HIGH SPEED DIGITAL LLRF FEEDBACKS FOR NORMAL CONDUCTING CAVITY OPERATION

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Abstract

In the first half of the year 2014, the MTCA.4 based LLRF control system will be installed at several facilities (FLASH RF Gun, REGAE, PITZ, FLUTE/KIT). First tests during the last year show promising results in optimizing the system for high speed digital LLRF feedbacks (reducing system latency, increase internal controller processing speed). In this contribution we will present further improvements in latency and performance optimization of the system, results and gained experience from the commissioning of the system at the mentioned facilities.

INTRODUCTION

The new MTCA.4 based LLRF system for FLASH and XFEL [1–3] is designed for controlling up to 32 superconducting cavities by one common klystron. The structure of the LLRF system is optimized for multi channel processing. It is designed to measure and process up to 96 RF signals (forward, reflected and probe of 32 cavities) with up to six 10-channel analog down-converters (DRTM-DWC10) and ADC-boards (SIS8300L) (Fig. 1). All the data is send via the low latency link (LLL) to the main controller board (DAMC-TCK7) where the main control algorithms are implemented and all the data is processed. The computed control signal is send via the LLL to the vector modulator board (DRTM-VM2) to drive the klystron.

SINGLE CAVITY LLRF SYSTEM

For the single cavity LLRF and normal conducting facilities, the multi cavity system structure is optimized in terms of cost and performance. First, for the single cavity LLRF system in general less signals for the RF regulation have to be detected. Second, the higher bandwidth of normal conducting systems necessitate lower system latency for the fast digital feedback operation in terms of achievable feedback gain and RF field stability. Therefore a new analog front-end board is designed (DRTM-DWC8VM1), which is a combination of the DRTM-DWC10 and DRTM-VM2. It combines an 8 channel down-converter and a single channel vector modulator on one rear transition module (RTM) (Fig. 2). All the required data preprocessing and control algorithms can be implemented on the advanced mezzanine carrier (AMC) ADC-board (SIS8300L). By removing the two LLLs between ADC and controller, and controller and vector modulator, the system latency is reduced. Additionally, less hardware is needed, which means lower cost and lower probability of failure. For the single cavity controller firmware the preprocessing part (field detection) and the main controller algorithms are combined and integrated in the FPGA on the AMC ADC-board.

The general crate layout for the single cavity LLRF system is shown in Fig. 3. Here the planned system for the PITZ RF Gun is shown exemplary. It is installed in a two rack-unit MTCA.4 crate with six AMC and four RTM slots. The main crate infrastructure consists of a power module (Telkoor

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1kW), a management controller hub (MCH), a CPU, and a timing module (x2timer). The three AMC/RTM pairs are foreseen for the main LLRF controller (SIS8300L/DRTM-DWC8VM1), for signal monitoring (SIS8300L/DWC10), and machine protection (DAMC02/RTM-MPS).

**RUNNING FACILITIES/SYSTEMS**

In this section, a short summary of the facilities and their installation and commissioning status is given.

**XFEL/FLASH/PITZ RF Gun**

From LLRF system point of view the RF Gun at FLASH, XFEL, and PITZ is almost the same. It is an L-band 1.5-cell normal conducting cavity operating at 1.3 GHz with a loaded quality factor of approx. 20e3, an RF pulse length of up to 800 us, a pulse repetition rate of 10 Hz, and a target RF peak power of up to 6.5 MW. The waveguide distribution differs a little. At the XFEL RF Gun the power from the klystron is split up into four waveguide arms and send down to the RF gun, where it is recombined, while at FLASH and PITZ it is just split into two arms (Fig. 4). The specialty for the LLRF on all of these RF Guns is the missing probe pickup. Therefore, a virtual probe out of the forward and reflected signal of the last directional coupler at the RF Gun is calculated and used for regulation.

**PITZ RF Gun**

At PITZ the new system was installed in March 2014 and is running in parallel to the old VME system like at FLASH (RF signals were split, too). After some issues with the timing system, first tests of driving with the new system were successfully performed in May 2014 (Fig. 5). A pulse length of 650 us and gradient of 30 MV/m (matches a forward power of approx. 4.7 MW) were achieved in feed forward mode. Due to the missing protection and exception handling system no feedback tests were performed. Due to a longer shutdown period at PITZ (amongst other installation of a new RF Gun) no further tests could be performed. Next tests are scheduled for the second half of this year. Latest end of this year a permanent operation of PITZ with the single cavity LLRF system is considered.

**REGAE**

REGAE is a small S-band accelerator operating at 3 GHz with an RF pulse length of up to 6 us and a repetition rate of 50 Hz. It is build up of a 1.5-cell RF Gun followed by a 4-cell RF Buncher cavity, both driven by a common klystron. The power is split in the ratio 1:4 (buncher:RF Gun) and a waveguide phase shifter in the RF Gun arm is used to adjust the phase between buncher and RF Gun. Since REGAE started operation in November 2011, it is running with an MTCA.4 LLRF system which is based on the multi cavity scheme [5]. Since May 2014, REGAE is running with the new single cavity LLRF system. One advantage of the new...
Figure 5: First operation of the PITZ RF Gun with the single cavity LLRF system. On the right side, the calculated virtual probe is shown in amplitude and phase.

Single cavity scheme is the reduced latency compared to the old one. Comparative results are shown in Tab. 1.

<table>
<thead>
<tr>
<th></th>
<th>Multi Cavity</th>
<th>Single Cavity</th>
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</thead>
<tbody>
<tr>
<td>VM Output</td>
<td>464 ns</td>
<td>360 ns</td>
</tr>
<tr>
<td>RF Gun Probe</td>
<td>736 ns</td>
<td>608 ns</td>
</tr>
<tr>
<td>Controller Input</td>
<td>1040 ns</td>
<td>664 ns</td>
</tr>
</tbody>
</table>

First tests of feedback operation of the RF Gun at REGAE were carefully performed and show slight stability improvements. Further investigations and optimization of controller parameters are necessary to get reliable results. Especially at REGAE, where one common klystron is driving both structures without isolators in the waveguide distribution, the cross coupling from one cavity to the other and vice versa, disturbs the regulation performance of the LLRF system. Further studies are scheduled. To reduce the latency caused by long cables from the cavity to the LLRF system and to the klystron, a rearrangement of the location of the LLRF system is scheduled within the next two month. The LLRF system will be placed in the REGAE tunnel closer to the cavities. Furthermore it is planned to implement a model based predictive controller to get rid of the remaining system latency.

**OUTLOOK**

During the second half of this year, further facilities will be equipped with the new single cavity LLRF system. In this section these facilities are shortly presented.

**FLUTE**

FLUTE is a new test facility currently being built at the Karlsruhe Institute of Technology (KIT) in collaboration with DESY and PSI [6]. It is a normal conducting S-band accelerator operating at 3 GHz with 5 ns pulse length and a repetition rate of 100 Hz. It consists of a 2.5-cell CTFII Gun from CERN and a DESY type traveling wave linac structure, both powered by a common 45 MW klystron. The power is split by a 3 dB hybrid and a phase shifter. The LLRF system is provided by DESY and will be a copy of the REGAE single cavity LLRF system. Compared to REGAE, at FLUTE circulators will be installed in front of the RF Gun to reduce crosstalk between the structures.

**PITZ Booster**

The LLRF system for the PITZ booster will be a copy of the LLRF system for the PITZ RF Gun. Instead of the single directional coupler in front of the RF Gun, the booster has two probe pick-ups, which will be used for the regulation. Installation and commissioning is scheduled for second half of 2014.

**PITZ/XFEL TDS**

As part of the special longitudinal beam diagnostic for XFEL, several transverse deflecting structures will be installed at XFEL and one at PITZ, too. The first TDS for the XFEL injector and the one 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 us and a repetition rate of 10 Hz. The LLRF system will be mainly a copy of the REGAE/FLUTE LLRF system. Installation and commissioning is scheduled for September 2014.

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**REFERENCES**


