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PERFORMANCE OF THE MICROTCA.4 BASED LLRF SYSTEM AT FLASH

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Abstract

The Free Electron Laser in Hamburg (FLASH) is the first linac which is equipped with a MicroTCA.4 based low level RF control system. Precise regulation of RF fields is essential for stable and reproducible photon generation. FLASH benefits from the performance increase using the new developments like, accurate and precise field detection devices. Further enormous increase of processing capabilities allow for more sophisticated controller applications which better the overall performance of the regulation.

INTRODUCTION

The Deutsches Elektronen-Synchrotron (DESY) in Hamburg is currently building the European X-ray Free electron laser (E-XFEL) [1]. This hard X-ray light source generates up to 27000 coherent laser pulses per second with a duration of less then 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. Increasing performance requires a powerful and fast digital system, which was found with the Micro Telecommunications Computing Architecture (MicroTCA.4) [2], offering the following advantages:

- High measurement precision
- Low latency and parallel processing
- Compact system standard
- Redundancy and radiation resistance
- Modularity and scalability

DESY currently is operating the free electron laser (FLASH), 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 for testing, developing and performance benchmarking in advance of the XFEL commissioning [3].

INSTALLATION AT THE FLASH FACILITY

After two years of test system installations, the complete LLRF system for all superconducting RF stations was upgraded to the MicroTCA.4 standard during the shutdown in 2013. A picture of one of the installation places inside the accelerator tunnel is given in Fig. 1.

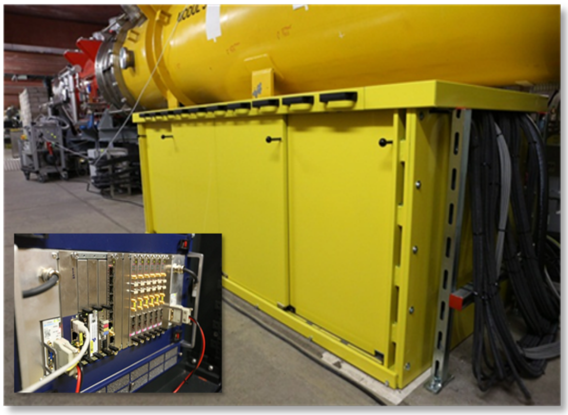

Figure 1: Installation of MicroTCA crates inside the FLASH tunnel underneath the accelerator module. The radiation shielding (yellow cabinet) protects the electronic rack inside. The insert shows the MicroTCA crate installed in this rack.

All measurement signals are split between the new MicroTCA.4 and the previous LLRF systems, which is kept in standby mode. This setup allows for an independent observer system for qualification of the regulation performance. Demonstration of reliable operation was as important a task as the FLASH upgrade to the most recent LLRF system. Operation experience gathered at FLASH during the installation and commissioning phase can be directly applied to the European XFEL. First experimental results show excellent system performance capabilities. The FLASH upgrade is also a key milestone for the European XFEL. Installation inside the accelerator tunnel in particular poses new challenges. Possible radiation-driven events, e.g. single event upsets (SEU), might cause sudden malfunction of the sys-

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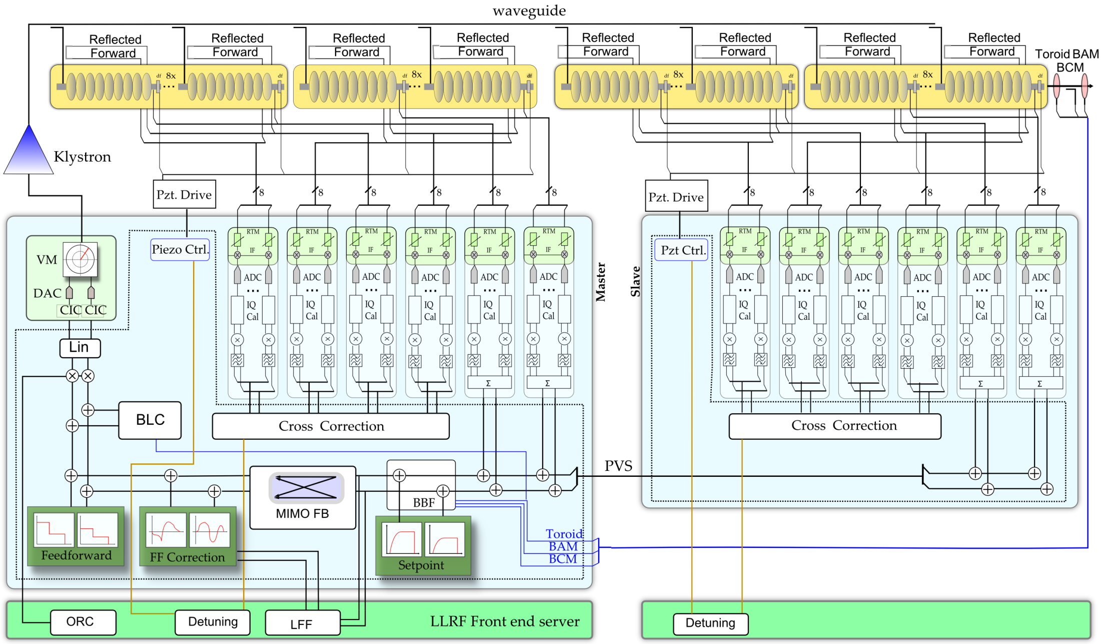

Figure 2: Basic layout, here with master and slave architecture of the LLRF regulation loop for E-XFEL and FLASH. Communication between the master and slave system is done using optical links, as well as for connecting further subsystems to the LLRF (marked as BAM, BCM and Toroid).

tem. Effective shielding and redundant layout of critical components are essential to guarantee the reliability of the system. This is the first time that permanent operation of an MicroTCA.4 based LLRF system in an accelerator facility of this scale is demonstrated. The experience that has been gained during this time directly affects ongoing upgrades, but also serves as a system demonstration for the proper operation of the European XFEL.

PERFORMANCE MEASUREMENTS

The scope of the LLRF system is to provide a stable RF field, both during a single RF pulse and for several consecutive pulses. A typical pulse consists of three phases, where the second phase (flat-top phase) is used for beam acceleration. Here, the RF field must be kept constant to provide each electron bunch with the same amount of energy. Fig. 3 shows the regulated RF field in amplitude during the flat-top phase as an example for one accelerator module.

This RF field stability measurement was performed for all MicroTCA.4 equipped LLRF stations. The given field stability requirements of $dA/A < 0.01\%$ in amplitude and $dP < 0.01$ deg in phase are fulfilled, as shown in Tab. 1.

RF stability measurements only show the in-loop characteristic, i.e. the quality of the implemented controller. However, essential for the machine performance is the gained energy of the electron bunches. Precision measurement of this parameter is done at FLASH by an indirect method using a beam arrival time monitor (BAM) after dispersive sections. Energy differences for individual relativistic electrons transform into arrival time changes, which is the principle of a bunch compressor. To determine the RF field regulation performance the same effect is used, by keeping all RF parameters constant and measure the residual fluctuations with the BAM. Incoming arrival time jitter is suppressed by off-crest bunch acceleration. The measured arrival time jitter presented in Fig.4 can be traced back to the RF field stability and the measurement accuracy itself.

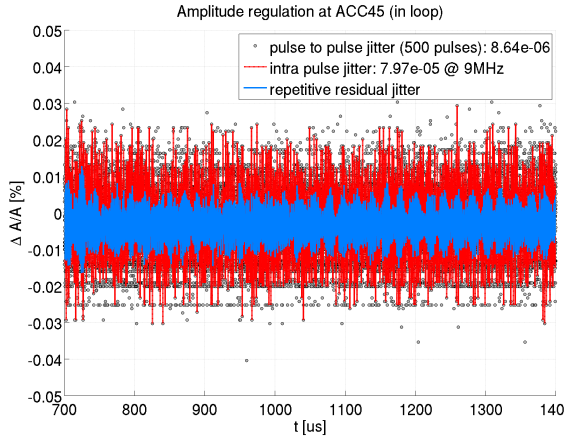

Figure 3: Measurement of the relative amplitude stability during the flattop of 500 consecutive RF pulses. The plot shows the individual measurement points (grey), the repetitive residual jitter (blue) of these data points and an exemplary single pulse (red).

Compared to measurement taken with the previous LLRF system, and improvement of the overall stability by more

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Table 1: Stability Measurement Results Taken from FLASH

Stability @ 9MHz	ACC1	ACC39	ACC23	ACC45	ACC67
Ampl. intra pulse	0.0067	0.0266	0.0055	0.0079	0.0069
Ampl. pulse to pulse	0.0017	0.0053	0.0012	0.0009	0.0019
Phase intra pulse	0.0100	0.0233	0.0074	0.0099	0.0089
Phase pulse to pulse	0.0028	0.0108	0.0017	0.0023	0.0031

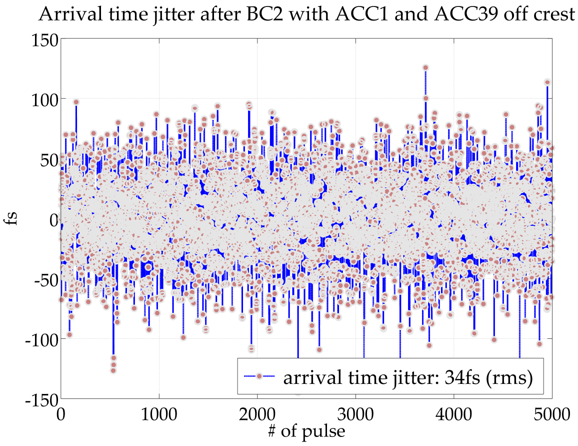

Figure 4: Measurement of the arrival time jitter for 5000 consecutive pulses after the first bunch compressor using a BAM. The first acceleration modules are operated off-crest to minimize incoming arrival time jitter influence by the RF gun, and emphasize the RF field stability contribution from the first accelerator modules.

then a factor of 2 is achieved. The measured residual jitter is not essential reflecting the LLRF system stability. The references frequency for the LLRF system and the BAM are generated by two different sources, the master oscillator and a master laser oscillator respectively. Synchronization between both systems and therefore the measurement deflection is in the same order as the achieved residual jitter of 34 fs (rms), which means the LLRF performance might even be better then detectable. Further improvements can be achieved by using a fast beam-based feedback approach which has already been demonstrated with the previous LLRF system [4].

To the date the system is in permanent operation, and does improve the overall machine performance. Ongoing long term studies and upgrades, mainly on the software, further improve the system. In order not to interfere with the machine, a test system has been installed, using an equal setup and signals in parallel. Here software development tests are done, and malfunctions which have been found during operation can be repeated and solved in a safe environment having real conditions.

SUMMARY AND OUTLOOK

The installation of the MicroTCA-based LLRF system at FLASH demonstrated the capability of reliable operation and showed a performance increase of the RF field regulation. Additional beam-based measurements confirm the LLRF system improvement by more then a factor of two. Recently, the system has been upgraded to support future operation extensions. In addition, an MicroTCA-based LLRF system for the normal-conducting RF gun has been installed. First measurements and tests are currently in progress. For 2014/2015, several user runs at FLASH and installations of the first LLRF systems for the European XFEL are planned. The MicroTCA-based LLRF system is evolving from prototyping stage to large-scale production. Several research centers within the Helmholtz Association, as well as external partners, consider using the system as new technology standard. Within DESY, the MicroTCA technology has also been chosen for several subsystems, besides LLRF, for the European XFEL. Measurements show that on-going performance increase is necessary to meet stability requirements towards 0.001 % in amplitude and 1 mdeg. in phase, requested by state-of-art FEL experiments.

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