AIP Conference Proceedings

Refurbishment of radiation-damaged undulators

M. Tischer, P. Neumann, A. Schöps, and P. Vagin

Citation: AIP Conference Proceedings **1741**, 020022 (2016); doi: 10.1063/1.4952801
View online: http://dx.doi.org/10.1063/1.4952801
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1741?ver=pdfcov
Published by the AIP Publishing

Refurbishment of Radiation-Damaged Undulators

M. Tischer [a)], P. Neumann, A. Schöps, P. Vagin

Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany

[a)] Corresponding author: markus.tischer@desy.de

Abstract. Partial radiation damage has been observed over the previous five years of operation for a few of the PETRA III permanent magnet undulators at DESY. The degradation of the affected devices has been observed by a change in the energy tuning curves and the spectral properties of the undulator harmonics, and also by direct measurements of the peak field distribution of the magnet structure in the storage ring tunnel [1]. During the recent shutdown of the machine, two undulators were removed from the tunnel for repair. One of the devices (U29) has been retuned after flipping of all magnets of the hybrid structure. In addition to this temporary repair, one further magnet structure (U23) has been completely disassembled and refurbished by application of a rare earth diffusion process and a coating to the permanent magnets. We will report on the details of the refurbishment of these undulators which were both fully brought back to specifications and are meanwhile back in operation.

INTRODUCTION

Radiation damage of permanent magnets and other accelerator components has been a known problem at several synchrotron radiation facilities [2-4]. While the exposure to synchrotron radiation causes mainly corrosion of permanent magnets and poles, particle loss produces intense electron and neutron showers that may easily induce demagnetization effects. Many studies on radiation-induced demagnetization effects of permanent magnets and also insertion device (ID) magnet structures are reported, a compilation of references is given by Refs. [2] and [5].

At DESY's 6 GeV storage ring PETRA III, timing mode operation at 100mA top-up with only 40 bunches is frequently used. In this case, increased injection losses and a short life time below 2 hours cause severe radiation showers in particular in the small gap ID vacuum chambers. A recent tracking study [6] investigated the loss pattern and showed that injection losses cause the observed demagnetization effects at undulator PU01 which corresponds to the first vertical small aperture seen by the beam. On the other hand, Touschek-scattered particles with a large momentum deviation are predominantly lost in the vertical plane at locations where the beta function has a large variation with energy. Despite thermal pre-aging of the NdFeB magnets, demagnetization effects have been observed at several of the hybrid undulators over the previous years of operation, not only by spectral degradation but also by direct magnetic measurements of the peakfield distribution of the magnet structure in the storage ring tunnel [1]. During the recent shutdown of the machine, two undulators were removed from the tunnel for repair.

REPAIR OF UNDULATOR U29

The undulator U29 at the PETRA beamline P08 is a 2 m long device with 29 mm period length. It is the first device which was installed at PETRA III and is in operation since the beginning of 2009. As reported previously [7], the undulator shows signs of spectral degradation for already several years. The long shutdown of PETRA III in 2014 was the first opportunity to take out the undulator from the tunnel for inspection and repair in the magnet lab. The magnet structure was at first remeasured in the damaged state to correlate these data to the initial measurements and to measurements in the storage ring tunnel, where the magnetic peak field was checked by a simple appliance several times over the recent years. Fig.1 shows a comparison of these data and illustrates the demagnetization increase over time. It is clearly visible that the magnet structure is mainly damaged close to its upstream end and

Proceedings of the 12th International Conference on Synchrotron Radiation Instrumentation – SRI2015
AIP Conf. Proc. 1741, 020022-1–020022-4; doi: 10.1063/1.4952801
Published by AIP Publishing. 978-0-7354-1398-6/$30.00

experienced a peakfield loss of up to 4%. The demagnetization pattern builds up after the first few periods and reaches a maximum about 35 cm behind the undulator entrance before it slowly decays towards the downstream end of the device. PU08 is the upstream ID in a canted straight, the PU08 entrance therefore corresponds to a location with the tightest e-beam aperture. The aperture jump from the circular vacuum chamber of the adjacent upstream quadrupole magnet to the elliptical ID-chamber happens in a vertical taper section located 40 cm before the undulator entrance; this suggests that a distance of approximately 75 cm is passed until the radiation shower from scattered and then lost particles has developed its full impact. From the temporal development of the demagnetization profile in Fig.1, it can also be seen that the damage has not been caused by a single incident during the initial commissioning phase of the storage ring but has continuously built up over time; this is qualitatively also confirmed by thermo-luminescent dosimeters which are regularly read out as a long-term survey of all the ID straight sections.

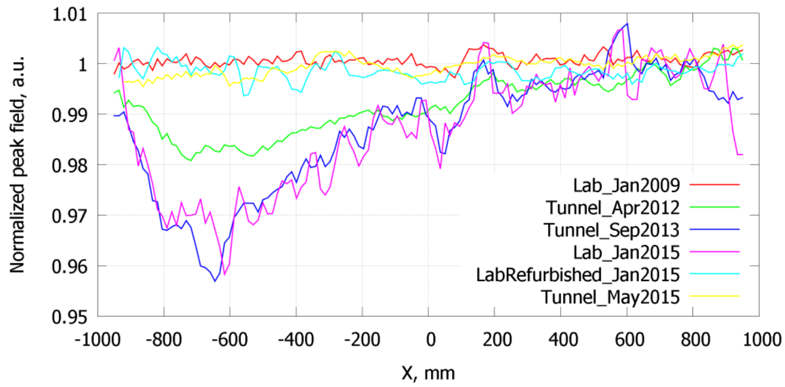

FIGURE 1. Temporal development of the demagnetization of undulator U29, which is the upstream device in a canted straight section. The measurements were done on-axis (z=0mm), the electron beam enters from the left side.

Figure 2 shows a spatial 2D field map of the magnet structure measured after removal of the undulator from the storage ring. The demagnetization patch at the upstream side of the structure is very prominent and also two other asymmetries are clearly visible: In the affected area, the magnet structure is damaged more at the bottom side and predominantly at the ring-outside part. The same spatial pattern is observed as for the damaged 23 mm period length (U23) undulator [1] which is located at an equivalent lattice position in the storage ring. There is up to now no clear understanding for either of the two aspects. While a vertical asymmetry in demagnetization could be explained by a systematic vertical orbit displacement with respect to the ID chamber center, such an effect cannot account for a transverse displacement of the hot spot by 20 mm or more.

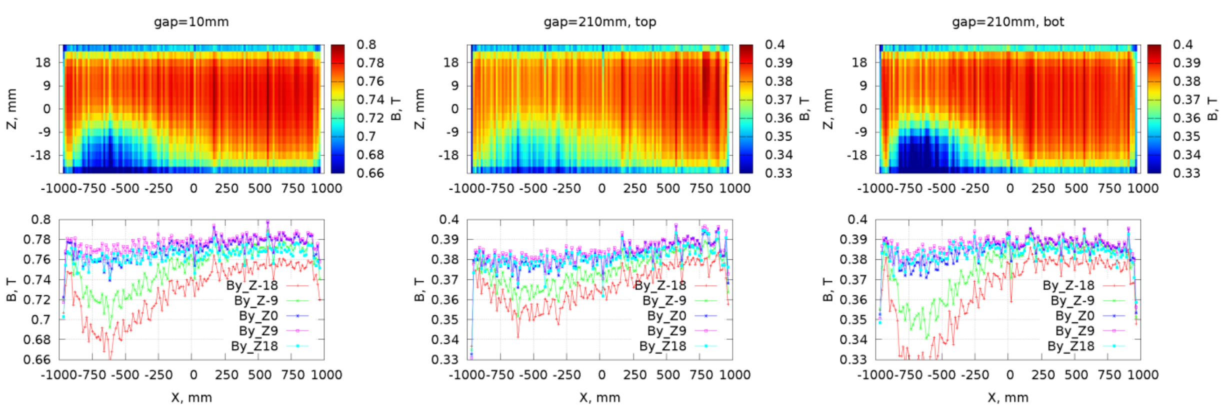

FIGURE 2. 2D-fieldmap (top) of the U29 magnet structure and field profile along the structure at different transverse z-positions (bottom), at closed gap, and separately for bottom and top magnet girder, measured at open gap (negative z-values correspond to ring outside, beam entrance at negative x-values).

Flipping of magnets upside down was applied in order to reestablish the old field level. This approach has been successfully used in the past for repair of several radiation-damaged undulator magnet structures at APS [8]. A beforehand flip test of several single magnets proved that the original field strength could be restored. It was, however, observed that also the magnets of the downstream part of the structure were slightly demagnetized as flipping enhanced the field by ~0.02T (2.6%). From the fieldmap in Fig.2 it can be seen that the damage in the downstream part is more uniform.

As an initial attempt for repair, all top and bottom magnets in the longitudinal subrange −1000…+200 mm had been flipped upside down. After several tuning iterations, a reasonable phase and trajectory error at closed gap could be achieved on-axis although some transverse effects remained. Although the trajectory was completely straight over the entire gap range, a strong gap dependence in the phase error (Fig.3) was obtained exactly at the transition from flipped to non-flipped magnets (around x~200mm). This effect can be attributed to a ~100µm step in the vertical pole position at this location introduced by tuning in order to obtain the same *K*-value and phase advance in the remaining part of the structure where magnets had not been flipped. Thus, a slightly different gap dependence of the *K*-value in the two different regions of the magnet structure resulted in a piecewise linear, i.e. nearly perfect, phase error where the different slopes correspond to slightly different emitted wavelengths. By means of a longitudinal taper as a feed forward correction, the remaining phase error could be improved by a factor of ~3 (Fig.3).

Nevertheless, the overall performance of this undulator was not yet regarded as satisfying, and finally all remaining magnets had also been flipped upside down. In this configuration, the undulator could easily be tuned back to specs with a remaining phase error of 1.4°…3.2° rms in the entire gap range. The maximum *K*-value of the device could even be enhanced by ~6% because a pole-overhang into the gap could be removed which was initially required for application of magnetic shims. In contrast to the positive experience at APS where magnetic tuning is mostly done by application of shims, an only partial flipping of magnets may lead to magnetic artefacts for a virtual shimming by pole height adjustment.

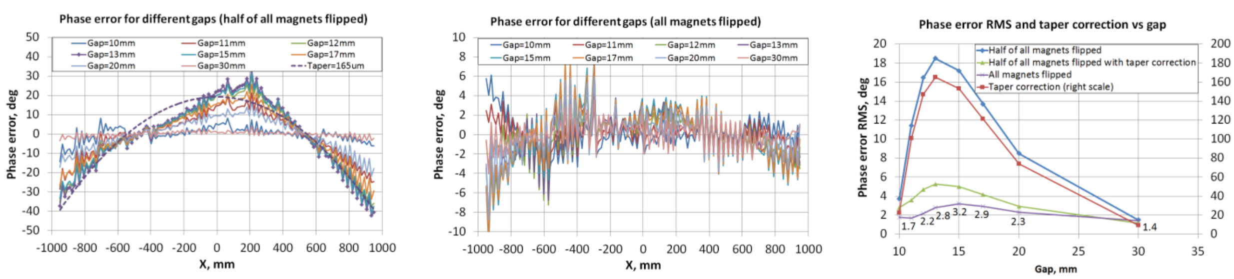

FIGURE 3. Phase error of U29 at an intermediate repair state where magnets had only partially been flipped (left); large gap dependent errors remained (right).Only after complete flipping of all magnets, small phase errors could be obtained (center).

REFURBISHMENT OF UNDULATOR U23

A 23mm period length undulator (U23) of 2m length is in operation at PETRA beamline P02 since late 2010. Before, the device was installed for half a year at beamline P01 which is the first straight section in the rebuilt octant of PETRA III. A peak field degradation of 6% was measured for this device, with a demagnetization pattern very similar to that of undulator PU08. It is interesting to note that both PU02 and PU08 correspond to equivalent lattice positions in the machine, i.e. the upstream location in a canted straight of a DBA-cell. A detailed characterization of the demagnetization effects of this undulator has recently been reported [9].

Similar to the U29 above, the demagnetization of the U23 has only minor effects on the trajectory, field integrals and their transverse dependence. There is, however, a deterioration of the phase error to 48° rms which leads to a drastic decrease in the emission of higher harmonics. In a first attempt and minimum approach, a bare retuning of the magnet structure was performed in order to restore the required properties. The initial peakfield value of 0.61T was reestablished by removing the 500µm pole-overhang into the gap which was originally used to place shims onto the magnets but is not needed anymore for the present tuning concept. The phase error was brought down to 5° rms at minimum gap. However, the tuning succeeded only on-axis and for one particular gap as the transverse non-uniformity of the field errors and their gap dependence could not be corrected just by pole tuning. Hence, a strong dependence of the phase error on the transverse position remained (factor of ~2 within ±2mm) which would make the spectral performance very sensitive to geometrical alignment errors of the undulator and to small orbit changes.

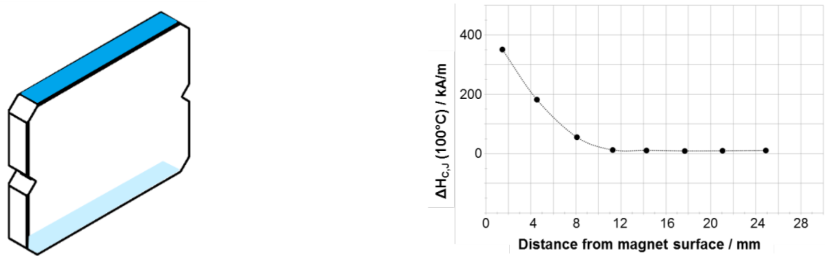

FIGURE 4. Top and bottom side of the U23 magnets (easy axis along the short edge) were treated by a rare earth diffusion process which enhanced the coercive field $H_{C,J}$ by about 350kA/m (4.4kOe) at the magnet surface [10].

As there is only a single U23 undulator in use at PETRA, it is not reasonable to consider a spare magnet structure for replacement. Flipping of all magnets causes a full disassembly of the entire magnet structure, therefore it was decided to completely refurbish and remagnetize the magnets. In the same course the magnets were hardened by applying a diffusion process of rare earth metals into the magnets. In a first step, a highly dispersed Tb-paste has been put onto magnet which is then diffused into the magnet during a heat treatment. Only the top and bottom faces of the magnets were treated in order not to sacrifice the tight dimensional tolerances along the easy axis of these previously manufactured magnets. The Tb particles predominantly migrate to the grain boundaries in the NdFeB magnets, stabilize the domains and therefore enhance the coercive field $H_{C,J}$. Due to the nature of the process, a gradient in the $H_{C,J}$ increase is obtained as shown in Fig.4. An increase of more than 4kOe could be obtained at the magnet surface where a large coercive force matters most. Afterwards the treated surfaces needed to be grinded and the entire magnet was etched before a TiN coating could be applied by sputter deposition. The latter was intended to improve the corrosion resistivity of the magnets against radiation aggravated radiochemistry. It was found after remagnetizing of the magnets that the average remanent magnetization B_r of all magnets was reduced with respect to the value of the original assortment by ~0.5%. This small and negligible decrease is attributed mainly to the grinding and etching process, and only to a much smaller extent to the rare earth diffusion process. After magnet sorting and reassembly of the structure, the undulator was tuned which resulted in a remaining phase error of 0.5°…1.5° rms throughout all gaps. The maximum *K*-value could be enhanced by 0.1 with respect to the original configuration.

REFERENCES

1. P. Vagin, O. Bilani, A. Schöps, S. Tripathi, T. Vielitz, M. Tischer, *“Radiation Damage of Undulators at Petra III”*, Proceedings of the IPAC2014 Conference, Dresden (2014) pp. 2019–2021.
2. J. Chavanne, G. Le Bec, *“Prospects for the Use of Permanent Magnets in Future Accelerator Facilities”*, Proceedings of the IPAC2014 Conference, Dresden (2014) pp. 968–973.
3. M. Petra, P. Den Hartog, E. Moog, S. Sasaki, N. Sereno, I. Vasserman, *”Radiation effects studies at the Advanced Photon Source”*, Proceedings of FEL2002, Nucl. Instr. and Meth. A **507** (2003) 422–425.
4. S. Sasaki, M. Petra, I.B. Vasserman, C.L. Doose, E.R. Moog , N. V. Mokhov, *“Radiation damage to Advanced Photon Source undulators”*, Proceedings of the PAC2005 Conference, Knoxville (2005) pp. 4126–4128.
5. X.-M. Maréchal, T. Shintake, *“Radiation damages on permanent magnets: challenges for the future light sources”*, Proceedings of the SRI2003 Conference, AIP Conf. Proceedings **705** (2004) pp. 282–285.
6. G.K. Sahoo, M. Bieler, J. Keil, A. Kling, G. Kube, M. Tischer, R. Wanzenberg, *“Investigation of Radiation Damage of Insertion Devices at Petra III due to Particle Losses Using Tracking Results with Sixtrack”*, Proceedings of the IPAC2015 Conference, Richmond (2015), in print; M. Bieler, J. Keil, G. Kube, G.K. Sahoo, M. Tischer, R. Wanzenberg, A. Kling, *“Radiation Damage of Insertion Devices at PETRA III – A Perspective View from Optics and Tracking Studies”*, ICFA Beam Dyn. Newslett. **66** (2015) 45–73.
7. P. Vagin, S. Francoual, J. Keil, O.H. Seeck, J. Strempfer, A. Schöps, M Tischer, *“Commissioning Experience with Undulators at PETRA III”*, Proceedings of the SRI2012 Conference, Grenoble, J. of Phys. Conf. Series **425** (2013) 032013.
8. I. Vasserman, S. Sasaki, M. Petra, *“Retuning of radiation-damaged undulators at APS”*, IMMW13, Stanford, California USA (2003).
9. M. Tischer, P. Vagin, *„Demagnetization Effects at PETRA III Undulators“*, ICFA Beam Dyn. Newslett. **66** (2015) 37–44.
10. Vacuumschmelze GmbH & Co. KG, Hanau, Germany; private communication.