ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMK032

RADFET INSTALLATION AT PAL-XFEL UNDULATOR

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Abstract

Two undulator beamlines, one hard X-ray and one soft X-ray, are in operation at PAL-XFEL. Radiation produced during the FEL operation may impair the magnetic property of the undulator magnets and affect the FEL performance. Accumulated radiation at the undulator sections is being measured by using optically stimulated luminescent dosimeters (OSLDs) once per few months. Over 10 Gy gamma ray was detected at some locations at both undulator beamlines. However, in the measurement using the OSLDs we do not have information on which accelerator operation modes produce such high level of radiation on the undulators. To measure accumulated radiation in real time, we installed radiation-sensing field-effect transistors (RADFETs). We report the characteristics of the RADFET sensors and the installation at the PAL-XFEL undulator beamlines.

INTRODUCTION

Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL-XFEL) is operational for users since 2017. PAL-XFEL has two undulator beamlines, one hard X-ray and one soft X-ray. The hard X-ray undulator line is placed at the end of the main linac, where an electron beam is accelerated up to 10 Gev. The soft X-ray line is branched at the 3 GeV point of the main linac and further accelerated up to 3.15 GeV. The soft X-ray undulators are installed in the separated tunnel from the main linac. Further information on the PAL-XFEL layout is found in Refs. [1, 2].

The hard X-ray beamline has twenty undulator segments. The undulator is a hybrid type with NdFeB magnets and FeCo poles. The period is 26 mm and the segment length is 5 m. The magnet gap is 8.3 mm. At the minimum gap, the effective flux density is 0.812 T and the deflecting parameter K is 1.973. The rms phase error of the undulator segment is 5 [3]. The beam commissioning of the hard X-ray undulator lines started in May 2016. The hard X-ray line is the main workhorse of PAL-XFEL user service at present.

The soft X-ray line has seven undulator segments. The undulator is the same type as the hard X-ray and the length is also the same. The period is 35 mm and the minimum magnet gap is 9.0 mm. At the minimum gap, the effective flux density is 1.016 T, and the deflecting parameter K is 3.321. The rms phase error is also 5°. The soft X-ray beamline is an early stage of user service and was not used heavily during the last six months.

Radiation accumulation at the undulator magnets during beam operation is a concern at PAL-XFEL as other XFEL facilities. It is known that a kGy level of radiation dose demagnetizes the undulator magnets [4]. The OSLDs installed at the PAL-XFEL undulator segments gave us a hint on the radiation dose: The undulator at the maximum radiation position, the 1st segment in the hard X-ray undulator line, may need tuning in a few years.

Since OSLDs could not be mounted all the time due to high radiation dose and they did not give real-time information, we installed RADFET sensors at the selected undulator segments. In this article, we introduce the specification and installation of the RADFET systems and show the initial measurements with the RADFET sensors. We also discuss plans for the radiation monitoring of the PAL-XFEL undulator.

RADFET SYSTEM

The DOSFET-L02 system installed in the PAL-XFEL undulators are made by Elettra - Sincrotrone Trieste [5]. The DOSFET-L02 system can monitor the accumulated radiation dose on the RADFET sensor in real time by measuring the threshold voltage of the RADFET chip. Each RADFET chip has two RADFET sensors. The RADFET chip is fixed in a mount board. Four RADFET mound board can be connected to a controller unit via USB3.0 cable. The cable length can be as long as several tens meters. The specification of the controller unit is summarized in Table 1.

Table 1: Specification of DOSFET-L02 Controller

Parameter	Value
Channels	4
Readout Current	10 µA
Readout Voltage	up to 26.7 V
Readout Voltage Noise	< 60 µV
ADC Resolution	24 bit
Thermometer Accuracy	±0.5°C absolute (rms), <0.01°C relative

TY1003 RADFET sensors from Tyndall [6] are used. The threshold voltage of the TY1003 RADFET sensor changes with accumulated radiation as

$$\Delta V_T\,(\mathrm{volt}) = \mathrm{A} \times \mathrm{Dose}^{\mathrm{B}}\,(\mathrm{Rad}), \tag{1}$$

where the A and B coefficients are provided from the vendor as Table 2. The sensitivity of a RADFET sensor to radiation dose varies with the bias voltage to the sensor. We use a 0 V bias because the sensitivity is large enough for the radiation dose at PAL-XFEL undulator section. With a DOSFET-L02 system, an accumulated radiation dose up to kGy can be measured with a 1 mGy accuracy.

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Table 2: TY1003 RADFET Sensor Calibration Coefficients for 0 V Bias

Dose Range	A	B	sigma A	sigma B	R-square
0 – 30 kRad	0.01687	0.5403	3.5649E-4	0.00215	0.99715
0 – 10 kRad	0.00752	0.6324	4.0968E-4	0.00620	0.99466
0 – 5 kRad	0.00319	0.7400	2.3184E-4	0.00894	0.99614
0 – 1 kRad	8.25726E-4	0.9281	2.21047E-5	0.00403	0.99991

INSTALLATION

Total twelve sensor mounts and three controller units were installed into the undulator segments in November 2017. For the selection of the installation points, the measured dose with OSLDs which ware installed by the radiation safety team, was considered. Four sensor mounts were installed at the first two undulator segments of the hard X-ray beamline, where the radiation dose was usually higher than other location. Four sensors were installed at the 11th and 12th undulator segments of the hard X-ray beamline. These undulators are 2nd and 3rd segments after the self-seeding section. Other four sensors were installed at the 2nd and 3rd undulator segments in the soft X-ray beamline. The controller units were installed in the gallery outside the undulator tunnel.

The mounts and controllers were connected with USB3.0 cables with lengths up to 50 m. For each cable connection, two short cables with a few meter length and one long cable with a few tens meter length were used. One USB3.0 male-to-male connector was used between the cables.

The sensor holders were installed on the upper magnet structures of the undulators as shown in Fig. 1. Installation at the bottom structures was not possible due to the limited space. The holders are moved vertically with the magnet structures. Both OSLD and RADFET sensor were mounted on the holder to compare the radiation dose measurements. The measured dose values from OSLDs and RADFET sensors were well matched. After a couple of weeks, the OSLDs were dismounted to prevent overdose.

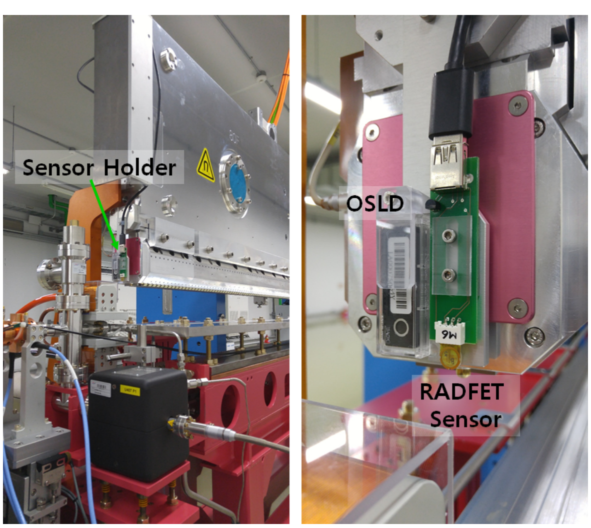

Figure 1: DOSFET sensor installed at PAL-XFEL undulator magnet structure.

MEASUREMENTS

The controller units are communicated to a server via Ethernet. The output voltage is read every ten minutes and saved in the server so that the radiation dose can be monitored in the control room.

The accumulated dose strongly depends on the machine operation condition. Figure 2 shows the accumulated radiation dose at the first two undulator segments in the hard X-ray line since November 2017. The RADFET sensor mounted upstream of the first undulator segment shows the highest dose. The second highest dose is measured upstream of the second undulator segment. The sensors mounted downstream of the segments show doses about 10 Gy. When there is no dose accumulated, the output voltage drops stiffly. The radiation dose measurement may be underestimated due to this voltage leak at the RADFET chip. The flat region in

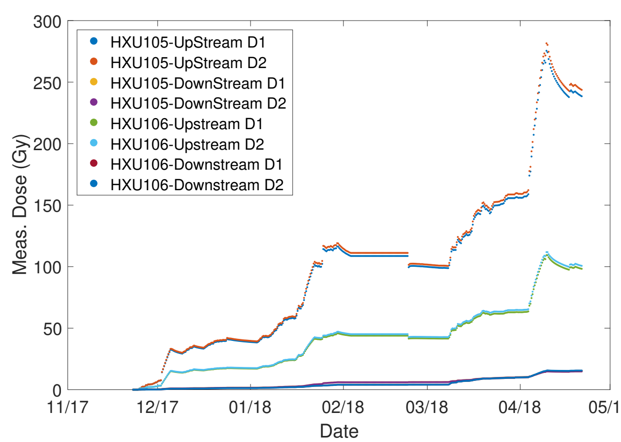

Figure 2: Accumulated radiation dose in Grey at the first two undulator segments in the hard X-ray line.

February 2018 was due to the archive server fault. When there was no signal from the sensor, the same value was recorded repeatedly without refresh.

The accumulated doses at the 11th and 12th undulator segments in the hard X-ray line are shown in Fig. 3. Only the sensor mounted upstream of the 11th segments shows a relatively higher value. There were dose jumps in March and April 2018. The dose increase in March was caused by the test of the self-seeding section. The increase in April took place with the dose jump in the first two undulator segments (see Fig. 2).

In the soft X-ray line, the dose was highest upstream of the 3rd undulator segment, and the next highest dose value

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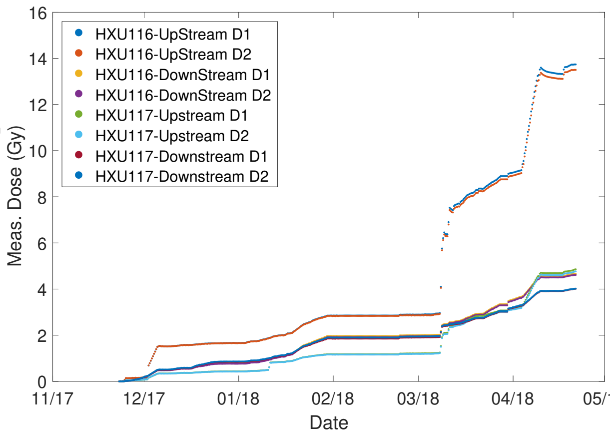

Figure 3: Accumulated radiation dose in Grey at the 11th and 12th undulator segments in the hard X-ray line.

was measured downstream of the 2nd segment (Fig. 4). The same behavior was measured with OSLDs. The signal from the sensor installed upstream of the 3rd undulator segment is missing most time until January 2018 because the USB3.0 connection was not good. The connection was tightened in late January 2018, and the voltage was read correctly since then.

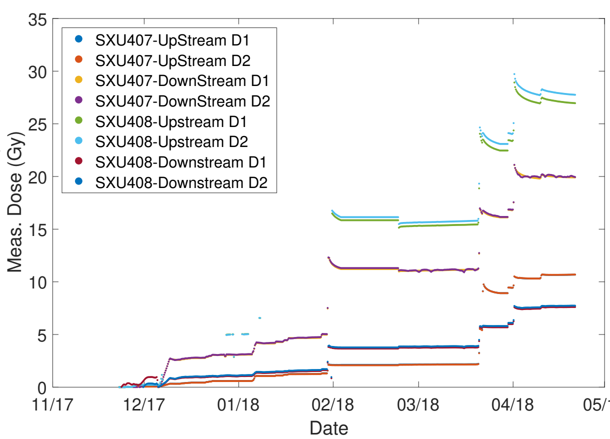

Figure 4: Accumulated radiation dose in Grey at the 2nd and 3rd undulator segments in the soft X-ray line.

The accumulated dose in the soft X-ray line is far lower than as at the first two undulator segments in the hard X-ray line. However, the radiation dose in the soft X-ray line may also be serious when we take account the operation time of the soft X-ray.

SUMMARY AND OUTLOOK

Twelve RADFET sensors were installed at the undulator segments in the PAL-XFEL undulator lines in November 2017 to monitor the accumulated dose in real time. Twenty more sensors will be installed in the second half of 2018. The accumulated dose is about 300 Gy at the first segment in the hard X-ray line and the dose is about 100 Gy at the second segment. The radiation doses at the other locations are relatively low. However a fast dose increase during machine study is sometimes observed.

A lead block with a 100 mm thickness, a 200 mm width and a 300 mm height was installed direct upstream of the first undulator segment in the hard X-ray line in April 2018. The effect of the lead block to the radiation dose at the undulator segments will be studied for a long term.

A radiation test undulator similar to one at the European XFEL [7] will be installed upstream of the first undulator segment of the hard X-ray line in late 2018. The test undulator is designed to be dismounted easily. The accumulated radiation dose at the test undulator and the magnet field profile change will be compared with direct field measurements in the magnetic measurement lab. It will help us to understand the radiation effect to the undulator performance.

Since beam operation in the hard X-ray undulator line started one and half years before the sensor installation in November 2017, the accumulated dose at the first segment could be as high as kGy or higher already. During the initial beam commissioning period, the radiation dose might be especially high. Such high dose may cause demagnetization of the magnet structure. A new hard X-ray undulator segment is under production. When the undulator is ready, the first segment in the hard X-ray line will be replaced with the new one, and the field profile of the used magnets will be investigated.

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