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SWISSFEL ELECTRON BEAM DIAGNOSTICS TOOLS AND THEIR CONTROL SYSTEM COMPONENTS

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Abstract

The main driving part of the X-ray free electron laser facility (SwissFEL) at Paul Scherrer Institute (PSI) is a compact electron linear accelerator (linac). The machine is highly optimized to generate a superior FEL radiation with the lowest suitable electron beam energy. In order to meet extremely stringent SwissFEL require-ments for electron beam quality and stability, a variety of advanced beam diagnostics tools were developed and implemented at PSI. All these tools are integrated into the SwissFEL control system. The paper describes basic control elements of advanced electron beam diagnostics tools and their operational performance.

INTRODUCTION

The X-ray free electron laser facility (SwissFEL) at Paul Scherrer Institute (PSI) is driven by a normal conducting linear accelerator (linac), which generates electron bunches with a repetition rate of 100 Hz and charges in the range from 10 pC to 200 pC. In order to provide user experiments with extremely stable, brilliant and ultrashort (~10 fs) photon pulses, which are tunable in the whole wavelength interval from 0.1 to 7 nm, the operations of the SwissFEL machine pose very challenging demands on a number of relevant electron beam parameters, such as the bunch energy, charge, length, arrival time, compression, transverse position, profile, etc. A series of Beam Diagnostics Monitors (BDMs) developed at PSI allows one to obtain all those parameters online. Each BDM is a beam instrumentation device dealing with a particular beam parameter (e.g., arrival time).

In the SwissFEL control system environment, BDMs are implemented as Beam Diagnostics Tools (BDTs), which are based on the PSI Generic Beam Diagnostics Electronics (GBDE) platform in the VME standard and Advanced Data Processing and Control System (ADPCS) setup concept.

GENERIC BEAM DIAGNOSTICS ELECTRONICS PLATFORM OVERVIEW

The GBDE platform is schematically shown in Fig. 1. It combines BDM specific detectors and front-end electronics with common solutions for digitization, FPGA based digital signal processing and interfacing [1]. The platform is very efficient for interacting with control systems.

The analogue signals from BDM detectors are collected by front-end electronics, which is implemented as mezzanine boards sitting on standard PSI Analogue Carrier (PAC) cards. The electronics is in charge of signal conditioning, which is detector specific and typically deals with the optimization of dynamic ranges, signal-to-noise performance, input/output levels, etc.

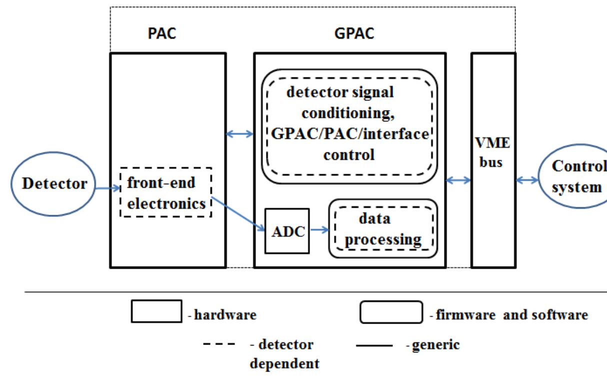

Figure 1: PSI GBDE platform schematics.

PAC output signals are read out by Generic PSI ADC Carrier (GPAC) cards, where they are digitized by fast ADC mezzanine boards and then processed digitally. The major ADC board type that is used for SwissFEL beam diagnostics applications has eight 12 bit 500 Msps ADCs. The ADC sampling clock is provided externally by the SwissFEL reference distribution system [2] or a locally generated BDM clock signal. GPAC cards also regulate GPAC working parameters and handle the communication with the external control system (via the VME bus) and electronics, such as, for instance, PAC cards. All GPAC control and data processing functions are supported by the firmware and software running on several FPGA and embedded CPU (PowerPC) modules.

Two VME bus memory blocks are allocated for the communication of GPAC cards with the control system. Memory mapped GPAC control and status registers make up the GPAC Control Block (GCB). The GPAC Data Block (GDB) comprises the results of signal processing by GPAC firmware and software.

We note that the GPAC firmware, which is in charge of the communication with the control system, is common for beam diagnostics applications. In particular, it maps GPAC control and status registers into GCB, timely reacts on commands from control applications by monitoring this block, and generates the VME bus interrupts. On the other hand, the ADC outputs are processed by firmware and software, which are detector dependent. In major applications, the data processing is triggered externally.

The GBDE platform gives beam diagnostics physicists and electronics engineers a generic way of the BDM development. As the result, their main efforts are concentrated on BDM specific electronics, firmware and software.

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ADVANCED DATA PROCESSING AND CONTROL SYSTEM SETUP CONCEPT

The described above GBDE platform provides a natural, VME bus based, way for integrating BDMs into the control system. The platform also makes it possible for beam diagnostics applications to perform a lot of signal and data processing functions directly on the used GPAC cards. This allows notable computing resources of input-output controllers (IOCs) of the control system, which are usually engaged for such functions, to be allocated for advanced data processing and control tasks.

The integration of BDMs into the SwissFEL control system as well as the development and deployment of advanced beam diagnostics data processing and control tasks in the control system environment are significantly simplified with the use of the Advanced Data Processing and Control System (ADPCS) setup concept, which was formulated and realized at PSI.

Based on this concept, each BDM is supported by its dedicated ADPCS setup. Each setup consists of common and BDM specific software and hardware.

Common ADCPS hardware elements are an IOC and an event receiver (EVR) card, which are placed into one VME crate together with the associated GPAC and PAC cards. For the SwissFEL project, such a GPAC handling IOC is IFC 1210 intelligent FPGA controller board (from IOxOS) with a Power PC dual core processor. The EVR is a new generation EVR-VME-300 card (from Micro-Research Finland), which interfaces the SwissFEL timing and event distribution system.

The ADPCS setup software consists of three parts: GPAC Interface Control (GIC), Operational Conditions Control (OCC) and Advanced Data Processing (ADP) software. The development of ADPCS software is done in the frames of the PSI application development environment that uses Git for software revision control as well as powerful software installation and loading tools [3]. The core of this environment is the EPICS toolkit that provides control system developers with a variety of robust control solutions.

Several software packages were developed at PSI to support ADPCS setup software.

The software of VME bus Memory Handling (VMH) package is implemented as an extension of a generic device support software module (regDev) on top of the memory mapped (mmap) access and IOxOS FPGA (Tosca) drivers [4]. This software allows one to efficiently handle VME cards with the use of standard EPICS records directly referencing registers and memory of those cards. The templates of such records and numerous examples of their use are the essential part of the package.

A wide variety of scientific data manipulation functions are provided by the Mathematical Support (MS) package, which is based on the GNU Scientific Library [5]. The most important functions for beam diagnostics applications are on-line statistics (e.g., mean, standard deviation, variance, higher moments, etc.) in specified time frames and signal fitting (e.g. Gaussian). All these functions are engaged as parts of standard EPICS subroutine records.

The Instrument Interface Handling (IIH) package provides a standard way of dealing with serial (RS232) devices. Based on the StreamDevice software [6], this package reduces all related control development process to few standard steps: listing serial device commands into a standard protocol file, creating an EPICS database with the use of record templates referencing those commands, and running this database on any IOC, which has a serial port available for interfacing the device.

The Embedding MATLAB (EML) package allows one to convert MATLAB programs in C codes, compile them, embed into EPICS and run on any IOC. As the result, closed loop control applications, which are written in MATLAB and have moderate (around 100 Hz) update rates, can achieve a time deterministic performance [7]. The interaction between ADPCS software parts and support packages mentioned above are schematically shown in Fig. 2

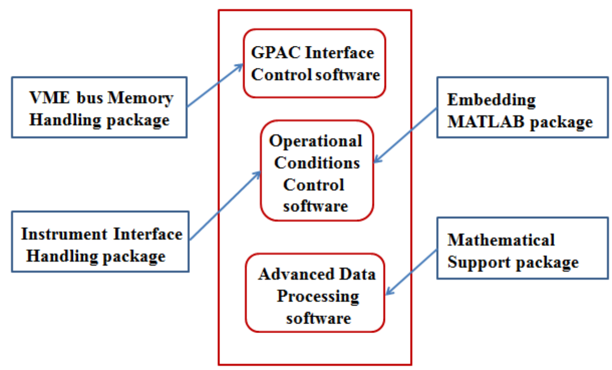

Figure 2: ADPCS software parts and their support packages.

The GIC software deals with the communication between the IOC and GPAC. It is represented by EPICS records directly associated with GPAC registers and data by pointing their VMH package based device/driver support software to the corresponding parts of GCB and GDB VME bus memory blocks. This software allows the control system to handle GPAC/PAC electronics and access BDM data processed by GPAC firmware/software. We note that EPICS records associated with GPAC registers are common for all BDMs, whereas records dealing with GPAC data are BDM specific but can easily be created based on standard templates.

In order to provide reliable beam diagnostics parameters, the operational conditions of BDM detectors and their electronics (e.g., temperature, humidity, voltages, etc.) must be continuously monitored and kept close to their optimal values. In the frames of ADPCS setup concept, this task is performed by the BDM specific OCC software supported by the IIH and EML packages. As a rule, this software runs on IOCs directly interfacing the BDM specific control hardware.

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Any additional data transformation functions, which are needed to be applied to BDM measurement results, are delegated to the ADP software, which is supported by the MS package and can run on any control system IOC. The common part of this software is represented by a set of EPICS records providing BDM data statistics in any specified time frames (e.g., 1 hour, 24 hours, etc.).

The ADPCS setup concept gives control system engineers a standard way of dealing with PSI advanced beam diagnostics monitors. This way significantly simplifies the integration of such monitors into the control system environment.

In order to keep the overall SwissFEL beam synchronous data consistency, beam diagnostics systems have to provide a deterministic time response at 100 Hz beam repetition rate.

If control and data processing algorithms for such systems are relatively simple, as in case of Beam Loss Monitors [8], then their realization on GPAC FPGA systems is straight forward and fully covers the required time deterministic aspects.

However, any complex control or data processing algorithm requires a lot of effort to be implemented and maintained on FPGAs. In these conditions, the ADPCS setup software allows one to achieve the required time deterministic aspects by running such algorithms directly on EPICS IOCs under RT patched Linux. As a result, all development and maintenance problems are significantly simplified.

ADPCS setup software and hardware implementations for SwissFEL beam diagnostics applications demonstrate how EPICS, which is intended for slow control tasks, can be enhanced for dealing with time deterministic aspects in conditions of 100 Hz beam synchronous operations.

For example, the Bunch Arrival-time Monitor [9] measurement result is a combination of two readouts. The first one is the GPAC ADC output, which provides the modulation of the reference laser pulse. The second one is the position of the MX80 motor (from Parker), which is used for zero crossing feedbacks. In the SwissFEL, there are movable chicanes, which influence the bunch arrival time for many tens of picoseconds. These arrival time changes are measured by the motor positions, which should be read out in a time deterministic way. The MX80 is controlled via RS232 but its controller can output raw encoder quad signals, which are counted by the ECM514 (from Kramert) VME card in a time deterministic (triggered) mode. As the result, the positions, which carry the arrival time information, are measured time deterministically.

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CONCLUSION

The PSI Generic Beam Diagnostics Electronics platform and Advanced Data Processing and Control System setup concept allow one to develop beam diagnostics tools based on generic hardware and software solutions, which are powerful, reliable and easy to implement. Being automatically integrated into the accelerator control system and providing deterministic time response functionalities synchronized with the SwissFEL electron beam, such tools are valuable instruments for online machine setting up and operations.

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