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Personal Safety Interlock System Based on Siemens Safety PLC

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Abstract. The proton therapy system is currently one of the internationally recognized high-performance cutting-edge radiotherapy equipment. When the proton therapy system is running, secondary radiation and induced radiation such as gamma rays and neutron radiation will be generated during various stages such as beam generation, injection, acceleration, extraction, and transmission. Even after a period of time after shutdown, there will still be residual radiation fields, which pose a threat to the personal safety of on-site personnel. Therefore, it is crucial to design an effective personal safety chain system. This article designs and develops a personal safety interlock system for the cyclotron production and debugging room of the proton medical system production base of CGN Medical Technology (Mianyang) Co., Ltd. The personal safety interlock system uses Siemens safety PLC and safety programs to embed safety procedures into the operation and maintenance process of the cyclotron, achieving functions such as master key switch control, accelerator gate beam flow interlock, ventilation delay door opening interlock, site clearance patrol system interlock, and personal dose system interlock, to protect the personal safety of on-site personnel. The system has been put into operation and passed the on-site inspection of environmental protection supervisors.

Keywords: Proton therapy system; Cyclotron; Safety PLC; Safety interlock system; Radiation; SIL3.

1. Introduction

The cyclotron in the proton therapy system of CGN Medical Technology (Mianyang) Co., Ltd. is designed with an extraction capability of 230 MeV, and the maximum extracted beam current is 750 nA. During the production, commissioning, and operation of the cyclotron, high-intensity secondary radiation and induced radioactive radiation are generated, including neutrons, gamma rays, and harmful gases such as ozone. These radiation sources can cause significant harm to the human body and will not disappear for a short period of time after the accelerator is shut down. Therefore, a personal safety interlocking system has been designed and constructed for the production and commissioning area of the cyclotron. The core purpose is to ensure the safety of personnel involved in production commissioning and entering the control area through a series of safety measures and interlocking mechanisms, and to prevent radiation leakage and accidents [1].

Due to the high reliability, scalability, real-time self-detection, simple maintenance, and adaptability to various complex environments of programmable logic controllers (PLCs), most personal safety interlock systems for accelerators at home and abroad are designed and constructed based on them. The personal safety interlock system of the China Spallation Neutron Source (CSNS) is based on the high-performance and high stability Japanese Yokogawa series PLC design [2]. The personal safety interlock system of High Energy Photon Source (HEPS) is designed and constructed based on PILZ PSS4000 safety PLC [3,4]. The personal safety interlock system of the Heavy Ion Research Facility in Lanzhou (HIRFL) at the Institute of Modern Physics, Chinese Academy of Sciences adopts the Phoenix RFC 460R series redundant PLC as the core logic control [5,6]. The Heavy Ion Medical Machine (HIMM) personal safety interlock system of Lanzhou Kejin Taiji New Technology Co., Ltd. uses S7-4125H redundant PLC [7]. The major renovation project of Beijing

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Electron Positron Collider (BEPCII) uses OMRON series PLC to design and construct a personal safety interlock system [8].

2. System Design

2.1 Design Principles

The design of the personal safety interlock system should meet the minimum criteria required by national standards. The system follows the design principles of people-oriented, redundancy, independence, failure safety, optimal cut-off, self-locking, and easy operation and maintenance [6,8,9,10].

People-oriented: Prioritize the safety of on-site personnel and ensure that the beam can be quickly and accurately shut off in any situation to prevent on-site personnel from being exposed to unplanned irradiation.

Redundant design: Multiple interlocking methods and devices are employed to enhance the reliability and safety of the system. Even if one interlocking method fails, other methods can still ensure system safety.

Independence: The operation of the personal safety interlock system in each region is not affected by other systems, and the personal safety interlock system can independently make judgments and perform safety operations at any time.

Failure safety: When the digital display problem or malfunction of the components that affect the safety performance of the safety interlock system occurs, the interlock system can automatically execute the predetermined safety operation, keeping on-site personnel in a safe environment.

Optimal cut off: The personal safety interlock system is granted the highest priority for beam cut off. According to the system settings, the safety interlock system is capable of cutting off the beam in any situation when the accelerator is in use.

Hardware is the most reliable: Due to numerous factors that affect the normal operation of software, the critical input and output signals of the safety interlock system should be managed by hardware inputs/outputs.

Self-locking: Key devices such as emergency stops and key switches that affect safety in the safety interlock system should have self-locking functions to prevent automatic resetting when unsafe factors are not eliminated.

Easy to operate and maintain: The system design should be simple and clear, making it easy for operators and maintenance personnel to understand and operate. At the same time, detailed operation manuals and maintenance guidelines should be provided to ensure the normal operation and long-term stability of the system.

2.2 System Composition

The hardware of the personal safety interlock system includes: the upper-level computer, main controller+I/O modules, junction box, main key switch, emergency stop button, area clearance button, sound and light alarm device, infrared light curtain, emergency door release button, door interlock actuator, door header display LEDs, and other equipment.

In terms of safety and reliability, the personnel safety interlock system is designed with a SIL3 safety integrity level. The main controller PLC, emergency stop button, area clearance button, sound and light alarm device, anti-following infrared light curtain, access control limit node, door interlock actuator, and door head display are all safety equipment that meet the SIL3 standard requirements.

2.3 Design of Safety Interlocking Function

The operating conditions of the safety interlock system include: clearing in progress, clearing completed, preparing and confirming the beam release, beam release allowed, beam release stopped, ventilation in progress, ventilation completed, personnel authorization to enter, etc. The safety

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interlock system switches between various operating conditions based on the comprehensive judgment of its own system equipment status (buttons, light curtains, switches, system and equipment status, etc.), personal dose management system status and data, and access control system equipment and data. The accelerator control system controls whether the accelerator is allowed to emit beams based on the various operating conditions of the safety interlock system. The schematic diagram of the interlocking signal of the personal safety interlocking system is shown in Fig. 1.

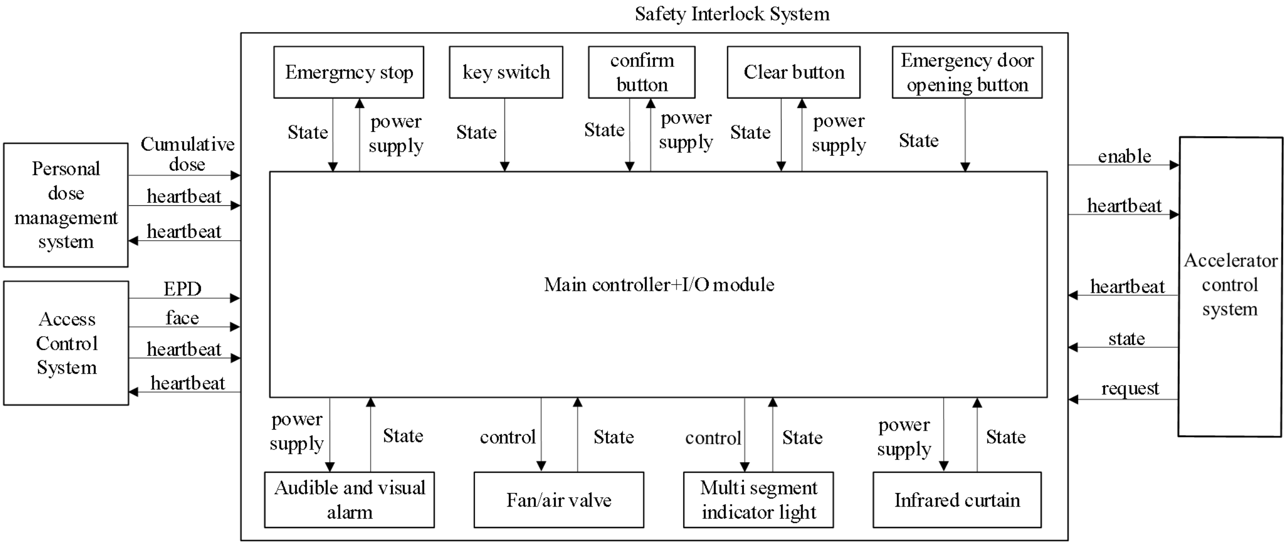

Fig. 1 Safety interlock system interlocking signal diagram

The functional flowchart of the personal safety interlock system is shown in Fig. 2.

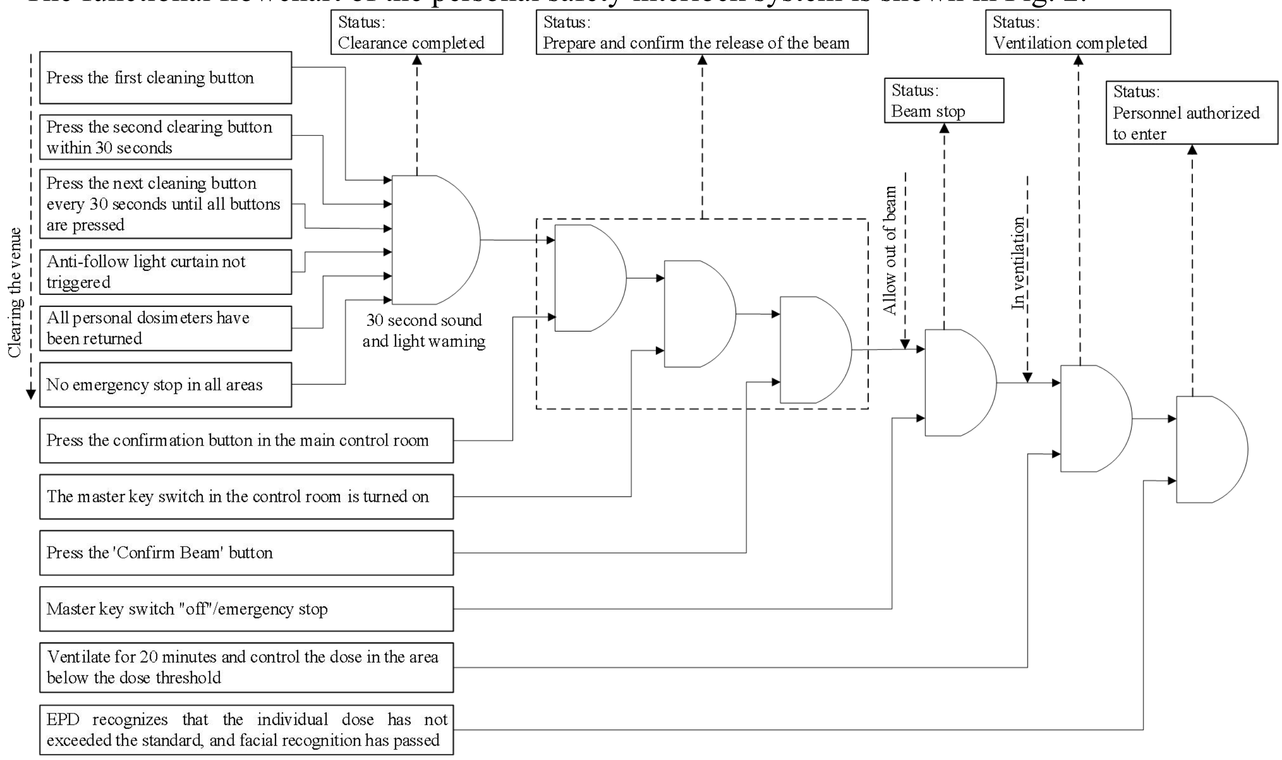

Fig. 2 Function flow chart of safety interlock system

The detailed description of the functional process of the personal safety interlock system is as follows:

Setp1: During the "cleaning process", the cleaning personnel are authorized to enter the accelerator room. According to the predetermined cleaning route, after pressing the first cleaning

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button, the cleaning prompt sound will be activated, and the next cleaning button will be pressed every 30 seconds. During this period, if the anti-follow system detects someone entering, the sound and light alarm will disappear, and the inspection needs to be restarted from scratch. After all the cleaning buttons in the current area are pressed on time, the current area will be cleared, and the cleaning completion light outside the door will light up. The current area door will be closed, completing step 1. During this period, any operation to open the door will reset the clearing status and the current area must be cleared again.

Step2: When step 1 is completed and all personnel's personal dosimeters have been returned, and no "emergency stop" has been pressed in any area during this period, step 2 is completed and the safety interlock system is in the "clearance completed" state.

Step3: When step 2 is completed, first press the "Confirm" button in the main control room to indicate that the clearing operation is completed and confirm again; Turn the master key switch to the "on" position again, indicating that the safety interlock system allows the accelerator to release the beam. If you want to release the beam at this time, press the "release confirmation" button on the upper computer, and the accelerator can release the beam.

Step4: Beam stop ", beam stop is divided into emergency stop and normal stop. Emergency stop is achieved by pressing the emergency stop button in any area to stop the beam current; Normal stop, complete the beam stop by turning the master key switch to the "off" state. Regardless of how the beam is stopped, if the beam needs to be discharged again, the above three steps must be repeated.

Step5: When the beam stops, immediately enter the ventilation state and set a ventilation time of 20 minutes.

Step6: Ventilation completed ", when step 5 has been ventilated for 20 minutes and the dose rate in the control area is below the dose limit, authorized personnel from the system are allowed to enter the control area.

Step7: Personnel authorized entry ": After confirming that the personal dose has not exceeded the limit through the" personal dose management system "and" access control system ", and that the facial recognition has passed dual authentication, personnel are authorized to enter the control area.

3. Implementation of Personal Safety Interlocking System

The personal safety interlocking system of the proton therapy system cyclotron production and commissioning area of CGN Medical Technology (Mianyang) Co., Ltd. adopts Siemens S7-1513-F safety PLC as the main controller, equipped with safety I/O modules, relays, buttons, switches, indicator lights and other equipment. The PLC program is developed using two types of programs: standard programs and safety programs. The upper computer is developed using the stable configuration software Portal Wincc. The overall system has reached SIL3 safety level, forming a fault safety system. The safety interlock system architecture is shown in Fig. 3, and the system's functional workflow is shown in Fig. 2. The physical components used in the system are shown in Fig. 4. Figures 4a, 4b, 4c, 4d, and 4e respectively show the cleaning button, sound and light alarm light, emergency stop button, infrared light curtain, and photos of the door suction device.

The input of PLC and devices such as buttons, switches, and indicator lights is evaluated using a 1oo2 evaluation method, powered by internal power supply, and differentiated analysis of input status is conducted to ensure the correct and effective input of the system, thereby ensuring the safety and reliability of the personal safety interlock system.

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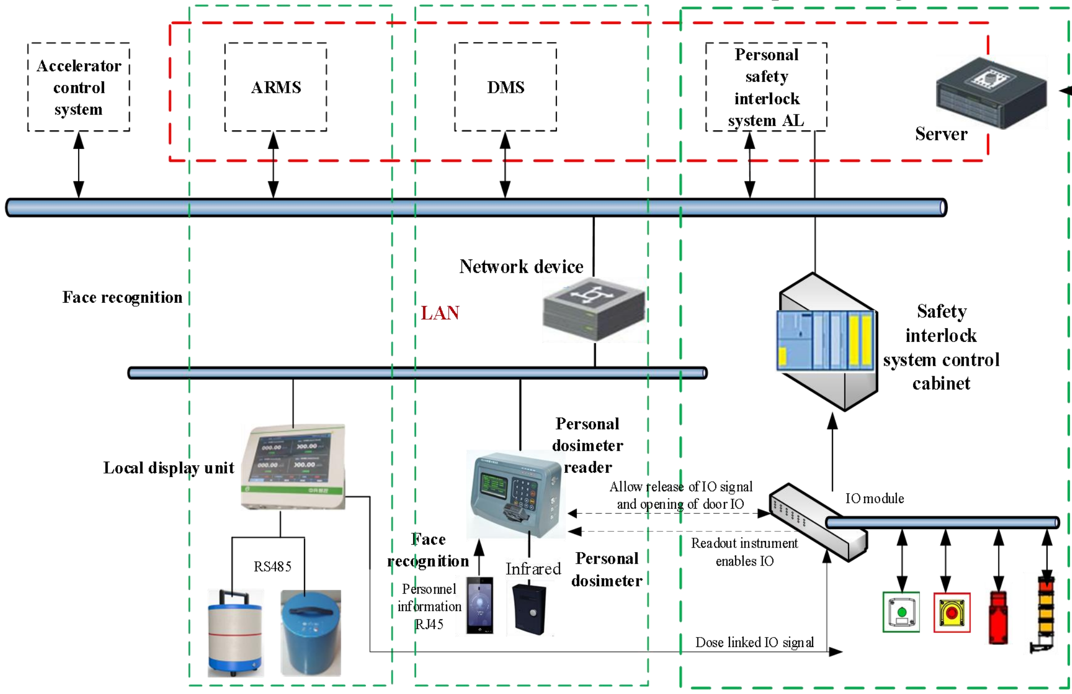

Fig. 3 Safety interlock system architecture diagram


Fig. 4a Search button


Fig.4b Sound and light alarm lights

Fig.4c Emergency button


Fig.4d Infrared curtain


Fig.4e Magnetic Door Holder

Fig. 4 Physical pictures of some devices used in the system

4. Summary

The personal safety interlock system for the proton therapy system cyclotron production and commissioning area of CGN Medical Technology (Mianyang) Co., Ltd. meets national and industry standards, and uses Siemens safety PLC, safety input/output equipment, and safety PLC programs. The system has a safety level of SIL3, greatly ensuring the reliability and stability of the safety interlock system and the ability to protect the personal safety of on-site personnel. The system has been put into operation and passed the on-site inspection of environmental supervisors and obtained a radiation safety license. The successful experience of this system can also provide ideas and references for the design and construction of other personal safety interlock systems.

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