BEAM PROFILE MEASUREMENTS
WITH VISIBLE SYNCHROTRON LIGHT ON MAX-II

Å.Andersson, M.Eriksson, MAX-Lab, Lund, Sweden
O.Chubar, RRC Kurchatov Institute, Moscow, Russia

Abstract

Beam profile & size measurement results obtained on MAX-II with different methods using visible range synchrotron radiation will be reported. In addition to the "standard" beam profile measurement scheme based on focusing lens, "Lloyd's Mirror" interference scheme was used to independently measure the transverse beam sizes. For each experimental scheme, high-precision wave-optics based calculations of synchrotron light characteristics were applied to determine the electron beam parameters to sufficiently high accuracy.

1 INTRODUCTION

Visible synchrotron radiation (SR) is widely used as a tool for beam profile and emittance measurements on storage rings and SR sources [1]- [3]. However, inherent features of he SR emission and diffraction effects could make the interpretation of the measured profiles difficult if the actual beam size is very small. For the low emittance third generation SR sources, it has been questionable if one could stay in the visible range, or one should be forced to move to the VUV or X-ray range in order to suppress the diffraction effects. In the perspective of performing beam size measurements on the third generation SR source MAX-II [4] (see Tab. 1), it has been the authors intention to stay in the visible region, and by help of wave-optics based calculations, not suffer from, but rather take advantage of the inherent SR emission effects.

Table 1: Some MAX II parameters and lattice parameters at the observation point.

Injection energy	.47 GeV
Nominal energy	1.5 GeV
Bending radius	3.33 m
Nom. Hor. Emittance	9 nmrad
Betax ; Betay ; Eta	1 m ; 9 m ; 0.01 m

Two independent methods have been used, both utilising the visible range SR from a bending magnet. One is the "standard" method [5] where a lens is used to focus the SR and form an image of the electron beam. A position-sensitive detector is then positioned in the image plane. The other method [6] is based on the Lloyd's mirror scheme. Part of the emitted SR distribution is reflected by a flat mirror. The reflected and the direct light will then interfere and form a pattern of bright and dark fringes, at which position a detector is placed. The visibility of these fringes is strongly dependent on the electron beam size.

2 THE DIAGNOSTIC BEAMLINE

In Fig. 1 can be seen a schematic top view of the MAX-II diagnostic beamline. The source point is 6 deg from the entrance edge of the bending magnet. We use a SiC mirror, attached with a liquid gallium interface onto a water-cooled copper block, for 90 deg extraction of the visible SR. A spherical symmetric fused silica lens is placed just after the SiC mirror. Movable baffles are restricting the horizontal acceptance of the beamline. The vacuum tube is extended to a position quite close to the lens case detector , in order to suppress possible effects of vacuum window irregularities. Interference, polarisation and neutral density filters are for the same reason placed close to the detector. In the case of Lloyd's mirror measurements, the lens is moved out of the light path, while a flat Sital glass plate, acting as a gracing incidence mirror, is positioned either horizontally or vertically outside the vacuum window. The detector is then realigned to catch the interference pattern. The detector used in either case, is a Sony XC-77CE CCD sensor, with 11.0 μm square pixels.

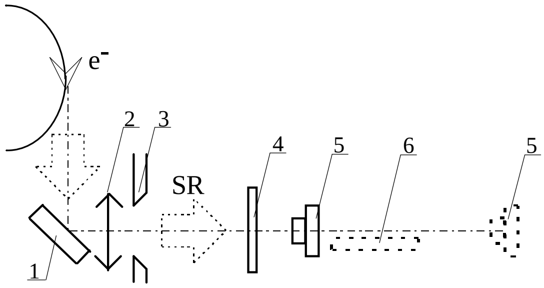

Figure 1: Beamline. 1-SiC Mirror, 2-Lens , 3-Baffles , 4-Vacuum window , 5-Detector , 6-Glass plate

3 THE LENS METHOD

3.1 On Theoretical Basement

The wave-optics treatment of synchrotron radiation diffraction and focusing was the subject of several former works [7] - [9]. We have followed the outlines given in ref [5], which very shortly can be described as follows:

In the well-known classical Kirchhoff approach [10], the diffraction phenomena is formulated with respect to a monochromatic spherical wave (a solution of a homogeneous Helmholtz equation). If one applies the Green formula to the spherical wave describing function, and uses the Kirchhoff boundary conditions, then one obtains the standard Fresnel-Kirchhoff diffraction formula [10]. In the case of synchrotron light emitted by a single electron, one can also follow the above formalism with the only difference that instead of the spherical wave, the Fourier transformation of the retarded potential (describing the monochromatic SR) should be taken. The effect, often called a depth-of-field, will in this way be included in the wave-optics treatment. One can now compute the intensity distribution of the focused SR being emitted by a single electron, or zero-emittance electron beam. This distribution we will call the transfer function.

A transfer function computed from the above considerations, is shown in Fig. 2. It corresponds to the electron energy E = 0.47 GeV, λ = 360 nm, distance from geometrical radiation point to lens 280 cm, lens diameter 48 mm, horizontal slit width 27 mm, optical magnification -1.08 (the values of the real measurements geometry). Numerical estimations show that a 10 nm bandwidth effect to the transfer function values is within 1 - 3 %.

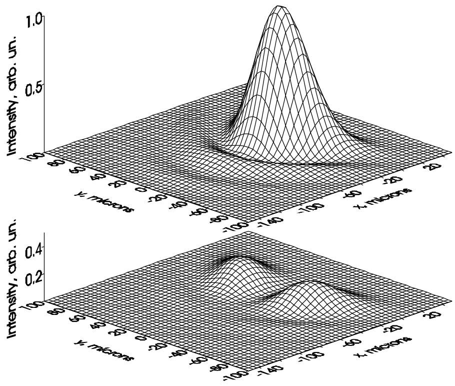

Figure 2: σ- (upper) and π- polarisation components of the transfer function computed for the parameters of the real measurements geometry.

Finally, for incoherent SR, the intensity distribution corresponding to a finite transverse emittance beam can be found as a result of integration of the zero-emittance distribution with a phase space particle density distribution, over all the transverse phase space of the beam.

3.2 *Results of the Measurements*

Measured beam profile images at 0.7 mA, with different polarisation filter positions, and the geometrical parameters listed in chapter 3.1, are shown in Fig. 3.

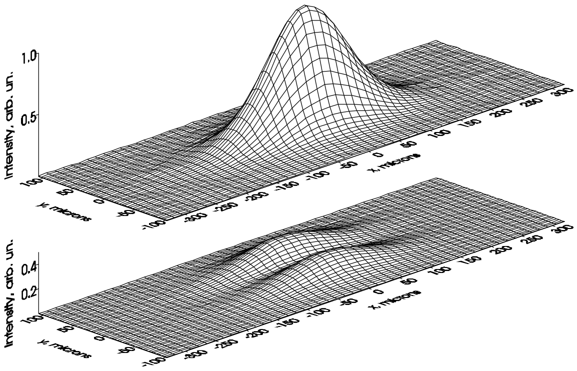

Figure 3: Measured beam profile images at low beam current, where either the σ- (upper) or π- polarisation component of the SR was used.

From the two figures above we see that, for low currents, in the vertical case we measure essentially the transfer function. This means that we have come close to the physical limitation of the method. On the other hand, it shows that the precision of the Kirchoff diffraction theory adapted to SR can be practically verified.

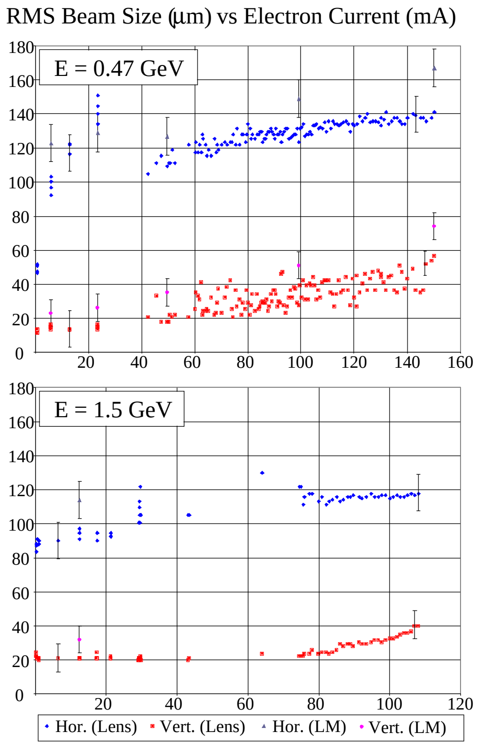

Figure 4: RMS Beam sizes versus beam current.

The results of the beam size measurements with lens, at different beam currents are presented in Fig. 4. The data points represent actual beam sizes. One can note that in the vertical direction the measured small beam sizes correspond to (see lattice parameters in table 1) emittances around 20 pmrad. However, the relative uncertainty is rather large when the actual σ_y goes below say 20 μm. One way to overcome the uncertainties, could be to closely look at the intensity minimum in the π- component case. Anyway, high-precision calculation of the transfer function and effective reconstruction procedures are necessary to make the lens based beam diagnostics method applicable for measuring such small beam sizes. The above situation requires implementation of an independent method to measure the beam sizes.

4 LLOYD'S MIRROR METHOD

As compared to a previous implementation [6] of this method, an improvement allowing the practical use of the method for determining small beam size values was done. The problem was that, in order to get high precision at measurements of small beam sizes with this method, mirrors of large length (1 - 2 m) were needed. Our improvement was that in the data processing procedure we took into account diffraction from the mirror edges, which makes valuable contribution to the resulting intensity distribution if detector is offset from the mirror edge. This allowed us to use mirrors of 40 cm length for beam size measurements on MAX-II.

At the Lloyd's mirror measurements, the distance from geometrical radiation point to mirror edge was 559 cm, and 286 cm (at vertical size measurements) from the other mirror edge to the detector. At these measurements, we used an interference filter for 560 nm at 2 nm RMS bandwidth.

Figure 5 shows examples of registered intensity profiles in the interference pattern at vertical size measurements and the corresponding computation best-fits at different electron beam current values: 6.3 mA (I) and 150 mA (II). The essentially smaller visibility of fringes in the case II testifies that beam size is significantly larger at 150 mA than at 6.3 mA.

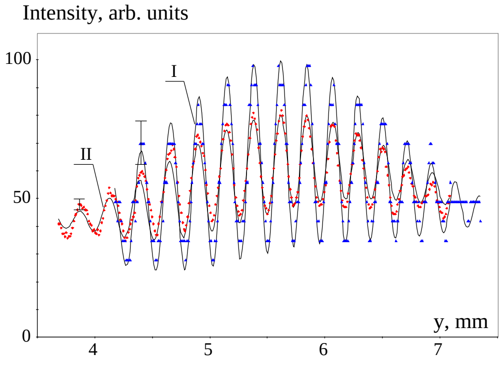

Figure 5: Registered intensity profiles in the interference pattern at vertical size measurements and the corresponding best-fits. I (6.3 mA current): best fit gives $\sigma_y = 22 \pm 9$ μm. II (150 mA current): $\sigma_y = 76 \pm 7$ μm.

The beam size measurement and fitting results at different current values are presented in Fig. 4, along with the Lens method data. Unfortunately, the Lloyd's mirror and Lens measurements were not done simultaneously, and the machine modes of operation were not exactly identical at the two series of measurements. However, the tendency is that the Lloyd's Mirror method gives larger beam size values. One of the possible explanations is that this is a result of a systematic error due to larger actual interference filter bandwidth than the one certified by the vendor. Independent precise measurements of the interference filter characteristics are prepared.

5 CONCLUSIONS

The diagnostic beamline serves as a good platform for beam profile and emittance measurements. The lens method gives the possibility to measure beam sizes well below the MAX II design values. However the ring allows for even smaller vertical sizes, where we reach the physical limitation of the method. On the other hand, this means that the precision of the Kirchoff diffraction theory adapted to synchrotron radiation can be practically verified in the visible region on MAX-II.

The Lloyd's mirror method, again within precise wave-optics considerations, gives a possibility to go further down at determining small beam size values.

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