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RADIATION DAMAGE OF UNDULATORS AT PETRA III

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Abstract

In the new octant of PETRA III, there are 14 undulator beamlines covering photon energy range from 0.3keV to 150keV. There are also 80m of damping wigglers in order to achieve a low emittance of 1nmrad. Some of these devices, operating at PETRAIII since 2008, accumulated total radiation doses of about 100kGy.

Visible corrosion at the magnet structures of some permanent magnet undulators setting in after a few years and a high dose rate measured regularly by thermoluminescent dosimeters (TLDs) gave reason to inspect the magnetic field of all insertion devices in the PETRA tunnel. This paper presents details of the magnetic field degradation caused by radiation damage to the undulator magnets. For some undulators changes in the spectral properties of the generated light were observed. It was measured with different taper settings in order to partly compensate the nonuniform demagnetization along the structure. The results are compared with the data from the sFLASH undulators and measurements of special 3 pole "sacrificial" undulator, installed in FLASH. Its magnetic field is periodically remeasured and shows field amplitude decrease of 1% per 16kGy accumulated dose.

RADIATION DAMAGE

During the last 5 years of operation, the radiation dose in the new octant of PETRA III has been measured continuously by means of TLD800 dosimeters, which were placed on both ends (up- and downstream) of all 14 undulators onto the vacuum chamber and were exchanged routinely. Since then, a total radiation dose of a few tens of kGy in average and up to more than hundred at particular locations has been accumulated. Such high doses cause failures of electronic parts, permanent magnet demagnetization and material degradation. Also corrosion of undulator magnets and poles was observed at some locations. Air ionization and ozone creation together with humidity form a highly aggressive corrosive environment in the tunnel.

For some undulators, magnetic field degradation was also observed by changes in the spectral properties of the emitted light. Mostly the upstream side of an undulator accumulates higher doses than the downstream part, which causes a non-uniform demagnetization along the undulator magnetic structure. This leads to a spectrum broadening, as different parts of the undulator have different magnet field strength and thus a different emitted wavelength. This problem could be partly corrected by tapering the undulator gap, however the demagnetization profile is not linear along the device [1].

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PEAK FIELD MEASUREMENTS IN TUNNEL

To confirm that the observed spectral changes were caused by radiation demagnetization of permanent magnets, the undulators' magnetic field was remeasured in the tunnel. It is not possible to measure the field on the beam axis with closed undulator gap because of space constrains due to the vacuum chamber. Therefore top and bottom magnet modules were measured separately at fully opened gap. The magnetic field was measured using two AD22151G integrated hall sensors, with a ADS1232REF ADC board for digitizing the sensor voltage.

The sensors were mounted on a carriage that used the bottom magnet module as a reference for the vertical position. The assembly was manually moved along the undulator and the Hall probe voltage was continuously digitized in time. The data had no longitudinal coordinate reference, however only the peak amplitude was required to be measured. The position information could be extracted from the measured data by finding positive and negative extremum positions. Although this setup did not allow to measure the absolute field amplitudes and field integrals, in order to compare directly to the results of measurements in the lab performed before installation into the tunnel, still it was well suited to determine relative field changes along the magnet structure. The reproducibility of the measured data over several repetitions is 0.1%. However because of measuring both girders separately, and because absolute fields level could not be determined due to poor vertical and transverse positioning, the total accuracy is only 1% (Fig. 2). Which is significantly worse than in the lab.

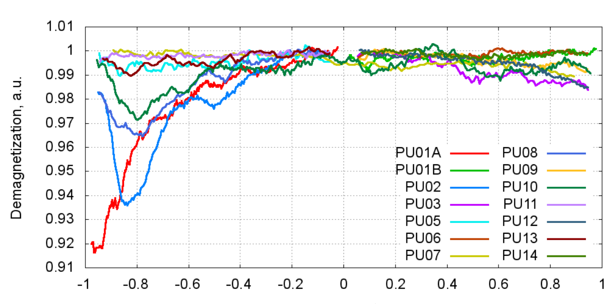

Figure 1: Demagnetization of PETRAIII undulators, horizontal axis is normalized to the length of a straight section.

There are 9 straight sections in the rededicated PETRAIII octant with 14 undulators installed. Some devices are paired in a straight section. The first ones of these show a stronger demagnetization, mainly from upstream part. The second devices show less demagnetization, mainly on the downstream end (Fig. 1).

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PU02 UNDULATOR MEASUREMENTS

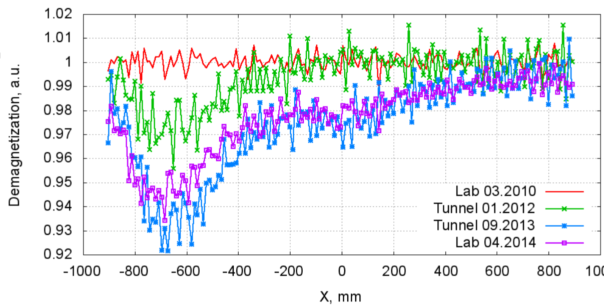

Figure 2: PU02 undulator demagnetization progress.

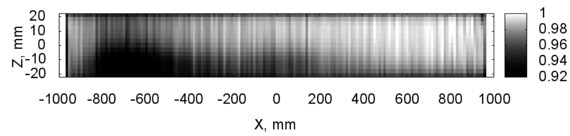

Figure 3: PU02 undulator demagnetization 2D fieldmap at closed gap=10mm, normalized to the initial field amplitude.

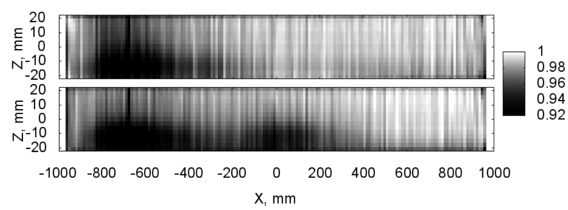

Figure 4: PU02 undulator demagnetization fieldmap measured for top and bottom modules separately at open gap.

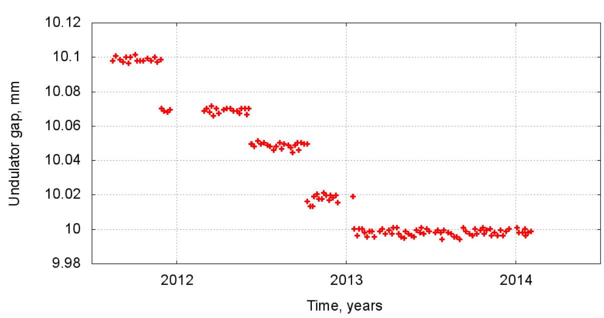

Figure 5: PU02 gap setting to reach 60keV on 7$^{\text{th}}$ harmonic is decreasing over time to compensate demagnetization, till it reaches minimum gap defined by vacuum chamber size.

During the current shutdown a few devices were removed from tunnel and properly remeasured in the lab. Measurements show a transverse non-uniformity of the demagnetization (higher field decrease at "ring-outside", negative Z), which is also different for top and bottom magnet modules (Fig. 3, 4). The demagnetization is highly localized longitudinally around X=-700mm and does not have its maximum in the beginning. That would indicate a localized source of radiation, close to the undulator entrance, for example where the decreasing aperture of the vacuum chamber could cause additional beam losses.

Despite the strong field losses of ~6%, the trajectory straightness was not really affected, as a significant number of poles were demagnetized. Thus field changes on neighbouring poles with opposite signs were similar, having only minor impact on field integrals (Fig. 6).

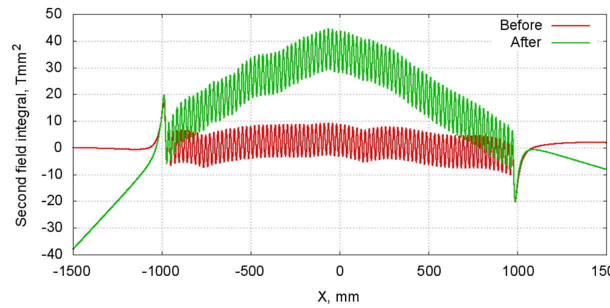

Figure 6: PU02 trajectory before and after demagnetizaton.

In contrast to that, the effects of demagnetization on the phase error is much more severe, since different parts of the undulator have different field amplitude and thus different emitted wavelength, causing the phase error increase even to the values over π.

The damage to the magnets is localized to the part which is close to the beam axis, therefore flipping of the magnets upside down could, for some time, fully correct field errors due to demagnetization, since the field contributions from the magnet parts far away from the beam axis is much lower.

For this particular device it was decided to refurbish the magnets. The magnets will be remagnetized, the coercivity will be enhanced by a rare earth diffusion process to strengthen the grain boundaries and after all an additional coating will be applied to prevent them from corrosion by exposure to synchrotron radiation.

DAMPING WIGGLER MEASUREMENTS

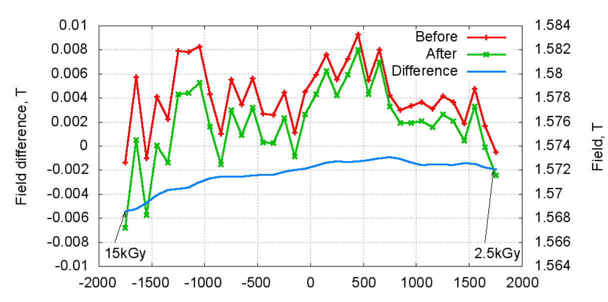

Figure 7: DW05 peakfields after 5 years of operation.

A review of one of the damping wigglers in the lab showed only slight demagnetization mainly on the upstream end. Since this is the first wiggler in a long straight damping

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wiggler section, the full dose measured by TLDs can be attributed to the particle losses, and not to synchrotron radiation. The total accumulated dose measured is 15kGy at the upstream side, and 2.5kGy downstream. This is more or less consistent with the magnetic measurements, showing a demagnetization of 5mT (0.3%) at the upstream and only 1mT at the downstream end, which however is only slightly above accuracy level of these magnetic measurements.

"SACRIFICIAL" UNDULATOR AT FLASH

To study radiation damage effects at FLASH, a special 3-pole undulator (with +0.5;-1;+0.5 poles) is installed right before the SASE undulator section. Correlating the periodically remeasured magnetic field of this device with the TLD data for the accumulated dose shows that the magnetic field degradation is 1% per 16kGy of accumulated dose.

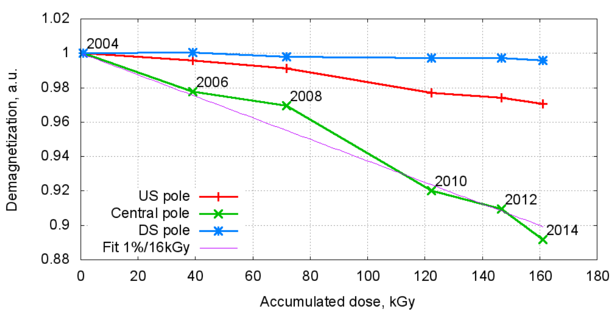

Figure 8: Sacrificial undulator demagnetization.

The up- and downstream poles show less demagnetization as they have smaller magnets. Therefore demagnetization fields are lower than for the normal magnets in the center. In addition to that the downstream magnets are shielded by preceding poles.

CONCLUSIONS

Despite of the demagnetization rate of 1% per 16kGy measured for the sacrificial undulator at FLASH, the sFLASH undulators with an accumulated dose of 20kGy show no noticeable demagnetization (<0.3% limited by accuracy of the measurements in the tunnel).

Synchrotron radiation in the PETRA III storage ring aggravates radio chemistry which leads to corrosion of magnet structures, however this is not the cause for the demagnetization. Demagnetization of magnetic structures and their corrosion are not correlated.

For the undulators installed in pairs in straight sections the first IDs show demagnetization from the upstream side, while the second ones are damaged from downstream side. This indicates demagnetization by particle losses. At these positions the vertical beam size is largest in each undulator cell, since the vertical beta function has its minimum int the center of straight section, between two paired undulators. Losses are higher at the upstream end of the first undulators, where aperture is decreasing for the straight section.

The total dose measured by TLDs can not properly serve as indicator for radiation damage to the magnets because the TLDs can not distinguish between particles and synchrotron radiation.

Despite of an accumulated dose of 15kGy the damping wiggler at PETRA III shows 4 times lower demagnetization compared to sacrificial the undulator at FLASH. There are several possible reasons for this: the different electron beam energy and the different radiation spectrum in these machines, different TLD sensitivity, different magnet geometry and demagnetizing fields.

In order to compensate for the demagnetization of the PU02 undulator, gap settings to reach the same wavelength were decreasing over time until reaching the minimum value defined by vacuum chamber. Therefore it was decided to refurbish the magnets during current one-year shutdown for building PETRA III Extension. After that, further improvements in beam lifetime and more careful machine operation should reduce beam losses and therefore radiation damage to the insertion devices.

REFERENCES

[1] P. Vagin, S. Francoual, J. Keil, O. H. Seeck, J. Strempfer, A. Schöps, M. Tischer "Commissioning Experience with Undulators at PETRA III", Proceeding of SRI2012, Lyon, July 2012, http://iopscience.iop.org/1742-6596/425/3