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THE PROGRESS AND STATUS OF HEPS BEAMLINE CONTROL SYSTEM*

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Abstract

HEPS (High Energy Photon Source) will be the first high-energy (6 GeV) synchrotron radiation light source in China, which is mainly composed of accelerator, beamlines and end-stations. In the phase I, "14+1" beamlines and corresponding experimental stations will be constructed. The beamline control system has completed the design of the control system scheme based on the EPICS framework. And it will soon enter the stage of engineering construction and united commissioning. Here, the progress and status of beamline control system are presented.

INTRODUCTION

The High Energy Photon Source (HEPS) [1], which is a high energy kilometre-scale ring-based light source with a double-bend achromat (DBA) design, is the first high energy diffraction-limited storage ring (DLSR) light source under construction in China (Fig. 1).

Figure 1: A bird's eye view of HEPS.

To satisfy some major demands of the nation and to further cutting edge scientific development, "14+1" beamlines and corresponding experimental stations will be constructed [2] (Fig. 2).

In order to simultaneously complete the construction of 15 beamlines control system on schedule, a set of standards is developed to design and build control systems for beamlines, minimizing heterogeneousness, to ensure that the control system has good stability, reliability, flexibility, availability, reliability etc.

Beamline control system of HEPS is designed and developed, based on the EPICS framework. This paper presents the progress and status of HEPS beamline control system.

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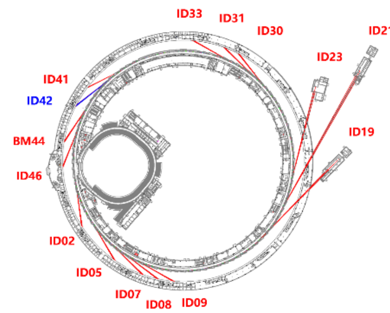

Figure 2: Beamlines layout in HEPS Phase I.

CURRENT STATUS OF BEAMLINE CONTROL SYSTEMS

Beamline control system of HEPS is designed and developed, based on the EPICS [3] framework (Fig. 3).

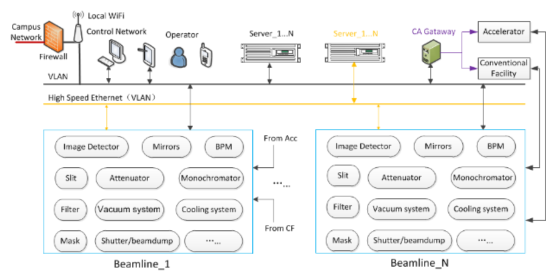

Figure 3: Overall structure of beamline control system.

This paper presents the progress and status of HEPS beamline control system.

Automated Deployment of the Software

Each beamline has many front-end controllers that need to deploy OS (operating system) and EPICS applications, so it is necessary to design and build a software deployment system to complete the above tasks.

In the process of HEPS beamline control system construction, there are multiple controllers (terminal PC, IPC, workstation and server, etc.) need to configure the OS, if only rely on access to the traditional installation media on such as CD/DVD-ROM or USB driver, etc., the workload is large and inefficient, and the distribution of the OS is not easy to manage, therefore, a set of parallelized batch deployment of OS schemes is required.

PXE (Pre-boot Execution Environment) is technology created by Intel Corporation, which allows automated provisioning OS of servers or workstations over a network [4]. It works in Client/Server mode, where the client controller downloads the OS image from the server over the network to implement the deployment of the client'OS (Fig. 4).

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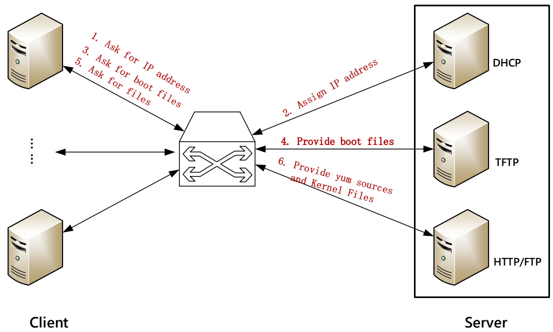


Figure 4: PXE deployment operating system.

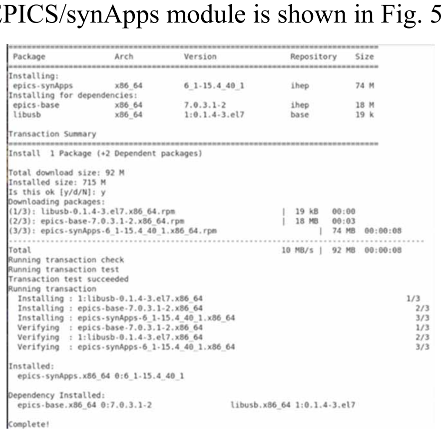
EPICS is an open-source software, which is widely used worldwide to create distributed soft real-time control systems. It has also a large collaborative and active community. EPICS and its application components are designed and developed modularly.

In order to improve software reusability and take advantage of the ease of OS package management, EPICS BASE, synApps and other software components are configured as yum sources, so that developers can easily build their beamline control systems in a short period of time. Table1 shows different distribution of the Linux operating system and their package tools.

Table 1: Linux Distribution and Package Tools

OS	Format	Tools
Debian	.deb	apt, apt-cache, apt-get, dpkg
Ubuntu	.deb	apt, apt-cache, apt-get, dpkg
CentOS	.rpm	yum
Rocky	.rpm	yum
Fedora	.rpm	dnf
FreeBSD	.txz	make,pkg

The HEPS beamline control system will use the CentOS/Rocky Linux with file format of ".rpm" and a package management tool of "yum". The yum source of EPICS BASE and synApps has been established in the laboratory, and as the project progresses, other EPICS component modules are continuously put into the yum source depository for management. The package configuration process for the EPICS/synApps module is shown in Fig. 5.



```
================================================================================
 Package              Arch          Version                Repository    Size
================================================================================
Installing:
 epics-synApps        x86_64        6_1-15.4_40_1          ihep          74 M
Installing for dependencies:
 epics-base           x86_64        7.0.3.1-2              ihep          18 M
 libusb               x86_64        1:0.1.4-3.el7          base          19 k

Transaction Summary
================================================================================
Install  1 Package (+2 Dependent packages)

Total download size: 92 M
Installed size: 715 M
Is this ok [y/d/N]: y
Downloading packages:
(1/3): libusb-0.1.4-3.el7.x86_64.rpm                      |  19 kB   00:00
(2/3): epics-base-7.0.3.1-2.x86_64.rpm                    |  18 MB   00:03
(3/3): epics-synApps-6_1-15.4_40_1.x86_64.rpm                   |  74 MB  00:00:08
--------------------------------------------------------------------------------
Total                                                10 MB/s |  92 MB  00:00:08
Running transaction check
Running transaction test
Transaction test succeeded
Running transaction
  Installing : 1:libusb-0.1.4-3.el7.x86_64                                  1/3
  Installing : epics-base-7.0.3.1-2.x86_64                                   2/3
  Installing : epics-synApps-6_1-15.4_40_1.x86_64                            3/3
  Verifying  : epics-base-7.0.3.1-2.x86_64                                   1/3
  Verifying  : 1:libusb-0.1.4-3.el7.x86_64                                   2/3
  Verifying  : epics-synApps-6_1-15.4_40_1.x86_64                            3/3

Installed:
  epics-synApps.x86_64 0:6_1-15.4_40_1

Dependency Installed:
  epics-base.x86_64 0:7.0.3.1-2                libusb.x86_64 1:0.1.4-3.el7

Complete!
```

Figure 5: Installation process of the synApps module.

Standardization of Stepper Motion Control System

The motion control system is the most important subsystem of the HEPS beamline control system. The task of the motion control system is to manipulate the mechanical devices such as monochromators, mirrors and slits, to alter the properties of the X-ray, which satisfies the end-station users.

The general motion control system consists of the computing unit (CU), the motion controller (MC), the motion drive (MD), the motor and controlled mechanical devices (Fig. 6).

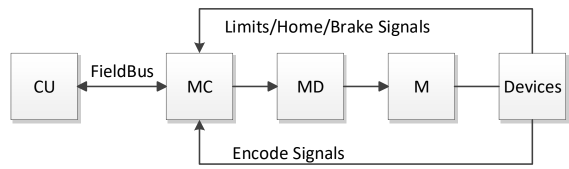


Figure 6: The component of motion control system.

According to statistics, there are more than a thousand motorized actuators used in beamlines of HEPS Phase I, and the types of motors are stepper motors, servo motors, piezoelectric motors, etc. In fact, more than 90% are stepper motors, which include two-phase and five-phase motors.

In most synchrotron facilities worldwide, they have their own standardized stepper motion control systems [5], either commercialized or in-house developed, which optimizes ease of deployment, with a compromise between performance, functionality, and cost.

The HESP stepper motion control system (SMCS) is composed of a rack with power supply, the motion controller (SPiiPlus EC), pulse-direction-encode interface module (PDIcl), and driver boards. Up to 8 racks can be linked together via EtherCAT， to control a total of 64 motors. SPiiPlus EC and PDIcl are commercial products from ACS Motion Control company [6].

According to different scenarios, two kinds of motion control crate are designed and integrated, which are 4-axes with motion controller (Fig. 7) and 8-axes without motion controller (Fig. 8).

Figure 7: 4-axes motion control crate.

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Figure 8: 8-axes motion control crate.

Based on FPGA, SPiiPlus EC is capable of implementing complex motions, such as the trajectory planning and event trigger in its buffers (Fig. 9).

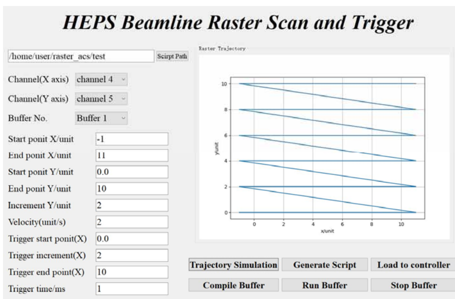

Figure 9: The trajectory planning in the buffer.

SPiiPlus EC is a multi-threaded programmable controller, which can be controlled by multiple hosts or IOCs simultaneously via physical connection. There are two communication protocols or interfaces between the IOC and the SPiiPlus EC controller. One is ACSPL+ command sets, and the other is SDK (ACS.service).

As a middle layer, ACS.service is responsible for the scheduling and exchanging data between IOC and SPiiPlus EC controller. Motor_IOC implements basic motion functions through ACSPL+ command sets, and complex movements are done in buffers by calling SDKs (Fig. 10).

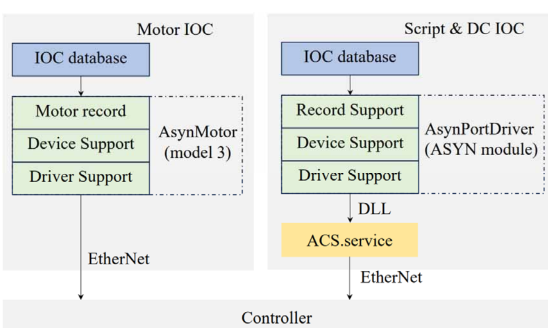

Figure 10: The software framework of SMCS.

Motion Control Instances of Core Components

As the HEPS project progressed, many beamline core components arrived for laboratory testing. At the same time, the control system develops its control application.

A monochromator is an optical dispersing device that is used to select a narrow band of light from a wider range of wavelengths available at the input. And A double crystal monochromator system typically deflects the beam. To change the monochromator energy in fixed energy steps, nonlinear movement is required by the monochromator motors between each step. Here (Fig. 11) is an application example of BE DCM (BE beamline: Transmission X-ray Microscope Beamline), based on the EPICS/Optics module [7].

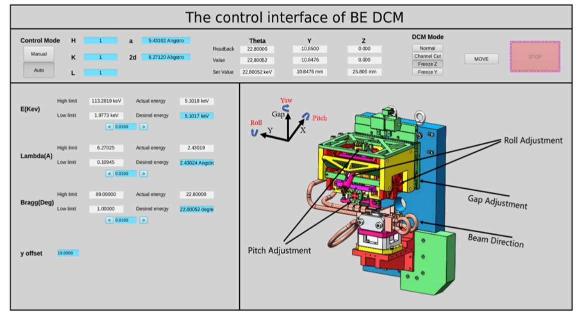

Figure 11: OPI of BE DCM.

A compound refractive lens (CRLs) is a commonly used X-ray optical component for photon beam conditioning and focusing on the beamlines of the synchrotron radiation facility. A transfocator is an array of CRLs that can be plugged in and out of the x-ray beam to change the overall focal distance. When the focus distance of x-ray beam is adjusted through the CRLs transfocator, it needs to be reconfigured to place a different CRLs combination in the beam path (Fig. 12).

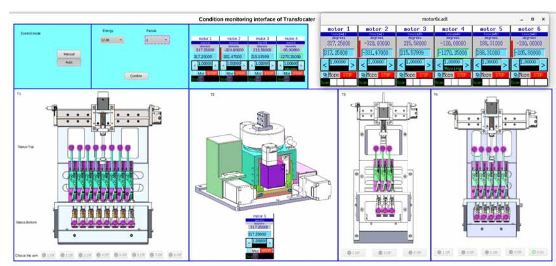

Figure 12: The OPI of CRLs transfocator.

In addition to stepper and servo controllers, there are also devices that are driven by the piezo motor. Here is a list of piezo motors such as SmarAct, Attocube, PI, PiezoJena and so on. We have developed an EPICS driver for Jena nano-positioning stage and implemented the function of any waveform (Sine/rectangle/triangle), whose parameters, such as the amplitude, frequency, number of signal points, can be set (Fig. 13).

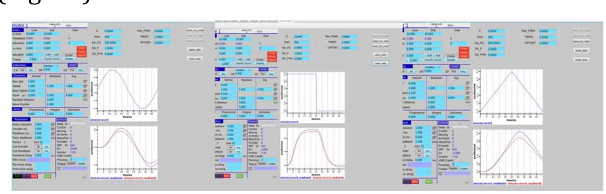

Figure 13: The OPI of Jena nano-positioning stage.

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XBPM Measurement

XBPMs are very useful for beam position measurement and stability observation in beamline. Although there are several kinds of XBPM sensors, such as wire-scan, blade-type, thin-diamond and so on, only an electronics measurement system is required to convert the weak current signal into beam position information. The commercial XBPM electronics measurement instrument—LiberaPhoton [8] is chosen and satisfies above requirements. It is an embedded device with EPICS interface, so it could be integrated into control system seamlessly. The in-house prototype of XBPM electronics measurement unit with 8-channel has been developed and its EPICS driver is being developed simultaneously.

Detector

The detectors are the most important instruments of the HEPS experiment end-station. Various detectors are used in experimental end-stations, including area detectors, spectroscopic detectors, point detectors, scintillator and visible light detectors, etc. Most detectors are Commercial-off-the-Shelf and EPICS/synApps provides the IOC examples and drivers of above detectors.

Due to the experimental needs of the experiment end-station, the IOC and driver of Dhyana 6K*6K detector and in-house developed APD detector have been written respectively (Fig. 14). HIKROBOT's industrial camera will be used for recording fluorescent targets, which is also supported by ADGenICam module of areaDetector.

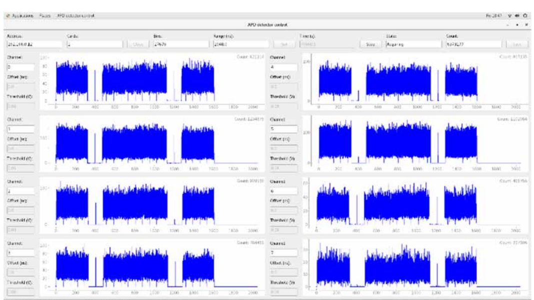

Figure 14: OPI of in-house APD detector.

Fly-scan Experimental Test

Point-by-point area scanning technology has become a very popular technology for synchrotron radiation facilities along with an ultra-high spatial resolution for the beam, which allows users to resolve the elemental composition, content, and structure, etc. of samples.

The fly-scan experimental system triggers the multi-axis motion sample stage and data acquisition of the detector simultaneously, so as to coordinate data collection under conditions of accurate time and position. The fly-scan system can thus improve the efficiency of area scan mapping and minimize the influence of factors such as instability and irradiation damage.

A fly-scan experiment on standard samples (Cu grids) was successfully conducted by HEPS beamline control system in cooperation with the Beijing Synchrotron Radiation Facility (BSRF) 4W1B end-station on Apr. 2022 (Fig. 15). The experimental results show that fly-scan experimental system helped reduce the scan time at the BSRF/4W1B end-station from hours to minutes per sample.

In one word, beamline end-station will provide users with more efficient measurement, with such a fly-scan approach.

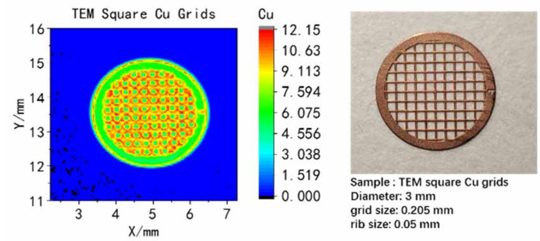

Figure 15: Cu grids 2D mapping image in fly-scan.

Information Issue

With the development of intelligence and mobility, the information of HEPS accelerator and beamline end-station is released and displayed through smart devices, such as smartphones and iPads, to get the status of the synchrotron radiation facility anytime, anywhere. Also, the WeChat [9] is the most popular and free instant messenger in China.

There are two types of information released through WeChat (Fig. 16), one is static information such as an introduction of end-station, experimental time allocation, duty shift, etc., and the other is the real-time status of the beamlines and end-stations.

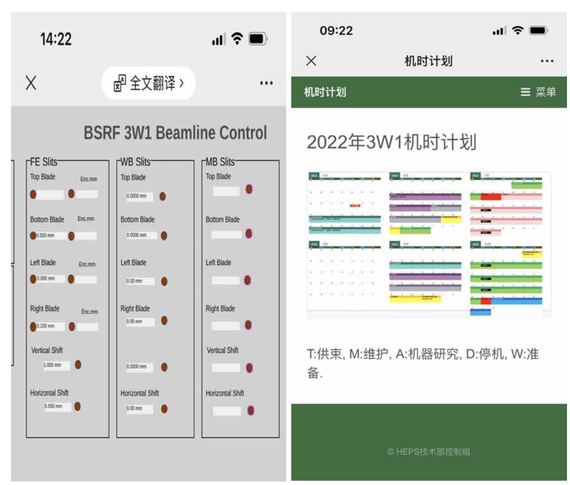

Figure 16: The information issue in WeChat.

CONCLUSION

The HEPS will be the first high-energy light source in China. Up to now, the HEPS booster ring is commissioning. At the same time, the various equipment is being installed at storage ring and beamlines. The control group team is responsible for the simultaneous construction of the control system of 15 beamlines and end-stations, which will all be put into trial operation by the end of 2025.

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