ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THCPA02

ESS ACCELERATOR SAFETY INTERLOCK SYSTEM

D. Paulic†, S. L. Birch, M. Mansouri, A. Nordt, Y. K. Sin, A. Toral Diez
European Spallation Source ERIC, Lund, Sweden

Abstract

Providing and assuring safe conditions for personnel is a key parameter required to operate the European Spallation Source (ESS). The main purpose of the Personnel Safety Systems (PSS) at ESS is to protect workers from the facility's ionising prompt radiation hazards, but also identify as well as mitigate against other hazards such as high voltage or oxygen depletion. PSS consist of three systems: the Safety interlock system, the Access control system and the Oxygen deficiency hazard (ODH) detection system.

The Safety interlock system ensures the safety functions of the PSS by controlling all hazardous equipment for starting the beam operation and powering the RF-powered units and allowing its operation when personnel is safe. This paper will describe the ESS PSS Accelerator Safety interlock system's scope, strategy, methodology and current status.

INTRODUCTION

The ESS, currently under construction, consists of a 600-metre long linear accelerator (hereinafter referred to as the Accelerator), accelerating protons to 2 GeV. The Accelerator is operated in pulsed mode with beam pulses of 2.86 ms length at a maximum repetition rate of 14 Hz. The proton beam is sent to a rotating, helium-cooled tungsten target, where neutrons are created due to the spallation process. The neutrons are guided further towards the large variety of state-of-the-art neutron instruments. [1, 2] One of the key parameters to operate ESS is to provide and assure safe conditions for personnel. At the ESS organisation, the Integrated Control Systems (ICS) division is responsible for developing, implementing and operating the PSS relevant systems.

The ESS PSS has been split into three major sections: the Accelerator PSS, the Target PSS and the Neutron Instruments PSS (a separate PSS system is required for each neutron instrument). The focus of this paper is on the Accelerator Safety Interlock System, as a part of the Accelerator PSS. It includes PSS controlled areas in the Accelerator, as shown in Figure 1.

Accelerator

The ion source produces a beam at 75 keV 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 beam characteristics can be diagnosed and are further optimized for acceleration throughout the Drift Tube Linac (DTL) consisting of 5 tanks.

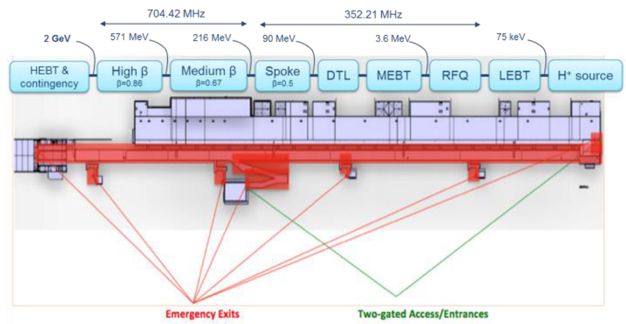

Figure 1: Accelerator PSS controlled area.

The superconducting section consists of 26 double-spoke cavities (SPK), 36 Medium-Beta Linac (MBL) elliptical cavities and 84 High-Beta Linac (HBL) elliptical cavities. [1, 2] After acceleration to 2 GeV, the beam is transported to the target through the High Energy Beam Transport (HEBT) section, where some contingency space is left for potential future upgrades.

ACCELERATOR PERSONNEL SAFETY SYSTEM

The main role of the Accelerator PSS at ESS is to protect workers from the facility's ionising prompt radiation hazards within the Accelerator controlled areas. This shall be valid for all operational modes of the facility. The system will also be used to mitigate against other hazards, and this section will briefly describe all identified hazards within the scope of Accelerator PSS, the approach for implementing functional safety and additional requirements that should be included in system design.

Scope

The Accelerator PSS will control access into the Accelerator area through the two entrances marked in green in Figure 1. Each entrance will have a double-gated access station to only allow authorised workers to gain entry into controlled areas. There are seven emergency exits doors, which mark the boundary of the Accelerator controlled area and the position of all these doors will be monitored by the Accelerator PSS control system.

No access to these controlled areas will be allowed when Accelerator is in operation or when some of Accelerator components are energised (see the list of interfaces with the Accelerator systems below).

Subsystems

The Accelerator PSS consists of two main subsystems: the SIS and the Accelerator Access Control System

† denis.paulic@esss.se

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THCPA02

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

(ACS). The former will be described in the following section, whilst the main function of the latter is preventing the entry of personnel to specific, controlled areas, in case of unsafe conditions inside these areas. In addition, personnel will be alerted about the potential presence of a hazard through various signalisation lights and sounders.

Functional Safety

The international standard IEC 61508 [3] provides an overall safety lifecycle structure for functional safety and is a good practice in similar facilities to develop safety-related systems. The Accelerator PSS follows that lifecycle for system development.

Since only proven-in-use commercial off-the-shelf (COTS) components will be used in implementing the Accelerator PSS, the software will be designed, tested, commissioned, validated and operated in accordance with IEC 61511 [4].

Additional Requirements

On top of system requirements (integrity and functional) for satisfying above mentioned standards, as part of the license application, the Swedish Radiation Safety Authority (SSM) has requested that ESS PSS shall meet SSM2014-127-1 [5] and SSMFS 2008-27 [6] requirements that include the following:

- Radiation risk analysis shall be carried out before the facility is taken into operation.
- 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.

Hazards

The PSS team went through several hazard identification meetings with the stakeholders of Accelerator systems. As a result, the Accelerator PSS mitigates against the following hazards inside the Accelerator PSS controlled area:

- Ionising prompt radiation from the proton beam,
- Ionising prompt X-Ray radiation from the RF systems,
- Electrical hazard (high voltage)
- Magnetic field hazard,
- Radio frequency (RF) field hazard.

There is also a risk of oxygen deficiency hazard (ODH) inside the Accelerator PSS controlled area, for which the separated system is being developed by PSS team, independently of Accelerator PSS. The ODH detection system is described in [7].

After all the hazards are identified in the Accelerator, the Equipment Under Control (EUC) [3] is defined and the hazard and risk analysis is carried out. For the risk analysis process, the PSS team uses Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) methods in the Isograph software tool [8].

The results from the risk analysis process are then used to define requirements needed to realise the interfaces with the different Accelerator systems that will be used for implementing relevant Accelerator PSS safety functions. The EUC will be primarily made up of systems, devices and components that are used in the acceleration process and hence in the process of producing radiation that personnel needs to be protected from.

SAFETY INTERLOCK SYSTEM

Objective

The term “interlock” in this context describes the action of switching off the hazardous equipment with the purpose of removing the hazard. The Safety Interlock System (SIS) ensures that no ionizing prompt radiation from proton beam or RF cavities, electrical, magnetic and RF field hazard is present in the Accelerator controlled areas whilst access is given to personnel. It also ensures safe conditions in case of other unexpected events where personnel can be protected by the action of switching off (interlocking) equipment.

Requirements

At ESS, the Accelerator Division (AD) defined the overall safety requirements for the Accelerator PSS. Table 1 extracts those relevant for the SIS.

Table 1: Safety Interlock System Overall Requirements

Requirement ID	Description
Req_1	Switch off beam and all hazardous equipment if anybody tries to enter the PSS controlled area during the operation of beam and/or any of the hazardous equipment.
Req_2	Provide a solution to manually switch off beam and hazardous equipment from inside the PSS controlled area.
Req_3	Prevent beam operation and operation of hazardous equipment if access to PSS controlled area is allowed.
Req_4	Switch off the proton beam upon receiving an interlock signal from the radiation monitoring system that has detected an elevated dose critical for personnel in a specific/controlled (monitored) area.
Req_5	Prevent all hazardous equipment operation, which is not procedurally prepared for testing, if access to PSS controlled area is allowed.

The requirements Req_1 and Req_4 require the system to activate interlock and switch off beam if anybody intrudes into PSS controlled area, or if radiation levels outside the controlled area unexpectedly increased during

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THCPA02

beam operation, whilst Req_3 and Req_5 require the system to keep the interlock active during beam shutdown. These requirements are then combined with the ones requested by the SSM and included in system's lifecycle for defining architecture, design and interfaces. They also define the basis for naming the SIS safety functions, as shown below:

- Beam interlock upon intrusion to…
- Beam interlock upon receiving unexpected feedback from…
- Beam interlock upon high level of radiation in…
- RF interlock upon intrusion to…
- RF interlock upon receiving unexpected feedback from…
- Beam and RF interlock upon manual request.

Beam-OFF Station

The main input to fulfil the requirement Req_2 is the status of Emergency stop (E-stop) buttons that are installed on the Beam-OFF stations [9]. The Beam-OFF station is an in-house designed PSS device that will enable workers to switch off beam (remove the hazard) from inside the PSS controlled areas. It will be developed, tested and verified according to above mentioned functional safety standard. The final number of such devices in the Accelerator PSS controlled areas is not defined yet, but the maximum distance between the two will be 30 m.

Interfaces with the Accelerator Systems

To implement above mentioned requirements, the Accelerator SIS interfaces with all Accelerator systems and equipment that can create a hazardous situation needed to be established.

The proton beam ionising prompt radiation and high voltage hazards will be removed by switching off the ion source plasma and extraction systems before allowing access of personnel or upon intrusion of personnel.

As an additional layer of protection ensuring the proton beam is removed, the RFQ modulator and RFQ low level radio frequency (LLRF) systems will also be switched off to remove the hazard from prompt ionising radiation arising from the proton beam.

To increase plant availability the permit to power the ion source plasma system is left active during the facility maintenance periods. This means that the ion source plasma generation system will be switched off only in case of an emergency shutdown (required in Req_1 and Req_4, for example).

All RF systems will be switched off to mitigate against ionising prompt X-ray radiation and RF electrical field hazards by switching off the following systems:

- The MEBT bunchers (3 total)
  - Solid state amplifier (SSA) system,
  - LLRF system,
- The DTLs (5 total)
  - Modulator system,
  - LLRF system,
- The Spoke cavity (13 total)
  - Tetrodes,
  - LLRF system,
- The MBL elliptical cavity (9 total)
  - Modulator system,
  - LLRF system,
- The HBL elliptical cavity (21 total)
  - Modulator system,
  - LLRF system.

The PSS contactors [8] will be installed into the incoming power of these systems and de-activated to remove the hazards in the tunnel by removing the 24 V signal to the actuator's control coils to de-energise the power ensuring a fail-safe state (de-energise to trip).

Sensors and Architecture

In case of access to PSS controlled area, the SIS ensures no beam operation and no operation of RF hazardous equipment is allowed. This is implemented by connecting position switches to a PLC-based interlock system, which is connected to the Accelerator systems mentioned above.

PSS safety position switches will be installed on each door in the Accelerator PSS controlled area for purpose of monitoring their state (open or close). These inputs will be used by SIS for detecting intrusion to PSS controlled areas or ensuring a closure of specific area/room.

In addition, the SIS also ensures that no beam operation is allowed in case of detecting increased radiation dose levels through designated radiation monitors in supervised areas.

The architecture of the Accelerator PSS is described in [10] and methodology is presented in [11]. Figure 2 shows the interfaces of the SIS.

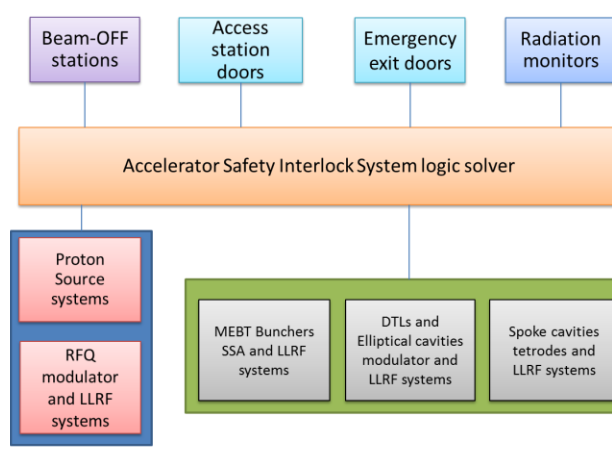

Figure 2: SIS interfaces.

Current Status

It has been decided that the Accelerator PSS will be commissioned in two stages. The first stage is called PSS1 and will include the normal conducting part of the Accelerator (first 60 metres). It will be commissioned and validated to ensure controlled and safe access of personnel to the Accelerator equipment within the PSS1 con-

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THCPA02

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

trolled area. The hazard and risk analysis and definition of interfaces with the systems for PSS1, which also includes the SIS, is on-going. Once the PSS1 is commissioned and validated, the next step will be to upgrade the system for second stage, which includes the complete Accelerator and has the complete SIS operational.

CONCLUSION

The ESS is close to an installation of first systems that require the functional Safety interlock system to assure personnel safety inside the PSS controlled areas. Its design for the first stage of commissioning is expected to near completion in the next ten months.

REFERENCES

[1] R. Garoby, "Progress on the ESS project construction", in *Proceedings of IPAC2017*, Copenhagen, Denmark, 2017, paper MOXBA1.

[2] S. Peggs (ed.), "ESS Technical Design Report", ESS-doc-274, Apr. 2013, http://eval.esss.lu.se/DocDB/0002/000274/014/TDR_online_ver_all.pdf

[3] IEC61508-2010: "Functional Safety of Electrical/ Electronic/Programmable Electronic Safety-related Systems".

[4] IEC61511-2016: "Functional safety - Safety instrumented systems for the process industry sector".

[5] SSM2014-127-1 "Review of application for licence for activity involving ionizing radiation", chapter 10.

[6] SMFS 2008-27 "The Swedish Radiation Authority's regulations concerning operations at accelerators and with sealed radiation sources".

[7] A. T. Diez *et al.*, "ESS Accelerator Oxygen Deficiency Hazard Detection System", in *Proceedings of ICALEPCS2017*, Barcelona, Spain, 2017, paper TUPHA106.

[8] Isograph, https://www.isograph.com

[9] D. Paulic *et al.*, "ESS Personnel Safety Systems Test Stand", in *Proceedings of ICANS2017*, Oxford, UK, 2017, paper id 22771.

[10] M. Mansouri *et al.*, "Accelerator Personnel Safety Systems for European Spallation Source", in *Proceedings of IPAC2017*, Copenhagen, Denmark, 2017, paper TUPIK080.

[11] S. L. Birch *et al.*, "Personnel Safety Systems for the European Spallation Source", in *Proceedings of IPAC2015*, Richmond, VA, USA, 2017, paper MOPTY046.