ACCELERATOR PERSONNEL SAFETY SYSTEMS FOR EUROPEAN SPALLATION SOURCE*

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Abstract

The European Spallation Source (ESS) is a collaboration of 17 European countries to build the world's most powerful neutron source for research. ESS is under construction since 2014 and it will produce first neutrons in 2019. The linear proton accelerator is composed of normal conducting sections plus the superconducting linac. When operational, such facilities include various hazards, such as ionizing radiation, high voltage and oxygen deficiency. The accelerator Personal Safety System (PSS) limits exposure to them and ensures personnel safety in the accelerator tunnel. It will be developed in accordance with IEC 61508 standard (Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems), which has become a good practice in similar facilities to develop safety related systems. This paper gives an overview of the accelerator PSS and its subsystems. The progress of the accelerator PSS design and the selected software and hardware technologies will also be described.

INTRODUCTION

The ESS accelerator is a 600-meter linac, located 4 meters underground. In the linac, the ion source produces a proton beam that is transported through a Low Energy Beam Transport (LEBT) section to the Radio Frequency Quadrupole (RFQ) where it is bunched and accelerated up to 3.6 MeV. In the Medium Energy Beam Transport (MEBT) section the transverse and longitudinal beam characteristics are diagnosed and optimized for further acceleration in the Drift Tube Linac (DTL). The first superconducting section consists of 26 double-spoke cavities (SPK). The spoke-cavities are followed by 36 Medium Beta Linac (MBL) cavities and 84 High Beta Linac (HBL) elliptical cavities. After acceleration, the beam is transported to the target through the High Energy Beam Transport (HEBT) section [1].

The accelerator PSS will be developed to personnel from radiation hazards by controlling access to PSS controlled areas and interrupting the machine operation in case unsafe conditions occur. This system is based on Programmable Logic Controller (PLC) technology using two independent safety PLCs in a fail-safe configuration.

The accelerator PSS will be developed, validated and maintained in accordance with IEC 61508 standard.

The PSS design and operation shall also meet the requirements by the Swedish Radiation Safety Authority (Strålsäkerhetsmyndigheten; SSM) which has a mandate from the Swedish Government within the areas of nuclear safety, radiation protection and nuclear non-proliferation [2].

Figure 1 shows the general layout of ESS accelerator tunnel and its access points and emergency escape routes.

The strategy implemented to mitigate against dangerous situation for personnel has led to the provision of four subsystems in PSS: Access Control System, Safety Interlock System, Radiation Monitoring System and ODH Detection System. The first three systems are integrated into a two-train failsafe PLC system, while the ODH Detection System is a completely independent system which will interface the rest of PSS through hardwire signals.

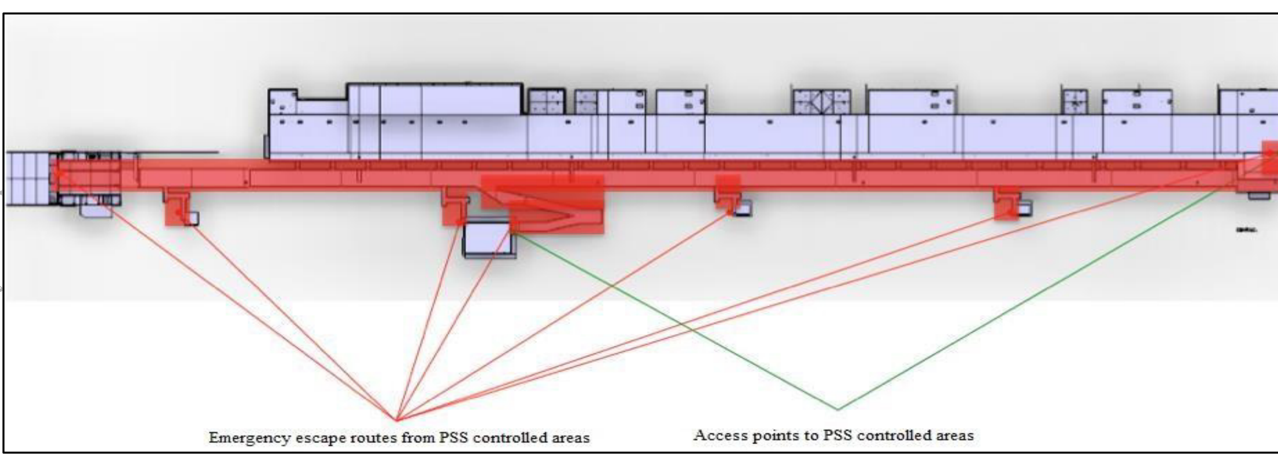

Figure 1: Accelerator PSS controlled areas, highlighted in red.

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PSS ARCHITECTURE

As part of SSM requirements, the accelerator PSS consists of two trains (red train and blue train), where each train contains sensors, Siemens S7 1500 series safety PLCs, the distributed I/O peripherals and actuators. The two trains are configured separately and work independently. The dual PLC system is adopted for higher reliability because the PSS only permits some actions when both PLC systems make same judgement. For example, the accelerator subsystems can only be operated when both red PLC and blue PLC systems permit the operation. The two PLCs run identical safety programs and functions, while the standard functions are included only in the red train. All signal paths are hardwired from equipment (sensors and actuators) to the distributed I/O peripherals. The distributed I/O peripherals are connected to the PLCs in a ring topology over PROFINET protocol. The safety I/O modules communicate via PROFIsafe, which is a safety communication technology designed as a separate layer on top of the fieldbus application layer to reduce the probability of data transmission errors. PROFIsafe uses error and failure detection mechanisms such as: consecutive numbering, timeout monitoring, source/destination authentication, and cyclic redundancy checking (CRC).

The PLC I/O peripherals are distributed in various locations in klystron gallery building (housed in dedicated PSS racks). Considering the distance and potential electromagnetic and radiofrequency interferences in the environment where PSS is installed, the ring topology mentioned earlier will be implemented using single-mode fibre optic cables.

ACCESS CONTROL SYSTEM

The function of the accelerator access control system is to provide a physical barrier to accelerator PSS controlled areas. As shown in figure 1, there are two access points to the accelerator tunnel, one in the Frontend building, and one in HEBT loading bay building, through which personnel can access the tunnel and material can be transported in/out of PSS controlled areas. Also, seven emergency escape routes are foreseen, so that personnel can escape from the accelerator tunnel if hazardous event(s) occur.

The personnel access control is implemented by installing double-door security airlock systems. The airlock system ensures entry of personnel to PSS controlled areas upon identification (using card readers), and single person entry/exit to PSS controlled areas using pressure contact mat inside the airlock. There is ongoing study to integrate the dosimetry system into access control system, to ensure personnel carry their radiation badges when they enter PSS controlled areas.

There are four different access modes to accelerator tunnel: a) Open access, which is mainly used during facility shutdown period, where authorized personnel will be granted access to the accelerator tunnel. In this mode, the number of personnel present in the PSS controlled area can still be limited through card reader system and PSS software. b) Restricted access, which is used during short stops of accelerator, where the person receives a personal key as a token to get access to the accelerator tunnel. PSS will not permit the accelerator to restart, until all tokens are returned and parked in place. c) Search, where a maximum of three authorized personnel will be granted access to accelerator tunnel to carry out search patrol, ensuring the PSS controlled area is empty of personnel prior to accelerator start. d) Radiation Protection (RP) survey, when a dedicated team get access to tunnel to measure radiation level from any activated equipment in PSS controlled area. The open or restricted access permit will be issued based on RP survey result.

SAFETY INTERLOCK SYSTEM

The accelerator safety interlock system ensures no ionizing radiation from beam or RF cavities is present in accelerator tunnel during access to PSS controlled area. It will also interlock the gamma blockers to protect the personnel in the accelerator tunnel against residual activation from activated target and tuning beam dump. The detection of any intrusion to PSS controlled areas or pressing any beam-off button during beam operation will result in placing the acceleratortor in a safe position through interlocking PSS Equipment under Control (EUC), as listed below:

- EUC to stop the accelerator proton beam:
  - a) The Ion source plasma generator system
  - b) The Ion source extraction system
  - c) The RFQ system
- EUC to mitigate against X-ray hazards from RF cavities:
  - a) MEBT bunchers RF cells
  - b) DTLs RF cells
  - c) Spoke cavities RF cells
  - d) MBL elliptical cavities RF cells
  - e) HBL elliptical cavities RF cells
- EUC to mitigate against residual activation:
  - a) Gamma blocker, in the line of sight of the target wheel.
  - b) Gamma blocker, in the line of sight of the tuning beam dump.

According to the access control system mode, the safety interlock system can permit proton beam operation as shown in Table 1.

Table 1: Access Mode vs. Proton Beam Destination

Access mode	Proton beam destination
Open, Restricted, Search, RP survey	Beam to LEBT Faraday Cup
No access to accelerator tunnel	Beam to tuning beam dump
No access to target PSS controlled areas	Beam to target

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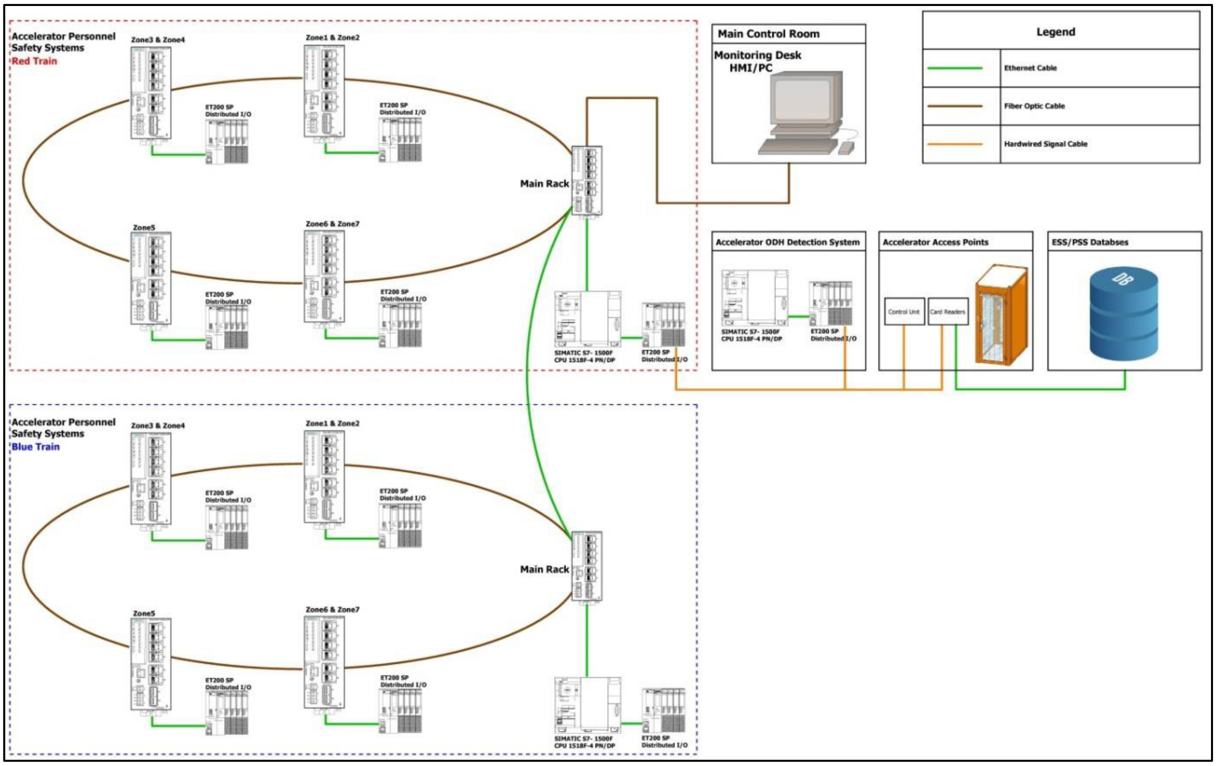

Figure 2: Accelerator PSS architecture.

RADIATION MONITORING SYSTEM

Radiation monitoring is one of the means to limit the exposure of personnel to ionizing radiation, and verify that annual dose of the worker does not exceed the legal limits. The radiation monitors measure the radiation dose equivalent rate at work places in accelerator supervised areas, and signal the presence of excessive radiation via local and remote alarms to alert personnel to evacuate accessible areas in case radiation levels exceed predefined radiation alarm thresholds.

In addition, the designated radiation monitors also interface accelerator PSS, to inhibit access to PSS controlled area and also stop proton beam, in case critical radiation levels are detected in supervised areas.

The radiation monitors should provide data (measured values, time stamps, status, etc) at desired frequencies, and the collected data should be stored in specific databases, as it might be useful post-mortem to understand time, level and causes of radiation leak [3].

ODH DETECTION SYSTEM

Cryogenic cooling is essential for various equipment of the accelerator such as superconducting Linac and cryomodule test stand, which will be provided with helium. The use of cryogenic fluids can be associated with oxygen deficiency hazard (ODH) due to the displacement of oxygen in air lowering its volumetric concentration below the acceptable value of 18% O2. Following a preliminary assessment to determine an ODH class for each area potentially subject to oxygen deficiency, an ODH detection system should be developed for four accelerator buildings; the Helium Compressor Building (HCB), Cryogenic Transfer Line Gallery (CTLG), Coldbox Building (CXB), and the Accelerator Tunnel (AT) [4]. In essence, the ODH detection system is a PLC-based alarm system (Siemens S7 1500 series safety PLC), which will function independently from PSS. The Oxigraf O2iM oxygen deficiency monitors will be installed in various locations of the buildings mentioned earlier, to detect any potential oxygen deficiency hazard. The Oxigraf monitors use laser diode absorption technology to measure oxygen concentration in the gas sample, through pumping gas sequentially from up to four input sample ports. Upon detection of ODH in the area, the alarms (lights and sounders) will be triggered.

CONCLUSION

Although a huge amount of work has been carried out, additional work is required to finalize accelerator PSS hazard analysis, architecture, and test the PSS hardware and software [5]. The accelerator PSS design is expected to near completion during the next 12 months.

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