PERFORMANCE OF THE PETRA III APPLE II UNDULATOR

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Abstract

A 5m-long APPLE II undulator has been built in collaboration between Helmholtz-Zentrum Berlin and DESY Hamburg. Magnetic field measurements after the final shimming in the laboratory are presented. The device has been installed in the storage ring and machine studies have been performed. The tune shifts in the elliptical and the inclined mode are in agreement with predictions from theory. The dynamic field integrals have successfully been minimized in the storage ring with so-called L-shims (rectangular iron sheets) which are placed at the undulator center at the magnet edges.

INTRODUCTION

The 6 GeV ultra low emittance storage ring PETRA III [1] is in operation since 2009 [2]. 14 planar undulators [3, 4] deliver linearly polarized light over a wide energy range. An APPLE II with a period length of 65.6 mm is dedicated for the production of light with variable polarization in the range of 250-3000 eV. This UE65 device has been built in collaboration between HZB and DESY [5]. The design is based on the BESSY UE112 APPLE undulator design. New features have been added such as a four-axes gap drive. The key components have been reinforced or redesigned to account for the strong 3D-forces in the inclined mode of operation.

MAGNETIC FIELD MEASUREMENTS

The undulator will be operated only on the first harmonic and, thus, the degree of circular polarization will be close to 100%. The phase errors are of minor importance in this case. However, the field integrals have to be low within a transverse range of ±20 mm to be compatible with top up operation (injection into a closed gap). All four magnet rows are movable. In the elliptical mode only two rows are needed. In the inclined mode the motion of two diagonal rows provides a tilt angle range of the linear polarization of 0-90°. The range from 90-180° is covered when the other two rows are moved. Usually, the absolute direction of the row movement is not important if the relative movement is correct. Due to the strong forces, however, the transverse bending of the magnet girders depends on the choice of the two magnet rows in combination with the absolute motion direction (for details see [5]). Therefore, we have defined an allowed and a forbidden movement in the inclined mode without any restriction in the parameter space.

The local fields have been measured with a 2-axis SENTRON Hall probe 2MR-4A. The effective fields and the corresponding lowest photon energies are given in Table 1.

The phase errors for the first harmonic have been extracted from the scans (Table 2). Even at lowest gap they are below 4° in linear and elliptical mode. In the inclined mode (allowed movement direction) the phase error is around 8°. Principally, this value can be reduced by a factor of two adjusting a small gap taper in longitudinal direction. However, it is not needed for the first harmonic. For the forbidden movement, the transverse girder bending results in a phase error of about 20°.

Table 1: UE65 Effective Fields as Measured at Smallest Gap of 11 mm

operation mode	row phase [mm]	effective field [Tesla]	1st harmonic [eV]
hor. linear	0	1.190	189
vert. linear	32.80	0.969	280
elliptical	16.40	1.077	229
inclined	16.40	0.762	438

Table 2: Phase Errors (rms) at Smallest Gap of 11 mm

operation mode	row phase [mm]	phase error [°]
horizontal linear	0	3.40
elliptical (5/8)	16.4	2.89
elliptical (5/8)	-16.4	3.04
vertical linear (5/8)	32.8	3.38
inclined (5/8)	16.4	8.71
inclined (6/7)	-16.4	7.41

The field integrals have been determined with a single moving wire. The data given in Fig. 1 are averaged over 10 scans.

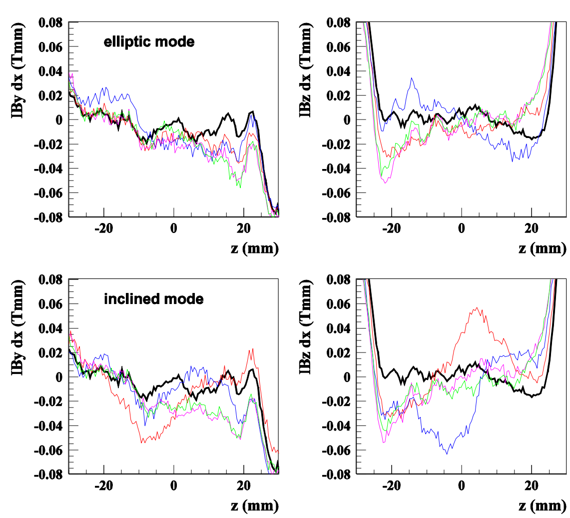

Figure 1: Field integrals at smallest gap of 11 mm. The data are plotted for the elliptical and the inclined mode. The row phases are 0 mm (black), +16.4 mm (red), -16.4 mm (blue), +32.8 mm (magenta) and -32.8 mm (green).

SHIMMING OF THE DYNAMIC FIELD INTEGRALS

Though the positron energy of PETRA III is rather high the dynamic field integrals have to be minimized with L-shaped Fe-shims. This type of shim has been proposed by Chavanne [6] and was applied successfully to several BESSY II APPLE devices [7]. The dynamic field integrals for the UE65 are derived from an analytic model which is parameterized with respect to the gap and the row phases for all operation modes [8]. The equations are based on a Fourier decomposition of the transverse field distribution of a single pair of magnet rows where the Fourier components enter in the expressions.

The dynamic field integrals amount to nearly 0.6 Tmm with strong gradients close to the beam axis (Figure 2). The optimized L-shim quadruple for the UE65 consists of four shims, one on each row, with the following geometry: length = half a period, width = 2.8 mm, height within the air gap = 4 mm. Using RADIA [9] the effect for 100 µm shims has been evaluated. A thickness of 214 µm minimizes the residual oscillations (Figure 2). Related L-shims have been glued with the undulator installed in the storage ring tunnel.

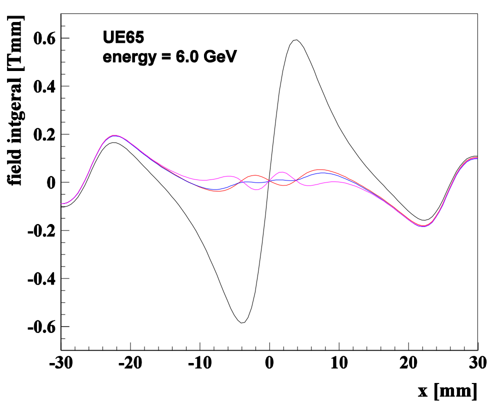

Figure 2: Dynamic field integrals of the UE65 in the 6 GeV PETRA III storage ring (black). Residuals for various shim widths and strengths are plotted where the strength is related to a norm shim quadruple as calculated with RADIA (see text): Width / strength = 2.0 mm / 2.50 (red), 2.8 mm / 2.14 (blue), and 4.0 mm / 1.90 (magenta).

MACHINE COMMISSIONING

The interaction of the dynamic multipoles of UE65 with the beam of PETRA III has several negative effects on the beam properties. The change of the undulator gap, the shift of the row phase, and the movement of the beam position inside the undulator affects the closed orbit and the linear optics. Measurements of the betatron tunes as a function of the beam position were used to determine the influence on the optics of PETRA III before and after the installation of the L-shims.

To move the beam parallel to the undulator axis symmetric closed orbit bumps have been used. The range of the beam positions produced by the orbit bumps was limited in the horizontal plane to ±8 mm by the maximum allowed current of the four corrector magnets. In the vertical plane it was limited to ±2.5 mm due to the decreasing lifetime near the physical aperture of the vacuum chamber of the undulator. Before the measurement the closed orbit has been corrected to the golden orbit in both planes inside UE65.

The L-shim quadruples were optimized for the vertical linear mode which has the strongest influence on the optics. All other modes can't be fully compensated by the L-shims. Due to mechanical constraints of the vacuum chamber at the time of the measurement the minimum gap was 12.5 mm and therefore slightly bigger than the design value of 11 mm. Therefore only a partial correction of the tune shift in all operation modes was expected.

The shift of the betatron frequency as a function of the beam position for the horizontal inclined mode, the elliptical mode and the vertical inclined mode is shown in Fig. 3 (from top to bottom). The beam positions displayed are relative positions to the golden orbit inside UE65. The measured horizontal tune shift is labeled with dots whereas the vertical tune shift is marked by crosses. The measurement before the installation of the L-shims is shown with blue markers, the measurement after the installation with red markers.

In addition to the measured tune shift values, theoretical calculations of the tune shift with and without L-shims are shown in Fig. 3. These calculations use a simplified RADIA [9] model of UE65. The tune shift as a function of the beam position was derived from a potential $U(x,y)$ based on a calculation method of P. Elleaume [12]. Measurements and theoretical predictions agree very well.

Besides the dynamic multipole fields of the undulator additional multipole fields are produced by the four corrector magnets generating the closed orbit bump. These fields are mainly sextupole fields scaling with the kick of the corrector magnets. This additional tune shift is comparable in its size with the tune shift produced by the dynamic field multipoles of the undulator. To separate both effects the tune shift has been measured with an open gap. The tune shift has been fitted with a polynomial of third degree and was subtracted from the measured data.

As expected the vertical linear mode has the strongest influence on the optics of PETRA III. The horizontal tune shift as a function of the x-position in this mode reaches a value of nearly 3 kHz. The horizontal tune shift in the elliptical mode is only half of that value. In the horizontal linear mode it is even smaller with -650 Hz. The vertical tune shifts in all modes are almost negligible with absolute values ≤ 200 Hz.

After gluing the L-shims to UE65 the measurement was repeated under the same conditions. The tune shifts with installed L-shims (red markers) show a significant reduction of the effects of the dynamic multipoles in all modes. The tune shift in the vertical linear mode could be reduced by a factor of more than three. The remaining tune shift is now smaller than 1 kHz and the remaining optic distortions are almost negligible for the operation of UE65 in PETRA III. Due to the minimum gap size of 12.5 mm at the time of the measurement the compensation can only partly compensate the tune shift in this mode. It is expected that the tune shift should almost vanish for a gap size of 11 mm.

All curves show a shift of ≈1 mm between the measurements and the theoretical prediction by RADIA (which is not the case in the vertical plane). The reason for this is an intentional shift of 1 mm of the horizontal golden orbit inside the undulator due to the demands of the users of the beamline of UE65.

The influence of UE65 on the lifetime and the injection efficiency of PETRA III was also measured in different operation modes. A reduction of the dynamic aperture could not be observed. The reason for that might be the relatively high energy of 6 GeV of PETRA III supressing dynamic effects of any insertion device by a factor of $1/E^2$.

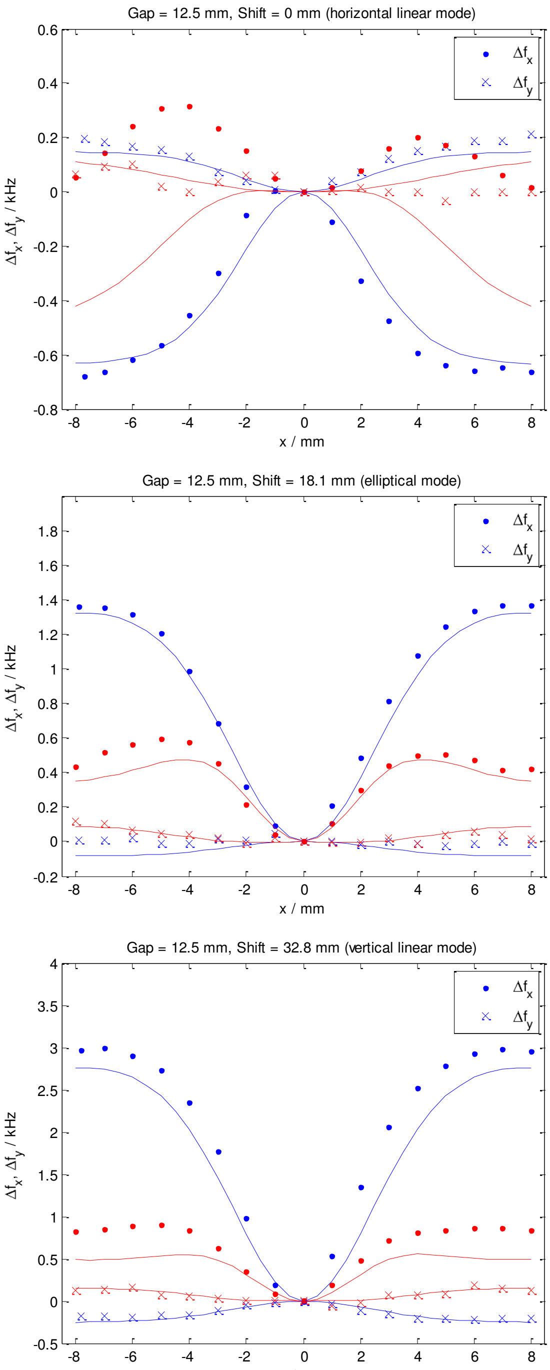

Figure 3: Shift of the horizontal (dots) and vertical frequency (crosses) as a function of the horizontal beam position before (blue) and after (red) the installation of the L-shims. The data are shown for the horizontal, the elliptical and vertical linear mode (from top to bottom). The lines are the theoretical tune shifts with and without L-shims.

CONCLUSIONS

The magnetic field measurements of the UE65 show that the spectral properties will be close to perfection for the entire energy range 250-3000 eV in all operation modes. The magnetic results also prove the success of the careful mechanical design considering the strong 3D forces of this 5 m long APPLE II undulator. The tune shifts of the PETRA III beam induced by the dynamic multipoles of the UE65 were studied in detail and were found to be in very good agreement to theoretical predictions. They could successfully be minimized by application of L-shims onto the magnet structure. The remaining effects are small and will presently not need an active compensation scheme.

REFERENCES

[1] PETRA III Technical Design Report, DESY 2004-035; http://petra3.desy.de.
[2] K. Balewski, Proceedings of IPAC, Kyoto, Japan, 2010, pp 1280-1284
[3] M. Barthelmess et al., Proceedings of the EPAC, Genoa, Italy, 2008, pp 2320-2322.
[4] M. Tischer et al., Proceedings of the EPAC, Genoa, Italy, 2008, pp 2317-2319.
[5] J. Bahrdt, H.-J. Baecker, W. Frentrup, A. Gaupp, M. Scheer, B. Schulz, U. Englisch, M. Tischer, Proceedings of the EPAC, Genoa, Italy, 2008, pp 2219-2221.
[6] J. Chavanne et al., Proceedings of the EPAC, Vienna, Austria, 2000, pp 2346–2348.
[7] J. Bahrdt, W. Frentrup, A. Gaupp, M. Scheer, SRI2006, Daegu, Korea, Published: 2007 AIP Conference proceedings 879 (2006) p 315-318.
[8] J. Bahrdt, G. Wüstefeld, Phys. Rev. ST Accel. Beams 14, 040703 (2011) 1-27.
[9] O. Chubar et al., J. Synchrotron Radiation 5, 481 (1998).
[10] J. Bahrdt et al., Nucl. Instr. and Meth. in Phys. Res. A, 516 (2004) 575-585.
[11] J. Bahrdt et al., Proceedings of the FEL Conference 2004, Trieste, Italy, 2004, pp 610-613.
[12] P. Elleaume, Proceedings of the EPAC, Berlin, Germany, 1992, pp 661-663.