ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA028

OPERATION OF NORMAL CONDUCTING RF GUNS WITH MicroTCA.4

M. Hoffmann*, V. Ayvazyan, J. Branlard, Ł. Butkowski, M. Grecki, U. Mavrič, M. Omet, S. Pfeiffer, H. Schlarb, C. Schmidt, DESY, Hamburg, Germany
A. Piotrowski, FastLogic, Łódź, Poland; W. Fornal, R. Rybaniek, WUT-ISE, Warszawa, Poland

Abstract

During the last half year, the MicroTCA.4 based single cavity LLRF control system was installed and commissioned at several normal conducting facilities at DESY (FLASH RF gun, REGAE, PITZ RF gun and Booster, and XFEL RF gun). First tests during the last year show promising results in optimizing the system for high speed digital LLRF feedbacks, i.e. reducing system latency, increasing the internal controller processing speed, testing new control schemes, and optimizing controller parameters. In this contribution we will present results and gained experience from the commissioning phase and the first time period of real operation.

INTRODUCTION

The well known problem with normal conducting cavities is the temperature dependency of the resonance frequency, which introduces the main source for RF field fluctuations. The stability of the temperature defines the stability of the cavity field. For the RF gun cavities used at FLASH, XFEL and PITZ, the temperature coefficient is about 20 kHz/K. The required RF field stability is 0.01 % in amplitude and 0.01° in phase. The stabilization of the temperature for the RF guns at FLASH, XFEL and PITZ is quite challenging, because of the long RF pulses of typically 500 to 800 μs, which represents a massive heat load of typical 20 kW to the cooling system. In case of an interlock, the heat load has to be absorbed by the cooling system in a short time, while during normal operation the system has to be very accurate and keep the temperature of the gun constant below 0.03 K peak-to-peak. A further disturbance source comes from the the driving chain primary the klystron. Its stability is mainly defined by the stability of the modulator high voltage. The task of the RF controller is to suppress these disturbances. Temperature fluctuations are a slow effect, which degrades the pulse-to-pulse stability, while the klystron high voltage stability can be seen even within the RF pulse. During the commissioning phase of the new MicroTCA.4 based LLRF system at the FLASH, XFEL and PITZ gun, the main source of disturbances turned out to be quite different from facility to facility.

CONTROLLER DESIGN FOR RF GUNS

Due to the high bandwidth of normal conducting cavities of about 60 kHz (compared to superconducting cavities with about 200 Hz), the latency in the control loop of a normal conducting system is critical for the feedback controller design. It introduces a phase roll-off over the frequency, which makes the proportional feedback unstable at high feedback gains. One method to compensate this effect is the integration of a lead-lag element. The lead-lag element increases the phase margin of the closed loop transfer function in a certain frequency range, which allows to shift the area of instability to slightly higher controller gain. Additionally, it introduces an integrative part to the controller, which increases the feedback gain at lower frequencies and therefore to higher disturbance rejection. In our standard controller

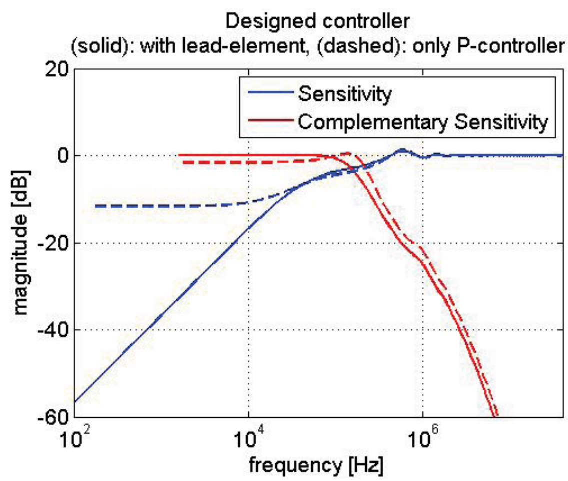

Figure 1: Sensitivity (S) and complementary sensitivity (T) function of the designed controller for the FLASH gun with lead-lag element (solid) and P-controller (dashed).

firmware, a two dimensional multiple input multiple output (MIMO) controller with second order transfer functions for each path is implemented [1]. This MIMO structure allows to compensate coupling between the real and imaginary part of the cavity field. Nevertheless, for the RF guns the main diagonal transfer functions are configured as a lead-lag element with an additional low pass filter. The low pass filter simply helps to reduce the loop back of the measurement noise, since the cavity bandwidth is just a few tens of kHz, while the detection bandwidth is several MHz. Fig. 1 shows an implementation example of the sensitivity function (S) and the complementary sensitivity function (T) of this controller. S describes the suppression of the disturbances. The S and T of a simple proportional feedback controller are shown in Fig. 1, for comparison purposes. In the low frequency regime the effect of the integrative part of the lead-lag element is clearly visible.

FLASH RF GUN

The FLASH gun is running since January 2015 with the new MicroTCA.4 based LLRF system. The system was running in parallel, already commissioned and tested during the

* m.hoffmann@desy.de

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA028

last half year. The new MicroTCA.4 hardware with improved RF front-end and 16 bit ADCs gives a better resolution compared to the former VME based system. The achieved rms stability of the VME system was 0.07° in phase and 0.07% in amplitude. With the new hardware and designed controller, the remaining rms jitter of the RF field in the FLASH gun is in the range of 0.05° to 0.015° in phase and below 0.015% in amplitude (Fig. 2). The stability of the water regulation is typically in the range of 0.03 K peak-to-peak, which is already at the quantization limit of the temperature readout hardware.

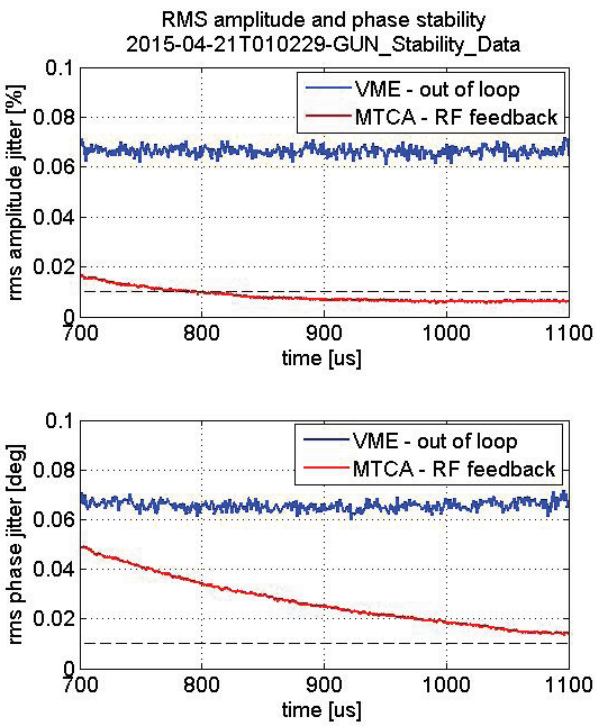

Figure 2: RF field stability (rms) of the FLASH gun during the flattop in amplitude and phase, averaged over 1 min.

XFEL RF GUN

Since December 2013, the conditioning and operation of the XFEL gun is ongoing with the MicroTCA.4 LLRF system without any major problems. Beginning of 2015, a first detailed signal calibration based on power meter measurements was done. During this time the first beam at the XFEL injector was accelerated and used for successful beam diagnostic commissioning in the injector. In the last days, the feedback operation was tested with slightly adapted controller settings. The achieved rms field stability in the XFEL gun were in the range of 0.03% in amplitude and 0.06° in phase, measured over 5 minutes. It turned out, that the modulator high voltage shows oscillations, which time structure are correlated to oscillations visible on the probe phase. An exemplary pulse is shown in Fig. 3. Additionally, a correlation between oscillations in the temperature of the gun

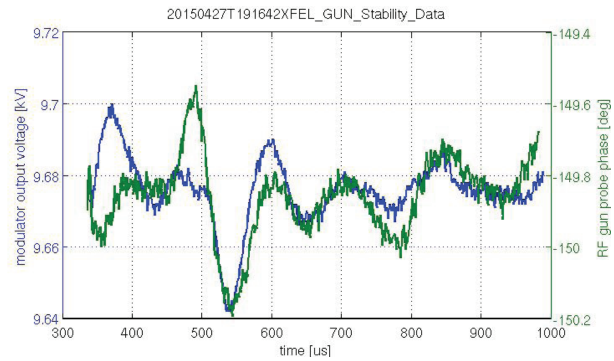

Figure 3: Modulator high voltage and gun probe phase during the flattop at the XFEL gun.

(0.2 K peak-to-peak) and the probe phase (0.5° RF phase peak-to-peak) is visible, too.

PITZ RF GUN

The installation and the first operation of the MicroTCA.4 based LLRF system take place in summer 2014. Since then, the new LLRF system was used for conditioning the RF gun at PITZ. In the beginning of 2015, beam performance

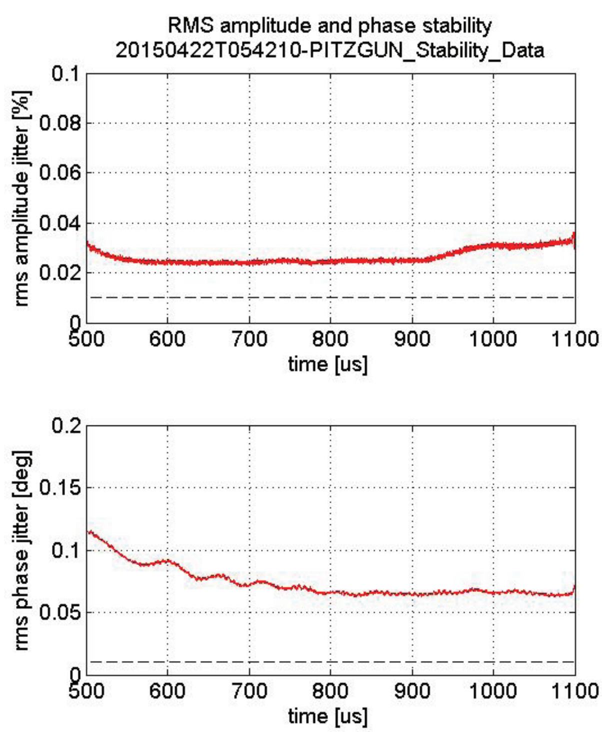

Figure 4: RF field stability (rms) of the PITZ gun during the flattop in amplitude and phase, measured over 5 min.

studies (e.g. emittance and phase stability measurements) started [2]. Since this time, the LLRF system is operated in full feedback mode (i.e. with fast feedback and learning feed-forward). In March 2015, a recalibration of the virtual probe was done, the feedback parameter and the learning feed-forward settings were optimized, and the system was

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA028

updated to the newest firmware and server versions. It is now an exact copy of the system running for the FLASH gun, but the measured field jitter still shows less stability compared to the FLASH gun (Fig. 4). Tracking of different temperature sensors installed at the PITZ gun body shows a strong correlation between one of the inner sensor (Iris 5) and the gun probe phase (Fig. 5), while the sensor used for the water regulation (Iris 1) shows a temperature change of less than 0.05 K peak-to-peak, which is comparable to the values from FLASH.

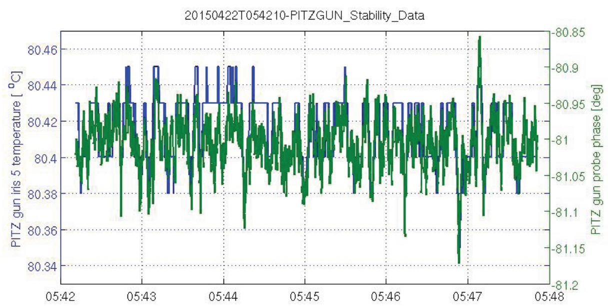

Figure 5: Gun probe phase and iris temperature (sensor Iris 5) at the PITZ gun.

OTHER FACILITIES

During the last year, not only RF guns were equipped with the new MicroTCA.4 based LLRF system. Four more systems/facilities already use the system or are in preparation.

PITZ Booster

The PITZ booster is a multi-cell normal conducting copper cavity operating at 1.3 GHz with up to 14 MV/m field gradient and RF pulse length of up to 900 μs. It is intended to increase the electron bunch energy in the PITZ facility by up to 20 MeV [3]. The LLRF system is nearly a copy of the PITZ gun system. The booster has two probe pick ups used for regulation, while in the case of the gun the filed control is based on the forward and reflected signals from a bidirectional coupler placed just at the input of the gun. The new MicroTCA.4 based LLRF system for the PITZ booster is installed and ready for commissioning.

PITZ and XFEL-TDS

The transverse deflecting structure (TDS) for the XFEL injector and for PITZ is a 14-cell normal conducting S-band structure operating at 3 GHz, with a variable pulse length of 0.1-3.1 μs. They will be used as a longitudinal beam diagnostic. For PITZ, the LLRF system is already installed and updated to the newest hard-, soft-, and firmware. It is ready for commissioning. For the XFEL injector TDS, the LLRF system is in preparation in the laboratory. The installation is scheduled for summer 2015.

REGAE

After the upgrade of the LLRF system to the new single cavity hardware in the beginning of last year, the REGAE system was running very reliably without major issues. Several experiments are ongoing and results are presented in [4]. Details about REGAE and a parameter identification of the coupled gun and buncher are shown in [5]. This model structure will be later used for a Smith-predictor implementation. Further tests are ongoing with an experimental controller setup to control simultaneously the buncher phase and the gun amplitude. These are the most critical contributions for the beam arrival time jitter at the REGAE detector. In addition, developments started to setup a DAQ system for the machine and experimental data, based on the FLASH DAQ system. It will be used for data analysis for the experiments and for slow server based feedbacks as well.

OUTLOOK

The operation of FLASH [6] and PITZ, and the XFEL installation and commissioning [7] with the MicroTCA.4 based LLRF system is intensely and successfully ongoing. Developments, like the latency optimized controller or the integration of a Smith-predictor for the single cavity system, are scheduled for the second half of 2015. Further studies on the disturbance sources for the RF guns at PITZ and XFEL have to be done. Additionally, further single cavity LLRF systems are in preparation for the accelerator FLUTE at the KIT [8] and for three more TDS systems for the XFEL.

REFERENCES

[1] C. Schmidt *et al.*, *Parameter estimation and tuning of a multivariable RF controller with FPGA technique for the Free Electron Laser FLASH*, American Control Conference, Seattle, Washington, USA, 2008.

[2] A. Oppelt *et al.*, *Facility Upgrade at PITZ and First Operation Results*, IPAC'15, Richmond, USA, 2015, These Proceedings.

[3] V.V. Paramonov *et al.*, *The PITZ CDS Booster Cavity RF Tuning and Start of Conditioning*, LINAC'10, Tsukuba, Japan, 2010.

[4] S. Manz *et al.*, *Mapping atomic motions with ultrabright electrons: towards fundamental limits in space-time resolution* , Faraday Discuss, Vol. 177, 2015.

[5] A. Schamineh Nawaz *et al.*, *Physical Parameter Identification of Cross-Coupled Gun and Buncher Cavity at REGAE*, IPAC'15, Richmond, USA, 2015, These Proceedings.

[6] M. Omet *et al.*, *Operation Experiences with the MTCA.4-based Digital LLRF Control System at FLASH*, IPAC'15, Richmond, USA, 2015, These Proceedings.

[7] J. Branlard *et al.*, *LLRF Commissioning of the European XFEL RF Gun and Its First Linac RF Station*, IPAC'15, Richmond, USA, 2015, These Proceedings.

[8] M.J. Nasse *et al.*, *Status of the Accelerator Physics Test Facility FLUTE*, IPAC'15, Richmond, USA, 2015, These Proceedings.