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DATA ACQUISITION SYSTEM FOR BEAM INSTRUMENTATION OF SXFEL AND DCLS*

Y.B. Yan†, Y.B. Leng, L.W. Lai, L.Y. Yu, W.M. Zhou, J. Chen, H. Zhao, C.L. Yu
Shanghai Synchrotron Radiation Facility (SSRF)
Shanghai soft X-ray Free-Electron Laser facility (SXFEL)
Shanghai Institute of Applied Physics, Chinese Academy of Sciences
Shanghai 201204, P.R. China

Abstract

The high-gain free electron lasers have given scientists hopes for new scientific discoveries in many frontier research areas. The Shanghai X-Ray Free-Electron Laser (SXFEL) test facility is commissioning at the SSRF campus. The Dalian Coherent Light Source (DCLS) has successfully commissioned in the northeast of China, which is the brightest vacuum ultraviolet free electron laser facility. The data acquisition system for beam instrumentation is based on the EPICS platform. The field programmable gate array (FPGA) and embedded controller are adopted for the signal processing and device control. The high-level applications are developed using Python. The details of the data acquisition system will be reported in this paper.

OVERVIEW

The Shanghai soft X-ray Free-Electron Laser facility (SXFEL) is being developed in two steps, the SXFEL test facility (SXFEL-TF) and the SXFEL user facility (SXFEL-UF). The SXFEL-TF is a critical development step towards the construction a soft X-ray FEL user facility in China, and is under commissioning at the Shanghai Synchrotron Radiation Facility (SSRF) campus. The test facility is going to generate 8.8 nm FEL radiation using an 840 MeV electron Linac passing through the two-stage cascaded HGHG-HGHG or EEHG-HGHG (echo-enabled harmonic generation, high-gain harmonic generation) scheme, as shown in Figure 1. The construction of the SXFEL-TF started at the end of 2014. Its accelerator tunnel and klystron gallery were ready for equipment installation in April 2016. The installation of the SXFEL-TF Linac and radiator undulators were completed by the end of 2016. In the meantime, the SXFEL-UF, with a designated wavelength in the water window region, began construction in November 2016. It was based on upgrading the Linac energy to 1.5 GeV, and the building of a second undulator line and five experimental end-stations. It is scheduled to be open to users in 2019[1].

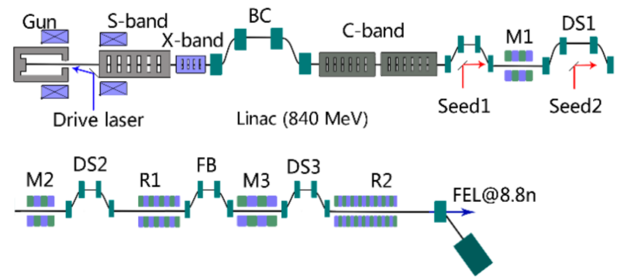

Figure 1: Schematic layout of the SXFEL-TF.

The Dalian coherent Light Source (DCLS) is a FEL user facility, which can deliver world's brightest FEL light in the energy range from 8 to 24 eV, making it unique of the same kind that only operates in the Vacuum Ultra Violet (VUV) region. It use a 300MeV Linac to produce fully coherent photon pulses in the wavelength range between 50-150nm by HGHG scheme. This project was launched at the beginning of 2012, and has successfully commissioned by the end of 2016. It was a close collaboration between the scientists and engineers from Dalian Institute of Chemical Physics and Shanghai Institute of Applied Physics, two institutes of Chinese Academy of Sciences.

The data acquisition system for beam instrumentation is a part of the SXFEL and DCLS control system, which is based on the EPICS (Experimental Physics and Industrial Control System) platform. The system architecture is shown in Figure 2. The FPGA (Field Programmable Gate Array) and embedded controller (such as Raspberry Pi, BeagleBone Black) are adopted for the signal processing and device control. The high-level applications are developed using Python.

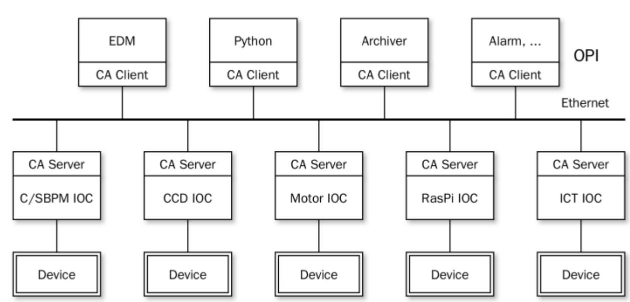

Figure 2: Data acquisition system architecture for beam instrumentation.

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† yanyingbing@sinap.ac.cn

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BPM IOC

The digital BPM signal processor was developed in SINAP, which meets the requirements of SXFEL and DCLS. They are used on the signal processing of both stripline BPM and cavity BPM[2-3]. The processor is a standalone system and provides 4 channels 120MSa/s, 16 bits ADC and Virtex-5 FPGA, as shown in Figure 3.

Figure 3: Digital BPM signal processor.

In the processor, an IMX6Q is adopt as the system controller. It is set to boot from a micro SD card, which is convenient for the batch production. The IMX6Q runs embedded Linux operating system and processes the raw data read from FPGA.

The IOC is based on the asynDriver, which is a general purpose facility for interfacing device specific code to low level communication drivers. Both the Fast Fourier Transformation (FFT) and Hilbert transform algorithms are implemented to calculate the amplitude and phase for each channel. The IOC architecture of digital BPM signal processor is shown in Figure 4.

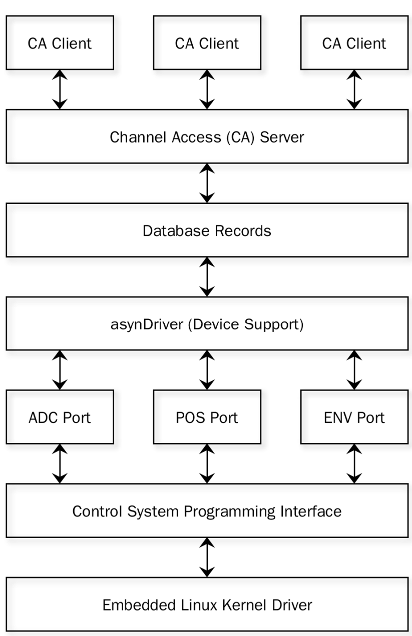

Figure 4: The IOC architecture of digital BPM signal processor.

In the SXFEL and DCLS control system, the EDM (Extensible Display Manager) is used as the default user interface. A unified integrated framework is designed and implemented. The BPM panels are also based on the framework, as shown in Figure 5.

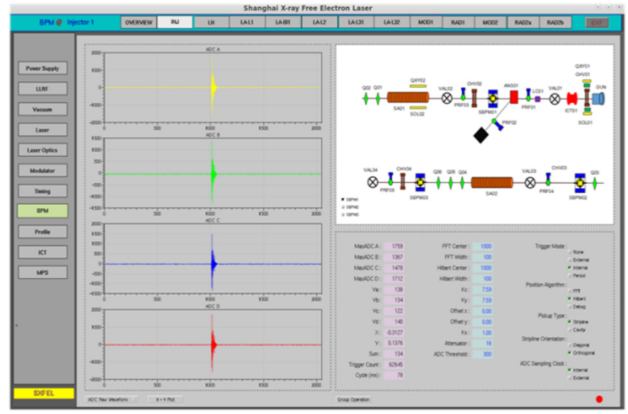

Figure 5: The stripline BPM panel of SXFEL.

The archiver is based on the PostgreSQL, which is a powerful, open source object-relational database system. The RDB Channel Archiver of CSS (Control System Studio) is adopted. Users can access the historic beam position data using the CSS Data Browser.

The high-level applications are important tools for system performance evaluation, physical parameters measurement, machine optimization, etc. They were written using Python. The CA (Channel Access) interface select PyEpics3 [4] and Cothread [5].

CCD IOC

The industrial cameras support multiple buses, such as FireWire, USB, GigE Vision, Camera Link, CoaXPress and so on. The GigE Vision is a globally accepted camera interface standard developed using the Gigabit Ethernet communication protocol. It offers the greatest technical flexibility in terms of bandwidth, cable length and multi-camera functionality. In the SXFEL and DCLS, the GigE Vision cameras (JAI and Basler) are adopted, which can simplify the system architecture. A dedicated network is employed to transmit the images to the servers.

The CCD IOCs are mainly responsible for the image acquisition of the beam profile measurement and laser diagnostics system. They acquire the image data from cameras via network switch and process on the servers (IBM System x3550 series). The software is based on the areaDetector. The image processing contains image rotations, flips, ROI (Region of Interest), profiles, etc. The EDM panels are shown in Figures 6 and 7.

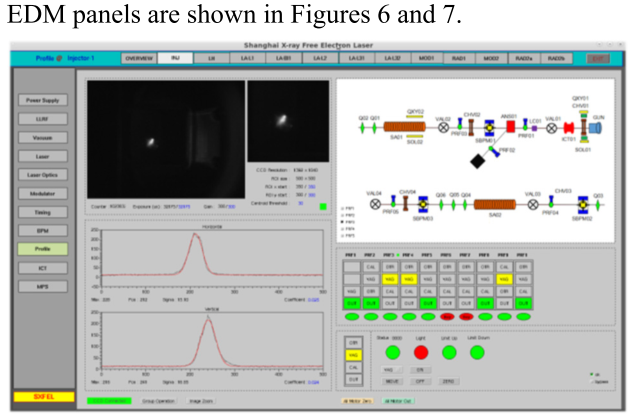

Figure 6: Beam profile measurement panel of SXFEL.

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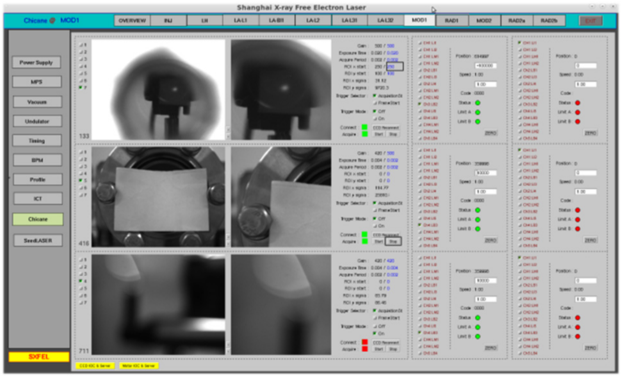

Figure 7: Laser diagnostics panel of SXFEL.

MOTOR IOC

In the beam instrumentation, microwave and laser diagnostics system of SXFEL and DCLS, the network-based step-servo motors (MOONS SSM24Q-3RG) are adopted. The motors integrate with controller, driver, encoder and digital I/O interface. The digital I/O can be used as limit protection, illumination control, etc.

The motors can be accessed via TCP/IP protocol. The IOCs are based on the streamDevice, which also runs on the IBM servers. The motors control panels are shown in the right part of Figures 6 and 7.

ICT IOC

The Keysight digital oscilloscopes are used for the data acquisition of integrated current transformers, which are LXI (LAN eXtensions for Instrumentation) devices. The LXI consortium defines standard ways for Ethernet-based instruments to communicate, operate and function. The data is transmitted to the servers through the dedicated network. The IOC software is based on the asynDriver and VISA (Virtual Instrument Software Architecture). The data rate can reach 20Hz for 4 Channels 50K waveform, as shown in Figure 8.

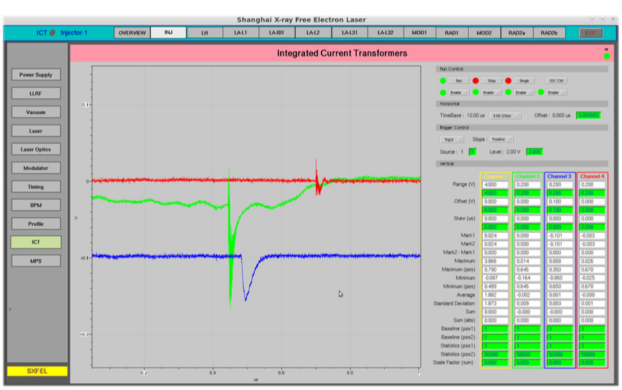

Figure 8: Beam charge measurement panel of SXFEL.

RASPI IOC

The embedded Linux boards, such as Raspberry Pi and BeagleBone Black are credit-card-sized single-board computers. They are low-cost and equipped with a huge array of GPIO (General Purpose Input Output), which can be used to take readings from sensors and control external devices. The active development community and open-source nature also make them ideal choices for many applications. They can be integrated with the accelerator control system [6].

In the SXFEL and DCLS, they were embedded in the customized chassis. The dedicated circuits were designed to control the power supply via electric relays. They run as the IOCs and control the power supplies of CCD cameras and step-servo motors remotely.

CONCLUSION

The data acquisition system for beam instrumentation of the SXFEL-TF and DCLS have been designed and developed. Up to now, the systems have operated steadily for one year, and play important roles during the daily operation and beam commissioning. With the new equipment installation of SXFEL-UF, more functionality will be added. Further optimization will be also carried out.

ACKNOWLEDGEMENT

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