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INTEGRATED APPROACH FOR ESS PERSONNEL SAFETY SYSTEMS

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Abstract

The European Spallation Source (ESS) is a state-of-the-art research facility currently under construction in Lund, Sweden. Upon project delivery, ESS will host the most powerful linear proton accelerator and a spallation target capable of producing the brightest neutron source in the world. In order to enable safe commissioning and operation of these potent systems, each system has a dedicated personnel safety system (PSS). Together they make up the ESS PSS, an integrated system of several PSS across the facility. These systems communicate with each other through a centralised interlink system, and together determine if the facility is ready for proton beam generation in the Accelerator and consequently neutron production at the Target Station. This paper provides a summary of the inner workings, along with a discussion on the approach and proposed strategies for overcoming the identified challenges.

INTRODUCTION

The European Spallation Source (ESS) facility consists of three main parts: the accelerator, target station, and a suite of neutron instruments.

The ion source, which is the first part of the accelerator, generates protons through evaporating electrons from hydrogen gas. The protons are then lead through normal conducting and superconducting accelerating structures to reach 96 % of the speed of light. The proton beam is then directed through a dogleg with bending magnets to the target station, which is referred to as Beam on Target (BoT). During normal operation, this is the primary beam destination. However, in certain circumstances, the beam may be directed to beam stops distributed in the accelerator tunnel. At the target station, the high-energy protons collide with a rotating tungsten target wheel, which releases neutrons through spallation. The neutron beams are then moderated, tuned and guided through a shielding structure (referred to as the Bunker) to experimental stations referred to as neutron instruments. There, researchers can use the particles as a probe for studying the inner structure, as well as the dynamic behaviours, of a selected sample for a broad range of scientific fields and endeavours. The initial instrument suite consists of 15 neutron instruments and one test beamline [1].

There are a number of hazards related to these systems, mainly radiation-related hazards such as prompt ionizing radiation from the proton beam and neutron beams, and gamma radiation from the target and moderators. ESS employs systems and administrative procedures to ensure the safety of personnel in the presence of radiation. In this regard, the key systems are the personnel safety systems (PSS). They are primarily safety interlock systems, which ensure that sources of prompt radiation are switched off to protect personnel in beam enclosures (e.g. accelerator tunnel, experimental stations, etc.) from exposure to prompt radiation, prevent entry to beam enclosures while sources are energized, and switch them off when designated predefined access functions are violated. Each part of the machine has a dedicated PSS: Accelerator PSS (ACC PSS), Target Station PSS (TS PSS), Bunker PSS, and several Instrument PSS. The full scope of PSS also includes e.g. accelerator test stands.

BACKGROUND

The PSS are designed consistently across the ESS facility in order to reduce design, installation, commissioning and maintenance cost and effort, and more importantly to improve system reliability. Each PSS is built using fail-safe Programmable Logic Controllers (PLC) and distributed Input/Output (I/O) modules with redundant sensors and actuators. Safety Instrumented Functions (SIF) are derived from the risk assessment and hazard analyses process, following the functional safety standard IEC 61511 [2]. The boundaries of the area in which PSS is responsible for mitigating designated hazards, i.e. *PSS controlled areas*, are also defined in the process. The SIFs are defined to e.g. switch off the hazardous equipment if an intrusion into the area is detected by the position monitoring switches on the access doors, or if an emergency switch-off button (ESOB) is pressed. For example, regarding an instrument PSS that entails closing a beam shutter (or *instrument shutter*) to block neutron particle flow to the experimental station. There are also SIFs related to radiation monitors that interface the PSS, e.g. a radiation monitor by the instrument shutter verifies the shielding integrity of the shutter when it is closed. If these radiation monitors alarm, the hazardous equipment is also switched off.

INTEGRATED SYSTEM

The personnel safety systems at ESS operate independently to support the safe operation of various parts of the machine and neutron instruments. However, they need to also work in concert to mitigate designated hazards. Most hazard controls methods are implemented locally, but in certain circumstances, a PSS requires to escalate an issue to ESS PSS and switch off the proton beam to target. The systems need to communicate with each other, and together determine if the facility is ready for proton beam genera-

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tion in the accelerator, and consequently neutron production at the target station and beam to the experimental stations.

Interlink System

There are certain requirements set for the means of communication. The ESS PSS are distributed across the whole facility, and therefore relatively long distances need to be supported. Response times need to be in the millisecond range for the implementation of SIFs. In addition, redundancy, high availability and scalability need to be considered. The solution is Nexus PSS, a PLC-based centralised interlink system, realised as a fiber optic ring network which interfaces each PSS through fail-safe hardwired connection. Media Redundancy for Planned Duplication (MRPD), as specified by IEC 61158 [3], is employed, where isochronous real-time data is transmitted bidirectionally in the ring. If any segment of the ring is interrupted (e.g. cable break, connection failure), the topology is reconfigured instantly (0 ms) to a line topology and as such communication between devices remains uninterrupted. This enhances fault tolerance, and thus availability. If a node is offline, ESS PSS falls to a safe state with proton beam switched off.

For customisability reasons, the ring topology was selected over other topologies (e.g. star with ACC PSS as hub). As such, signals are not limited to and from ACC PSS, but between any two PSS. The design as such accommodates future requirements for additional signals between the ESS PSS. The ring topology has a cost advantage as well, as the total length of fiber is less.

Facility Readiness

Nexus PSS collects information on the readiness for beam on target from each Instrument PSS, as well as TS PSS and Bunker PSS. If all systems are ready, then Nexus PSS deems the facility ready, and forwards the information to ACC PSS to evaluate if any action is needed. If the facility is not ready, the ACC PSS decides on switching off the proton generation based on the proton beam destination. If the beam is to dump, then the proton beam permit may remain enabled as the hazards are contained within the accelerator tunnel. However, if there is beam to target (i.e. neutron production), then ACC PSS disables the proton beam generation. Note that ACC PSS may decide to disable proton beam regardless of the facility state, based on its own local evaluation.

There are several scenarios that affect facility readiness. Consider a scenario where there is beam to target and a worker presses an ESOB, or an intrusion into the area is detected. In case of Instrument PSS, the instrument shutter is closed to block the neutron beam. However, if the instrument shutter does not close within a set time (e.g. due to failure), the Instrument PSS must escalate. To keep the workers safe, ACC PSS must act on the proton beam actuators (e.g. ion source) to switch off the proton beam, and thus stopping the neutron beam to the instrument. The Instrument PSS is then no longer deemed to be ready for BoT. In case of TS PSS and Bunker PSS, the readiness is revoked immediately as there is no equivalent to the closing of the instrument shutter for those systems.

Detection of high radiation is also a cause for escalation. As for the previous scenario, TS PSS and Bunker PSS escalate immediately. In case of Instrument PSS, a radiation alarm entails that the instrument shutter is leaking radiation. If access is permitted downstream the neutron beam, then the Instrument PSS must escalate. If access is not permitted, then there is no risk for workers, and operation may continue.

Bypass

Certain intervention activities (e.g. maintenance, updates or upgrades) of an instrument or an Instrument PSS may require the PSS to bypassed. In this context, that entails temporarily removing the PSS from the integrated ESS PSS in order to allow neutron production to continue. If bypassed, Nexus PSS ignores the Ready for BoT signal from the offline PSS. Additionally, compensating measures (e.g. lockout-tagout) and other operational procedures are followed to ensure continued safety at the instrument site.

Note that power loss during an intervention activity (even if bypassed) breaks one loop of the fiber ring, as the node no longer can relay a signal. In case of two bypassed instruments without power, the ring is completely broken. However, this is not normally a cause of concern as intervention activities are planned to occur during shutdown periods, and it is possible to patch the fiber ring to keep it operational.

Main Control Room

In addition to the aforementioned personnel safety systems, the fiber ring also interfaces the Main Control Room (MCR), which supports operation of the ESS PSS.

Each PSS employs a trapped key interlock system in order to ensure that operating procedures are performed as a predetermined sequence of events and that procedural steps cannot be circumvented. Solenoids trap keys in slots until a set of conditions are fulfilled. Keys from ACC PSS, TS PSS and Bunker PSS are gathered from their respective key exchange units to the integrated key exchange unit in MCR in order to permit access to the accelerator tunnel, proton beam generation and beam on target.

The operators monitor the state of each PSS through an integrated operator interface (OPI), reachable from any workstation connected to the ESS technical network. In case of emergency, the operator will press an ESOB in the MCR to interlock the proton beam.

CHALLENGES

Timing of Escalation

It is necessary to strike a balance between safety and availability when considering escalation. A system that is excessively sensitive would cause unnecessary interruptions of the operation of the whole facility. However, if the system is not sensitive enough, then personnel may become

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exposed to hazards. The proper timing of escalation for different scenarios is therefore crucial. The sensitivity is determined by how much time is allowed for the individual instrument shutter to close before escalating, and how long it takes for a person to be exposed to unacceptable dose levels.

The instrument shutters are pneumatically actuated. During operation, an air cylinder drives the actuator upwards, allowing the neutron beam to pass through a beam guide. Gravity drives the shutter to its closed state where the neutron beam is blocked by a shielding block (see Fig. 1). The Instrument PSS interlocks the air to the instrument shutter through a solenoid valve.

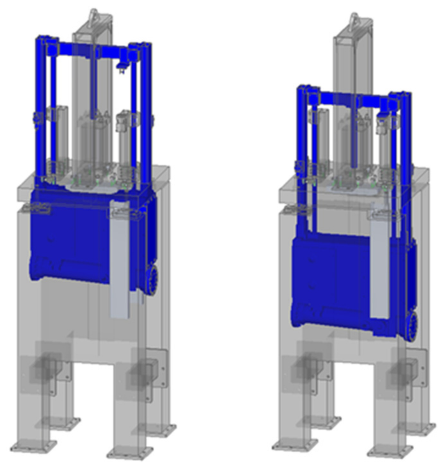

Figure 1: States of the instrument shutter.

The instrument shutters do not close instantly, and the closing time depends on many variables. e.g. shutter design (travel distance for the actuator, selected air cylinder, flow controllers), pneumatic pipes (route, diameter), and the airflow from the compressor. At ESS, there are several shutter types foreseen and each neutron instrument site is unique in layout and installation. As a consequence, the timing needs to be determined on a case-by-case basis for each system.

Even though it is favourable from a safety point of view for the closing time to be as short as possible, it is not feasible in practice as mechanical parts of the actuator may get damaged from the closing force, or cause excessive wear and tear over time. The reliability of the instrument shutter cannot be compromised.

The timing is planned to be determined during the integrated testing phase of the PSS commissioning plan where all interfacing subsystems of the neutron instrument have been installed and are ready for testing. At that stage, the variables have become constants, except for the flow controller. A variety of different fixed size orifice plates are to be used during testing to determine the proper size that supports the optimal closing of the shutter, i.e. fast enough to minimize the radiation exposure, and slow enough to minimize the mechanical damage to the shutter.

Another aspect of the timing is intrusion. Some access doors are heavy shielding doors that take a couple of seconds, or even minutes, to open. As of now, PSS registers an intrusion if the opening is more than a couple of millimetres. However, personnel may not be exposed to unacceptable levels of radiation until the opening is significantly wider. Depending on the radiation levels in the area, it might be possible to allow the shutter extra time to close before escalating specifically in intrusion scenarios. This approach would lessen the sensitivity, while not compromising on safety.

Expansion

From the start of the user programme, to steady-state operations and onwards, the ESS facility will undergo many evolutions. The expansion of the instrument suite is impending, as well as the ramp up of the accelerator to the maximum beam power of 5 MW. Design studies for a future particle physics program with a complimentary accelerator complex and an additional target station are advancing [4]. As the PSS are standardized and scalable systems, and they are thus inherently designed to accommodate changes. For dynamic environments as the test beamline, interfaces required for anticipated future operation are already established.

MRPD imposes a restriction on the maximum number of devices connected to the fiber ring. The limit is 32 devices and for the initial suite, including devices for Accelerator PSS, TS PSS, and Bunker PSS, the sum of active devices is 21. Each new instrument adds one device, allowing for a maximum of 25 neutron instruments connected to the fiber ring. As for now, the planned extension is to 22 instruments, and though possible to expand beyond that, technologies will likely have developed prior to being limited by the restriction. The contingency plan is a network of several rings.

CONCLUSION

The integrated approach achieves high availability and scalability. The ESS PSS are prepared for the upcoming goal of beam on target and trial neutron production, and beyond. However, the challenge regarding timing remains. Initially, a conservative number will be selected to err on the side of caution. During the trial process, the sensitivity will be meticulously adjusted to reach an optimal state.

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