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The PTB electromagnetic undulator for BESSY II

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The Physikalisch-Technische Bundesanstalt (PTB) will operate an electromagnetic undulator designed for radiometry at the BESSY II storage ring. The undulator has a period length of 180 mm, 21 full periods and a maximum magnetic induction of 0.46 T, resulting in a tuning range of the first harmonic from 5 to 150 eV at 1.7 GeV electron energy. Moreover, the electromagnetic design allows the undulator to be operated in a special mode with the period length doubled to 360 mm, thus accordingly shifting the tuning range to lower energies. The main design parameters of the undulator for radiometric applications, as well as measured magnetic field data, are presented.

Keywords: insertion devices; magnetic field measurement; storage rings.

1. Introduction

At the BESSY II storage ring, the PTB will operate a radiometry laboratory similar to that which is already successfully run at the BESSY I storage ring (Ulm & Wende, 1995, 1997). Moreover, in one straight section of the BESSY II storage ring, the PTB can operate its own insertion devices, thus supplying radiation alternately to three different beamline branches in the radiometry laboratory. The first beamline uses the direct undispersed undulator radiation for radiometry and spectroscopy. With the undulator operated at a small K-parameter, the radiation essentially consists of the first harmonic, which will be used as a calculable source of quasi-monochromatic radiation (Molter & Ulm, 1992). For this application, complete magnetic characterization of the undulator is essential. The second and third beamline branches are equipped with a normal-incidence and a grazing-incidence monochromator (Senf *et al.*, 1998), respectively, which cover the spectral range from 3 eV to approximately 1.9 keV. In the design of these beamlines, emphasis is put on excellent spectral purity of the monochromated radiation rather than on very high energy resolution since these beamlines will mainly be used for detector calibration relative to a cryogenic radiometer as a primary detector standard (Rabus *et al.*, 1997).

2. Undulator design

With the BESSY II storage ring operated at its normal electron energy of 1.7 GeV, the first undulator harmonics must be tunable to as low as 5 eV to have a spectral overlap with the energies of frequency-doubled lasers. In the special mode of operation of BESSY II at 900 MeV, the lowest energy of 3 eV of the normal-incidence monochromator beamline branch can then easily be reached. Since high thermal stability is desired, the 5 eV low-energy limit should be reached at minimum thermal load, *i.e.* the K-parameter should be as small as possible. The same argument holds for the spectral purity of the radiation. Therefore, a rather long period length at a modest magnetic field was chosen. On the other hand, the use of the quasi-monochromatic, calculable radiation required at least 20 periods for an energy resolution of at least 5% to be reached. With the length of the straight section available, this resulted in a period length of 180 mm.

Table 1
Main parameters of the PTB undulator/wiggler U180.

Type	Electromagnet
Overall length (m)	4.23
Period length λ_u (mm)	180
Gap (mm)	32
Transverse pole width (mm)	90
Number of full field periods	21
Weight (kg)	1800
Maximum magnetic field, $B_{\max}$ (T)	0.46
$K_{\max}$	7.7
Energy of 1st harmonic (K = 0.1) at 1.7 GeV (eV)	152
Energy of 1st harmonic ($K_{\max}$ = 0.1) at 1.7 GeV (eV)	5
Current for maximum field (A)	135
Electric power consumption (kW)	30
Turns per coil	48
Current density (A mm^{-2})	7.7

With this rather long period length and a modest maximum field strength of 0.46 T, the undulator could be economically built as an electromagnet, as was done by Bruker Analytische Messtechnik, Karlsruhe, Germany, in just over 1 year. The soft-iron comb-like upper and lower yokes were milled in one piece and are held apart by stainless steel brackets to form a C-structure-type undulator. The whole magnetic structure is stiffened with a thick aluminium plate on the back and rests on three *xyz*-

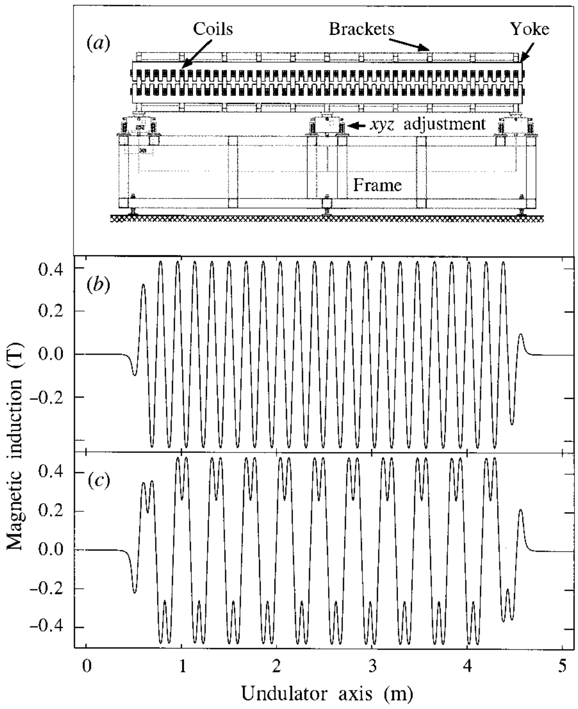

Figure 1
Schematic diagram of the PTB electromagnetic undulator for BESSY II (*a*), as well as the measured magnetic field on the undulator axis for maximum field in the normal mode of operation (*b*) and the mode of operation with doubled period length (*c*).

adjustable supports. The main water-cooled coils are connected in series. Since the end-pole determination was chosen to be of the 1/4, −3/4, 1 type, the end-pole coils have only this fraction of turns compared to the inner coils. In addition, the first and last poles are paralleled with a programmable shunt for further adjustment of the field integrals. In addition to the water-cooled main coils connected in series, each pole is equipped with a small, individually programmable correction coil, allowing an adjustment of the field by ±20 G. A sketch of the undulator layout can be seen in Fig. 1(*a*); the main design parameters are given in Table 1. Moreover, the current flow in certain coils can be reversed so that two adjacent poles are magnetically excited in the same direction, thus giving an undulator magnetic field with doubled period length.

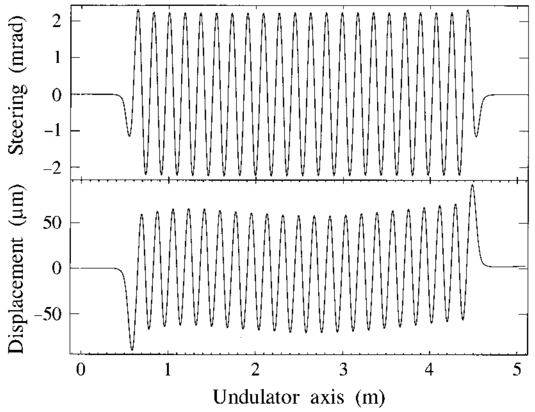

Figure 2

Electron steering and displacement within the undulator for the magnetic field in Fig. 1(*b*) and at BESSY II electron energy of 1.7 GeV.

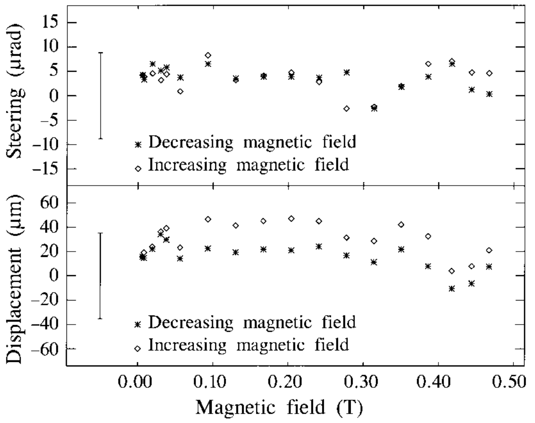

Figure 3

Upper part: electron steering at the end of the undulator (first field integral on the undulator axis; the electron energy was taken to be 1.7 GeV) for different magnetic fields of the undulator in the normal mode of operation. Lower part: the electron displacement at the end of the undulator (second field integral on the undulator axis; the electron energy was taken to be 1.7 GeV). The asterisks refer to the case that the magnetic field is changed from higher to lower values, the diamonds, to the case that the magnetic field is changed from lower to higher values. The error bars on the left show the accuracy of the magnetic field measurement: ±0.5 G m for the first integral (upper part) and ±2 G m^2 for the second integral (lower part).

3. Undulator magnetic field measurements

The device was magnetically characterized at the BESSY magnetic field measuring facility at Berlin-Adlershof. Here a measuring bench 5 m long is available for Hall-probe measurements along the undulator axis. The measured magnetic field data are then evaluated with the *ANALYZE* program (Kincaid *et al.*, 1992). As an example, Figs. 1(*b*) and 1(*c*) show the magnetic field along the undulator axis for the undulator at maximum magnetic excitation in normal operation and in the mode with doubled period length, respectively. The first and second field integrals along the undulator axis for the magnetic field of Fig. 1(*b*) are shown in Fig. 2.

For different magnetic excitation, the residual first and second integrals in terms of electron steering and displacement at the end of the undulator (normal mode of operation, 1.7 GeV electron energy) are shown in Fig. 3. The uncertainty of the field integral measurements is estimated to be 0.5 G m and 2 G m^2 for the first and second integrals, respectively. For off-axis scans within a region of ±30 mm horizontally and ±8 mm vertically, no difference in the field integrals could be observed within this uncertainty. So the fitted integrated multipoles comply with zero for this field region. The measured field data give rise to very optimistic expectations for good performance of the undulator once the BESSY II storage ring is put into operation in 1998.

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