STATUS OF THE PETRA III INSERTION DEVICES

M. Barthelmess#, U. Englisch, J. Pflüger, A. Schöps, J. Skupin, M. Tischer,
DESY, Hamburg, Germany

Abstract

The PETRA storage ring is presently reconstructed towards a third generation light source. In total, 14 undulator beamlines will be available in the new octant of the machine. We report on the status of the Petra III undulators. Three prototypes with 29mm period length, two 2m and one 5m long device, have been investigated by mechanical and magnetic measurements. The prototype results are the basis for the refined design of the remaining 8 planar devices which are in the procurement phase. We present preliminary magnetic results of the prototypes and also report on the APPLE2 and the In-Vacuum undulator for PETRA III.

INTRODUCTION

The PETRA ring at DESY, in the past used as a booster ring, is being reconstructed and converted to a dedicated 3rd generation light source since summer 2007 [1]. One octant of the machine will be completely remodeled for installation of 14 undulator beamlines with unprecedented brilliance, particularly suited for experiments with small or diluted samples requiring small beam size or extreme focusing conditions [2]. PETRA III will operate at an energy of 6GeV with a beam current of 100mA in top-up mode. The emittance of the new storage ring can be brought down to 1nmrad by means of damping wigglers that will be installed in two of the long straight sections of the machine. In total, there will be 20 permanent magnet wigglers of 4m length with fixed gap [3]. The first stored electron beam is expected in early 2009, first photon beam and start of beam line commissioning in the second half of the year.

The lattice in the new octant consists of nine double bend achromat cells. The beta-functions in the straights can be chosen individually for each cell, according to the beam size requirements of the different beamlines. A minimum half aperture of 3.5mm in the straight sections has been defined for reliable storage of the electron beam which results in a minimum magnetic gap of 9.5mm for the undulators.

Eight of the available straight sections provide space for a 5m long insertion device (ID). To enlarge the number of independently operable beam lines, five of these straights are broken up into two sections for 2m long undulators. Furthermore, in the straight section at the beginning of the new octant a 10m long undulator will be installed. In total, 14 undulators will be built, three IDs with 5m length, ten 2m long devices, and one 10m-undulator.

#miriam.barthelmess@desy.de

STANDARD UNDULATORS

Design

A common development on undulators has been started for PETRA III and the European XFEL [4], the other large project at DESY to be realized until 2012. The properties of these new insertion devices have to comply with the specifications of both projects, the XFEL setting more stringent requirements on the rigidity of the undulator support frame. Also specifications for the PETRA III IDs are tighter than those of present 3rd generation storage ring light sources regarding their magnetic properties, mechanical stability, and precision of the motion control system in order to make use of its small emittance. Aside from minor differences in the specification of magnetic field properties, the undulator requirements in both projects have a lot in common. The time schedules suggest that the construction effort for PETRA III and XFEL prototyping can be combined.

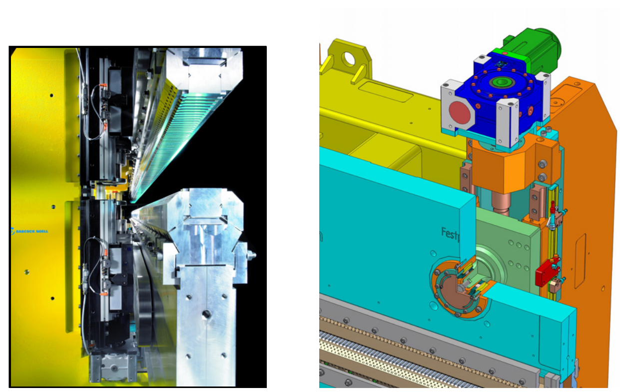

Figure 1: Details of the undulator mechanics for PETRA III and XFEL insertion devices.

Fig.1 illustrates several characteristic features of the mechanical support unit, which can have a variable length between 2 and 5m. A large girder cross section of 550 by 100mm² is used to minimize shear deformation. The girders are connected to massive guideways and lead screws integrated in the support columns using spherical supports. In this way the magnetic forces are transmitted and a rotational degree of freedom is provided. Thus by a set of adjusting screws the magnet girders can be aligned exactly parallel to each other for the main operational range of the gap. The mechanical design of the magnetic structure is an advancement of the well proven concept used for the FLASH undulators at DESY. 90cm long support segments for magnets and poles are clamped onto the girders. As a new feature, the fine-tuning of the magnetic field is not only realized by individual pole height adjustment but also by pole tilt. Each pole can be adjusted in height by about ±300µm and in tilt by ±2mrad, as shown in Fig. 2.

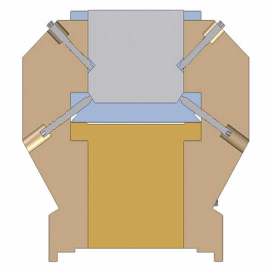

Figure 2: Magnetic tuning by pole height adjustment and pole tilt.

The standard undulator U29 is characterized by full energy tunability resulting in a period length of 29mm and a 1st harmonic position at E=3450eV corresponding to a maximum K-value of 2.2. Some beam lines dedicated to spectroscopy techniques require photon energies down to 2.4keV, and hence the spectroscopy undulator U32 needs a larger period length. The short period device U23 is built for hard X-ray scattering experiments and provides tunabability above the 3rd harmonic. Table 1 lists the device parameters.

Table 1: Parameters of the planar undulators. Power and source size values are given for a 2m long device and 100mA beam current

	U29	U32	U23
Minimum magnetic gap [mm]	9.5	9.5	9.5
Period length λ_U [mm]	29	31.4	23
Length L [m]	2 or 5	2	2
Peak field B_0 [T]	0.81	0.91	0.61
Deflection parameter K_{max}	2.2	2.7	1.3
1st Harmonic E_1 [keV]	3.5	2.4	8.0
Total power P_{tot} [kW]	3.0	3.8	1.7
On-axis power density [kW/mrad^2]	76	80	71
Power in 1x1mm^2 at 40m [W]	47	49	44
High-β source (10keV)	140 x 5.6 µm²	7.9 x 4.1 µrad²	
Low-β source (10keV)	36 x 6.1 µm²	28 x 4.0 µrad²	

Three standard undulator prototypes for PETRA III have been delivered and investigated by mechanical and magnetic measurements. The remaining eight 2m undulators are manufactured at present. Delivery will start this summer.

Measurement Results

The three prototype undulators with 29mm period length are in the tuning process at present. The structures are aligned mechanically to the measurement bench with a typical accuracy of ±100µm in horizontal and ±50µm in vertical direction. By Hall probe measurements parallelism to the bench and cancellation of any taper between the magnet girders are controlled. For the further tuning process it is important to guarantee a well defined and precise initial state of the magnet structure. Because all poles have some transverse play within the module to allow some tilt, they have to be shifted towards one reference side to reduce multipole errors. An adjustment gauge with two micrometer dials per pole is used to measure the pole position in order to adjust pole overhang and tilt angle relative to the non-magnetic support structure. Therefore on an absolute scale, accuracy is still influenced by girder flatness and height tolerance of the support structure. Using the four adjustment screws shown in Fig. 2, pole overhang is adjusted to 0.500 +/- .005mm and pole tilt to 0 +/-0.25mrad. First experience has shown that initialization done in this way gives a good starting value for the tuning procedures and reduces the further process to only one cycle of pole adjustment for the vertical and horizontal field component, respectively. A Hall-probe scan analyses the initial trajectory and assigns any errors to particular poles for which the according pole shift or tilt is calculated [5]. For the vertical field component, a local K optimization is used, based on the same principle. The local K parameter in each half period of the undulator is corrected by shifting pole vertically with the dial gauge control. By this means, the horizontal trajectory as well as the phase shake is improved. In Fig. 3 the final result of this correction is compared to the initial state. A phase with 1.2° rms phase shake is reached. Also an rms value of 10Tmm² in the second field integral and a kick of only -9mTmm are well within the PETRA III specifications.

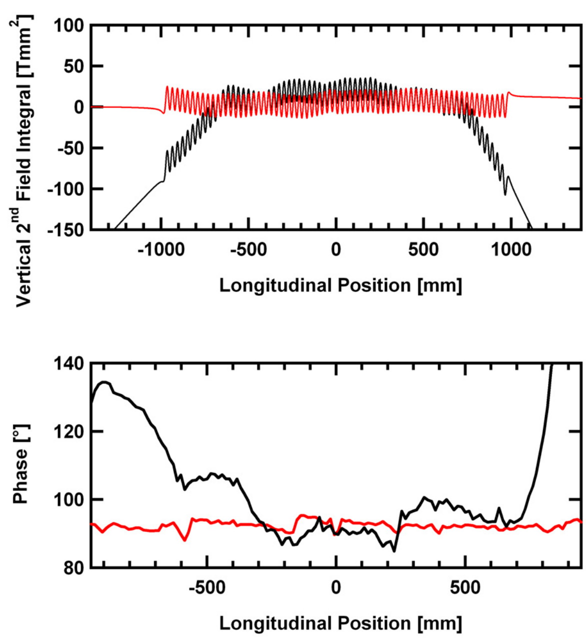

Figure 3: Vertical second field integral (top) and phase shake (bottom) after local K correction (red curves) compared to the initial state (black curves) of a 2m prototype undulator at 12mm gap.

In a second step, the vertical trajectory is adjusted by tilting particular poles. Unlike the local K correction, the correction of the horizontal field requires only a small number of pole adjustments. This is a result of the controlled initialisation as well. After adjustment, the horizontal second field integral has an rms of 3.4Tmm² and the residual kick is 9.6mTmm.

The last adjustment process comprises the correction of multipole components in transverse direction. By moving wire measurements of the first and second field integrals, multipole components are investigated. With the extended pole adjustment possibilities, multipoles can partly also be corrected by pole tuning rather than shimming. Poles can be tilted in an antiparallel manner or shifted horizontally in opposite directions. Both corrections do not effect previous alignments. In addition, conventional shimming will be applied.

Finally, the end poles of the undulator structure are trimmed to reduce the gap dependency of the first field integral in the range between 9.5mm and 200mm gap. Fig. 4 shows preliminary moving wire measurements of the gap dependence. Any remaining field integral will be eliminated by small air coils designed to correct 0.2Tmm.

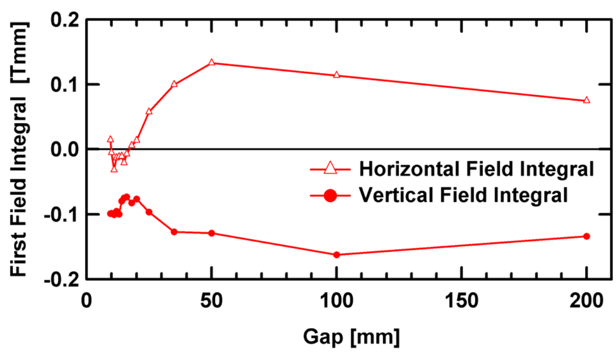

Figure 4: Gap dependence of the first field integral as measured by moving wire.

Control System

The control system for the PETRA III undulators is based on off-the-shelf standard components for industrial automation. The use of the high performance real-time fieldbus EtherCAT [6] makes it possible to run both the NC and the PLC as software tasks on a compact standard industrial PC instead of using expensive dedicated hardware. The gap drive consists of two independent servo axes for each magnet girder to allow for maximum flexibility, e.g., for tapering or beam height adjustment. Each of the axes is equipped with a multi-turn absolute rotary encoder to provide operational reliability even after a loss of power. The four axes are synchronized electronically via the NC. The PLC monitors all mechanically relevant operating conditions like the tilt of girders or limit switches. It also controls peripheral components such as power supplies for corrector coils and provides interfaces for communication with the global and beam line control systems.

The deformation of the support structure due to varying magnetic forces while changing the gap has been characterized carefully by an external gauge. This data is being used to correct for these gap deviations in the NC. Thus, at a 2m long prototype an accuracy and reproducibility of ± 9µm could be achieved for the gap control. The remaining deviations are mainly due to the mechanical backlash of the drive chain. In order to improve the accuracy to values better than ± 1µm, additional linear encoder systems similar to the ones presented by BESSY [7] will be mounted at the up- and downstream end of the girders.

SPECIAL UNDULATORS

An APPLE II undulator with 65.6mm period length is being built for the Variable Polarization Beamline. In the circular mode, the UE65 will cover the entire VUV energy range between 245eV and 2.5keV on the first harmonics. This undulator is developed in collaboration with BESSY [8]. Due to its length of 5m and a maximum *K* value of 6.7, large forces and moments have to be taken up by the magnet girders and the support frame. A detailed optimization of the mechanical design based on previous APPLE devices gives rise to only minimum deformations in the various polarization modes. All four magnet rows will be movable to allow for tilted linear polarization within ±90°. A four axes gap drive will be implemented which will be able to partly compensate a collective small girder deformation occurring in the antiparallel shift mode.

For the High Energy Material Science Beamline an in-vacuum undulator will be installed for generation of hard X-rays up to 300keV. This device with a period length of 19mm will have a magnetic length of 4m. A minimum gap of 7mm can be realized for the initial operation phase of the machine. The U19 will mainly be operated at high harmonics and will be tunable above the 5th harmonic at 50 keV.

In the long straight section before the new octant two 5m U32 undulators (see Tab. 1) with 12.5mm gap will be installed with the possibility to double the undulator length at a later stage of the project.

REFERENCES

[1] K. Balewski, *"Status of PETRA III"*, these proceedings; http://petra3.desy.de.

[2] H. Franz et al., *"PETRA III: DESYs New High Brilliance Third Generation Synchrotron Radiation Source"*, SRN 19, 25 (2006).

[3] M. Tischer et al., *"Damping Wigglers at the PETRA III Light Source"*, these proceedings.

[4] *"The European X-Ray Free-Electron Laser XFEL"*, Technical Design Report, edited by M. Altarelli et al., DESY 2006-097 (2007), http://www.xfel.eu.

[5] J. Pflüger et al., *"Field optimization by pole height adjustments"*, Nucl. Instr. and Meth. A429 (1999) 586

[6] www.etherCAT.org.

[7] J. Bahrdt et al., *"Undulators for the BESSY Soft-X-Ray FEL"*, Proc. of the 2004 FEL conference, 610-613

[8] J. Bahrdt et al., *"APPLE Undulator for PETRA III"*, these proceedings.