ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA058

GTHE CONTROL SYSTEMS OF SXFEL AND DCLS*

Y.B. Yan, J.G. Ding†, H. Zhao, H.F. Miao, Y.J. Liu
G.H.Chen, Q.R. Mi, H.J. Zhu, C.L. Yu, S.M. Hu
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 Shanghai Synchrotron Radiation Facility (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 control systems of the two facilities are based on EPICS. The embedded controllers, programmable logic controller (PLC) and field programmable gate array (FPGA) are adopted for the device control. The archiver is based on the PostgreSQL database. The high-level applications are developed using Python. The details of the control system design, construction and commissioning 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].

* Work supported by the National Development and Reform Commission (NDRC) and the National Natural Science Foundation of China (NSFC)
† dingjianguo@sinap.ac.cn

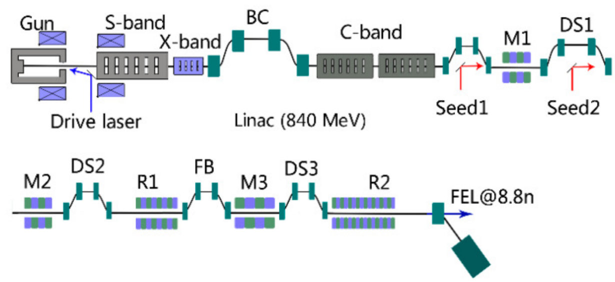

Figure 1: Schematic layout of the SXFEL-TF.

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 Chinese Academy of Sciences institutes.

The control systems of SXFEL and DCLS are responsible for the facility-wide device control, data acquisition, machine protection, high level database or web applications, as well as network and computing platform. They provide operators, engineers and physicists with a comprehensive and easy-to-use tool to control the machine components to produce high quality electron beam and free electron laser.

ARCHITECTURE

The control systems are based on the open-source software, which are the combination of Linux, EPICS and Python. The CentOS (Community enterprise Operating System) is selected, which is a free operating system distribution based upon the Linux kernel. The EPICS (Experimental Physics and Industrial Control System) is adopted to reach the balance between the high performance and costs of maintenance. EPICS is a set of open source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as particle accelerators, telescopes and other large scientific experiments[2]. The high-level applications are developed using Python, which is a widely used object-oriented programming language.

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA058

As shown in Figure 2, the control systems adopt the standard client-server architecture, which ensures the system scalability and avoids performance limitations. The major software is based on the latest stable release series of EPICS Version 3. The components of Version 4 will be evaluated and used partially for the middle layer services in the future.

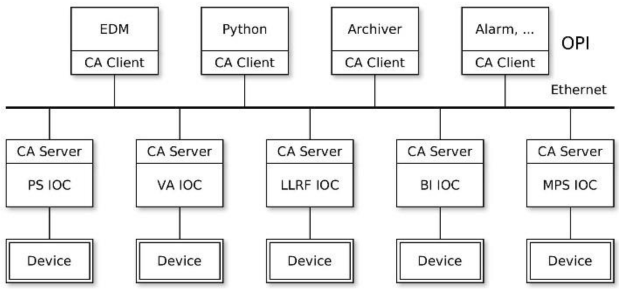

Figure 2: Control system architecture of SXFEL-TF.

SERVER AND IOCS

The central servers consist of several high-performance commercial computers, which provide the control system support services as the follows. They also provide the platform for high-level physics applications development and beam commissioning.

- EPICS Services: include the base, support modules, extensions, cross-compile support for different platforms. All console computers register on the server and use the shared resources, such as display manager.
- Network File Service: provide file sharing solution for the control system. The authorized clients can view and optionally store and update files on the server.
- Directory Services: used for the authorization of accessing resources. The NIS (Network Information Service) is adopted.
- Time Synchronization Service: use the NTP (Network Time Protocol) to synchronize the controllers, servers and console computers. It keep their internal clocks synchronized to a uniform reference time.
- Local YUM (Yellow dog Updater, Modified) Service: used to install or upgrade the software packages, which downloads all the packages from the mirror sites by the rsync utility.

In addition to the above, other services are boot service, web service, data backup service, software version control services, syslog service and so on.

The IOCs (Input Output Controllers) are the essential components of the control system. All the interfaces to hardware devices are through the IOCs. The summary data of the IOCs are listed in Table 1. For the SXFEL-TF, the total amount of PVs (Process Variable) is about 108K. For the DCLS, the total amount is about 58K. The most IOCs were built with the existing records and device support modules. The streamDevice is used for the devices with serial communication interfaces, including RS-232, RS-485, TCP/IP, etc. The netDev is used for communicating with Omron PLCs, s7nodave for Siemens S7 PLC. The custom IOCs are based on asynDriver, which is a general purpose facility for interfacing device specific code to low level communication drivers.

Table 1: IOC Summary of SXFEL-TF and DCLS

System	IOCs SXFEL-TF	PVs SXFEL-TF	IOCs DCLS	PVs DCLS
Power Supply	30	18K	12	7K
Vacuum	13	8K	6	3K
Modulator	5	3K	2	1K
UD,SFT,BBA	8	4K	4	2K
B/Chicane Movers				
BI/MW Movers	7	3K	3	2K
LLRF	7	2K	2	1K
BPM	48	4K	19	2K
ICT	3	1K	1	1K
CCD	7	60K	3	37K
Timing	3	3K	1	1K
MPS	7	2K	2	1K
Total	142	108K	54	58K

DEVICE CONTROL

Power Supply, Vacuum, Modulator, etc.

In the SXFEL-TF and DCLS, two types of device controllers are mostly used: PLCs (programmable logic controller) and intelligent local controllers. The PLCs implement complex control logic for the modulators, undulator motions, Q-magnetic movers of the beam-based alignment system, machine protection system, etc. The intelligent local controllers include the digital power supply controllers, vacuum gauge controllers, ion pump controllers, digital pulse generators, etc. These devices controllers connect to the IOCs via communication buses or Ethernet.

To facilitate the system management and maintenance, the unified software and hardware platforms are considered. The IOCs hardware must be COTS (Commercial Off-The-Shelf) products with the features of high performance and cost effective. Several possible hardware standards could be candidates, such as VME, compact PCI and industrial computers. The fanless embedded controllers DA-66x series from MOXA are selected as the IOC standards, which is shown in Figure 3. The controllers have 8 to 16 RS232/485 serial ports and 4 Ethernet ports. The IOCs run the unified software. Besides the streamDevice, netDev and s7nodave, the autosave and procServ modules are used as the standard configuration.

Figure 3: The embedded controllers DA-66x series.

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA058

Take the power supply control system for example. The digital power supply controllers embedded in the power supply crate. They connect to the IOCs via the dedicated network switch, as shown in Figure 4.

Figure 4: The power supply control system of DCLS.

LLRF

The low level RF (LLRF) control system is based on the MicroTCA.4 platform. The SIS8300-L digitizer cards from Struck Innovative Systeme are used, which have 10 Channels 125 MS/s 16-bit ADC, Virtex 6 FPGA and fast feedback DACs. The algorithms are designed and implemented, including IQ modulation, digital PI regulator, digital phase shifter, digital FIR filter, etc. The control panel is shown in Figure 5.

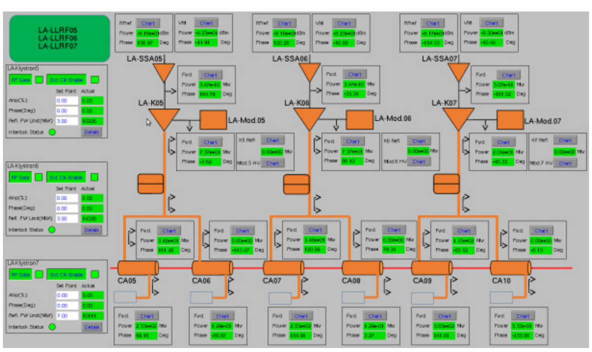

Figure 5: The LLRF control panel of SXFEL-TF.

Microcontroller

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 [3].

The BeagleBone Black boards were embedded in some 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 cameras and step-servo motors remotely.

DATA ACQUISITION

The data acquisition is mainly responsible for the image acquisition for beam profile measurement and laser diagnostics system and general LXI (LAN eXtensions for Instrumentation) devices.

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-TF and DCLS, the GigE Vision cameras are adopted, which can simplify the system architecture. A dedicated network is employed to transmit the images to the servers. The software is based on the areaDetector and aravisGigE modules. The image processing contains image rotations, flips, ROI (Region of Interest), profiles, etc. The panel of beam profile measurement is shown in Figure 6.

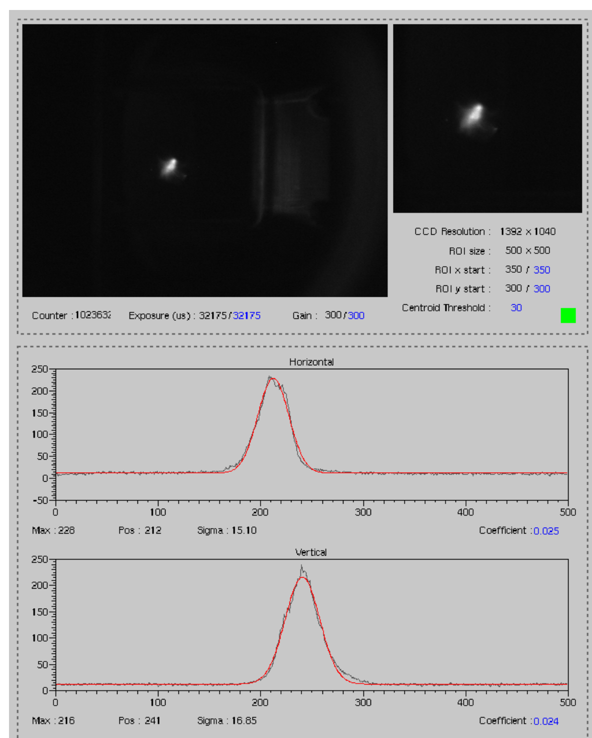

Figure 6: Beam profile measurement of SXFEL-TF.

The digital oscilloscopes are used for the data acquisition of beam charge measurement, which are LXI 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 was developed base on the asynDriver and VISA (Virtual Instrument Software Architecture). The data rate can reach 20Hz for 4 Channels 50K waveform.

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA058

NETWORK

The network is the important infrastructure for the distributed control system. The performance and reliability is critical. The Ethernet is used as the backbone of control network, as shown in Figure 7. Most of hardware devices connect to 1 Gbit access layer switches. The access layer switches have two connections to separate 10 Gbit core switches, which is designed to ensure the reliability. The VLAN (Virtual Local Area Network) will be adopted, which divides the network into multiple subnets.

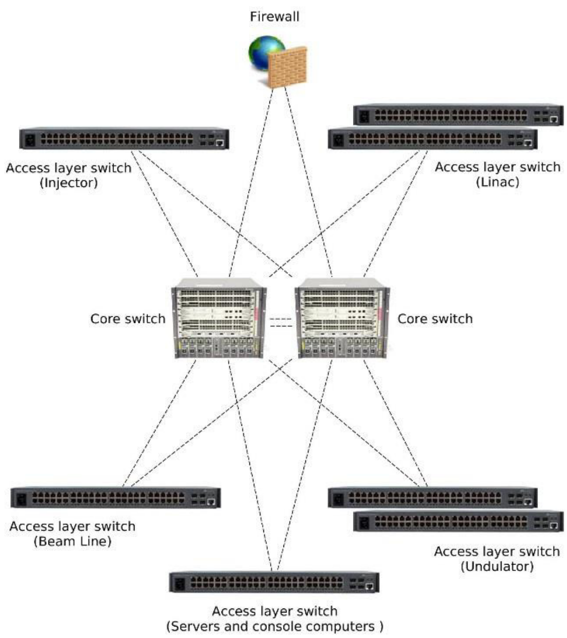

Figure 7: Control network architecture of SXFEL-TF.

OPI

The OPI (OPerator Interface) offers graphical user interface (GUI), command line interface (CLI) and high-level application programming interface (API) to operators, engineers and physicists. It allows them to interact with the machine components.

In the SXFEL-TF and DCLS, the EDM (Extensible Display Manager) is used as the default user interface. The integrated framework is designed and implemented, as shown in Figure 8.

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 access the historic data using the CSS Data Browser. The alarm system is implemented, which collects and summarizes all kinds of fault information. It can help the operators take the correct action at the correct time.

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

Figure 8: Control system user interface of SXFEL-TF.

TIMING

In the SXFEL-TF and DCLS, the dedicated femtosecond synchronization system is used for ultra-stable and ultra-low phase noise reference signal distribution for the critical systems. The timing system provides optical and electrical trigger signals to the accelerator equipment, including photocathode injector, laser, modulators, beam and laser diagnostic system. The cost-effective solution based on the high precision pulse and digital delay generators is selected, as shown in Figure 9 and 10, which meet the demands completely.

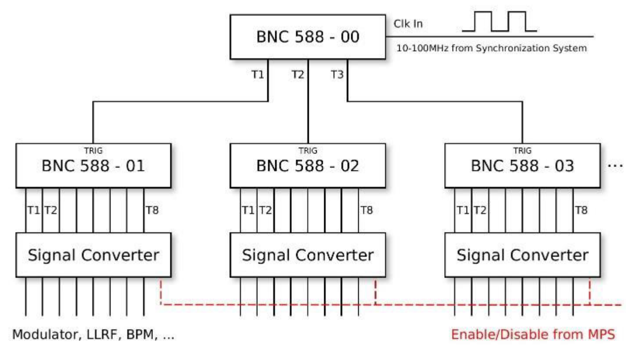

Figure 9: The schematic diagram of timing system.

The BNC 588 precision pulse and digital delay generator is chosen to build the global timing system, which has 8 output channels and offers 250ps delay and width resolution and 50ps internal jitter. It gets the reference clock from the synchronization system and generates pulse triggers to the accelerator equipment. The timing system is integrated in the whole control system. All pulse generators are connected to the IOC via Ethernet. The delay of each channel can be programmed by the clients.

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA058

Figure 10: Timing system of SXFEL-TF.

MACHINE PROTECTION

The Machine Protection System (MPS) is designed to protect the important machine components from damage when serious abnormal situations occur. The system must be robust and reliable. It receives the interlock signals from the hardware devices, performs the protection operations and reports the status to the operator interface layer. Take the vacuum system for example, the pressure in the vacuum chamber is continuously monitored via vacuum gauges and ion pump current. The vacuum valves are controlled by the machine protection system. An interlock action will close the proper isolation valves and stop the beam in case of anomalous pressure rises.

The system is based on Omron PLCs and adopts the hierarchical structure. It consists of one master station and several local sub-stations, as shown in Figures 11 and 12. The master station receives and summarizes the signals from sub-stations. The sub-stations control the executive devices, such as the vacuum valve and so on. The functions of operation modes management are employed in the system.

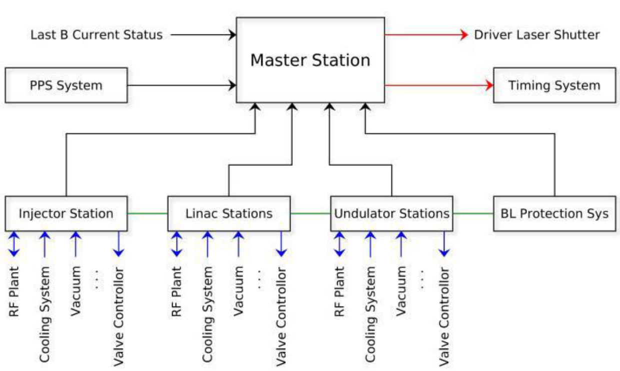

Figure 11: The schematic diagram of MPS.

Figure 12: Machine protection station of SXFEL-TF.

CONCLUSION

The control systems of the SXFEL-TF and DCLS have been designed and developed. Up to now, the systems have operated steadily for almost 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 in the future.

ACKNOWLEDGEMENT

We would like to thank everyone who contributed to this work through discussions and suggestions.

REFERENCES

[1] Z. T. Zhao *et al.*, "Status of the SXFEL Facility", *Applied Sciences*, 7(6), 607, June 2017.

[2] EPICS, http:// www.aps.anl.gov/epics/index.php

[3] Y.B. Yan, Y.B. Leng, *et al.*, "Application of Embedded Linux Boards in SSRF and SXFEL Control System", in *Proc. 7th International Particle Accelerator Conference. (IPAC'16)*, Busan, Korea, May 2016.

[4] PyEpics3, http:// cars9.uchicago.edu/software/python/pyepics3

[5] Cothread, http:// cothread.readthedocs.io

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA058