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DESIGN AND IMPLEMENTATION OF SUPERCONDUCTING BOOSTER CONTROL SYSTEM

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Abstract

In order to improve beam energy, a superconducting booster is built behind the tandem accelerator. The Control system is designed based on EPICS according to its functional needs. It gives a detailed description of hardware and software. The control system realizes data acquisition, network monitoring, Process variable (PV) management, database services, historical data analysis, alarm and other functions of remote device. The running result shows that the control system has fast response time and works stably and reliably, which meets the control requirement.

INTRODUCTION

Superconducting booster is a post-accelerator device of HI-13 tandem accelerator in CIAE. It is combined with tandem accelerator by bunching and chopping method to obtain higher beam energy. Such a combination of two devices enlarges the species of ions that exceed the coulomb barrier energy [1], which has scientific research value. The control system should not only keep the phase and amplitude of RF electric field in superconducting cavity stable, but also realize the functions of remote sequential switch, condition monitoring and interlocking protection for vacuum, cryogenic, radio frequency and motor subsystems. In addition, it should have good reliability and expansibility. Experimental Physics and Industrial Control System (EPICS) is a control system software tool for accelerators and other large-scale scientific experimental devices.It adopts server/client structure and has strong plasticity and expansibility. Since the 1990s, EPICS has been widely used in accelerator laboratories all over the world. Considering the requirements of upgrade project and the advantages of EPICS, the control system of booster is based on EPICS. All equipment control is integrated into EPICS system in order to save manpower and material resources, efficiently realize booster control and operation condition monitoring also.

SYSTEM STRUCTURE AND PRINCIPLE

Superconducting booster is located behind tandem accelerator for improving beam energy. In the physical design, a beam pulsing system, including traveling wave chopper and double drift buncher, is added at the front end of the tandem accelerator to improve the beam utilization and match the longitudinal acceptance of the booster. At the same time, a third stripper is installed before the beam of tandem accelerator injected into the superconducting boooster to improve the ionic charge state and make full use of the voltage gain of the superconducting cavity of the booster. In order to ensure that the beam has a sufficiently small envelope in the superconducting cavity, a new set of three-unit quadrupole lenses is installed at the front end of the booster. A set of phase stabilization system is installed to stabilize the phase of the pulse beam entering the amplifier. The structure of the superconducting booster is shown in Fig. 1. It is distributed at both ends of the tandem accelerator, which consists of XY guider, traveling wave chopper, double drift buncher, phase stabilization system, three-unit quadrupole lens, and auxiliary equipment such as radio frequency system, cryogenic system and vacuum system. According to the difference of beam energy, the front end of tandem accelerator is called low energy end, and the back end is called high energy end.

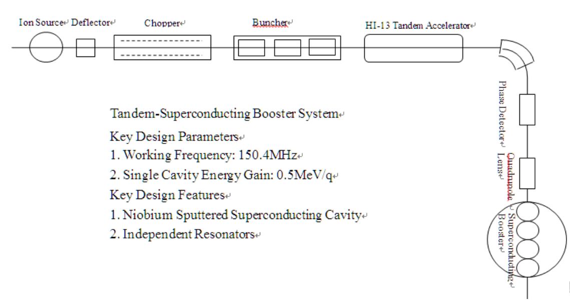

Figure 1: Systematic schematic diagram.

The basic principle of superconducting booster: the DC beam from ion source is cut into uniform pulsed beams by the transverse electric field generated by traveling wave chopper and modulated to 1ns pulse width by the longitudinal time-varying electric field generated by double drift buncher, then accelerated by tandem accelerator. When the phase of the pulse beam is synchronized with the phase of the high frequency electric field in the cavity, the particles are accelerated synchronously. When the pulsed beam enters the phase detector, it excites high frequency signal, which is used to adjust the phase of the pulsed system in the low energy band through the phase stabilization system, so that the phase of the pulsed beam which enters the booster is stable. The booster consists of four QWR (Quarter-Wave Resonator) copper-niobium sputtering superconducting cavities. The design index of the energy-increasing section is 2Mev/q.

HARDWARE DESIGN OF CONTROL SYSTEM

The equipment needed to be controlled in the pulsing system includes a set of frequency source to provide frequency and phase reference for superconducting booster and beam pulsation system; a set of chopper

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power supply to provide cutting pulse voltage sequence and compensation voltage to form synchronous cutting electric field with advancing ion beam; two sets of 6MHz/12MHz radio frequency controller and power amplifier lock the phase on the radio frequency (RF) reference and the amplitude on the pre-set value. These RF devices provide RS232 interface for parameter setting and status reading. MOXA serial server is used as IOC to communicate with these RF devices. It can connect up to 32 serial devices, which provides conditions for future system expansion.

The phase detector, the preamplifier and the phase controller at the high energy end constitute the phase stabilization loop system to implement pulse beam stabilization. The closed loop composed of the superconducting cavity, the RF controller and the power amplifier establishes a stable high frequency electric field to accelerate beam in the cavity. The control equipment includes a set of phase preamplifier, a set of phase controller, four sets of power amplifier, phase shifter and radio frequency controller. They are all equipped with RS232 interface. A MOXA serial server is used as IOC to communicate with these devices to realize remote monitoring and control of the operation state of superconducting cavity.

Superconducting booster has several motion control systems, which are responsible for the tuning and coupling of superconducting cavity. Motion module is used to drive Senchuang motor 86BYG350. Because the superconducting cavity works at 4.2K and is sensitive to working conditions, a cryostat system is equipped to provide a cryogenic environment, which requires real-time measurement and recording of temperature and pressure, force, vacuum, motor position and other parameters. The system uses a set of Yokogawa PLC module, CPU F3SP18 controls the operation of the equipment, and CPU F3RP61 acts as the embedded IOC to communicate with OPI.

XY guider and three-unit quadrupole lens are responsible for beam steering and focusing. The tuning and coupling of double drift buncher are realized by stepping motor. A set of PLC system is deployed at the low-energy end to monitor and control the reading and setting of equipment parameters.

The system provides a real-time beam energy measurement device, which consists of a vacuum chamber, a gold target and a gold-silicon surface barrier detector. The output signal of the detector is amplified by the preamplifier ORTEC 142B and enters the main amplifier ORTEC 572A. Then the particle number of each channel is recorded by the multi-channel counter AMPTEK MCA 8000D. It configures the Ethernet interface and transmits data to PC through the network. The data acquisition system on the PC processes the data to obtain the beam energy.

The superconducting booster control system is constructed based on EPICS framework, which realizes the control and condition monitoring of the above equipment. The overall structure of the system is shown in Figure 2.

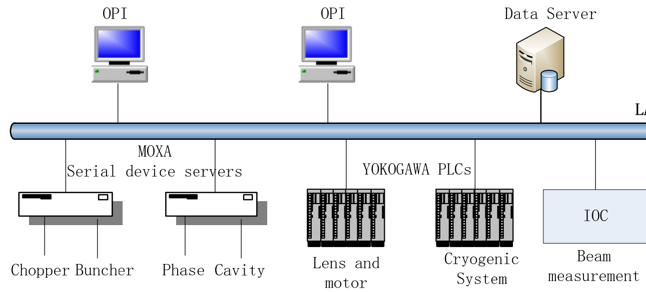

Figure 2: Structure of control system.

The hardware structure of the control system is divided into three layers: Operator Interface (OPI), Input/Output Controller (IOC) and Device Controller. OPI is set in the central control room and Windows operating system is installed. IOC is PLC real-time CPU module F3RP61, MOXA serial port server and PC respectively, in which serial port server is connected with radio frequency equipment of each system through RS232 interface. Yokogawa PLC is connected with cryogenic equipment and motor. The beam measurement system is connected PC IOC by LabVIEW-EPICS interface. The control system uses two IOC/MOXA serial servers, two IOC/PLC CPUs and one IOC/PC; two sets of PLCs are configured with Analogy Input (AI), Analogy Output (AO), Digital Input (DI), Digital Input (DO) and motion module to control high-energy and low-energy end equipment.

SOFTWARE DESIGN OF CONTROL SYSTEM

The sequential control CPU and embedded CPU F3RP61 module are installed on Yokogawa FA-M3 PLC board. EPICS control program including device driver, device support, record support and the creation of real-time database can be deployed on F3RP61 through cross-compiling. EPICS application program of host computer can be mounted and run in F3RP61 module in the form of network file by using minicom command or network. Then F3RP61 becomes embedded EPICS IOC [2]. The PLC program is edited in sequential control CPU, which read data from memory, execute instructions, and output results to I/O memory to control the operation of equipment. F3RP61 accesses internal relays, data registers and file registers of sequential control CPU periodically, and processes the input and output of I/O module and data transmitted by communication module. The software structure is shown in Figure 3.

The control interface of radio frequency equipment is mainly RS232 asynchronous communication mode with the same communication protocol format. The ASynDriver provided by EPICS ASYN software package can be used to connect the controlled device with the interface of the low-end driver layer, while the Stream

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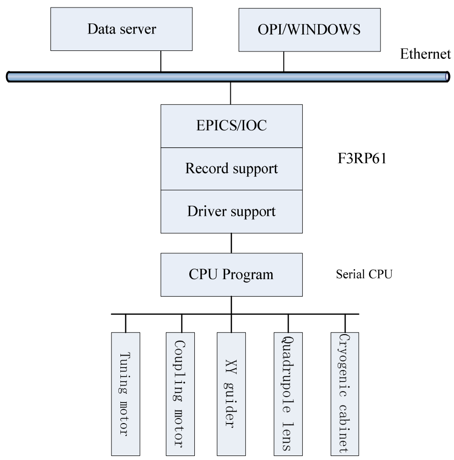

Figure 3: Device driver and IOC architecture.

Device module has a communication interface with the upper software device support module of the AsynDriver. Aiming at the asynchronous communication interface and character stream control mode of radio frequency equipment.EPICS software system is configured in DA682 and protocol file is written to define the communication protocol between radio frequency equipment and front-end IOC. The system transmits and receives string data based on StreamDevice module to realize remote control of front-end intelligent equipment [3-4]. The software structure of the RF system is shown in Figure 4.

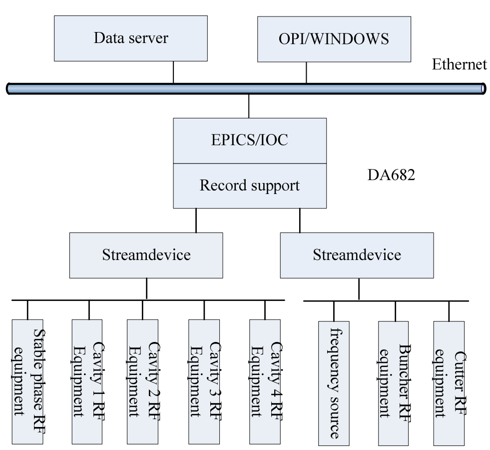

Figure 4: Software architecture of RF system.

OPI interface is developed with CSS (Control System Studio). We select plugin source according to need and export the regenerated CSS program [5-6] through Eclipse. It integrates the functions of monitoring interface display, PV volume management, database service, historical data analysis and alarm. The beam pulse interface developed under Windows operating system is shown in Figure 5.

The historical data of the control system is stored in MySQL database. The connection with local or remote database is set up through JDBC interface. Data Browser of CSS can view the historical data of multiple PV at the same time. The database also supports channel archiver binary data query.

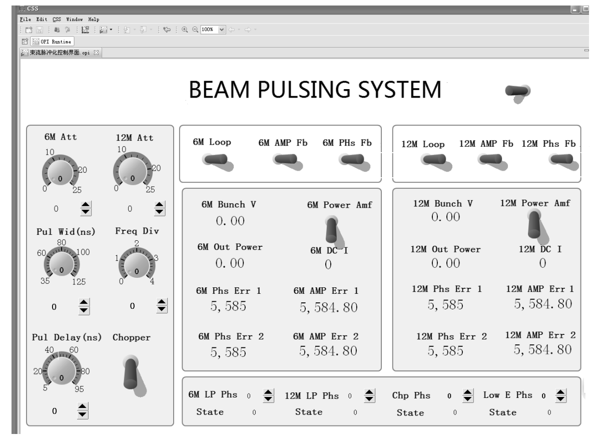

Figure 5: Control interface of beam pulsation system.

The alarm status of the control system is also stored in MySQL database. Operators can view alarm status, history alarm or change alarm configuration through the Alarm Tree and Alarm Table plug-ins of CSS.

CONCLUSION

The hardware of control system uses Yokogawa PLC and MOXA serial server as EPICS IOC to communicate with the controlled equipment according to the physical application of superconducting booster and the functional requirements of control system. The control system completes the functions of data acquisition, network monitoring, historical data storage, alarm and operation interface design of remote equipment, and realizes beam chopping, bunching and energy increasing. At present, the control system has been put into operation in 2016. The system runs steadily and reliably, which satisfies the actual needs of the tandem upgrading project.

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