ABSOLUTE MEASUREMENT OF THE MLS STORAGE RING PARAMETERS

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Abstract

The Metrology Light Source (MLS), the new electron storage ring of the Physikalisch-Technische Bundesanstalt (PTB) located next to BESSY II in Berlin - Adlershof is dedicated to metrology and technological developments in the UV and EUV spectral range as well as in the IR and THz region. The MLS can be operated at various electron beam energies up to 630 MeV and at electron beam currents varying from 1 pA (one stored electron) up to 200 mA. Moreover, it is optimized for the generation of coherent synchrotron radiation in the far IR/THz range. Of special interest for PTB is the operation of the MLS as a primary radiation source standard from the near IR up to the soft X-ray region. Therefore, the MLS is equipped with all the instrumentation necessary to measure the storage ring parameters needed for the calculation of the spectral photon flux according to the Schwinger theory with low uncertainties.

INTRODUCTION

Electron storage rings with calculable bending magnet radiation according to the Schwinger theory are used as primary source standards for radiometry at several national metrology institutes [1]. Since the spectral range covered by electron storage rings extends far into the X-ray region, their usage for radiometry considerably expands the spectral region as compared to that covered by blackbody radiators, which are routinely used for conventional radiometry from the IR to the UV region. For more than 25 years PTB has been taking advantage of this, at the now-closed BESSY I electron storage ring, at BESSY II and now at the MLS.

Prerequisite to the operation of an electron storage ring as a primary source standard is – in addition to sufficient stability - the knowledge of the parameters needed for the calculation of the spectral photon flux according to the Schwinger equation [2]. At the MLS electron storage ring [3] PTB has installed and is operating all the equipment for the measurement of the storage ring and geometrical parameters needed for the calculation of the spectral photon flux with high accuracy [4].

The parameters are: the electron energy, the magnetic induction at the radiation source point, the electron beam current, the effective vertical source size Σ_y, the vertical emission angle, the distance d between the radiation source point and a flux-defining aperture of known size. Σ_y is derived from the vertical electron beam size σ_y and beam divergence $\sigma_{y'}$ according to $\Sigma_y = \left(\sigma_y^2 + d^2\sigma_{y'}^2\right)^{1/2}$.

MEASUREMENT OF THE PARAMETERS

At the MLS the electron beam current and electron energy can be varied over a wide range in order to create tailor-made conditions for special applications and calibrations, as can be seen in Tab. 1, which lists the main parameters of the MLS. The instrumentation for the measurement of the storage ring parameters must be apt to cover that wide range. Especially for the determination of the electron beam current, the electron energy and magnetic induction at the source point the relative uncertainty of the measurement must be better than 0.1 %. The setups and results for the determination of the parameters are described in more detail below, with emphasis on the measurement of the electron beam energy and electron beam current, since they require the most sophisticated technique.

Electron Beam Energy

The electron beam energy can be ramped to any value from 105 MeV (injection energy) up to the maximum energy of 630 MeV and is determined by the method of Compton back-scattering of laser photons [5]. Therefore, a CO_2 - laser beam is superimposed anti-parallel to the electron beam and the photons scattered in the forward direction of the electron beam are measured by an energy-dispersive detector, the channel energy of which as been calibrated by radio-nuclides.

Table 1: Main MLS parameters

Parameter	Value
lattice structure	double bend achromat
circumference	48 m
electron energy	105 MeV to 630 MeV
magnetic induction of the bending magnets	0.23 T to 1.38 T
characteristic wavelength characteristic photon energy	3.4 nm to 735 nm 1.7 eV to 364 eV
electron beam current	1 pA to 200 mA
natural emittance (design value at 600 MeV)	100 nm rad
injection energy	105 MeV

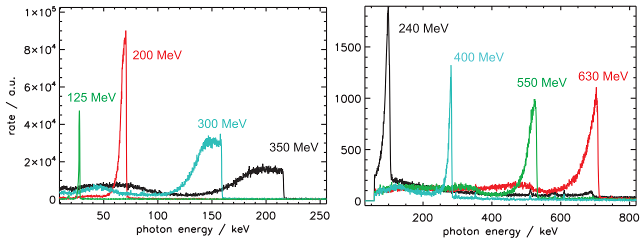

Figure 1: Typical spectra of Compton-backscattered photons for lower (left) and higher (right) electron beam energies.

From the cut-off energy of the scattered photons, the electron energy can be determined.

The cut-off energy varies from 20 keV up to 710 keV for the MLS operated at 105 MeV and 630 MeV, respectively. To cover this wide range, two different detectors have been used as well as a slightly different optical path: For the high energy end, i.e. electron energies from 630 MeV to 250 MeV, an HPGe coaxial detector with a large crystal is used (EG&G GEM-100220-P). Due to the large Ge crystal, this detector has a good efficiency for the detection of high energy photons but is not suited for low energy photon detection because of its thick Ge dead layer and thick Al entrance window. This detector system is energy-calibrated by using ^{60}Co and natural radioactivity background lines. The backscattered photons penetrate the mirror used to superimpose the laser beam. For the low energy side of the backscattered photons, i.e. for electron energies of 400 MeV to 105 MeV, a LEGe detector with Be entrance window and rear contact (Canberra GL 2015) is used. This detector is optimized for the detection of low energy photons above 3 keV but its efficiency rapidly decreases for photon energies above approx. 100 keV. This detector system has been energy-calibrated by ^{57}Co. In this case, the mirror used to superimpose the laser beam was positioned in such a way to let the scattered photons pass without interaction. Nevertheless, the scattered photons have to penetrate a viewport that terminates the vacuum system and that ultimately limits the detection of low energy photon to approximately 20 keV. Typical spectra are shown in Fig. 1. Measurements in the overlapping region show good agreement for either detector system or optical alignment.

Based on these measurements the electron energy can be correlated to the current of the bending magnets in the storage ring. Fig. 2 shows the proportionality factor that relates the electron beam energy to the bending magnet current. A typical saturation and hysteresis behaviour can be seen. The red lines show an analytical approximation (sum of a straight line and two exponential functions) for the part with increasing bending magnet currents (up) and decreasing bending magnet currents (down).

Electron Beam Current

The stored electron beam current can be varied by more than 11 decades from a maximum current of 200 mA down to one stored electron (1 pA).

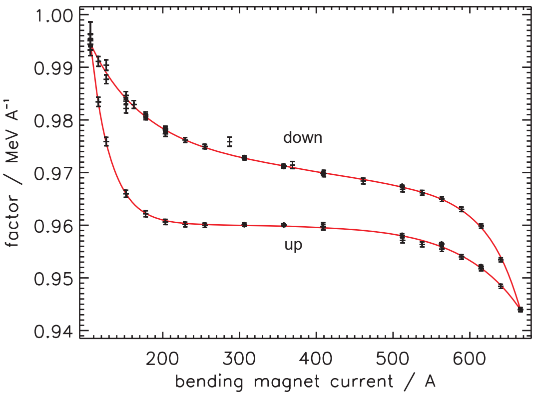

Figure 2: Proportionality factor between bending magnet current and electron energy.

Currents in the upper range, i.e. above 1 mA, are measured with two commercially available DC parametric current transformers (Bergoz). Electron currents in the lower range, i.e. below approx. 1 nA, are determined by counting the number of stored electrons. For this, the electrons are gradually kicked out of the storage ring by a mechanical scraper that can be moved closely to the electron beam, while measuring the step-like drop of the SR intensity by cooled photodiodes. Electron beam currents in the middle range, i.e. from about 100 pA up to 1 mA, are determined by three sets of windowless Si photodiodes with linear response that are illuminated by SR attenuated in intensity in some cases by different filters. The calibration factors of these photodiode-filter combinations, which relate the photocurrent to the electron beam current, are determined by comparison with the electron beam current measured at the upper and lower end of the range as described above. Figure 3 shows the measurement of the electron beam current for a few stored electrons. For these measurements the lifetime of the electron beam, being normally several hours, is artificially reduced by a scraper, which is placed close to the electron beam.

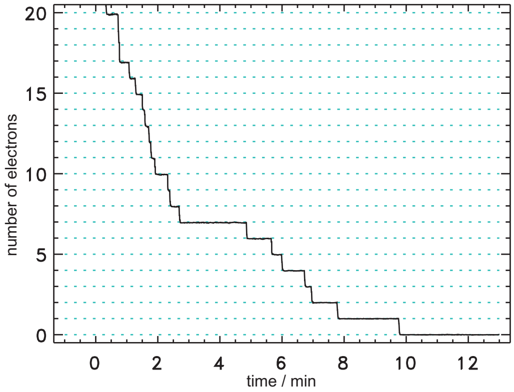

Figure 3: Single electrons stored in the MLS.

Other Parameters

For the measurement of the magnetic induction at the radiation source point, the bending magnet vacuum chamber is designed in such a way that, after a beam dump, a nuclear magnetic resonance probe can be brought to the location of the radiation source point. The magnetic field map of the bending magnet in the area of the radiation source point has been measured and is sufficiently flat so that small displacements of the probe position from the actual source point are tolerable [4]. Fig. 4 shows the measured ratio of magnetic induction and bending magnet current.

First measurements for the determination of the effective vertical source size have been performed. A set-up for the optical imaging of the electron beam has been put into operation for the determination of the electron beam source size (Fig. 5). A different set-up for the measurement of the vertical source size was tested: A 10 mm x 10 mm area photodiode with a 8 µm Al filter was moved vertically through the synchrotron radiation beam in a distance of 2.5 m from the source. The measured photocurrent was then modelled by calculations with the Schwinger equation, adjusting the parameter for the vertical source size to fit the data. Fig. 6 shows the measurements (symbols) and the corresponding calculation (lines), for the MLS operated at 630 MeV with large (black) and minimum (red) vertical coupling, yielding an effective source size of 0.8 mm and 0.25 mm, respectively. The relative uncertainty of this approach is estimated to be about 20 %, which is sufficiently accurate for most applications. The geometrical parameters are determined as is described in [6].

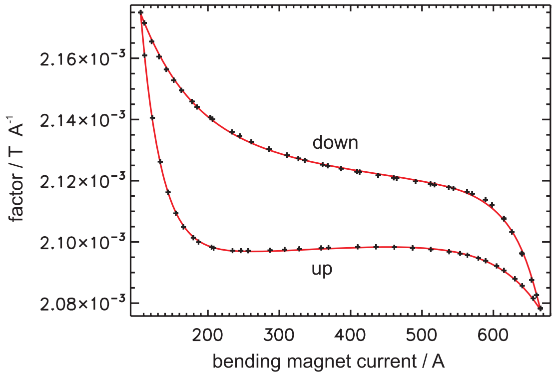

Figure 4: Proportionality factor between bending magnet current and magnetic induction.

SUMMARY

The set-up for the measurement of the parameters for the calculation of the spectral photon flux of the MLS bending magnets has been put into operation successfully. The electron beam energy, magnetic induction at the radiation source point and the electron beam current can be determined with relative uncertainties better than 0.1%.

This enables PTB to operate the MLS as a primary source standard from the near IR to the X-ray spectral region with an uncertainty below 0.2 % in the calculation of the spectral photon flux [4].

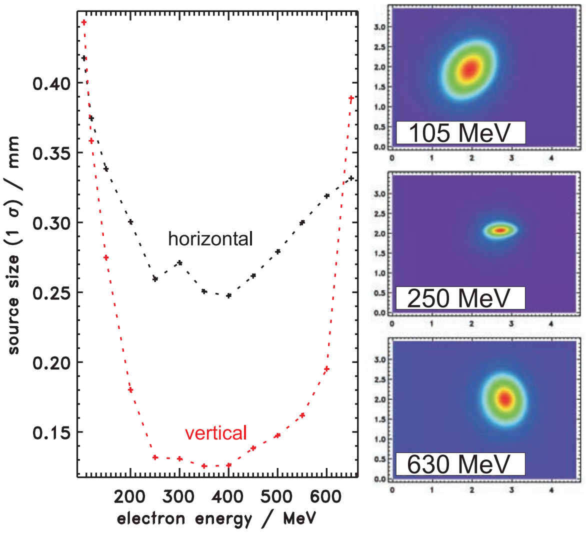

Figure 5: Source size (left) determined from the optical image of the electron beam (right, examples) for various electron beam energies. At low electron beam energies, the beam size is blown up due to trapped ions. At 630 MeV the vertical size increased mainly because of large coupling.

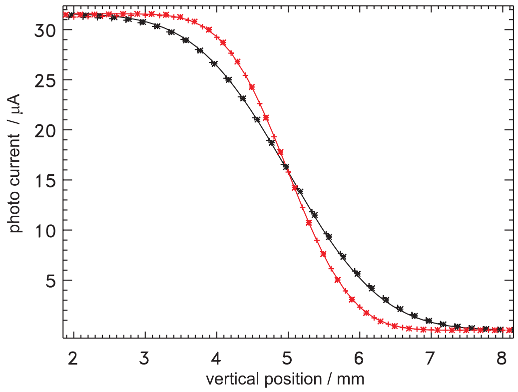

Figure 6: Signal of a 10 mm x 10 mm area photodiode with an 8 µm Al-filter while being moved vertically into (*) and out of (+) the synchrotron radiation beam. The solid line is the appropriate calculation according to the Schwinger theory. The black and red graphs are for the MLS operated with a large and a minimum vertical coupling at an electron energy of 630 MeV, respectively.

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