KLYSTRON MEASUREMENT AND PROTECTION SYSTEM FOR XFEL ON THE MTCA.4 ARCHITECTURE

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Abstract

The European X-ray Free-Electron Laser (XFEL) is under construction at the DESY in Hamburg. The driving engine of the superconducting accelerator will be 27 RF station. Each of an underground RF station consists from multi beam horizontal klystron (MBK) which can provide up to 10MW of power at 1.3GHz, high voltage (HV) pulse transformer (PT) and waveguide distributing system (WDS). The XFEL should work continuously over 20 years with only 1 day per month for maintenance. In order to meet so demanding requirement a lifetime of the key element of RF station the MBK, should be as long as possible. In the real operation the lifetime of the tube can be thoroughly reduced by service conditions. To minimize the influence of service conditions to the klystrons lifetime the special fast protection system named as Klystron Lifetime Management System (KLM) [1] has been developed. The main task of this system is to detect all events which can destroy the tube as fast as possible, then stop input power to the tube and send signal to stop HV pulse. The tube recovery procedure should depend on the kind of events has happened. KLM is based on the standard Low Level RF (LLRF) Mi-cro TCA technology (MTCA.4 or xTCA) [2] system for XFEL with additional DC channels. This article gives an overview of implementation of measurement and protection system installed at klystron test stand.

INTRODUCTION

The klystron is a specialized linear-beam vacuum tube. At XFEL for each of 27 RF stations Multi Beam Klystron will be used. Each of them can produce 10 MW of power with repetition rate of 10Hz, 1.7ms HV and 1.5ms RF pulse length at 1.3GHz. Those are very expensive devices. Lifetime of the tube should be in excess of 60,000 hours. This is not always easy to achieve. Comparing it to the lifetime of klystron dispenser cathode which with beam loading of 2.A/cm^2 can provide average lifetimes of 145,000 hours we can see that there is still place to extend life time of the tube. Another problem with the klystrons is stability of work. At FLASH in DESY about 50% of accelerator downtime is caused by klystrons and modulators.

There are a few factors which can reduce lifetime and reduce stability of the tube**.**

- Bad vacuum: indicates ions current, RF and HV breakdown;
- RF breakdowns: destructs cavity surface and can pollute RF window that increases reflected power;
- Gun arc: destructs the cathode and anode surface and can pollute HV insulator and cathode;
- High RF reflections: beam loses;
- Work in deep saturation: beam loss, bad vacuum;

To prevent occurrence of the destructive factors the fast interlock is required. The Klystron Lifetime Management system (KLM) which is fast interlock and measurement system was developed in DESY.

SYSTEM OVERVIEW

In order to prevent any damage that could be made to klystron system detects exceptional events and reacts as fast as possible.

There is one main protection function: in case of any event detected, switch off RF driving signal. This detection is based on measurement of klystron signals. There are 6 RF signals form directional coupler at input and output of klystron and 4 DC signals from connection module and vacuum pump. Using them we can measure:

- reflected power at first klystron arm;
- reflected power at second klystron arm;
- reflected power at klystron input;
- forward power at klystron input;
- forward power at first klystron arm;
- forward power at second klystron arm;
- klystron high voltage;
- klystron high current;
- klystron vacuum pump current;
- light sensors;

By monitoring above signals we are able to create event detection functions:

- Correspondence of input and output power: RF breakdown inside tube detection;
- Reflection power check: detects to high reflection power, RF breakdown detection;
- Too high input power: saturation check;
- High voltage breakdown;
- Bad vacuum detection;
- Gun arc detection;
- RF breakdown in WDS near klystron output windows;
- Level of partial discharge in HV system

Dependent on the kind of events tube recovery procedure is started. During recovery procedure klystron driving signal is controlled in such a way to ensure there will be no next event or if it will happen it will not do damage. It is done by slowly increasing power and pulse length.

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XFEL INSTALLATION

For the XFEL the Mi-cro TCA technology (MTCA.4 or xTCA) was chosen to support LLRF system. The same architecture will be used for klystron lifetime management system. KLM will be installed in the same crate as LLRF system. It consists of a Rear Transition Module and Advanced Mezzanine Card (RTM-AMC) pair with down-converts and digitizer board.

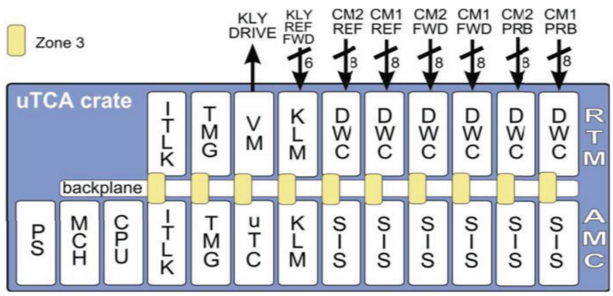

Figure 1: Top view of the MTCA.4 boards distribution.

Figure 1 shows LLRF crate with all boards. KLM is installed close to Vector Modulator (VM). On backplane there is interlock signal connection form KLM to the VM. In case of event, interlock signal switch off RF driving signal by switching off RF gate located on VM.

KLYSTRON TEST STAND

Test stand is used for tests of klystrons before they will be installed in XFEL tunnel [3]. Also it is good place for testing KLM before it will be used at XFEL. Measurement and protection system on xTCA platform was installed at klystron test stand in February 2013.

Implementation

For installation at klystron test stand standard hardware for LLRF control system for XFEL was used. System is built from:

- SIS8300 – AMC with FPGA and ADC board;
- DWC8300 – RTM down converter board;
- uTC – AMC controller board;
- uVM – vector modulator RTM;
- TIMAMC-01 – timing module;
- GE_ASLP11 – CPU module;
- NMCH-CM + ELMA 12 slot crate;

Signals form klystron are connected to the down converter board. 6 RF signals are down-converted from 1.3GHz to IF 54MHz and then with DC signals are sampled by ADC on SIS8300 board with clock with frequency of 81MHz. Next data is processed in the FPGA. All error detection and measurement is done in the FPGA. For power, amplitude and phase measurement non-IQ digital demodulation is used. Protection parameters can be set from front-end server running on CPU in the crate. In case of event all signals data is stored on hard drive for future analysis.

Klystron is driven by vector modulator on uVM board controlled by LLRF controller implemented on uTC board. Block diagram of system is on Fig. 2.

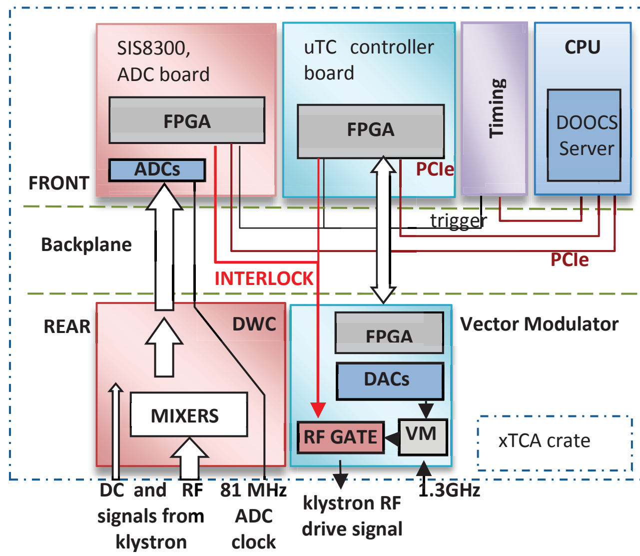

Figure 2: Block diagram of system.

Picture of crate with equipped boards is shown on Fig. 3.

Measurements

For every klystron the transfer curve for different voltages is measured. This function is used as the reference table in protection system. Also in future these measurements will be used for klystron linearization algorithms in LLRF control system.

Reaction Time

One of the most important parameter of interlock system is reaction time on event. This time of digital loop was measured. Form event on ADC input to the signal on the interlock line there is 400ns of delay. When we add all an analog part of the system (cables, amplifiers, RF gate etc.) total reaction time is about 600ns.

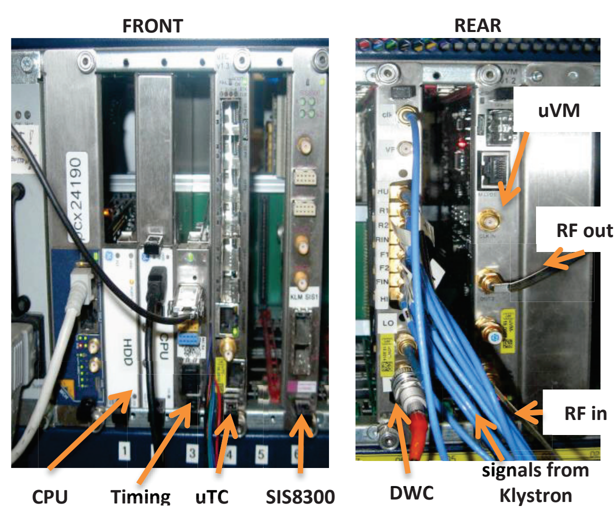

Figure 3: xTCA crate with boards at klystron test stand.

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ERROR EVENTS

In this section examples of errors detected by system at klystron test stand are presented. Events are from klystron MBK TH1802 from Thales.

RF Breakdown

Breakdown of RF generation happens inside the tube when beam loses direction. Beam hits cavity surface and destructs it.

Protection system measure klystron output power and compares it with expected value which is calculated from input power and transfer table. When difference cross protection level interlock is activated and RF diving signal is off. Klystron powers during RF breakdown are shown on Fig. 4.

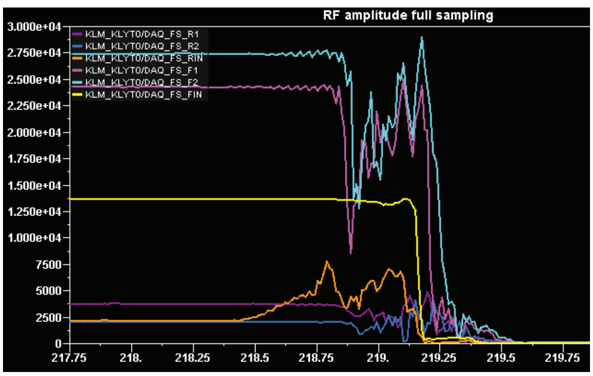

Figure 4: RF breakdown, plot of klystron power measurement.

Too High Reflection

High power reflection at out is caused by RF breakdown somewhere in WDS. RF breakdown in one of two MBK outputs redistributes the voltage in the MBK output cavity and is a reason of breakdown in cavity. Klystron powers during high reflection event at one klystron out are shown on Fig. 5.

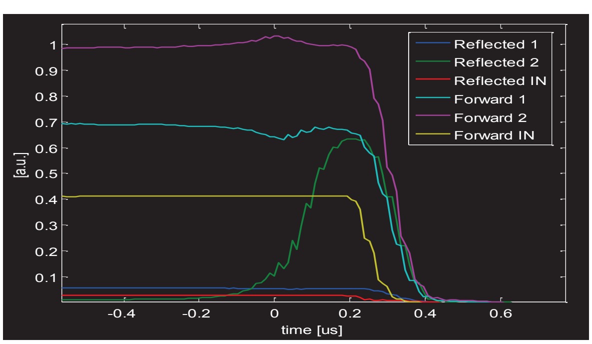

Figure 5: Too high reflection power at one of klystron outputs plots of klystron power.

High Voltage Breakdown

High voltage breakdown happens in the gun area of klystron. It causes power generation loses, decrease quality of vacuum, destructs cathode and damage the anode surface. High voltage and current of klystron during gun arc event are shown on Fig. 6, and klystron powers are shown on Fig. 7.

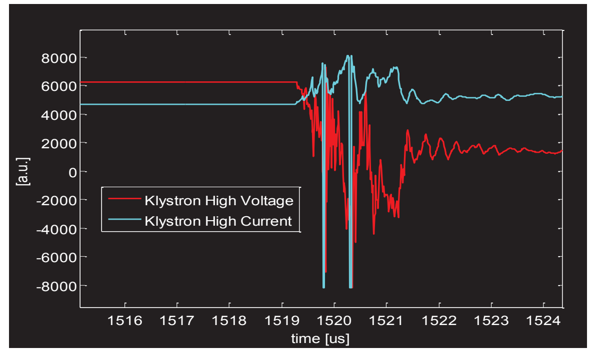

Figure 6: High voltage breakdown, klystron voltage and current.

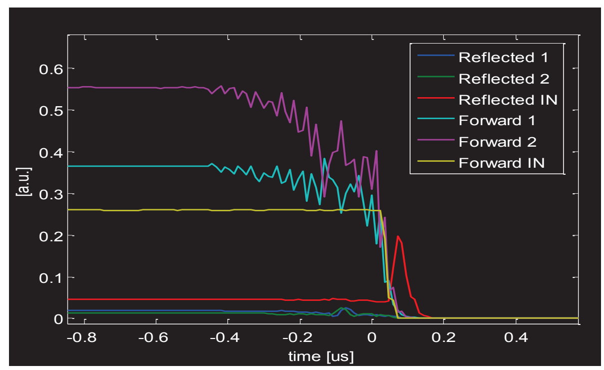

Figure 7: Klystron out power during high voltage breakdown.

CONCLUSION

Protection and measurement system was successfully installed at klystron test stand. It operates since February 2013. KLM can properly detect different kind of error events: RF breakdown, high reflection power, high voltage breakdown and bad vacuum. Reaction on those events is switching off RF driving signal. It is done with time around 600ns. It is enough for protection system but it is not enough for fast interlock system that will minimize influence of destructive factors. Most of delay is caused by SIS8300 digitizer board witch has high precision ADC that have latency. They are good for LLRF control system but are not good enough for fast interlock system. That is the reason new hardware for KLM with low latency ADCs will be design at DESY.

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