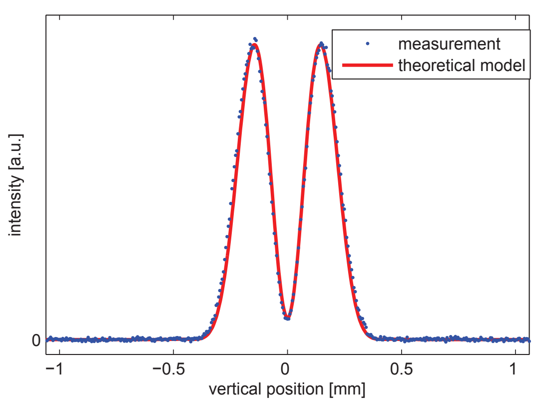

Figure 3: Vertical profile of imaged π-polarized SR at 488 nm wavelength. Measurement (blue dots) and SRW calculation (red lines). The vertical beam size is 11.5 µm.

of the MAX IV 3 GeV storage ring coupling and spurious vertical dispersion are not yet minimized it is not required to image in the near-UV. The diagnostic beamline is, however, prepared for wavelength ranges down to 250 nm in order to resolve vertical beam sizes less than 3 µm.

By introducing diffraction obstacles that cover various vertical angles of the SR (see Fig. 4), complementary measurement methods with a potentially higher sensitivity to the vertical beam size become available [2]. The obstacle heights range from 4.5 mm to 9 mm (from 1.83 mrad to 3.66 mrad vertical angle). A vertical profile measured using the obstacle diffractometer is shown in Fig. 5.

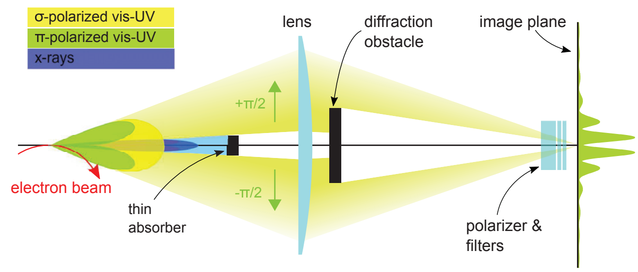

Figure 4: Schematic of the obstacle diffractometer technique.

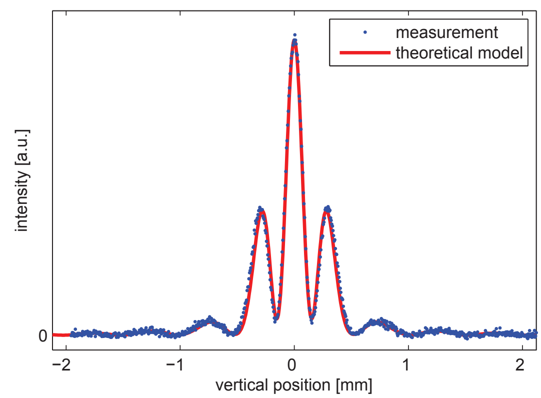

Figure 5: Vertical profile of imaged σ-polarized SR with 5 mm diffraction obstacle at 488 nm wavelength. Measurement (blue dots) and SRW calculation (red lines).

When using a double-slit with a narrow slit widths $2a$ the SR diffraction pattern can be predicted by analytical expressions [2, 4], see Fig. 6. These analytical expressions hold as long as the intensity variation over the slits, originating in the non-isotropic emission of SR, is small. Due to the narrow slits the intensity on the detector is, however, decreased by a factor 5 compared to a diffraction obstacle of same height.

Table 1: Summary of Vertical Beam Size Measurement Results

obstacle height [mm]	σ_y [µm] π-pol.	σ-pol.
-	11.5 ± 0.23	-
4	11.3 ± 0.17	10.5 ± 0.20
5	11.3 ± 0.21	10.7 ± 0.18
6	11.0 ± 0.15	10.7 ± 0.17
9	11.3 ± 0.21	10.6 ± 0.16

The beamsize results achieved with π-polarized imaging and with the obstacle diffractometer methods are shown in Table 1. With the combined result for the vertical beam size of 11.0±0.4 µm combined with beta functions from first

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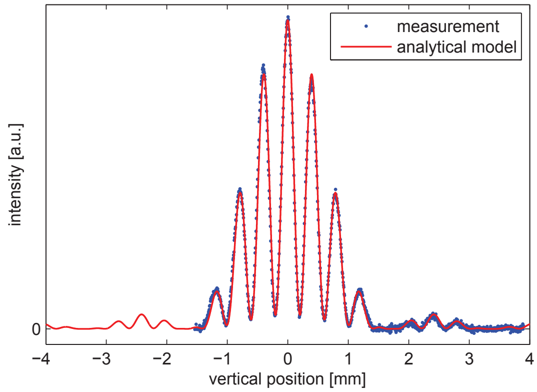

Figure 6: Vertical profile from a double-slit (d = 6.2 mm, $2a$ = 1.5 mm) at 488 nm wavelength. Measurement (blue dots) and analytical calculation (red line). The vertical beam size is 10.5 µm.

attempt LOCO fits in the source point ($\beta_x \approx 2.3$ m and $\beta_y \approx 18$ m) and measured dispersions of ≈ 3 mm in both planes the vertical emittance is 6.4±0.9 pm rad.

HORIZONTAL BEAM SIZE MEASUREMENTS

SR inherent diffraction effects occurring at large horizontal opening angles (>10 mrad) can be used to resolve the horizontal beam size. Since the diffraction pattern is more pronounced at longer wavelengths this requires imaging of SR in the near infrared. At large opening angles the variation of the magnetic field and the beta functions (Fig. 2) need to be taken into account in the theoretical model. Since the edge of the bending magnet is within the horizontal opening angle dipole edge radiation effects can be studied with this beamline. A thorough characterization and theoretical modeling of the electron beam and the diagnostic beamline is, however, required for accurate measurements under these conditions.

Currently the beamline is misaligned by a few mm such that the optical axis of the beamline deviates from SR emission tangent. This has been found by optical alignment and has been modeled in SRW in a basic approach (Fig. 7). Since the misalignment impedes measuring at the full horizontal opening angle it needs to be corrected to achieve sufficient resolution of the horizontal beam size.

BUNCH LENGTH MEASUREMENTS

An optical sampling oscilloscope is used for longitudinal bunch profile measurements. At low currents (no Landau cavity excitation) bunch length from natural energy spread could be verified, see Fig. 8. To verify bunch lengthening and to distinguish it from longitudinal oscillation a single-shot method is required and is planned to be implemented using a fast photo-diode and an oscilloscope.

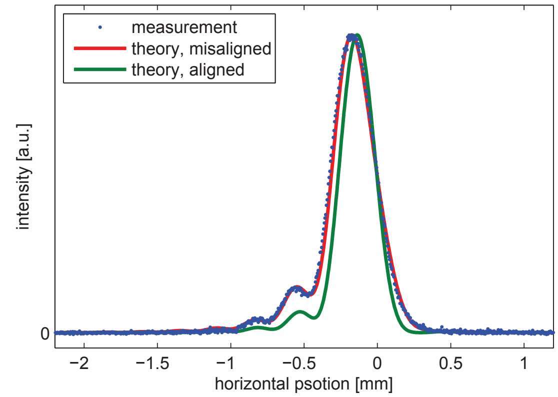

Figure 7: Horizontal profiles of σ-polarized SR at 930 nm for 8.2 mrad horizontal opening angle. The horizontal beam size is 24.5 µm.

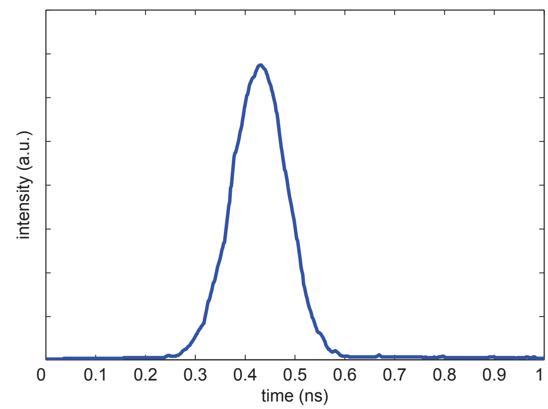

Figure 8: Longitudinal bunch profile measured at <1mA current. The rms bunch length is 55 ps.

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