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Properties of the Insertion Devices for PETRA III and its Extension

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Abstract. DESY presently operates 14 independent insertion device (ID) beamlines at its 6 GeV storage ring PETRA III. Besides the 2 m long standard undulators U29 and U32, several special IDs of up to 5 m length have been installed to meet the experimental requests for high energy X-rays, elliptically polarized light, and a higher degree of coherence. Two additional half octants of the ring have recently been reconstructed, in order to extend the experimental capabilities at PETRA III. The straight sections also allow for installation of IDs of 2 m or 5 m length. This article gives an overview of the ID key parameters, the spectral properties and the brilliance of the current undulators installed at PETRA III. It also presents the characteristics of some of the upcoming special IDs, like in-vacuum and short undulators.

INTRODUCTION

In 2007 and 2008, the PETRA ring at DESY was rebuilt from a booster for HERA to a low emittance synchrotron radiation source, called PETRA III, operating at 6 GeV. During the reconstruction, the FODO lattice was replaced in one eighth of the storage ring by eight double bent achromat cells, now accommodating insertion devices for 14 independent beamlines. The period length of the undulators varies from 23 mm (U23) for hard X-rays to 65.6 mm (UE65) for elliptically polarized light, their length from 2 m for the standard IDs up to 2 x 5 m for the nuclear resonant and inelastic scattering beamline P01.

To meet the increasing demand for beamtime, two additional sections of the tunnel were rebuilt in the framework of the PETRA III extension project in 2014. This allows for up to ten additional undulators for experiments in two additional halls. During the initial state of the project there will be constraints for the maximum heatload on the monochromator for some of these new beamlines. Therefore, the length of these undulators will be restricted to 10 full periods.

MAGNET DESIGN

Nearly all of the undulators for PETRA III and its extension are planar devices with an antisymmetric hybrid structure made from NdFeB-magnets and Vanadium Permendur poles. The width of magnets and poles is 75 mm and 55 mm, respectively, in order to provide a “good field” region of ±25 mm which is required for high injection efficiency. At minimum gap, the typical horizontal variations in the 1^{st} field Integral are below ±20 mTmm for this width. The end-poles are designed in a 1:¾:¼ configuration which has been optimized for minimum gap dependence in an iterative process using *Radia* [1].

Local tuning of the magnetic fields is done by virtual shimming [2] in order to minimize the phase error and to optimize the trajectory straightness. Each pole can be adjusted in height and tilt to allow for tuning of vertical and horizontal dipole and quadrupole contributions. By these means the RMS radiation phase error could be reduced to values below 1.5° for minimum gap while the beam trajectory could be flattened to values better than 4 Tmm^2 [3].

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UNDULATORS CURRENTLY OPERATED AT PETRA III

The storage ring PETRA III at DESY is being operated as a low-emittance synchrotron light source since 2009 [4]. Currently, 15 undulators are installed in the 9 straight sections of the storage ring to deliver synchrotron radiation for the individual experiments. The 2 m long standard undulators U29 have a period length of 29 mm and a maximum K-value of 2.2. They provide full energy tunability starting from their 1st harmonic energy at 3.5 keV. The spectroscopy undulators U32 with a period length of 31.4 mm and K_{max}=2.7 provide energies down to 2.4 keV. The 2 m long IDs are installed in pairs canted by 5 mrad and share 5 m straight sections. Also, there are special IDs which serve the needs of particular beamlines, which take up the full 5 m of the straights in the machine.

The APPLE II undulator UE65 with a period length of 65.6 mm provides synchrotron radiation with variable polarization, covering the energy range from 250 eV to 2.5 keV in the circularly polarized mode on its first harmonic. It was developed and manufactured in collaboration with the Helmholtz-Center Berlin (HZB) [5]. A 2 m long U23 undulator serves for hard X-ray applications like imaging. With a short period length of 23.0 mm it provides full energy tunability above its 3rd harmonic at 24 keV. A 5 m long U29 ID is in use for experiments which require X-rays with an enhanced degree of coherence. Finally, there is a 20 m long straight section, which can be equipped with up to four 5 m long IDs for applications which are usually limited by photon flux. Currently it holds two 5 m long U32 IDs for nuclear resonant or inelastic scattering. Due to constraints by the machine lattice the minimum gap of these devices is limited to 12.5 mm. This limits the maximum K-value for these devices to 2.0 and thus the minimum energy to 3.6 keV.

The main characteristics of all undulators are compiled in Table 1. They have been calculated for the usual operating current of PETRA III, which is 100 mA in top-up mode. Each undulator cell in the storage ring can be configured either in a high-β mode which provides 140 x 5.6 μm^2 source size and 7.9 x 4.1 μrad^2 divergence at 10 keV photon energy or in a low-β mode with a source size of 36 x 6.1 μm^2 and a divergence of 28 x 4.0 μrad^2. As can be seen from Fig. 1, the typical Brilliance emitted by the PETRA III undulators is in the order of 10^{20} to 10^{21} photons/(mrad^2 mm^2 0.1%BW) for the energy range covered by their first harmonic.

Table 1: Parameters for present PETRA III undulators for a beam current of 100 mA

	U29	**U32**	**U23**	**UE65***	**U29 5m**	**U32 10m**
minimum magnetic gap (mm)	9.5	9.5	9.5	11.0	9.5	12.5
period length λ_U (mm)	29.0	31.4	23.0	65.6	29.0	31.4
device length L (m)	2	2	2	5	5	2 x 5
number of periods	67	61	84	72	168	2 x 154
peak field B_0 (T)	0.81	0.91	0.61	1.03	0.81	0.68
deflection parameter K_{max}	2.2	2.7	1.3	6.3	2.2	2.0
energy of 1st harmonic (keV)	3.5	2.4	8.0	0.3	3.5	3.6
total power P_{tot} (kW)	3.0	3.8	1.7	11.8	7.5	10.7
on axis power density (kW/mrad^2)	76	80	71	0.17	190	300
power in 1x1 mm^2 at 40 m (W)	47	49	44	0.1	119	185

*circularly polarized mode

OPERATION EXPERIENCE

Since the beginning of operation in 2009 the total radiation dose for each insertion device is constantly monitored by thermoluminescence dosemeters (TLDs). Until now some of the undulators have accumulated total doses of more than 100 kGy. This caused some damage to the magnet structures by two independent effects. On the one hand there are corrosion effects aggravated by radio chemistry and on the other hand there are demagnetization effects which cause a degradation of the spectral performance of the IDs. This loss of magnetization could also be proven by magnetic measurements in the accelerator tunnel [6]. For two of the existing undulators it was necessary to rework or even refurbish the magnet structure [7]. In order to avoid further radiation damage to the insertion devices, additional electron beam scrapers have been installed to the machine upstream of the undulator section. In addition to that, the diagnostic capabilities in the accelerator tunnel were extended by beam loss monitors and Cherenkov fibers.

UPCOMING UNDULATORS FOR PETRA III

In the framework of the PETRA III-extension project [8] two new experimental halls are being built which will accommodate 10 more beamlines. The first of these will go into operation during this year.

For the upcoming beamline P61 the existing damping wiggler section in the north of the PETRA III storage ring will be used as radiation source [9]. This section consists of ten 4 m long wigglers with a period length of 200 mm and a peak field of 1.5 T at a magnetic gap of 24 mm. The focus of this beamline will be high energy X-ray scattering and imaging for materials science.

There will be other experimental stations dedicated to hard X-rays applications. The beamline P21 will be operated in collaboration with the Swedish materials science community. It will be equipped with a short period (λ_U=21.2 mm) in-vacuum undulator with a magnetic length of 4.0 m. It will allow for a minimum magnetic gap of 7.0 mm which will provide a maximum magnetic field of 0.7 T and a deflection parameter K_{max} of 1.4. The device will be used mainly above its 5th harmonic at 41.5 keV. A second identical in-vacuum undulator will be built in order to upgrade the existing PETRA III high energy beamline P07. It will replace the current 2 m long standard undulator U29.

The upcoming beamlines P64 and P65, which will focus on X-ray absorption spectroscopy will receive dedicated undulators U33 with a period length of 32.8 mm. With a maximum deflection parameter of K_{max} = 2.7 they will provide a minimum photon energy of 2.3 keV at the 1st harmonic.

While most of the beamlines for the PETRA III extension will receive cryogenically cooled double crystal monochromators (DCMs) after their frontends [10], some of the experiments will be equipped with a compact water-cooled DCM [11]. This monochromator design has already been proven successfully at several beamlines at DORIS. However it can accept only a limited amount of heatload, thus the total power and the power density emitted by the undulator has to be limited. This is why these experimental stations will be served by short undulators with only 10 periods. The magnetic design of these IDs and their mechanical support structure are already prepared to be upgraded to full scale (2 m long) undulators in the future.

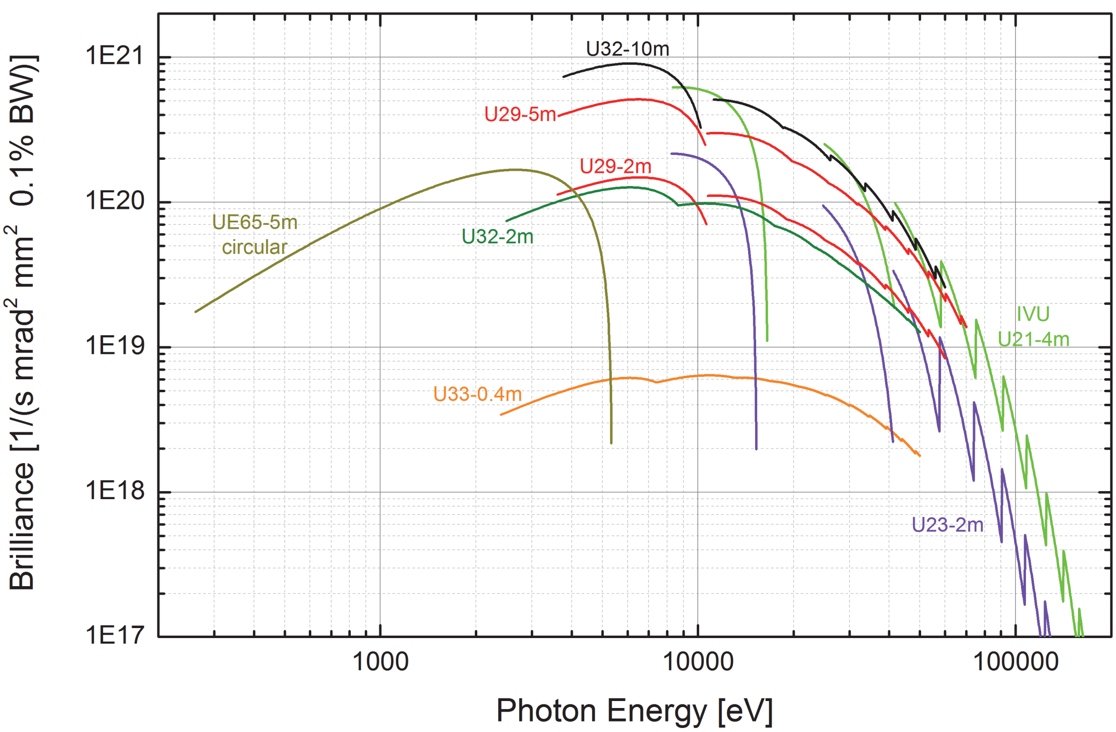

Figure 1: Brilliance-curves for existing and upcoming PETRA III undulators

The main characteristics of all upcoming IDs are compiled in Table 2. In case of the damping wiggler section the power through a 1x1 mm2 pinhole has been calculated for a position 40 m behind the last wiggler. Figure 1 shows the brilliance vs. energy curves for all existing and upcoming insertion devices calculated using *Spectra* [12]. The typical Brilliance for the 2 m long U33 undulators will be comparable to the existing U29 and U32 devices, whereas the typical values, the for the short 10 period U33 IDs will be approximately $7x10^{18}$ photons/($mrad^2$ mm^2 0.1%BW), as can be seen from the figure.

Table 2: Parameters upcoming PETRA III light sources for a beam current of 100 mA

	DW	**U21**	**U33**	**U33**
minimum magnetic gap (mm)	24	7.0	9.5	9.5
period length λ_U (mm)	200	21.2	32.8	32.8
device length L (m)	10 x 4	4	2	0.41
number of periods	10 x 19	184	58	10
peak field B_0 (T)	1.52	0.71	0.88	0.88
deflection parameter K_{max}	28.4	1.41	2.70	2.70
energy of 1^{st} harmonic (keV)	35.8*	8.3	2.3	2.3
total power P_{tot} (kW)	10 x 21	4.6	3.5	0.60
on axis power density (kW/$mrad^2$)	10 x 44	188	75	13
power in 1x1 mm^2 at 40 m (W)	121	115	46	8

*critical energy

REFERENCES

1. O. Chubar, P. Elleaume, and J. Chavanne, "A 3D Magnetostatics Computer Code for Insertion devices", Proceedings of SRI97, Himeji, Japan, J. Synchrotron Rad. **5** (1998), pp. 481-484.
2. O. Bilani, P. Neumann, A. Schöps, S. Tripathi, P. Vagin, T. Vielitz, and M. Tischer, "Magnetic Tuning of FLASH II Undulators", Proceedings of IPAC2014, Dresden, Germany, (2014), pp. 1235-1237.
3. P. Vagin, S. Francoual, J. Keil, O.H. Seeck, J. Strempfer, A. Schöps, and M. Tischer, "Commissioning Experience with Undulators at PETRA III", Journal of Physics: Conference Series **425** (2013), 032013.
4. H. Franz, O. Leupold, R. Röhlsberger, S.V. Roth, O.H. Seeck, J. Spengler, J. Strempfer, M. Tischer, J. Viefhaus, E. Weckert, and T. Wroblewski, "Technical Report: PETRA III: DESY's new high brilliance third Generation Synchrotron Radiation Source", Synchrotron Radiation News, Vol. **19**, No. 6, (2006), pp. 25-29.
5. J. Bahrdt, H.-J. Baecker, W. Frentrup, A. Gaupp, M. Scheer, B. Schulz, U. Englisch, and M. Tischer, "Apple Undulator for PETRA III", Proceedings of EPAC08, Genoa, Italy, (2008), pp. 2219-2221.
6. P. Vagin, O. Bilani, A. Schöps, S. Tripathi, T. Vielitz, and M. Tischer, "Radiation Damage of Undulators at PETRA III", Proceedings of IPAC2014, Dresden, Germany, (2014), pp. 2019-2021.
7. M. Tischer, P. Neumann, A. Schöps, and P. Vagin, "Renovation of Radiation-damaged Undulators", these proceedings.
8. K. Balewski, M. Bieler, J. Keil, A. Kling, G. Sahoo, and R. Wanzenberg, "PETRA III upgrade", Proceedings of IPAC2011, San Sebastián, Spain, (2011), pp. 2948-2950.
9. M. Tischer, K. Balewski, A. Batrakov, I. Ilyin, D.Shichkov, A. Utkin, P. Vagin, and P. Vobly, "Damping Wigglers at the PETRA III Light Source", Proceedings of EPAC08, Genoa, Italy, (2008), pp. 2317-2319.
10. H.Schulte-Schrepping, M.Hesse, M. Degenhardt, H.Krüger, R.Peters, H.B.Peters, and B.Steffen, "Photon Beamline Frontends for the PETRA III Extension Project", these proceedings.
11. K. Rickers, U. Brüggmann, W. Drube, M. Herrmann, J. Heuer, E. Welter, H. Schulte-Schrepping, and H. Schulz-Ritter, "Compact fixed-exit UHV DCM for XAFS", AIP Conference Proceedings **879**, (2007), 907.
12. T. Tanaka and H. Kitamura, "SPECTRA: A Synchrotron Radiation Calculation Code", J. Synchrotron Rad. **8** (2001), pp. 1221-1228.