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HEPS CONTROLS STATUS UPDATE*

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Abstract

The High Energy Photon Source (HEPS) is a planned extremely low emittance synchrotron radiation based light source located in suburban Beijing which requires high precession control systems for both accelerator and beamline controls. This paper outlines the overall design for control systems, including equipment control, fast orbit feedback, machine protection, controls network, database, high-level application architecture, and physics applications. Early plans for beamline controls are also reported.

INTRODUCTION

An ultra-low emittance and high brightness 4th generation synchrotron light source, the High Energy Photon Source (HEPS) designed by the Institute of High Energy Physics (IHEP), will start its construction by the end of 2018. To reach the high goals listed in Table 1, especially a scale of the order of about 2500 magnets and similar number of diagnostic devices, it is necessary to have accurate installation, state-of-art equipment and high precision controls with intelligence. Therefore, the control systems are vital for the HEPS which includes not only traditional control architecture design but also quality control for the project. Also, the HEPS control system covers not only the accelerator but also the first 14 beamlines which will be constructed at the same time. To build such a complex accelerator based user-facility, it is necessary to have an overall complete design for the control systems.

The HEPS control system design and test environment setup progress which includes database work, and accelerator and beamline controls, as well as the quality control tools being developed at this early stage of the project will be described in this paper.

Table 1: HEPS Main Parameters

Main parameters	Value	Unit
Beam energy	6	GeV
Circumference	1360	m
Emittance	58 (<40 anti-bend)	pm·rad
Beam current	200	mA
Brightness	>10^{22}	Phs/s/mm^2/mrad^2/0.1%BW
Injection	Top-up	
Bunch structure	680 bunch, high brightness mode 63 bunch, timing mode	

DATABASE WORK

In the modern data era, it is essential to record every useful data and store the data systematically in persistent stores. Furthermore, applications to utilize the data should be developed. Due to the large database work, it is necessary to divide the entire database into many nearly independent database modules and connect them via API (Application Programming Interface) or services. This way the database modules can be developed independently by many institutes and avoid the complexity of a single database. A few database modules can be merged via links of either device ID which is based on the role the device is played in an accelerator, or equipment ID which is merely a unique QR code or RFID.

Based on IRMIS [1], as listed in Table 2, there are 17 database modules identified. At this stage of the project, *i.e.* the design and early implementation phase, databases such as Parameter List, Naming Convention, and Magnet have been developed to suit the project's current needs. In addition, colleagues from another IHEP facility, the China Spallation Neutron Source (CSNS) is collaborating with the HEPS team to develop a Logbook and Issue Tracking database and application for CSNS's early operation need. Besides the 4 database modules currently under development, a few others like Accelerator Model/Lattice, Physics Data and Machine State, and Work Flow Control/Traveler have been developed by colleagues for other projects which can be migrated here easily. The rest of the database modules listed in Table 2 will be developed at later times while they are needed. HEPS select MySQL as the database primary tool. Details for the three under-developed databases are described below.

Table 2: Planned Database Work

Parameter List	Logbook and Issue Tracking	Cable
Naming Convention	Maintenance/Operation	Security
Magnet	Inventory	Alarm
Accelerator Model/Lattice	Survey and Alignment	Machine Protection/Interlock
Equipment and Configuration	Work Flow Control/Traveler	MPS Postmortem
Physics Data and Machine State	Document DB	

Design Parameter Database

This is a database which stores the essential HEPS parameters for keeping track of different design versions. The database schema was based on ESS design [2] with necessary modifications to fit HEPS own needs.

Naming Convention Database

For a large accelerator project like HEPS, everything has to be named according to strict rules or it is hard to manage the names. The HEPS Naming Convention database provides such a systematic tool for generating names automatically according to rules which will be applied to both accelerator and beamline experiment instruments.

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Magnet Database

There are about 2500 magnets in HEPS with many types. The Magnet database provides a whole magnet lifetime data storage throughout from design, manufacture, test, operation and maintenance phases. At present, the design for data tables of design and several test methods has completed.

ACCELERATOR CONTROL

HEPS accelerator controls is EPICS-based, distributed systems. The system design principles are applying industrial standards, global timing system for both accelerator and experiments, and modularized subsystems for easy upgrade and maintenance. The overall accelerator control system architecture is shown in Fig. 1 with Device, Middle, and Presentation layers. The Device layer provides the control interface, such as μTCA, PXI or PLC, to devices. The Middle layer performs data assembly and persistence, and online analysis computation. Details for some control system components are described below.

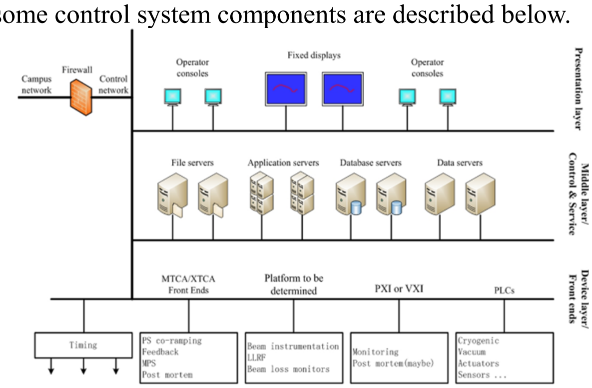

Figure 1: HEPS accelerator control system architecture.

Device Control

Presently HEPS selects the latest EPICS version 3 as the control system platform. The EPICS-based device control will choose mostly industrial standard with EPICS driver support. Besides fast communication networks for global timing system and fast machine protection system, the standard communication is through EPICS Channel Access (CA) protocol.

Fast Orbit Feedback

For the extremely low emittance requirement, a fast orbit feedback (FOFB) system is required to suppress orbit oscillations caused by ground vibration, magnet power supply ripple and other possible causes. The goal of FOFB is to reach 300 Hz – 1 kHz of bandwidth with 576 Beam Position Monitors (BPM) and 192 correctors in each transverse plane. As shown in Fig. 2, The BPMs and correctors are arranged to 16 nodes with each node as star topology, while the 16 nodes are connected in ring topology. The communication among the 16 nodes is bi-directional and through 10 Gigabit Global Links. For each node, the FOFB computation is done via Field-Programmable Gate Array (FPGA). Studies for better power supply response, computation algorithms are underway.

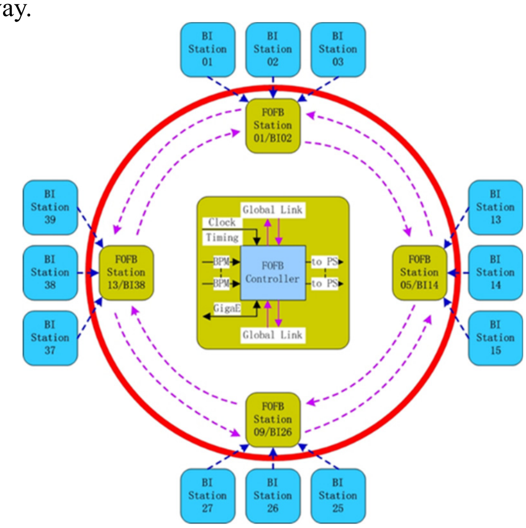

Figure 2: HEPS fast orbit feedback system architecture.

High-level Applications

As shown in Fig. 3, application flow can be divided into three layers: data, software API or services, and application GUI. For better software architecture and reusability, same functions appear in multiple applications should be converted to either regular callable APIs or service APIs in the middle layer. Furthermore, due to the nature of the functions, it is better to separate them in three groups so they don't mixed together and lose the flexibility: control system API, physics and general-purpose API, and machine learning API. The three API groups are also released independently as separate software packages. Details for these APIs will be described below.

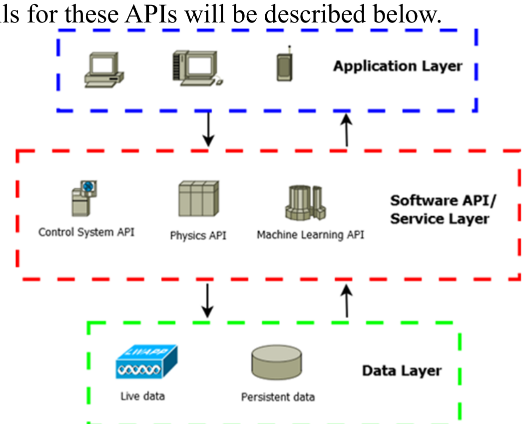

Figure 3: HEPS control system architecture.

Control System API

HEPS accelerator as well as optical beamline is based on EPICS control systems. APIs such as CA calls are packaged along with connection exceptions and operation loggings, so application developers do not have to go through tedious details. If there is any need for swapping with another control system, one can simply replace the EPICS wrapper with a different one. HEPS is considering CS-Studio API as the control system API platform.

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Physics and General-purpose API

Physics API provides physics specific functions such as online model calls, and general-purpose API supports certain operations like parameter scan or correlation plot. HEPS is considering a Java-based Open XAL [3] toolkit includes not only definitive accelerator data structure but also quite comprehensive functions for most accelerators. On the other hand, beamlines can have a similar platform(s) for their physics needs.

Machine Learning API

As the artificial intelligence (AI) and machine learning (ML) is gaining momentum in many fields, it is also attracting attention for accelerators and user-facility related Big Data research. A Machine Learning API platform has been developed for accelerators to ease the use of some popular ML APIs such as Scikit-Learn and TensorFlow. For instance, APIs for pre-processing raw data prior to applying the actual computation algorithms, and the computation result showing in visual form for easy read should be provided. All these can be done with simple APIs to cut development effort. With such a platform, physicists can use Python, a popular scripting language, to develop quick data analysis applications. One can switch among ML platforms as well as algorithms for easy tests. The ML API will also be responsible for converting data format to suit many popular Big Data platforms.

BEAMLINE CONTROLS

As shown in Fig. 4, HEPS beamline control system architecture is similar to the accelerator controls'. For better manpower resources sharing, the HEPS optical beamline control is also handled by many accelerator controls experts. Also, it is not practical to have each beamline possessing its own database experts and handle all computing needs, for example. Many tools and platforms built for the accelerator can also be shared by the beamlines. Standards like naming conventions and EPICS supported devices are also shared.

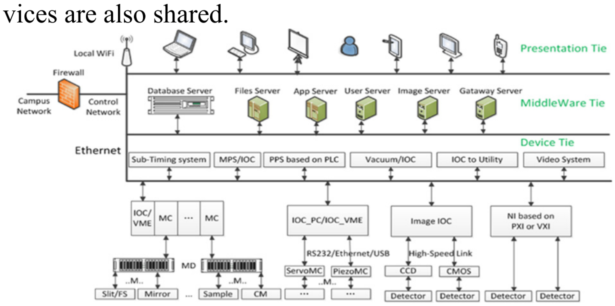

Figure 4: HEPS beamline control system architecture.

The beamline data may be much more structured than the accelerator data. Therefore, EPICS 7 which support complicated data structure is considered as the data protocol for packaging the beamline and experiment data. Still, the data structure has to be compatible for future mobile applications.

The data acquisition (DAQ) is considered along with the beamline controls. For the nature of fast DAQ and large amount experiment data storage requirements, online data reduction and analysis is essential for the beamlines. Standard data format should be chosen for compatibility with various data analysis tools and shareable among institutes.

PROJECT SUPPORT

To better integrate project data with technical data, HEPS business sector's procurement database and the Inventory database will be linked for better cost control and future operation maintenance utilization. The link between these two databases will be a unique equipment ID in the form of bar code, QR code, or RFID. Applications will be developed to take advantage of these joint databases. Other project databases include document server and personal folders may be on SharePoint platform, but still can be connected with MySQL databases with simple programming.

CONCLUSION

The HEPS control systems have been initially designed and a few tasks have been started. Modern technologies will be applied to the actual implementation. For the software shareable between accelerators and optical beamlines as well as experiment stations, collaborations are formed. Starting from project supports like databases and project management tools, the controls team is also design and development work in many areas. All the databases are saved in GitHub repository for easy collaboration access [4]. This overall modularized architecture design gives us the most flexibility and efficiency for development yet ensure high-quality and reliable products. Also, researches in new fields such as Big Data analysis have been started for such a future synchrotron light source.

ACKNOWLEDGEMENT

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