ACCURATE ELECTRON BEAM SIZE MEASUREMENT AT THE METROLOGY LIGHT SOURCE

R. Klein, G. Brandt, R. Thornagel
Physikalisch-Technische Bundesanstalt, Abbestraße 2 – 12, 10587 Berlin, Germany
J. Feikes, M. Ries, G. Wüstefeld
HZB, Albert-Einstein-Straße 15, 12489 Berlin, Germany.

Abstract

For the operation of the Metrology Light Source (MLS), the dedicated electron storage ring of the Physikalisch-Technische Bundesanstalt (PTB), as the national primary radiation source standard from the near infrared to the vacuum ultraviolet spectral region, all storage ring parameters which are relevant for the calculation of the radiant intensity by the Schwinger equation have to be known absolutely with small uncertainties. For the measurement of the effective vertical electron beam size a Bragg polarimeter, operating at a photon energy of 1103 eV, has been designed and successfully put into operation.

INTRODUCTION

Electron storage rings with calculable bending magnet radiation according to the Schwinger theory [1] are used as primary source standards for radiometry at several national metrology institutes [2]. The PTB uses the electron storage rings BESSY II and the MLS [3] for this purpose [4].

The calculation in the case of electron storage rings with an electron beam having a finite size and an angular spread is described in detail in [3]. The spectral radiant power through an aperture of radius r placed at a distance d and at a certain photon energy E can be expressed in the form

$$\Phi_E = \Phi_E\left(E; W, B, I, \Sigma_y; Y, d, r\right) \quad (1)$$

with W being the electron beam energy, B the magnetic induction at the source point, I the electron beam current, Σ_Y the vertical effective source size and Y a possible vertical offset from the orbital plane. All these parameters must be measured. In this paper we describe the measurement of the vertical effective source size, which is defined as

$$\Sigma_Y = (\sigma_y^2 + d^2\sigma_{y'}^2)^{1/2} \quad (2)$$

and may be regarded as the projected source size at the location of the aperture. It is related to the vertical size σ_y and vertical angular spread $\sigma_{y'}$ of the electron beam. As for all parameters, the uncertainty in the determination of the effective vertical source size contributes to the uncertainty of the calculated radiant power. The influence is dependent on the photon energy, the angular acceptance and the value of the effective source size. Normally a relative uncertainty of 20 % is sufficient, for small effective source size it can be even worse (see Fig. 1).

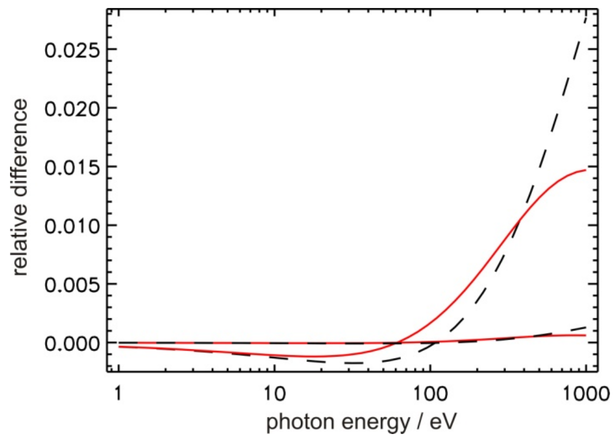

Figure 1: Influence of a 20 % uncertainty in the effective vertical source on the calculation of the spectral radiant power through an aperture of radius 5 mm (black, dashed curve) and 10 mm (red curves) at a distance of 15 m. The values of the effective source size was assumed to be 0.5 mm (almost straight curves) and 3 mm (strongly bended curves).

Bending magnet radiation is highly polarized (Fig. 2). For a zero effective source size, the polarization component of the synchrotron radiation (SR) perpendicular to the orbital plane vanishes in the orbital plane and shows a maximum above and below the orbital plane. For an increasing effective source size, the dip in between the two off-plane maxima starts to fill. This is a very sensitive indicator for the value of the effective source size (Fig. 3), that was already exploited with a similar device constructed at the electron storage ring BESSY I some decades ago [5].

THE BRAGG POLARIMETER

The direct, undispersed SR from the bending magnet passes an Aluminium filter of 8 µm in thickness and an aperture of 5 mm x 25 mm (horizontally and vertically) before it reaches a Beryll crystal. The Beryll crystal reflects the incoming synchrotron radiation by 90° in the orbital plane onto a CCD-camera chip. The crystal acts simultaneously as a monochromator due to the Bragg condition and as a polarizer due to the Brewster condition. So only photons at 1103 eV with a polarization component that is perpendicular to the orbital plane are deflected. The Aluminium filter takes away unwanted false light and suppresses possible higher diffraction orders (Fig. 4). Figure 5 shows a photograph of the device.

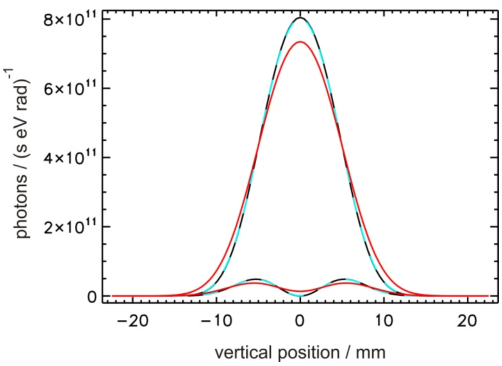

Figure 2: Vertical distribution of the photon flux at a photon energy of 1103 eV at a distance of 15 m for 5 mm horizontal acceptance and 1 mA electron beam current. The upper curves show the photon flux for both polarization complements, the lower curves only the component perpendicular to the orbital plane. The black curve is calculated for vanishing eff. vertical source size, the blue and red ones for 0.5 mm and 3 mm, respectively.

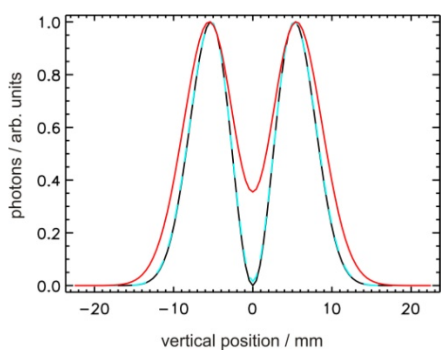

Figure 3: Normalized polarization component perpendicular to the orbital plane as in Fig. 1.

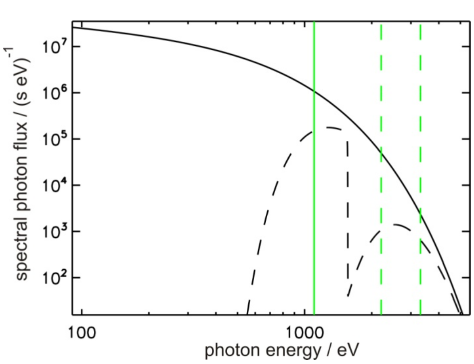

Figure 4: Calculated spectral photon flux through an aperture of 1 mm x 0.1 mm at 15 m distance for the MLS operated at 630 MeV and an electron beam current of 1 mA. The solid curve shows the spectrum incident on the Al-filter, the dashed the transmitted part through the filter. The green vertical lines indicate the reflected photon energy (1103 eV, solid line) and its higher orders (dashed lines).

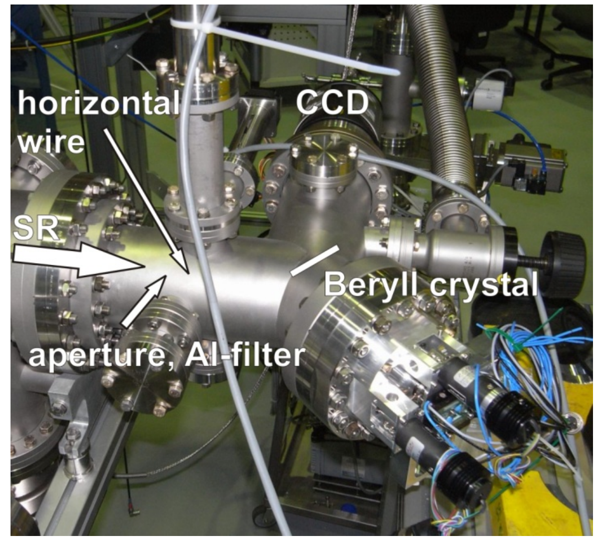

Figure 5: Photograph of the Bragg polarimeter. The major components are marked.

The device is mounted at the end of the MLS white light beamline [6] at a distance of 15 m from the radiation source point. This beamline is used for the calibration of radiation sources [7] or energy dispersive detectors or wavelength dispersive spectrometers [8]. So the great advantage of the Bragg polarimeter is that it measures directly the value needed at the location where thereafter the calibration is performed.

A typical CCD image is shown in Fig. 6a (note that the long size of the image is in the vertical direction). The two bright areas resulting from the maxima of the polarization component above and below the orbital plane are clearly seen, as well as the dark frame resulting from the above mentioned aperture. Unfortunately, the crystal surface shows a messy structure, that causes a non-uniform reflection. Nevertheless, if all CCD pixels are summed up in the horizontal direction and are binned, the effect of this non-uniformity is strongly mitigated, resulting in a measured distribution of the perpendicular polarization component as shown in Fig. 6b (black and red crosses). Stray light, mainly originating from the crystal reflection, has a deteriorating effect since it also fills the dip in between the two maxima. To correct for this effect, a thin horizontal wire, movable in the vertical direction, is placed between the filter and the crystal. The shadow of this wire can be clearly seen in the CCD image and the signal level in this shadow area is defined as the zero level. The measured vertical distribution is then matched to the distribution calculated by the Schwinger equation with the vertical effective source size as the only varying parameter. The green line in Fig 6b shows the fitted line, the red crosses indicate the fitted measurement points. The points within the shadow area of the aperture and of the wire (black crosses) are ignored for the fitting procedure. Typical uncertainties in the fit parameter are in the order of 1 %. Including the uncertainty in the other parameters and in the straight light subtraction an overall relative uncertainty of 5 % is obtained.

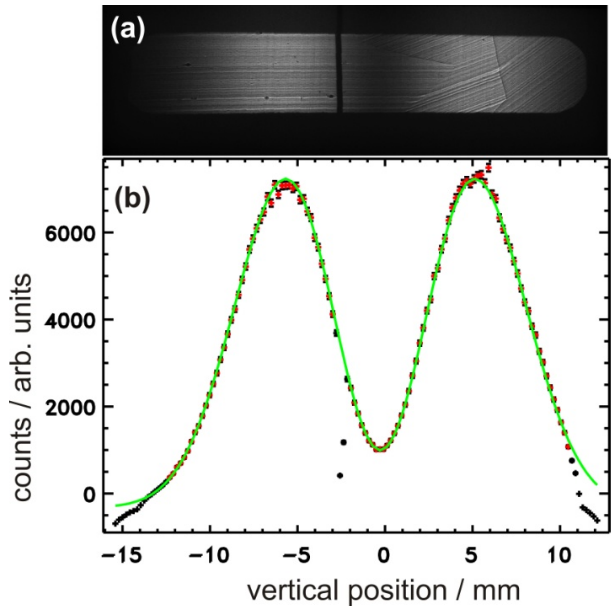

Figure 6: (a) Typical CCD image recorded at a distance of 20 m from the source point, the acquisition time was 10 s at an electron beam current of 5 mA; (b) Resulting measured vertical distribution of the perpendicular polarized component, see text for details.

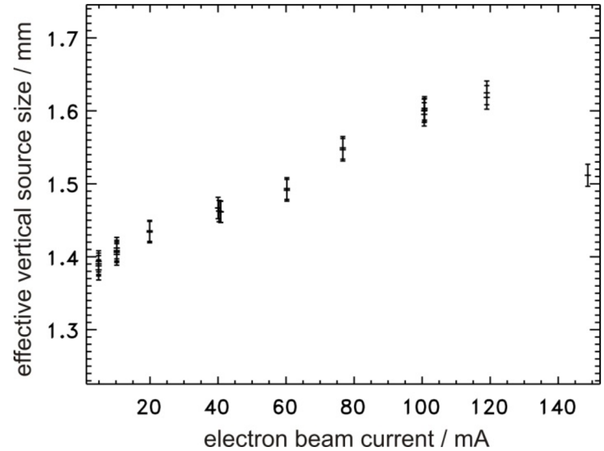

Figure 7: Effective vertical source size measured with the Bragg polarimeter for various electron beam currents. At some values of the electron beam current multiple measurements have been performed.

RESULTS

In a first run a series of measurements were performed for different electron beam currents from 5 mA to 150 mA, and the MLS electron energy set to 630 MeV. Figure 7 shows the resulting values of the effective source size. The error bars only indicate the uncertainty in the fitted value, not contributions due incorrect straight light subtraction or uncertainties in the other parameters need for the calculation of the vertical distribution.

The effective source width shows the same behaviour as measured with an optical imaging system [9, 10]. At 630 MeV and around 120 mA beam current a longitudinal multi bunch instability develops which leads to an increase of the mean bunch length. This leads to a decrease of the mean charge density inside the bunch reducing the transverse bunch blow up caused by multi particle scattering processes. This explains why the effective emittance is reduced above 120 mA.

In order to compare the absolute values, the effective vertical source size must be scaled somehow to the vertical electron beam source size σ_y. We did this by using the calculated lattice functions of the MLS with the relation

$$\sigma_{y'} = \sigma_y \sqrt{1+\alpha_y^2} / \beta_y = 0.267\ \sigma_y \qquad (2)$$

which yields with eq.(1) for a distance $d = 15$ m the direct relation $\Sigma_Y = 4.1\ \sigma_y$. The absolute values of the vertical electron beam size measured with the Bragg polarimeter are then about 30 % less the values obtained with the optical imaging system. Taking into account the uncertainty in the calculated lattice functions, the limited resolution of the optical system due to diffraction and a miss-focussing of the optical imaging system, which was observed at the last system commissioning, the agreement is satisfactory for the moment but might be improved with an appropriately aligned optical system.

SUMMARY

A Bragg polarimeter for the measurement of the effective vertical source size was successfully put into operation at the MLS. The measured value is needed for the operation of the MLS as a calculable primary source standard. The obtained relative uncertainty for typical MLS beam sizes is in the order of 5 % and more than sufficient for all applications. Comparison of the results obtained with the Bragg polarimeter with the values obtained with an optical imaging system show satisfactory agreement.

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