COMMISSIONING OF THE NEW ONLINE-RADIATION-MONITORING-SYSTEM AT THE NEW EUROPEAN XFEL INJECTOR WITH FIRST TESTS OF THE HIGH-SENSITIVITY-MODE FOR INTRA-TUNNEL RACK SURVEILLANCE

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Abstract

The new Embedded Online-Radiation-Monitoring-System, developed for the 17.5 GeV superconducting European XFEL (E-XFEL) that is currently being built between the DESY campus at Hamburg and Schenefeld at Schleswig-Holstein [1,2], has been commissioned in a first system test setup at the E-XFEL Injector. As most of the electronic systems for machine control, diagnostics and safety of the E-XFEL will be located in cabinets inside the accelerator tunnel, the test setup incorporates all system parts like cabinet-internal and -external monitor electronics, infrastructure interface boards, firmware, software, cabling and sensors. Hence the commissioning system setup gives the possibility for first operation of the complete online radiation monitoring system under realistic environmental conditions in terms of irradiation, electro-magnetic interference (EMI) inside the injector tunnel, as well as operational and control system aspects. Commissioning results and measurements based on different internal and external sensor channels will be presented here, together with recent measurements done at different radiation sources using the high-sensibility mode for intra-rack radiation monitoring.

INTRODUCTION

The European XFEL that is currently being built between the DESY campus at Hamburg and Schenefeld at Schleswig-Holstein [1,2], will provide high duty cycle, ultra short X-Ray beams at wavelength about 0.5 Å with extreme brilliance. 27000 pulses per second are possible due to the super conducting 17.5 GeV linac, providing an electron beam with the corresponding time structure. The beam can be distributed into 3 undulator sections of about 200 m length, each consisting of about 30 undulators. Due to the overall length of the facility of about 3.4 km located in the city area of Hamburg, the installation of all parts including the electronics was chosen to be inside of a single tunnel system.

Due to the environmental conditions of the installation in a single tunnel, the control of beam losses and radiation damage is essential. Hence a new Embedded Radiation-Monitor-System (DosiMon) has been developed. The DosiMon system has been designed for measurement of γ-radiation at various appropriate electronics-internal and rack-external measurement points and dose levels. For future extension, the system design already incorporates provisions for measurement of Neutron-radiation in similar measurement point setups.

Most of the electronic systems cabinets for machine control, diagnostics and safety of the E-XFEL located in the accelerator tunnel are shielded, based on pre-estimated radiation levels and the expected damage threshold for standard non radiation hard electronics [3]. The current expansion state of the DosiMon system provides an online γ-radiation dose measurement inside those cabinets for this task.

External radiation detection sensors will also be used in addition to monitor e. g. the dose rates in the SASE undulator regions. Lifecycle estimates for the electronics and the sensitive undulators will trigger alarms, before significant radiation damage occurs. Furthermore, the online data from the dosimetry network allow correlating dose rates with machine settings, and thus to detect and to avoid dangerous operation modes.

A complete new modular system architecture has been designed for the DosiMon as shown in Fig. 1 and Fig. 2. The basic readout principle is similar to the reader design developed for undulator radiation measurements at the Fermi accelerator at Elettra-Sincrotrone Trieste(Italy) [4]. Corresponding orienting tests at the DESY Linac II [5] have demonstrated operation with zero-biased RadFets at DosiMon-comparable prototype testboards for a high dynamic range of ~1 Gy to >1000 Gy (e. g. for lifetime surveillance of the undulators in the XFEL SASE sections) at reduced sensitivity. Further calibration measurements have been taken at Fermi at Elettra [6] in a similar dose range, which can be used for start of commissioning at the XFEL. In addition to the zero-bias mode for enhanced dynamic range at a reduced sensitivity, the system also enables a high-sensitivity +18V bias-mode of the RadFet sensors, working in a reduced dynamic range.

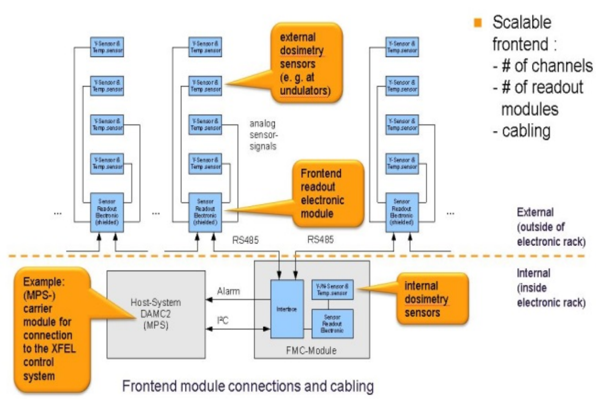

Figure 1: XFEL DosiMon basic system architecture.

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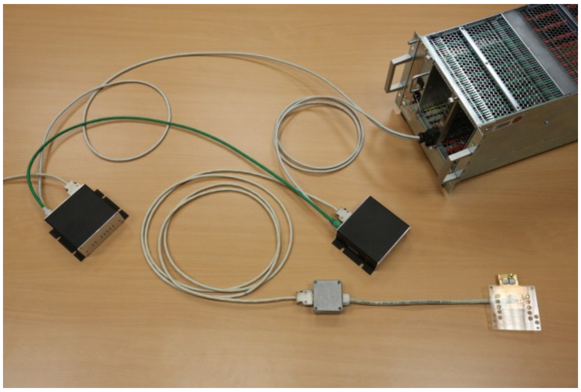

Figure 2: XFEL DosiMon system components.

A fingertip-sized, online-readable RadFet-type [7] RFT-300-CC10G1 sensor from REM Oxford Ltd. [8] has been successfully used throughout all tests and measurements and has consequently been selected as an appropriate γ-radiation sensor for series production. The sensor principle and key parameters are described in [4,7].

TEST SETUPS FOR COMMISSIONING

Since April 2015 various distinct system properties of the new XFEL radiation-monitoring system and several different test setups have been implemented and tested in operation at different accelerators and facilities at DESY. These test setups will be described in the following section, together with their goals and results:

1. full pre-series system test setup at XFEL Injector
2. calibration measurement with a Cs-137 calibration source at DESY's D3 personal radiation safety group
3. full series system test setup at the Flash RF-Gun
4. system test setup at the DESY 2 booster synchrotron
5. EMI test at functional Undulator setup.

SYSTEM TEST AT THE XFEL INJECTOR

After the first operation of XFEL gun with beam in the beginning of 2015, a complete pre-series system has been installed at the XFEL injector for commissioning test. The system was configured with internal and external measurement points both at +18V bias-mode for measurement of γ-radiation from em-showers induced by losses and dark current of the XFEL Gun. Due to delays in the completion and the restart of the XFEL injector, the commissioning test with beam had to be postponed, so that only the technical commissioning without beam could be successfully tested so far. Fig. 3 shows the external readout module and the sensor at the XFEL Injector. The installed pre-series system contains the FMC mezzanine board [9] with an internal sensor on it, sitting on a DAMC2 AMC carrier card for the XFEL machine-protection-system inside a MTCA.4 for physics standard crate [10]. Two external radiation monitor readout-electronic modules are connected together two the FMC-card in a ring-topology. One readout electronics is located below the XFEL gun (see Fig. 3). The other was positioned near the injector dump.

Successful readout of all sensors connected to both external readout-modules proved for the system operability as prepared for XFEL Injector operation, is currently delivering only noise without beam.

Figure 3: external readout module and sensor at the XFEL Injector.

COMMISIONING AT THE FLASH GUN

Another full pre-system test setup has been installed during the summer 2015 at the injector of the FLASH accelerator at DESY to enable commissioning of the DosiMon system with beam. The FLASH accelerator, served as a test facility for XFEL and provides similar electrical and operational conditions up to 2400 bunches with 20pC to 2nC at arbitrary bunch patterns and a maximum RF-pulse length of 800us at up to 1.25GeV. The test setup contains a FMC mezzanine-card with an internal RadFet-sensor and a corresponding TLD close to the RadFet as a reference. Connected to the FMC, an external sensor-readout-module is located inside the rack-shielding.

Figure 4: full system setup at Flash RF-gun rack.

Two external sensor boards are connected to the readout-module, one located between the rack-roof and

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the acceleration module ACC#1 and the other located downstream at the lower edge of the rack in direct vicinity of an online personal-safety-dosimeter (Pandora).

The installed XFEL DosiMon system uses identical pre-series components like the ones located in the XFEL Injector. All RadFet sensors are operated in +18V-bias-mode for high sensitivity. The energy range at the FLASH system test setup position is up to 130MeV and the bunch timing of FLASH is similar to the XFEL system. All additional measurements and results with beam presented here where taken from the test setup at FLASH as shown in Fig. 4 as a reference for XFEL operation.

Fig. 5 shows the corresponding dose progress diagram of the personal-safety-dosimeter beside the downstream sensor. The RadFet readout voltage diagram shown in Fig. 6 depicts the uncorrected voltage over time of both dose-correlated RadFet channels at the downstream sensor.

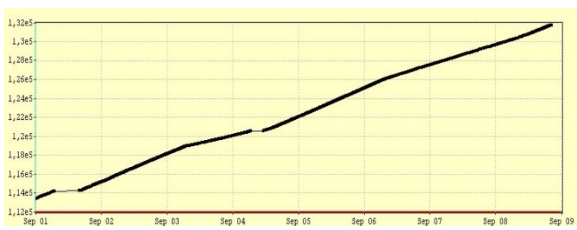

Figure 5: dose level [µSv] vs time (Pandora)

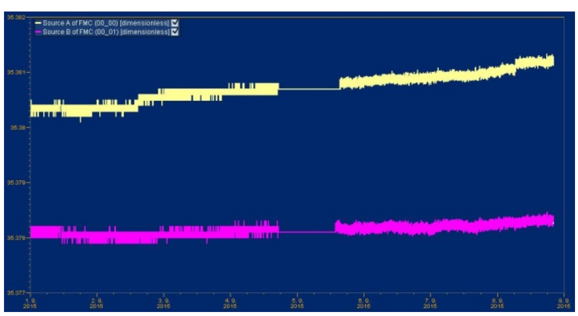

Figure 6: uncorrected RadFet threshold voltages vs time (interrupted signal due to archive development work).

While the temperature at the measurement point remains in a small regime around an average (not shown here), the uncorrected threshold voltages of the RadFet show an increasing signal, correlated with dose level as shown in the reference dosimeter diagram. Detailed dose calculation is underway, based on the first calibration of the +18V-bias-mode presented here. The FMC-internal RadFet inside the rack (Fig. 4) also shows a slight reaction, corresponding to the uncorrected dose of approximately below 11 mSv that was seen by the reference TLD100 nearby the RadFet.

CS-137 CALIBRATION MEASUREMENT

The new DosiMon radiation-monitoring system for XFEL enables a +18V-bias-mode for the RadFet sensors, intended for measurements at low dose rates and dose levels down to approximately 10 mGy, as will be used for operation inside shielded electronic cabinets in the XFEL. This mode is also called rack-surveillance mode, because a RadFet-/TLD-sensor-pair is mounted on a FMC board, typically located inside an electronic rack. After orienting pre-tests at the Linac II at DESY had shown the principle functionality of the high sensitivity mode [5], a RadFet connected to a testboard with readout electronics similar to the DosiMon pre-series has recently been tested in a Cs-137 calibration test setup as shown in Fig. 7. The RadFet, located on a sensor-holder pcb, positioned in the figure on the left side of the radiation semicircle was positioned in a distance of 30cm in front of a common standard Cs-137 source (pellet at radiation semicircle center position). For reference, 2 further TLD100 where placed nearby the RadFet and a set of additional 4(-6) TLD100 were located in the same distance to the source on the opposite side of the 30cm radius semicircle (right).

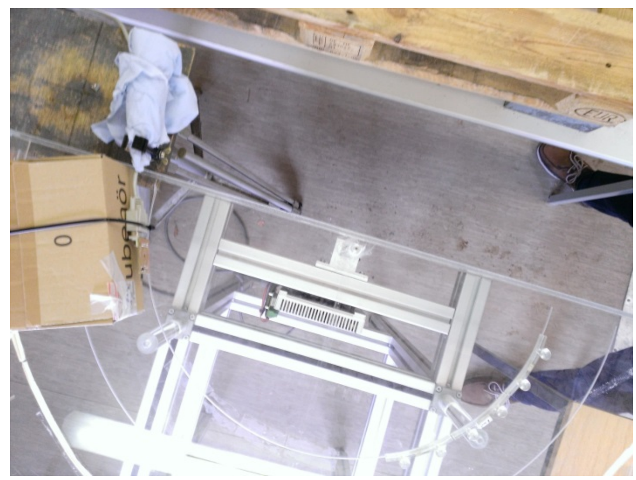

Figure 7: Cs-137 calibration setup (top view).

The radiation test setup was located inside a metallic standard container and had a strong room temperature-dependence from the outer environmental air temperature. The RadFet ambient room temperature as shown in Fig. 8 was logged by the Pt1000 temperature sensor located on the sensor-holder nearby the RadFet.

The RadFet was irradiated in two subsequent phases with approximately 1 week of duration each together with the reference sensors (13.7 days in total). Over both phases, the irradiation with constant dose rate by the Cs-137 source was only interrupted by very short breaks of 18 minutes in total for exchange of the TLD100 reference sensors. Hence, the relative error below 0.1% has been neglected in the further discussion.

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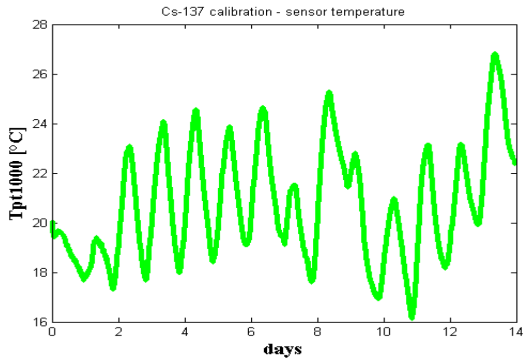

Figure 8: ambient temperature of the RadFet during Cs-137 irradiation.

The overall dose deposited on the RadFet sensor over this time was ~105 mSv (the TLD100 reference sensors that were used for cross-calibration measure dose equivalent). The threshold voltages of the 2 RadFet channels on the chip were monitored by the new readout system together with the room temperature and other internal parameters.

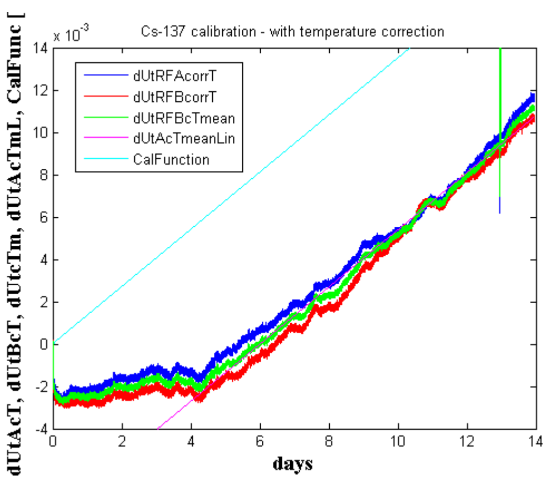

Figure 9: temperature-corrected threshold voltages [V] vs time of an un-irradiated RadFet at Cs-137 irradiation.

Figure 9 shows the mean (green curve) of the temperature corrected theshold voltages of both RadFet channels (red, blue) over the whole irradiation phase. The short peak after 13 days is probably an artefact from a short period of a transient external EMI-event to the electronics. In general, a recent orienting test measurement has shown that the pre-series electronics is sufficiently insensitive against typical EMI-disturbances induced by the strong drives of a XFEL undulator. The data correction at the Cs-137 calibration measurement includes systematic electronic errors and temperature dependence of both RadFet sensors. As this measurement has only been done with a single RadFet up to now, no statistical errors could be investigated yet. It can be seen from the green curve (mean of both RadFet channels), that the measured signal is overlayed by a short-term decreasing initial charge balance current and another, probably temperature-dependent effect over the first four days, that is not yet fully understood. As an initially linear response from a fresh RadFet is physically expected for very low dose levels until well above 100 mGy, the mean RadFet threshold voltage (green curve) shown in the diagram has been estimated by a linear fit (magenta) in the linear range of the curve. For correction of these overlayed effects, the fit was shifted to zero offset (cyan curve). Further measurements are needed, if these overlayed effects have to be corrected or vanish by statistics.

In combination with the linearly increasing dose level (up to ~105 mSv), this linearly fitted function results in a ‘linear threshold voltage to dose’-calibration function for the lower dynamic range. As expected, the result in a range of 5.639 Sv/V falls in between the measurements done at former times at Fermi at Elettra for +9V- and +25V-positive bias mode [6].

TEST SETUP AT DESY2 BOOSTER RING

For the test of the high-sensitivity bias-mode, 2 RadFets with bias-voltage of +9V and +18V have been irradiated over a period of 5 months in an electronics room close to the Desy2 booster synchrotron. The RadFet readout was done by a system testboard with readout electronics similar to the DosiMon pre-series electronics. Radiation level reference measurement points were taken periodically every 2 weeks by consecutive high precision TLD100 measurements. The reference measurements were supplemented by an online γ- and neutron-sensitive radiation monitoring system for personal safety [11] at the same location. This measurement was intended to show measurement performance at high energies up to 6 GeV at high bunch duty-rates of 1 MBunches/s. As a long-term test, this measurement is intended to show fading (annealing) influence with the +18V-bias-mode used for XFEL.

As expected from the Pandora measurements showing a significant amount of neutron radiation at the measurement location, all TLD100 reference measurements showed clear influence from the presence of neutrons, leading to a significant overestimation of γ-dose levels from the unshielded TLD100s. Detailed investigations for quantification of the neutron impact on the TLD measurements were conducted, using differently shielded TLD100 sensors, to enable neutron-correction of the TLD100 total dose results and gain pure γ-reference results. In addition, the pre-estimation of the +9V-biased RadFet readings showed only small response over the first 2 weeks of permanent accelerator operation and significant dose build-up, as seen by the reference sensors.

A first estimate of the expectable dynamic range for the DosiMon series system yielded to an adequate sensitivity at the low dose range (startup-region) and a clearly sufficient dynamic range well above the goal of 10Gy for a +18V-biased RadFet. Hence a second +18V biased RadFet was introduced in the measurement run and showed analogue results over the measurement period. Analysis of the data taken from the DESY 2 run is highly

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dependent on the results from the TLD100 and Pandora references correlated to the operation phases of the DESY 2 accelerator. Hence data analysis is ongoing, based on the Cs-137 calibration data presented above.

After first operational long-term measurements of the +18V bias-mode RadFet at the DESY2 accelerator, +18V bias-operation was chosen for the default high-sensitivity radiation monitoring mode for intra-rack surveillance inside the XFEL.

CONCLUSION

Different test setups have been successfully implemented and commissioned at different accelerators at DESY for the test of distinct system properties of the new radiation-monitoring system for XFEL.

An additional calibration measurement based on +18V-biased RadFet sensors has been successfully done with a CS-137 calibration source as a first calibration run of the systems high-sensitivity rack-surveillance mode.

All tests and measurements mentioned above have shown, that the new radiation-monitoring-system for the European XFEL works for all included zero- and positive-biased external and all positive-biased internal measuring points within all internal and external electronic system components (sensor measuring points).

OUTLOOK

The following list shows further steps, that are planned for commissioning and further development:

- Commissioning of the DosiMon system at the XFEL injector with beam (Nov. 2015)
- Measurements for the estimation of impact from the readout timing on RadFet response
- Release of the pre-series design for series production of components
- Advanced calibration measurements for the external and the high-sensitive internal mode (removal of statistical errors, clarification of the overlaying effects at the startup range of the high-sensitivity mode)
- Advanced measurements for the estimation of fading influence on the measured dose values in external sensor- and high-sensitivity internal sensor-mode
- Measurements for the estimation of neutron impact on RadFet response
- Measurements for the estimation of energy impact on RadFet response
- Calibration measurements in high-sensibility mode at Co-60 source for improved calibration up to 1.2MeV energy range.

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