ESS Personnel Safety Systems Test Stand

D Paulic¹, S L Birch², M Mansouri³ and Y K Sin⁴

¹ Deputy Group Leader, Protection and Safety Systems, European Spallation Source ERIC, Lund, Sweden
² Senior Engineer, Protection and Safety Systems, European Spallation Source ERIC, Lund, Sweden
³ Engineer for Safety Critical Systems, Protection and Safety Systems, European Spallation Source ERIC, Lund, Sweden
⁴ IEC61508 Electrical Controls Engineer, Protection and Safety Systems, European Spallation Source ERIC, Lund, Sweden

E-mail: denis.paulic@esss.se

Abstract. Providing and assuring safe conditions for personnel is a key parameter required to operate the European Spallation Source (ESS). The Personnel Safety System (PSS) primarily prevent workers from the facility’s ionising radiation hazards, but also identify as well as mitigate against all other hazards such as high voltage and oxygen depletion. The PSS test stand is being developed in the ESS Protection Systems (PS) lab. It will be used for simulation, testing and verification purposes of any system, equipment, function and procedure developed by the PSS team. At the later stage of the project it will facilitate preparation for operation, maintenance and periodical testing of PSS, and hence it should be as similar as possible to real system. This paper describes the ESS Personnel safety systems’ test bench design, devices, and implemented functions.

1 Introduction

The European Spallation Source ERIC (ESS), currently under construction, consists of a 600m long high power proton linear accelerator (Linac), accelerating proton pulses of 2.86ms length to the energy of 2GeV with a repetition rate of 14Hz. The proton pulses then interact with a rotating tungsten target wheel. Neutrons are created due to the spallation process and further guided through 22 different neutron beam lines towards the experimental stations. It is expected to have the first protons on target mid 2019 [1]

The Integrated Control Systems (ICS) division is responsible for the design, procurement, installation, commissioning and validation of all personnel safety systems at ESS.

2 Personnel safety systems

Like in many other facilities within the accelerator research field, the personnel safety systems (PSS) at ESS will be designed, manufactured, tested, commissioned, validated, operated and decommissioned in accordance with IEC 61508 international standard [2], which proved to be the best practice for developing such systems. On top of this, as part of the license application, the Swedish Radiation Safety Authority (SSM) has requested that ESS PSS meet SSM2014-127-1 [3] and SSMFS 2008-27 [4] requirements that include following:
• Radiation risk analysis shall be carried out before the facility is taken into operation.
• A formalised search of each PSS controlled area shall be carried out before the facility is operated.
• Two independent technical design solutions should be used in each system.
• External events, single failure, common cause failures, redundancy, diversity and separation shall be taken into account when developing the system.

The PSS primarily prevent workers from the facility’s ionising radiation hazards, but also identify as well as mitigate against all other hazards such as oxygen depletion hazards (ODH), high voltage hazards, magnetic field hazards, laser hazards and motion control hazards.

The PSS controlled areas are hazardous areas where personnel might be affected if the beam is on or if any of hazardous equipment within the area is powered. They include: on-site cryogenic module test stand, Linac, target utility rooms, bunker and 22 neutron instruments (each instrument will have individual PSS). Some of these areas will be divided in smaller zones to facilitate various procedures. For example, the Linac has been divided into several zones that are separated by fenced gates, which facilitates the search procedure (i.e. reduces the time needed to search accessed areas).

There are four main personnel safety systems:
• Safety interlock system – ensures that if the beam is permitted there is no access to PSS controlled areas and vice versa, if access is allowed beam is not permitted. In case of emergency (e.g. intrusion to controlled area) it hard switches-off all hazardous equipment under control.
• Access control system - monitors the conditions for enabling the entry stations and controls door opening and access subsystems.
• ODH monitoring system – prevents the entry to controlled areas in case of ODH and reports the alarm by activating signalization lights.
• Radiation monitoring system – stops the proton beam by switching-off the designated equipment under control (i.e. ion source plasma generation and high voltage extraction systems) if radiation level goes beyond specific thresholds in some supervised areas.

3 PSS test stand

For simulation, testing and verifying different PSS systems, equipment, functions and procedures PSS team decided to build a test stand. Its development started in February 2015 and is still on-going in the Protection Systems (PS) lab at ESS. At the later stage of the project it will facilitate preparation for operation, maintenance and periodical testing of PSS, and hence it should be as similar as possible to final install system.

3.1 Layout

The PSS test stand consists of a caged area, which represents the PSS controlled area (see Figure 1), with double-door entry station, an emergency-exit door next to it, a section door which represents the gate between two PSS zones within the PSS controlled area, and two PSS cabinets painted in RAL 2000 (orange, ESS PSS specific color). In addition to above mentioned entry station, there are several access control subsystems (e.g. message display system, card readers, etc.) that will be used for simulating and testing different entry and exit procedures. The position of each door is monitored constantly in PSS test stand control system through pairs of mechanical and magnetic safety switches with self-diagnostic functions and in-built redundancy.
3.2 Test stand devices

Figure 1 shows the layout of PSS test stand devices and equipment under control (EUC) inside the controlled area. The main functions of these devices are signalization and protecting people in case of hazard and preventing them from entering the hazardous areas in such cases. Below are listed some of the commercial-off-the-shelf (COTS) devices and equipment that are currently installed in PSS test stand:

- Physically separated two-train safety PLC system
- Rack HMI-s as PSS supervision stations
- Two-door security airlock system (SAS) entry station
- Beam-off stations
- Swipe card door access system
- Key exchange
- Public address system
- Message display system
- PSS blue and red area lights
- PSS contactors

3.2.1 Beam-off station. The beam-off station is an in-house designed PSS device which will be installed in all PSS controlled areas and will be used for several functions and procedures. The final number of beam-off stations in all controlled areas is not defined yet. The main purpose is to enable workers to switch-off beam (remove the hazard) from inside the PSS controlled areas in case of emergency. Each beam-off station will also have a search button, two light towers for signalisation and a buzzer for search procedure. Its preliminary design is shown in Figure 2. Two of them are currently installed at PSS test stand.
3.2.2 **Entry station.** A commercial-off-the-shelf (COTS) 2-door security airlock system manufactured by Gunnebo is used as an entry station at PSS test stand. It is a robust station which allows single-person entry, has two hours of battery back-up in case of power failure and glass doors so that personnel can see if the station is occupied, as well as the status of signalisation lights inside the controlled area before or during the entry process. A pair of Siemens safety switches is installed on each door for position monitoring, and doors are internally interlocked, which means that both cannot be open at the same time. There is also possibility for a real-time visual feedback to supervision system through the camera installed inside the station.

3.2.3 **Safety PLCs.** Two physically-separated, independent Siemens S7 1500 fail-safe programmable logic controllers (PLC-s) are used for functional safety implementation, principally through safety functions in the software, in order to bring the system to a safe state or maintain it in a safe state in case of a dangerous event [5]. Both PLCs run exactly the same safety program in parallel, but all standard components and non-safety functions are implemented only on one of them, which is therefore considered to be a main PSS PLC. The ODH monitoring system will be independent of this 2-train system, implemented in a separated rack and PSS team is still evaluating if a safety PLC will be needed for this. All PSS sensors and actuators are connected to these PLCs through local Siemens ET200SP distributed I/O stations with fail-safe I/O modules.

3.2.4 **ODH monitors.** Two Oxigraf O2iM oxygen deficiency monitors are installed and currently being tested at PSS test stand. They measure and display the oxygen concentration in gas sample drawn through the instrument. Gas is pumped sequentially from up to four input ports, through the oxygen sample cell, and out the exhaust port. There are several relays inside the monitor that can be used in ODH monitoring PLC control system.

4 **Test stand functions**

4.1 **PSS test stand key exchange system**

The key exchange system installed in PSS test stand has two different set of keys: one set in main PLC cabinet which represents the key exchange that will be placed in the Main Control Room (MCR) and will be used by the operator for selecting access modes and issuing beam permit; and other one inside the entry station for the type of access which requires having a key as a safety token (see the description of Restricted access in a following subsection).

This system is trapped key interlock type, which means that a safe sequence of operations is enabled through transfer of keys that are either trapped or released in a predetermined order. For example, a main key is used to remove the power for all hazardous EUC; this main key is then released and can be used to choose one of the access modes by inserting it into appropriate lock, which will then, in case of access with key, enable releasing appropriate access key. The action of taking this access key will lock (trap) the main key in place and it will remain trapped until the access key is returned to key exchange. Two access modes have already been developed and tested at PSS test stand and will be described in
following sections. Table 1 shows all the modes that are currently implemented in PSS test stand control system.

| Mode          | Access status                          | Hazardous EUC permits                           |
|---------------|----------------------------------------|-----------------------------------------------|
| Beam ON       | No access                              | All ON                                        |
| Area closed   | No access                              | According to requirements                      |
| Open access   | Allowed – no key required              | According to requirements                      |
| Search        | Allowed – limited number of people, key required | According to requirements                      |
| Restricted access | Allowed – limited number of people, key required | According to requirements                      |
| Alarm         | No access                              | All OFF                                        |

4.2 Search procedure

The purpose of formalised search is to make sure nobody’s left in the controlled areas before issuing the beam permit. It will be done by authorised search team (or teams) of two people who will have a dedicated search key for entering the controlled areas. A safety program ensures that search is broken when required. Each beam-off station includes a search button, a search light and a buzzer that are used for search procedure. Search lights inform the search team which search button shall be pressed next, and buzzers are used to inform people inside the controlled area that search process is ongoing. If any door opening is detected during search or pre-defined search time is exceeded, the search process has to be re-done from beginning.

4.3 Entry to PSS controlled area in Open access mode

In Open access mode, a person can enter the PSS controlled area if authorized, but search is broken upon entering the area. Entries are counted by PSS software and can be limited inside the software if required.

4.4 Entry to PSS controlled area in Restricted access mode

In Restricted access mode search is not broken upon entry, but person must to take a key to enter the controlled area. It’s very practical and time-saving to have such mode, especially in case of quick interventions, because the search process doesn’t have to be done after and mechanically beam permit cannot be issued if all keys are not returned to key exchange. It’s limited by number of keys in entry station’s key exchange. The PSS test stand currently allows the entry of maximum 3 people in this mode.

4.5 Beam imminent warning and ODH signalization

For risk reduction purposes and to increase the awareness of some hazardous events, PSS will change all the lights inside controlled areas to blue when the beam permit is issued and to red if ODH alarm goes off. At PSS test stand, one blue and one red light are installed to test procedures in such cases. The outcome is showed in Figure 3. Besides these lights, each beam-off station will have its own red and blue lights for informing workers in case of hazard (see Figure 2). All mentioned lights are controlled by PSS safety program and their functionality testing will be part of PSS annual maintenance procedures. In parallel to above mentioned lights, a PSS public address system will inform personnel if hazard occurs.
5 Conclusion

The ESS is close to an installation of first systems that will require functional personnel safety systems. Thus, it is important to test and verify the concept, design, devices and all procedures in PSS test stand to ensure the PSS safety functions, but also to provide proper system integrity. Since the requirements for PSS are still being defined, the current PSS design is not mature enough. Therefore, PSS test stand will play a crucial role in coming years to improve PSS design and deliver required systems on time.

References
[1] Yeck J 2015 Neutron facility: European Spallation Source is on track Nature 519 7543 291
[2] IEC61508-2010 Functional safety of Electrical/electronic/programmable electronic safety related systems
[3] SSM2014-127-1 Review of application for licence for activity involving ionizing radiation chapter 10.
[4] SSMFS 2008-27 The Swedish Radiation Authority’s regulations concerning operations at accelerators and with sealed radiation sources
[5] Birch S L et al 2015 Personnel safety systems for the European Spallation Source Proceedings of IPAC2015 MOPTY046