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OPERATION EXPERIENCES WITH THE MICROTCA.4–BASED LLRF CONTROL SYSTEM AT FLASH

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Abstract

The Free–Electron Laser in Hamburg (FLASH) at Deutsches Elektronen–Synchrotron (DESY), Hamburg Germany is a user facility providing ultra–short, femtosecond laser pulses down to the soft X–ray wavelength range. For the precise regulation of the radio frequency (RF) fields within the 60 superconducting cavities, which are organized in 5 RF stations, digital low level RF (LLRF) control systems based on the novel MicroTCA.4 standard were implemented in 2013. With the newly installed system, an outstanding LLRF performance was achieved so far, positively impacting the FLASH stability and operation capabilities. Also valuable experiences with failures potentially due to radiation, overheating, and ageing as well as with the general operation of the control system could be gained. These have a direct impact on the operation and on the performance of FLASH and will allow future improvements. The lessons learned are not only important for FLASH but also in the scope of European X–ray Free–Electron Laser (XFEL), which will be operated with the same LLRF control system.

INTRODUCTION

The Deutsches Elektronen–Synchrotron (DESY) in Hamburg is currently building the European X–ray Free Electron Laser (E-XFEL) [1,2]. This hard X-ray light source will generate up to 27000 coherent laser pulses per second with a duration of less than 100 fs and a wavelength down to 0.05 nm. For this, electrons have to be accelerated to 17.5 GeV using a 2 km particle accelerator based on superconducting radio frequency technology. Precision regulation of the RF fields inside the accelerating cavities is essential to provide a highly reproducible and stable electron beam. RF field regulation is done by measuring the stored electromagnetic field inside the cavities. This information is further processed by the feedback controller to modulate the driving RF source, using a low level RF system. Detection and real-time processing are performed using most recent FPGA techniques. Special calibration and fast processing techniques of the RF signals inside the system are required. Performance increase demands a powerful and fast digital system, which was found with the Micro Telecommunications Computing Architecture (MicroTCA.4) [3], offering the following advantages. It combines a high precision of measurements and with a low latency processing. It is designed for the parallel processing of a huge number of RF signals. The system standard is very compact. High reliability and availability is assured with redundancy and radiation resistance due to shielding. A further feature is the capability of remote software upgrades and maintenance. Modularity and scalability permit easy hardware system upgrades.

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DESY currently is operating the free electron laser (FLASH) [4], which is a user facility of the same type as XFEL but at a significantly lower maximum electron energy of 1.2 GeV. The LLRF system for FLASH is equal to the one of XFEL, which allows testing, developments and performance benchmarks in advance of the XFEL commissioning [5].

This fact is highly beneficial in preparation for the XFEL commissioning and operation. The FLASH LLRF system is successfully operated for about 2 years in the MicroTCA.4 framework demonstrating its capability of running a highly performing field regulation. They key question to be answered are:

1. What lessons have been learned for setup and commissioning of the LLRF system?
2. What problems have to be considered for operating the XFEL LLRF with MicroTCA.4 LLRF?
3. What efforts have to be addressed to further improve the system?

In the following these questions are to be discussed with the experience gained at FLASH. Due to the long operation at this facility, a large number of bug fixes could be achieved which is already beneficial since directly applicable to XFEL. Furthermore, vice versa FLASH benefits to a large extent, since requirements of the XFEL LLRF system are directly transferred to FLASH improving its performance.

SETUP AND COMMISSIONING OF THE LLRF SYSTEM

The LLRF system as well as all other subcomponents for the European XFEL main linac are installed within the accelerator tunnel which has a major impact of the system

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architecture. First of all the limited space requires a compact system which is further distributed into two subsystems in order to minimize cable length and signal delays. Further the radiated environment requires shielding of the electronic components and fast failure detection and treatment. Finally limited access demands robustness and redundancy in critical components and devices. In the scope of the upgrade of FLASH with the MicroTCA.4 system, the LLRF has been placed inside the tunnel to study these conditions. A picture of the shielded rack tunnel installation for FLASH is given in Fig. 1.

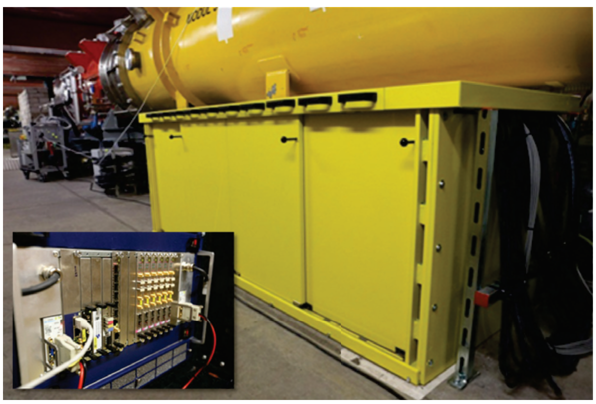

Figure 1: LLRF installation for the first accelerator controls in FLASH underneath the superconducting cryomodule ACC1. Within the small picture an inside view of the rack is given. The yellow housing is a radiation shield protecting internal electronics.

During the installation phase infrastructure like cable paths, cooling concepts and workflows could be optimized. The space constraints in FLASH are higher since this system is installed to a running facility containing other subcomponents. Especially maintenance of the system and upgrades from prototype to pre-series components tuned out to be elaborate tasks. Further a frequently maintained database of installed components is essential to track errors since hardware is floating between locations in this project state.

OPERATION EXPERIENCE

During operation some downtime has been allocated due the following reasons. CPUs and MCHs network connections were failing, which could only be resolved by rebooting the respective crates. Failures of SSDs occurred due to failing of raid controllers. The damage could not be traced back to radiation. A faulty soldered joint at the local oscillator downconverter (LO DWC) of ACC39 was found. This has been a onetime issue and does not suggest further problems. The network connection was lost, which resulted in a loss of communication to the rack and the capability of remote control. Several software and firmware bugs were found and could be fixed. After rebooting the crate not all cards were started. The corresponding MicroTCA management problem has been solved. Human induced errors while operating the system occurred. Fig. 2 is showing the downtime distribution for the RF stations and Fig. 3 for the failure type.

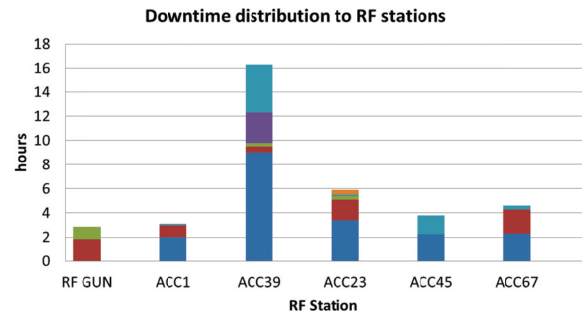

Figure 2: Ovreview for FLASH concerning statistics.

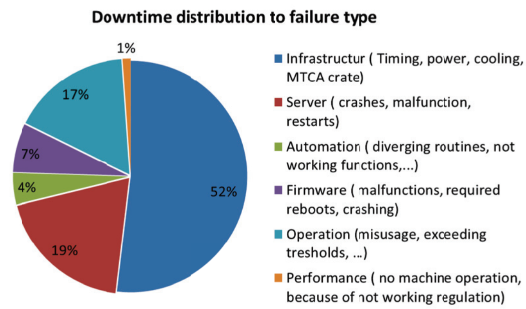

Figure 3: Statistic overview for MicroTCA installation and corresponding issues.

Until now no problems with ageing or direct influences of radiation could be observed. Only an increasing number of disk failures of the SSDs at the RF gun could be related to such an issue but not proven. In order to monitor the radiation levels at the crate thermoluminescent dosimeters (TLD) and an online radiation monitoring system were installed [6]. These devices are placed at exposed locations allowing a detailed analysis of the doses distribution over the whole LLRF installation. Fig. 4 shows as an example TLD1 in a bag located as close as possible to the MicroTCA.4 boards in the LLRF rack of ACC1/39. Furthermore, in Fig. 5 the measured doses of all TLDs are plotted versus time of 13 month. The biggest source of radiation appears to be at the beginning of the accelerator. Due to this the measured doses of TLD1 to TLD4 are in general higher compared to TLD5 to TLD8.

FURTHER STEPS TOWARDS HIGHER REGULATION PERFORMANCE

One of the major bottlenecks of each regulation is the measurement accuracy of the signals influenced by the detection system itself and/or in combination with its environment. Typical issues are the sensitivity of high frequency electronics to conditional changes in temperature and hu-

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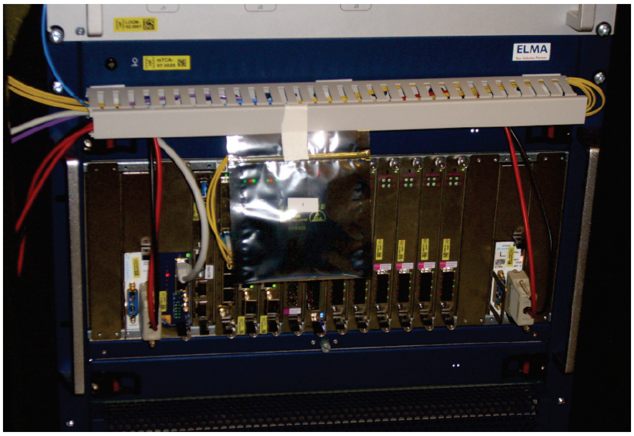

Figure 4: TLD1 located close to the MicroTCA.4 boards in the rack of ACC1/39.

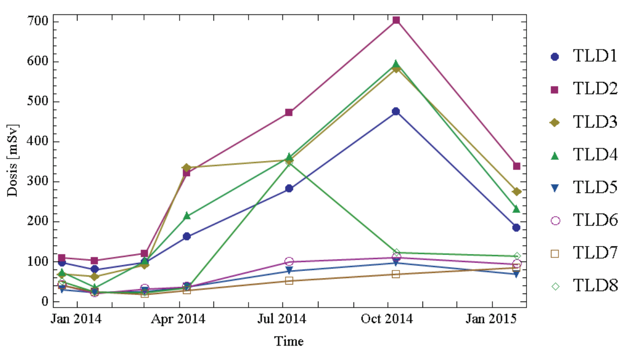

Figure 5: History of doses measured with TLDs at ACC1/39 (TLD1 to TLD4) and ACC23 (TLD5 to TLD8).

midity. It has been measured that minor changes in these conditions already changing detected fields more than the regulation requirements permit. Installation of detection and compensation techniques have been started and successful measurements are done. In addition it is planned to improve the RF reference distribution systems by combination with an optical synchronization system along the accelerator and subsystems. Jitter in between RF and beam monitoring and measurement devices are minimized. The down–conversion and sampling of the IF signal has been thoroughly studied and great emphasis has been put on the stability and resolution of the detected signal. It has been shown that almost a perfect processing gain (increase in SNR) due to vector–sum scaling can be achieved, which is a good indicator of a clean and uncorrelated detection.

A major work load has been put on stabilizing the MicroTCA.4 platform which because of its modularity and versatility introduces a complex layer of hardware management. The proper operation of management controller units is crucial for a reliable operation of the hardware. A proactive approach and good communication with industrial partners was a key step that allowed us to reach a stable state. The reliability of the system has been improved by having all the field replaceable units remotely programmable. The next major hardware upgrade will focus on mitigating environment induced drifts of the RF processing circuits. The first step is the drift calibration module (DCM) which has been successfully installed in ACC23.

Further effort is put into software, regulation and automation routines. The servers are being developed and improved constantly by adding functionalities and algorithms allowing better monitoring and control capabilities. With automation routines operation procedures can be performed in less time. Furthermore the chances for human induced errors are reduced.

SUMMARY AND OUTLOOK

At DESY FLASH the MicroTCA.4–based LLRF system is operated successfully for about 2 years. During this time a wide range of operation experiences were gained. Reasons for downtime are being tracked and evaluated. These turned out to be mainly firmware and software related. Both the achieved performance and the MicroTCA.4 platform itself are very satisfactory. No major issues were detected so far, which leads to the conclusion that the system design is suitable for the European XFEL.

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