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A plane-grating monochromator beamline for the PTB undulators at BESSY II

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At the BESSY II storage ring, the Physikalisch–Technische Bundesanstalt (PTB) will operate insertion devices dedicated to radiometric use. One branch of the appendant beamline system will be equipped with a grazing-incidence monochromator, described here. The monochromator concept is based on a plane grating operated in parallel light; therefore exact focusing is maintained for all photon energies irrespective of the angular setting at the grating. The monochromator has been optimized for small higher-order transmittance and high power throughput, as required by radiometric applications in the wide photon energy range from 20 eV to 1900 eV.

Keywords: radiometry; spectral purity; monochromators.

1. Introduction

The Physikalisch–Technische Bundesanstalt (PTB) will operate its own insertion devices in a straight section of the 1.7 GeV electron storage ring BESSY II. In cooperation between PTB and BESSY, three beamline branches have been designed for the radiometric use of undulator radiation: one for experiments using direct undulator radiation, another equipped with a normal-incidence monochromator and a third with a grazing-incidence monochromator.

For radiometric applications, such as detector calibration with a cryogenic radiometer (Rabus *et al.*, 1997) as primary detector standard, high spectral purity (less than 0.5% of the radiant power due to stray light from all beamline elements and due to higher orders) and high radiant power (P > 10 μW at 100 mA stored electron current at modest resolution) are required (Ulm & Wende, 1995). Hence, the design targets are slightly different from those for other undulator beamlines at BESSY II, where highest energy resolution and flux density are the centres of interest.

In the following, the details and the performance of the grazing-incidence beamline are discussed.

2. Description of the beamline

2.1. *Source*

The beamline will be alternately operated with a U180 (180 mm period) (Klein *et al.*, 1998) and a U49 (49 mm period) (Bahrdt *et al.*, 1996) undulator to cover a wide photon energy range from 20 eV to 1900 eV with maximum performance, *i.e.* high photon flux and small transmittance of higher diffraction orders.

An undulator spectrum consists of discrete harmonics of a fundamental energy with different angular distributions. The radiation in the central cone of the first, third and fifth harmonics is used as input for the monochromator. The corresponding radiant power output at harmonics with double and triple photon energy must also be considered, since they produce unwanted light in the second and third diffraction orders at the grating, *e.g.* the sixth and ninth harmonics of the undulator if the third harmonic is used. In most cases, it is sufficient to consider higher-order radiation up to the third diffraction order. A special case is the third harmonic of the undulator. In the lower energy range, it produces higher-order light in the third diffraction order, whereas

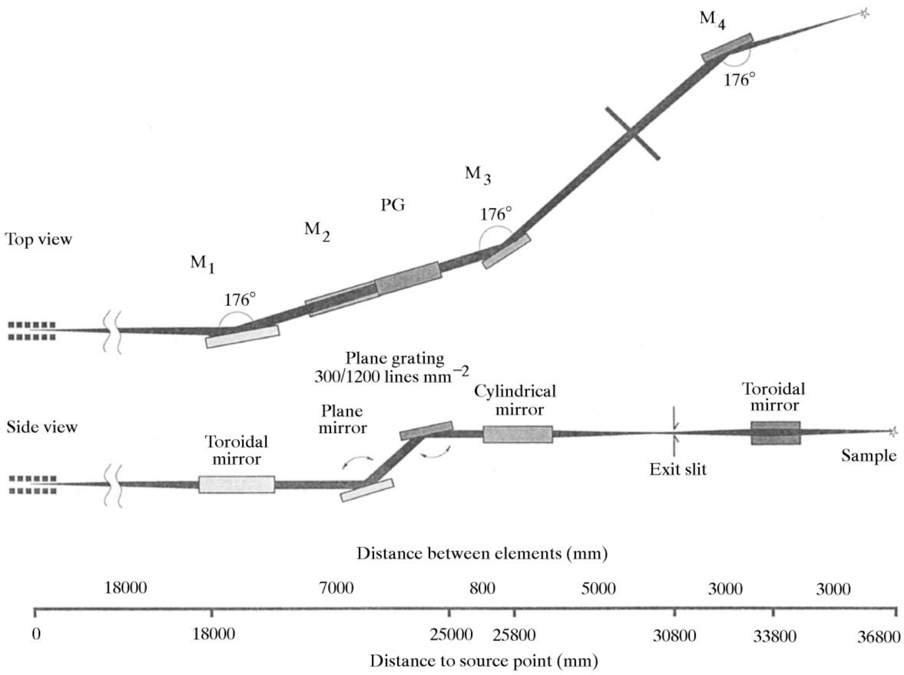

Figure 1
Optical layout of the grazing-incidence beamline.

in the medium energy range, it has to be used as the radiation source itself.

2.2. *Monochromator*

The design of our choice is an SX-700 type (Petersen, 1982) of plane-grating monochromator (PGM), working with parallel light on the grating. For a plane grating, the focusing condition is given by

$$r'/r = -\cos^2\beta/\cos^2\alpha \equiv -c_{ff}^2,$$

where r' is the virtual monochromatic image distance and r is the real source distance. α and β are the angles of incidence and diffraction with respect to the grating normal, respectively. In the usual SX-700 design, the c_{ff} value has to be a constant to fulfil the focusing condition for all photon energies E. In contrast, for collimated light, r and r' become infinity and exact focusing can be maintained independently of c_{ff} and E. Thus, the monochromator can be alternatively operated at different c_{ff} values or deviation angles and optimized for higher-order suppression, highest flux or highest energy resolution.

The optical layout of the whole beamline is shown in Fig. 1. The first optical element, 18 m downstream of the middle of the insertion device, is a horizontally deflecting water-cooled toroidal mirror (M_1). The mirror focuses the source to infinity and forms collimated light in both the vertical and horizontal directions. By means of precision drives, the mirror can be completely removed from the undulator beam, thus allowing experiments with direct undulator radiation to be carried out.

The plane-grating/plane-mirror assembly, equipped with two gratings (1200 and 300 lines mm^{-1}) and a long rotatable plane mirror, is located 7 m downstream of M_1. The rotation angles of both optical elements are measured by precision angle encoders, mounted directly on the rotation axes inside the vacuum chamber. The gratings as well as the plane mirror can be translated transverse to the optical axis. As a result, at different photon energies different coatings of the optics can be used for optimum higher-order suppression. Half the plane mirror and the 300 lines mm^{-1} grating surface is SiC-coated while the other half is coated with Au. All other optical elements are Au-coated.

A horizontally deflecting cylindrical mirror (M_3) focuses the diffracted light vertically onto the exit slit. The toroidal mirror (M_4) is applied for refocusing the beam in both the vertical and horizontal directions, onto the sample position. The spot size depends on photon energy and slit width. At 400 eV and a slit width of 200 µm the diameter is about 200 µm FWHM.

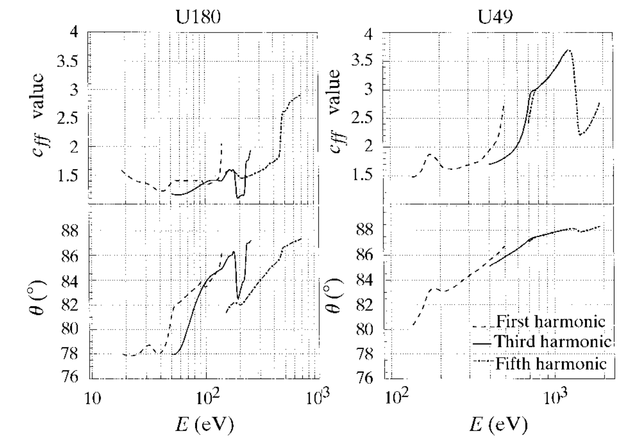

Figure 2
c_{ff} values and corresponding deviation angles θ as a function of photon energy E, optimized for higher-order suppression and maximum first-order flux (left, U180; right, U49).

3. Minimizing higher-order radiation

The most effective way to obtain high photon flux and, at the same time, small transmittance of higher diffraction orders is to optimize the grating parameters, *i.e.* coating, groove profile, line density and the total deviation angle, $2\theta \equiv \alpha - \beta$. For this purpose, a code developed for calculating diffraction efficiencies (Neviere *et al.*, 1982) was implemented in the *OPTIMO* optimization program. *OPTIMO* is based on principles of evolution strategy and is a repetitive optimization code originally developed to minimize optical aberrations at monochromators for highest energy resolution (Eggenstein *et al.*, 1990).

The radiant power output of the undulator combined with the filter characteristic, *i.e.* the spectral reflectance of the fixed optical elements, was used as the input for the optimization calculations. The optimization goal was to keep the ratio of the radiant power in higher diffraction orders to the total radiant power below 0.5%, while maximizing the radiant power in the first order.

After the grating parameters were specified, the c_{ff} value and the corresponding deviation angle were further optimized. In addition, the line density and the coating were selected for best performance in the energy range of the source harmonic. Fig. 2 shows the c_{ff} values and the corresponding deviation angles for U180 and U49, optimized for higher-order suppression with maximum radiant power in the first order. For this optimization target, a trend towards an increasing c_{ff} value and deviation angle can be seen. However, there are several exceptions, especially near the absorption edges of the coating material. At low energies, the optimization is limited by the angular scan range of the plane mirror and grating.

4. Radiant power output

Figs. 3 and 4 show the spectral power distribution at the end of the undulator beamline system when operated in the higher-order suppression mode. The radiant power output in the first diffraction order as well as in the corresponding higher orders is

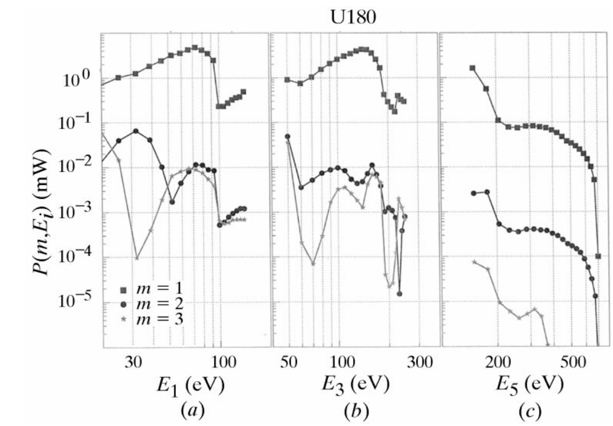

Figure 3
Radiant power output of the beamline in different diffraction orders as a function of photon energy using the U180 undulator as radiation source. (*a*) First harmonic, 300 lines mm^{-1}, SiC. (*b*) Third harmonic, 300 lines mm^{-1}, Au. (*c*) Fifth harmonic, 1200 lines mm^{-1}, Au. Resolving power $E/\Delta E$ = 100, storage-ring current 100 mA, electron energy 1.7 GeV.

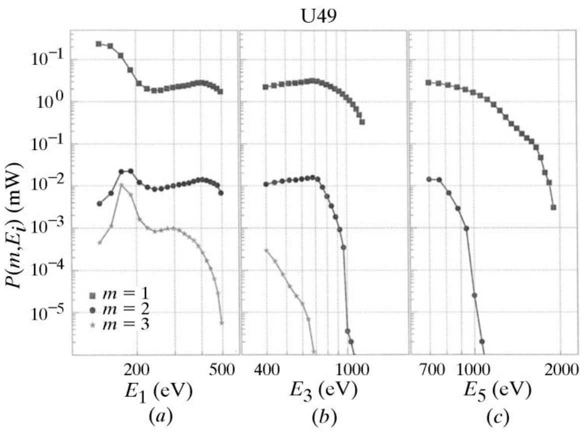

Figure 4
As Fig. 3 for the U49 undulator as radiation source. (*a*) First harmonic, 1200 lines mm^{-1}, Au. (*b*) Third harmonic, 1200 lines mm^{-1}, Au. (*c*) Fifth harmonic, 1200 lines mm^{-1}, Au.

displayed. Each subdivision of Figs. 3 and 4 represents a special combination of undulator harmonic and grating line number and coating while the grating is operated at the optimized c_{ff} values, as shown in Fig. 2.

The radiant power output of the beamline well surpasses the minimum requirement of 10 μW in the energy range up to 600 eV for the U180 undulator and up to 1900 eV for the U49 undulator. In the energy range 140–600 eV, about one order of magnitude in radiant power can be gained when U49 is used. 140 eV is the lower limit of the first harmonic of U49, at 1.7 GeV electron energy.

The other design target of higher-order radiation less than 0.5% can be achieved for photon energies higher than 50 eV. The range can be extended to photon energies down to 30 eV by inserting a thin aluminium filter. Nevertheless, the photon energy range below 30 eV will need to be covered by a normal-incidence monochromator designed for the third branch of the beamline system.

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