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PLC BASED VACUUM CONTROL AND INTERLOCK SYSTEM OF THE CYCIAE-230 SUPERCONDUCTING CYCLOTRON BEAM LINE

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Abstract

In the CYCIAE-230 superconducting cyclotron beam line, a vacuum system capable of providing a pressure of about 5E-4 Pa is required for particle beam transport. In order to provide adequate interlocking to safeguard the vacuum environment and ensure the regular transmission of particles within the beam line, a vacuum control system based on programmable logic controller (PLC) has been developed and integrated into the accelerator monitoring system. The PLC not only interfaces with the quick-acting relay based on interlocking signals but also interfaces with the equipment based on Profibus communication to monitor and control various parameters in the vacuum system, such as pump speed, vacuum pressure reading, valve status, water cooling status, etc. This work presents the structure and interface logic necessary for communication with a series of valves, vacuum gauges, and molecular pump controllers. Also presented is an interface approach between vacuum control and the rest of the accelerator control system.

INTRODUCTION

The CYCIAE-230 superconducting cyclotron leads out a proton beam with high energy and low current intensity, which is transmitted to the irradiation terminal through the beam line system. Figure 1 shows the complete layout [1].

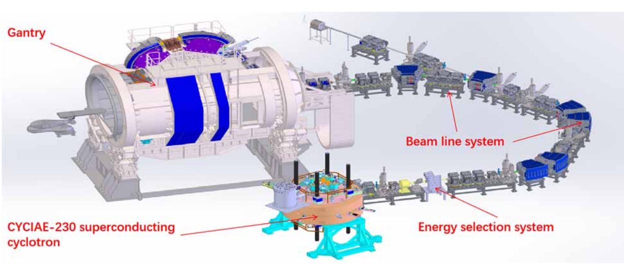

Figure 1: Layout of CYCIAE-230 and beam line.

Among them, the beam line control system is an essential part of proton therapy and is responsible for transmitting the proton beam with the energy needed for the therapy from the superconducting cyclotron to the therapeutic equipment. The general control equipment of the beam line includes: molecular pump power supply, mechanical pump, vacuum gauge, vacuum valve, water-cooled flowmeter, faraday cage, fluorescent target, etc. In this beam line control system, vacuum control and interlocking system is essential.

SYSTEM REQUIREMENT

The pneumatic system can control the opening and closing of the valves and correspondingly assist in the realization of the vacuum environment of the beamline. The water cooling system mainly ensures that the equipment, including molecular pumps, magnets, etc., works regularly at the appropriate temperature. In order to ensure the normal transmission of particles in the beamline, the vacuum system needs to provide a vacuum environment with a pressure of about 5E-4 Pa.

According to the design principle of obtaining an oil-free vacuum as much as possible and the requirement of vacuum degree, a molecular pump with a pumping speed of more than 300 L/s is selected as the vacuum obtaining equipment on the beam line, and a mechanical pump is equipped as the backing pump. Before starting the molecular pump, it is necessary to start the mechanical pump for vacuum pre-extraction, and the molecular pump can only be started when the vacuum is better than 1E-2 Pa. Figure 2 shows the layout of the beamline vacuum system.

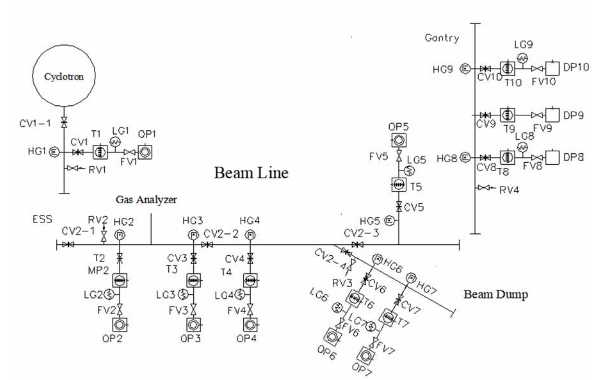

Figure 2: Layout of beam line vacuum system.

For machine protection and personal safety, it is necessary to design and add an interlocking system [2]. The vacuum interlock system will protect the vacuum gate valve to prevent it from accidentally closing during operation. At the same time, the interlocking system will also protect faraday cages, molecular pumps, magnets, and additional devices by monitoring temperature signals. If necessary, the beam line's vacuum interlocking system will notify the beam interlocking system to request that the beam be stopped to prevent additional operation [3].

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CONTROL SYSTEM

The PLC was used to develop the vacuum control and interlocking system for the beamline. The programmable logic controller (PLC) is chosen because it is more suitable for this task, especially because it can provide simple and economical solutions for logic control, process automation, and condition monitoring. At the same time, the familiar Siemens PLC is preferred for control. In addition, its standardized hardware and software components make it easy to assemble and program. Rapid controls for vacuum interlocks and machine safety are written in ladder logic for simplicity and speed [4].

In our controller, the Siemens series CPU 1516-3 is used, which is primarily used to realize equipment interlocking and running sequence control. Other modules used are the Siemens series distributed IO slave station IM155-6, the analog input module, and the digital input and output module. With the TIA system setup, the analog input module can choose an input range of 0~10 V voltage and 0~20 mA current. Figure 3 shows a ladder diagram of the vacuum degree calibration from the analog input module, which converts the voltages into digital vacuum values.

Figure 3: Ladder diagram of voltage to digital vacuum value.

For the control of the mechanical pumps, the main controller keeps the output at 24 volts, drives the contact wire package to close, and controls the remote control of the mechanical pump to open. The main controller outputs 0 volts, drives the contact to disconnect the wire package, and controls the mechanical pump to shut off.

For the control of the molecular pumps, the TC353 molecular pump controller is used in this beamline. Connect to the PLC via PROFIBUS, create the corresponding GSD file, and import it into Snep7 for configuration. The address of the corresponding molecular pump can be set through the dip switches on TC353. The molecular pump is then controlled remotely by TIA. Figure 4 shows the wiring diagram of the Siemens DP connector. Figure 5 shows the ladder diagram of the molecular pump control. Table 1 lists the definition of I/O data.

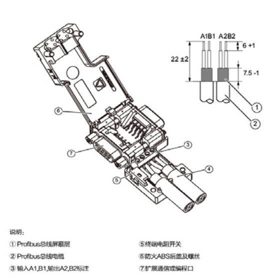

Figure 4: The wiring diagram of the Siemens DP connector.

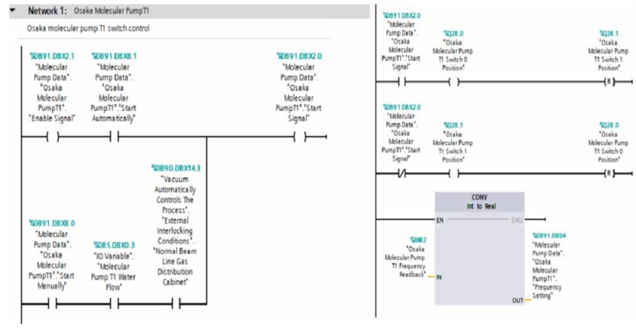

Figure 5: The ladder diagram of molecular pump control.

Table 1: I/O Data Definition

Name	Address	Length	Meaning
Status Byte		Byte Input	Length of data received in each communication
SDR	QB0	Byte Output	Control the start and stop of the equipment; when the output is 1, start the equipment; When it is 2, stop the equipment.
RSS	ID1	Byte Input	Status Word
RRS	PIW256-257	Word Input	Output frequency (rotational speed)

Due to the cost, stability, reliability, and ease of maintenance, the vacuum control and interlock system for this beamline was designed based on data communication between the CPU and distributed IO slave stations. The basic protocol for data transactions is called the Modbus protocol. It uses a query-response loop between the master and slave devices. The fundamental function codes are read from or written to a single or multiple register [5]. The protocol used on Ethernet is called Modbus TCP/IP. It basically inserts a Modbus frame into a TCP frame and sends it as a message. Packaging information can be found in the Modbus/TCP specification manual.

The basic control logic of the vacuum control and interlocking system is as follows: under the condition of ensuring the normal water-cooling and pneumatic state of the equipment, first close the vent valve, then close the gate valve of the beam line, and divide the beam line into four sections to extract vacuum. The mechanical pump and front valve are turned on for pre-pumping, and the molecular pump is turned on when 1E-2 Pa is reached for high vacuum pumping. Observe the number on the vacuum gauge, and when each section reaches the high vacuum state, open the gate valve of the beamline and complete the vacuum extraction. Figure 6 shows the block diagram of this control system.

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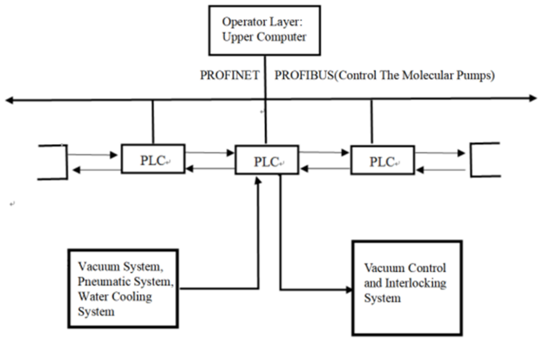

Figure 6: Control system block diagram.

This beam line water flow monitoring interlock system is monitored by piston pointer flow switches. This piston pointer type flow switch is equipped with a spring-supported piston. Based on the principle of magnetic induction, when the flow reaches a preset value, the mechanical structure triggers a magnetic switch to emit a switching signal for the on-off detection of the flow. Based on this working principle, the water flow signal can be converted into a digital signal, and the digital input signal module can be directly used to collect the water flow signal.

The main function of the PLC program is to call each functional module according to the actual work flow of the bench equipment. Figure 7 shows a flowchart of the PLC program.

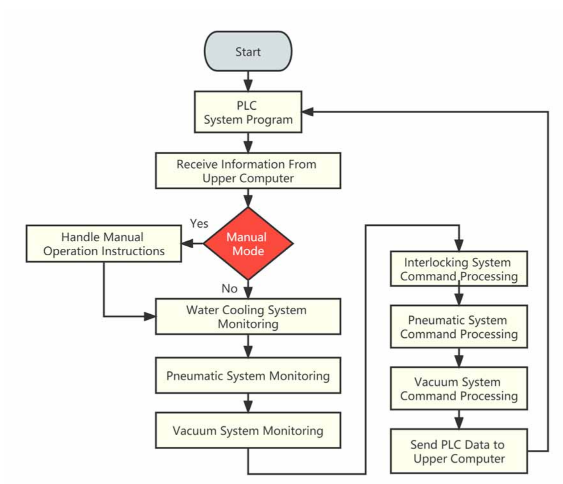

Figure 7: The flow chart of the PLC program.

The realization of the human-machine interface is based on the design pattern of the producer and consumer, and it is also designed for the CYCIAE-230 beam line control program.

Figure 8 shows the human-machine interface of the PLC based vacuum control and interlock system for the beamline. Figure 9 shows the interface of the vacuum gauge controller of the vacuum system, from which the vacuum state of this beamline can be seen. Among them, the input and output variables of digital quantities are mainly in a set state through a set cycle period. And the timer compares the timing delay of the operation code for each step with the condition of the next operation.

Figure 8: Human Machine Interface (HMI).

Figure 9: The interface of the vacuum gauge controller.

CONCLUSIONS

The vacuum control and interlock system of the beam line based on PLC has been successfully applied to the beam line of the CYCIAE-230 superconducting cyclotron and tested. The system can successfully operate valves, mechanical pumps, and molecular pumps and monitor the status of related equipment. Some vacuum interlocking operations are also being verified. At present, the beam line control system based on PLC is being further developed, which will make the beam line-related functions, including the beam diagnosis control system, more perfect and allow it to better adjust the proton beam from the accelerator to the treatment end.

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