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UPGRADE AND MODERNIZATION OF CSNS ACCELERATOR CONTROL SYSTEM TOWARDS CSNS-II*

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Abstract

The CSNS-II project, launched on 1st January 2024, aims to significantly enhance the beam power from 100 kW to 500 kW. The current accelerator control system, commissioned in 2018, was designed based on hardware and software platforms finalized in 2012. Over time, these systems have begun to exhibit obsolescence issues. To meet the advanced requirements of CSNS-II, a comprehensive upgrade and modernization of the control system is essential. This presentation outlines the overall upgrade plan and design considerations for the control system. The key upgrades include: transitioning the EPICS framework from version 3 to the modern and feature-rich version 7, migrating the hardware platform from VME to MTCA, adopting the latest Phoebus as part of the Control System Studio suite, incorporating support for big data analytics and artificial intelligence capabilities to enhance system performance and diagnostics. These enhancements will ensure the control system meets the demanding operational requirements of CSNS-II while improving reliability, scalability, and future readiness.

BRIEF INTRODUCTION OF CSNS AND UPGRADE PROJECT CSNS-II

The China Spallation Neutron Source (CSNS) is designed and constructed by the Institute of High Energy Physics, Chinese Academy of Sciences. The construction of CSNS includes an 80-MeV Linac, a 1.6-GeV Rapid Cycling Synchrotron (RCS), two beam transport lines, a solid target station of 100 kW, three initial neutron instruments and other utility facilities[1].The CSNS-II's plan for future improvements to the existing accelerator complex aims to deliver a beam with a minimum power of 500 kW for the target station. The schematic layout of CSNS-II upgrade project is shown in Fig. 1

The CSNS-II Linac will utilize multiple 324 MHz pulsed double spoke cavities and 648 MHz elliptical 6-cell pulse-capable cavities to achieve a peak beam current of up to 40 mA within the energy range of 80–300 MeV. The double spoke cavity portion should accelerate from 80 MeV to 165 MeV using 20 cavities in 10 cryomodules. The elliptical cavity portion of the Linac should accelerate from 165 to 300 MeV using 24 elliptical dressed cavities in 8 cryomodules [2]. The schematic layout of upgraded Linac in CSNS-II is shown in Fig. 2.

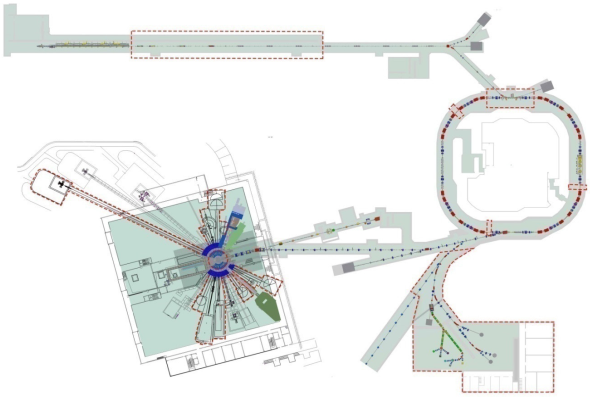

Figure 1: Schematic layout of CSNS-II.

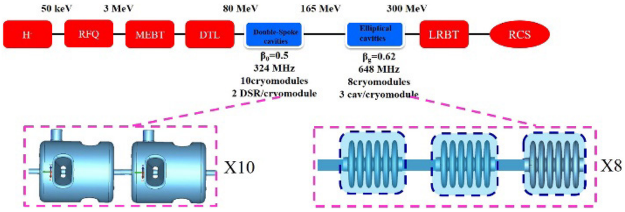

Figure 2: Schematic layout of CSNS-II Linac.

OVERALL DESIGN OF CSNS-II ACCELERATOR CONTROL SYSTEM

Main Tasks and Requirements of Control System

The primary task of the CSNS-II accelerator control system is to monitor, control, and protect the various equipment distributed along Linac, RCS and the beam transport lines. It provides a hardware and software platform for global control and information interaction, enabling operators, physicists, and system experts to stay informed in a timely manner and to monitor and operate the equipment remotely from the control room via human-machine interfaces (HMIs). Furthermore, the accelerator control system must provide global machine mode, operation mode, and beam operation management functions. Fig. 3 depicts the main functions of accelerator control system.

The main tasks required for the CSNS-II accelerator control system upgrading and modernization include the following aspects:

- Expand the timing subsystem and implement a globally high-precision synchronous timestamp based on the timing system.
- Optimize and update the machine protection system logic.

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- Establish new front-end control stations to achieve monitoring and control of newly added equipment.
- Enhance the performance of the control network.
- Expand the virtualization platform to improve data computing and storage capabilities.
- Design and establish a global accelerator fault analysis system.
- Design and develop database application and service software to enhance information capabilities

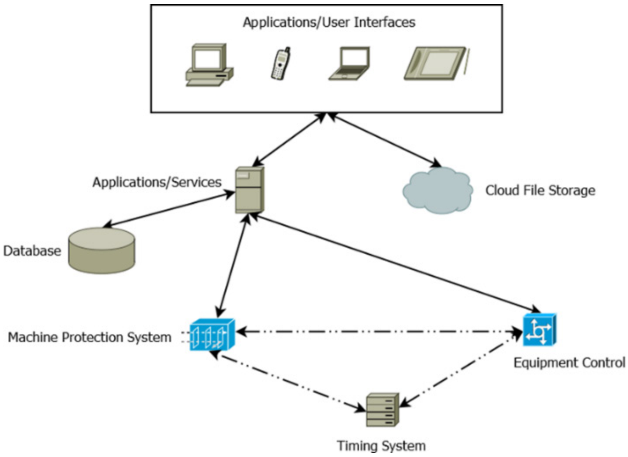

Figure 3: Functional diagram of CSNS-II accelerator control system.

Key Design Principles and Considerations

In developing the CSNS-II accelerator control system, a key consideration is to maintain the proven reliability, extensibility, sustainability of the existing EPICS-based architecture without introducing disruptive changes. However, issues related to hardware and software obsolescence must be systematically addressed, while keeping a close eye on advanced technologies for potential integration. Significant improvements are also required to upgrade the currently basic control room tools. Furthermore, the provision of big data and artificial intelligence resources should be considered to enhance system capabilities. A major challenge is that extended control system downtime is no longer feasible, necessitating that all upgrades be carefully phased in during scheduled outages.

The design of the CSNS-II accelerator control system should adhere to the following principles:

- Employ advanced, mature, and reliable technologies.
- Utilize standardized software and hardware, and maximize the use of commercial off-the-shelf (COTS) products to reduce costs.
- Consider potential system scalability and future expansion during the design phase.
- Prioritize domestically produced equipment to increase the localization rate of devices.
- Collaborate with other accelerator projects to enable sharing and joint use of certain technologies and achievements.

Overall Architecture of Control System

The overall architecture of the CSNS-II accelerator control system is shown in Fig. 4. It can be broadly divided into three layers: the presentation layer, the middle service layer, and the front-end control layer. According to the types of controlled equipment and functional task requirements, the CSNS-II accelerator control system is divided into multiple subsystems. These mainly include: the timing system, operation management system, PLC-based machine protection system, FPGA-based machine protection system, control network, virtualized server platform, database and service software, remote power supply control system, motion control system, ion source control system, SRF cavity interlock system, water cooling interlock system for normal-conducting cavities, vacuum control system and control rooms.

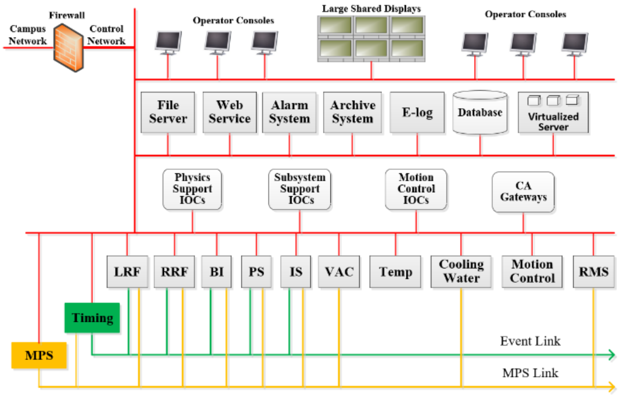

Figure 4: Overall architecture diagram of accelerator control system.

The main software and hardware selections for the CSNS-II accelerator control system are as follows:

- EPICS 7 [3]
- Debian
- synApps [4]
- Archiver appliance
- Phoebus
- VMware
- MicroTCA.4 platform
- Hyper-Converged Infrastructure

TIMING SYSTEM

The timing system is a global control system for the CSNS facility. The timing system provides triggers and clock signals to the facility-wide equipment, with strict timing relationships between these signals. The CSNS timing system adopts an advanced event-based digital timing architecture [5], which is currently widely used internationally. The event timing system primarily consists of an Event Generator (EVG), Event Receivers (EVRs), and event fan-out units. The EVG is connected to multiple EVRs in a multi-level star topology, using multimode optical fibers to transmit clock signals, trigger signals, and data information.

The CSNS-II timing system will continue to employ the event-based timing scheme. The overall design of the CSNS-II timing system is shown in Fig. 5. It consists of one master timing station and multiple subsidiary timing stations. The master timing station is responsible for generating and distributing distributed clocks and global event codes, while the subsidiary timing stations generate and output the final timing signals. Each subsidiary timing station responds to different event codes and outputs timing signals with independently adjustable pulse widths and delays. Depending on the signal reception method of the controlled equipment, these signals are transmitted via optical fibers, coaxial cables, or MicroTCA chassis backplane buses to the controlled devices.

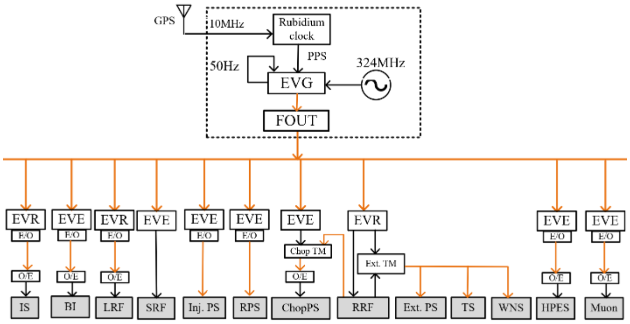

Figure 5: The diagram of timing system.

MACHINE PROTECTION SYSTEM

The CSNS-II machine protection system will continue to employ a combined approach utilizing a Fast Protection System (FPS) and a Normal Machine Protection System (NMPS). The FPS adopts an FPGA-based architecture, while the NMPS is implemented using a PLC-based solution. Input signals to the FPS primarily include signals from all beam loss monitors, as well as fault signals from the Linac RF systems and Linac magnet power supplies. Inputs to the NMPS mainly consist of personnel protection system signals, operation management system signals, vacuum valve interlock signals, and fault signals from RCS magnet power supplies and RF equipment. Fig. 6 illustrates the relationship diagram of the global safety interlock system for the CSNS-II facility.

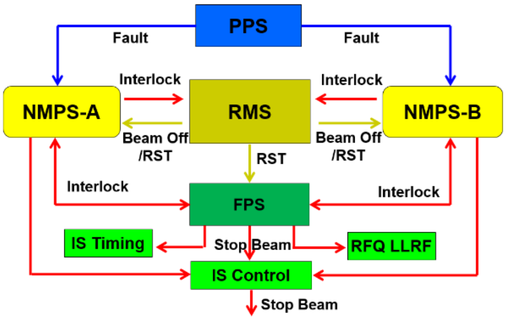

Figure 6: Overview of protection system interactions for CSNS-II.

FRONT-END CONTROLS

The CSNS-II accelerator features a large number of widely distributed devices, requiring integrated slow control or data acquisition at rates of 0.1–10 Hz. Given the high demands for control reliability and long-term stability, commercially available industrial-grade products such as PLCs, embedded industrial computers, serial port servers, and remote I/O modules are preferred for implementing the controllers.

The device-level control system architecture is illustrated in Fig. 7, which adopts a standard EPICS-based framework. Devices utilizing digital I/O and analog I/O—such as valves, vacuum gauges, and various vacuum pumps in the vacuum system—are controlled via PLCs. Equipment relying on serial communication protocols is first connected to serial port servers for protocol conversion. The EPICS IOC (Input/Output Controller) then communicates with these devices over TCP/IP to enable control and data acquisition. For devices equipped with native network interfaces, the IOC can communicate with them directly.

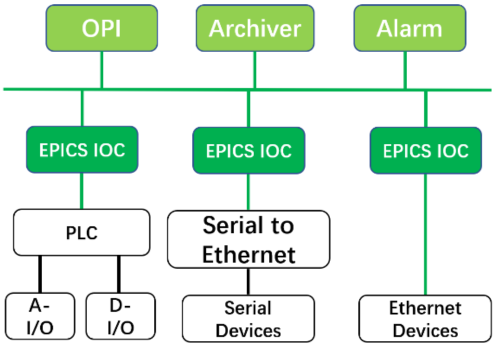

Figure 7: Diagram of front-end controls.

BEAM SYNCHRONOUS DATA ACQUISITION SYSTEM

The beam synchronous data acquisition system (BSDAQ) [6] is designed for the efficient storage and processing of data collected from hardware devices. The BSDAQ primarily collects data from beam instruments system and Linear Accelerator Radio Frequency (Linac RF) systems. The core architecture of BSDAQ comprises four key modules: the data assembly module, the data transmission module, the data processing and storage module, and the data access microservice module, as illustrated in Figure 8. These modules work in concert to ensure the accuracy and reliability of data collection.

BSDAQ employs a flexible global triggering mechanism that supports both periodic and random triggering, with the latter further categorized into manual triggering and fault triggering. This design enables the system to adapt to diverse operational requirements, ensuring stability and responsiveness under various scenarios.

The data collection process is carried out by the data assembly module, which is responsible for integrating data from hardware devices. The assembled data is then securely and efficiently transmitted via the data transmission module to Kafka, a distributed message queue system. The data processing and storage module performs hierarchical processing, including data formatting and stores the results in MongoDB databases and HDF5 files to improve data access efficiency. Finally, the data access microservice module provides a set of interfaces, which include RESTful (Representational State Transfer) APIs, allowing users to easily access and utilize the data

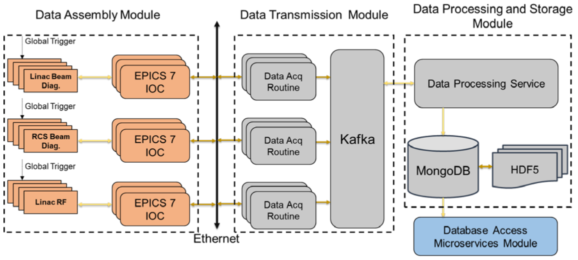

Figure 8: System overview of BSDAQ for accelerator.

WEB-BASED MONITORING SYSTEM FOR ACCELERATOR CONTROLS

During the construction, operation, and maintenance of the control system, a large amount of information is generated. Comprehensive utilization of this information can enhance the monitoring and fault diagnosis capabilities of the control system, thereby improving its maintainability and availability. To achieve this, an integrated information platform for accelerator control system monitoring is being developed. This platform will consolidate various types of control system-related information within a unified user interface.

The platform adopts a three-tier architecture, with the overall structure shown in Fig. 9. The bottom layer is the accelerator control layer based on the EPICS framework, comprising hundreds of IOCs from various accelerator systems and several PV Gateways. The middle layer is the service layer of the platform. Following a microservices architecture, software services in this layer operate independently and are interconnected via networks. The top layer is the presentation layer. To ensure compatibility across different operating systems, the user interface employs web technologies, allowing users to access the platform through a browser. The web interface uses a front-end and back-end separation architecture, leveraging REST API and WebSocket API to access data from the service layer.

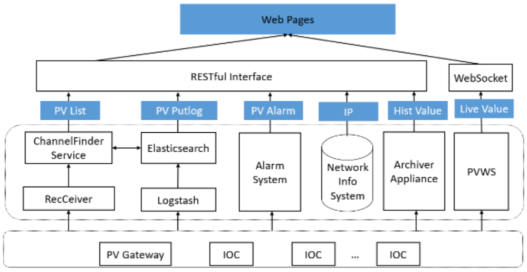

Figure 9: Diagram of web-based monitoring system for accelerator controls

CONCLUSION

The CSNS accelerator control system has been growing, evolving since original commissioning, some new technologies has been tested and put into operation. It is the time to modernize the control system towards CSNS-II requirements.

During the upgrade and renovation of the CSNS-II accelerator control system, the latest hardware and software solutions in the field of control will be adopted to maintain technological advancement and future scalability, while also providing data and application interfaces for future machine learning applications. The overall plan and software/hardware standards have already been established, and the entire upgrade is expected to be completed by 2029.

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