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RADIATION DAMAGE MONITORING AT PAL-XFEL

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Abstract

Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL-XFEL) has two undulator beamlines, one hard and one soft X-ray beamlines. These two undulator beamlines are in operation since 2017. To maintain the FEL radiation property, the B-field properties of the PAL-XFEL undulators need to be kept at certain level. Under the beam operation condition up to 10 GeV, the accumulated radiation can affect the permanent magnet properties of the undulators. However, the radiation damage of permanent magnet can be different by the operation environment and the geometry of the undulator. Accumulated radiation sensors and a miniature undulator with a few periods are installed in the PAL-XFEL hard X-ray undulator line to monitor the undulator radiation damage. In this proceeding, the radiation monitoring activities and the recent measurement results are introduced.

PAL-XFEL UNDULATOR SYSTEM

Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL-XFEL) has run user beamtime since 2017. Two undulator beamlines, one hard X-ray and other soft X-ray beamlines provide FEL by using up to 10 GeV for hard X-ray, and 3.15 GeV electron beam for soft X-ray beamline. The maximum repetition rate of electron beams is 60 Hz [1, 2]. The undulators are under radiation environment for about 250 days per year except for shutdown.

The hard X-ray beamline consists of twenty undulator segments, and one additional undulator segment. One additional undulator segment will be installed in the summer maintenance of the next year. For the soft X-ray, beamline consists of the seven undaultor segments. The hard and soft X-ray undulator segment have the same magnetic length, 5 m. The undulator period is 26 mm for hard X-ray and 35 mm for soft X-ray beamline undulator. The undulator is hybrid type based on NdFeB magnets and vanadium permendur poles [3]. The Vaccumschmelze VAVODYM 776AP, which has $H_{cJ,min}$ = 1670 kA/m, was chosen as NdFeB magnets [4].

To maintain the magnetic field strength and the quality of the XFEL facility, the radiation accumulation of undulator needs to be monitored and controlled. The demagnetization of NdFeB base magnets occurs for a kGy level of accumulated radiation dose. The demagnetization of the magnets can lead a undulator kick and K-value change [5, 6].

UNDULATOR RADIATION MONITORING

PAL-XFEL has two different types of radiation damage monitor for the undualtor system: on-line dosimeter systems based on the radFET sensor and a miniature hard X-ray undulator.

RADFET Sensors

As an on-line dosimeter system, the DOSFET-L02 systems from Elettra-Sincrotron Trieste were adopted (Fig. 1). DOSFET-L02 system can monitor the accumulated radiation dose by using the radFET sensors. This system measures the output voltage of the radFET sensors, and accumulated dose level can be estimated using the voltage difference of sensors [7].

Figure 1: DOSFET-L02 controller and sensor mount module from Elettra-Sincrotron Trieste.

After the commissioning of PAL-XFEL, the twelve radFET sensors were installed into the six undaultor segments in November 2017, as shown in Fig. 2. Before the radFET sensor installation, the OSLD sensors were installed for every undaultor segments from March 2017 to July 2017. Based on the OSLD reading result, the radFET sensor installation points were selected, where the measured dose is high. For the hard X-ray undulator beamline, the first two (HXU105 and HXU106) 11th (HXU116), and 12th (HXU117) undulator segments were selected. For the soft X-ray beamline, the 2nd and 3rd undulator segments (SXU407 and SXU408) were selected. The two radFET sensors were installed into each undulator's upstream and downstream upper manget structure. The TY1003 radFET sensors from Tyndall were installed for these six undulators segments [8].

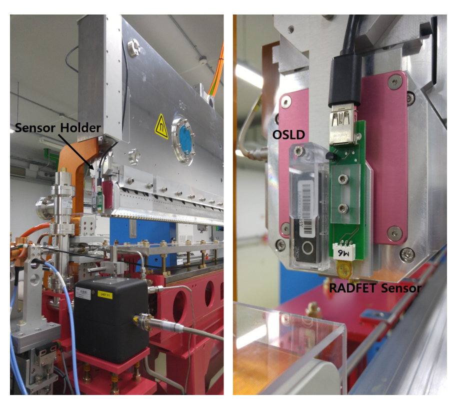

Figure 2: Installation of radFET sensors into undulator. The two sensors were installed into upstream and downstream face of undulator magnet structure [8].

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In November 2018, the additional twelve radFET sensors were installed into other six undulator segments. For this installation, other radFET sensors were used, RFT300-CC10G1 from REM Oxford Ltd. This sensor is known as a good fade aspect, which displays an artificial loss of accumulated radiation. The accumulated radiation dose for total eight of hard X-ray and four of soft X-ray beamline undulator segments are being monitored from 2019 beam time.

Radiation Damage Test Undulator

To estimate the relationship between the accumulated radiation dose and the demagnetization of NdFeB magnets under the hard X-ray beamline environment, the radiation damage test undulator (RTU) was fabricated and installed in winter maintenance 2018. The demagnetization of permanent magnet depends on the electron beam condition, and the undulator magnetic gap. To measure the effect of accumulated radiation dose of electron beams up to 10 GeV, the RTU was fabricated by using the same hard X-ray undulator's magnets and poles. Figure 3 shows the magnet structure of the RTU. The RTU has a 121.6 mm magnet structure length and 12 mm fixed gap. This RTU was designed for easy installation and de-installation for a B-field measurement during every winter maintenance period.

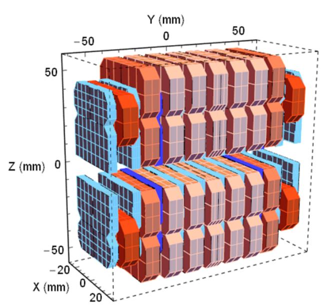

Figure 3: The magnet structure model of RTU. It consists of three period and end magnet sequence.

As shown in Fig. 4, the RTU was installed at the intersection upstream of U104, before the first undulator, HXU105. This U104 space is preserved as drift space now. One additional undulator will be installed at this position in 2020 summer maintenance. Two radFET sensors at the top and bottom positions of magnet structure's upstream face of RTU. Before the installation of the RTU, the B-field was measured by using the Hall probe. Figure 5 shows the measured field. The B-field measurement of the RTU is planned during every winter maintenance to monitor the demagnetization of the magnets. This result together with accumulated radiation dose level will be used as a guide of hard X-ray undulator's re-tuning.

RADIATION DAMAGE MONITORING RESULTS

Figure 6 shows all the radFET sensors readings on 25th July 2019. The maximum dose level was measured at the first hard X-ray undulator, HXU105. Considering the exposure day of sensor, the upstream part of HXU105 has been exposed to radiation dose ~ 0.71 Gy/Day in average, and this value is higher than 1.85 times comparing with the second highest accumulated dose undulator segment, HXU106. The total accumulated dose level of HXU105 also has a big difference between the upstream and downstream, as much as ~ 410 Gy.

Figure 4: RTU in field measurement bench (left) and installation in front of hard X-ray undulator beamline (right).

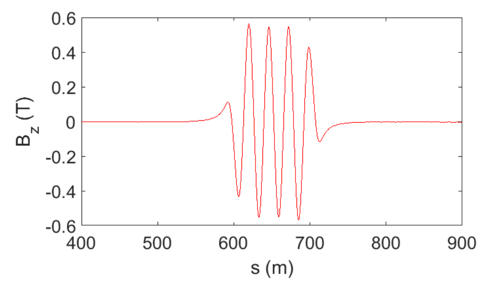

Figure 5: RTU B-field measurement result before installation.

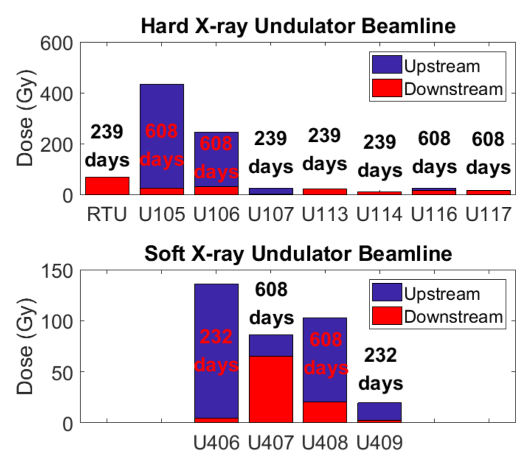

Figure 6: Accumulated radiation dose level of PAL-XFEL undulator segments on July 2019. The undulators with marked 608 days use a Tyndall sensor and other one is REM Oxford Ltd Sensor.

According to these measurement results, the radiation event usually occurs at the front of the undulator beamlines.

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The first one or two undulator segments act as radiation shield, protecting the later undulator segments. Also, most radiation dose is absorbed by the upstream part of the magnet structure. From these results, the upstream part of magnets has a higher possibility of demagnetization. However, unlike other cases, the second segment of the soft X-ray beamline has similar dose level between the up and downstream. This case, it looks like that radiation event occurs at the intersection of the undulator segment.

Figure 7 shows the HXU105 monitoring results from November 2017. The dose level is being monitored with Tyndall sensors. Each sensor unit consists of two sub radFET sensors, the one sensor unit gives two reading values, D1 and D2. As shown in Fig. 7, most of HXU105 radiation dose level sharply increased within an hours or day. However, after the sharp increase of dose level, the fade behavior of the radFET sensor was also large. The fade of a sensor decreases artificially actual accumulated dose level. The sensor's fade behavior was corrected so that the reading was kept constant during the voltage drop. The corrected reading is shown in the bottom graph of Fig. 7. Although, the sub sensors reading values are different, the estimated total dose level of HXU105 upstream part is ~ 900 Gy. However, this estimated value does not reflect the accumulated dose level during the PAL-XFEL commissioning period. Usually, it is known as a larger dose level is accumulated during commissioning period than normal operation period. Considering this, the total accumulated dose level of HXU105 upstream part could be estimated over the kGy level, which can lead a demagnetization. On the other hand, there's no clear evidence of demagnetization for HXU105, which can be figured out from the change of the beam trajectory kick angle of the undulator.

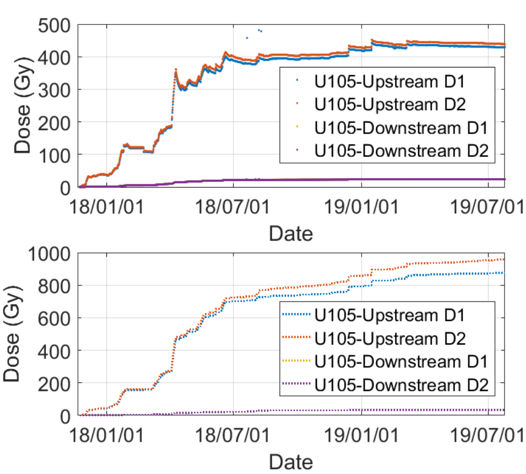

Figure 7: HXU105 radFET sensors reading from November 2017 to July 2019. Top graph shows a raw data from sensor and bottom graph shows a estimated actual accumulated radiation dose level by correcting the loss of sensor reading value.

To protect the HXU105 upper part, 100 mm thickness lead blocks were installed in front of HXU105 in April 2018. After the installation, the amount of stiff incremental of dose level was decreased, however, the RTU, installed in font of HXU105 in November 2018 reading does not shows a sharp incremental behavior. The radiation dose accumulated to the RTU up to now is about 80 Gy. From those measurement results, it looks like that the operational condition was changed to reduce the accumulated dose level.

SUMMARY

For the radiation damage monitoring of the PAL-XFEL undulators, the radFET sensors and the RTU were installed. The radFET sensors are monitoring twelve undulator segments and the monitoring result shows that the first hard X-ray undulator segments has a maximum accumulated radiation dose, ~ 1 kGy. Also, the sensor reading shows that the radiation dose shielded by upstream undulator magnet structures. Based on the measurement result, the lead block was installed to protect the HXU105 upstream magnet structure. The RTU was installed in the hard X-ray undulator hall November 2018. It will be used to study the relationship between the demagnetization of NdFeB magnets under the PAL-XFEL operation condition.

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