Development and Realization of the ESS Machine Protection Concept

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Overview

1. The European Spallation Source ERIC (ESS)

2. Damage potential of the proton beam at ESS

3. Machine Protection at ESS: scope and concept

4. Top level requirements and results from first prototypes

5. Governance of Machine Protection at ESS

6. Summary
ESS in Lund/Sweden

- Brightest neutron source
- 17 European member states
- First spallation neutrons: 2019
- Full power operation: 2025
- Decommissioning: 2065
- Investment: 1843 MEURO
- Sustainable energy concept
- 95% beam availability
ESS in September 2015
ESS aims to house the most powerful proton LINAC ever built.

Average neutron flux is proportional to average beam power.

Average beam power will be: **5MW**

Average beam current: **62.5mA**

Proton energy per pulse: **360kJ**

Repetition rate: **14Hz**

Pulse length: **2.86ms**
ESS Target and Experimental Stations

Target with rotating tungsten wheel
Synchronized to 14Hz
Helium cooled

22 different neutron beam lines

Monolith: r=6m, h=10m
Target Wheel
He flow around slices
At 5MW, one beam pulse has:

The same energy as a 7.2kg shot travelling at 1100km/h (Mach 0.93).

This happens 14 times per second.
Assuming **worst case** scenario:

Proton beam impinging perpendicularly on copper or steel (2mm beam size).

The fastest reaction time required to stop the proton beam is **4-5μs** (within the first 50m).

This includes detecting, processing and actual stopping of the proton beam.

It’s a challenging task, requiring **fast** systems!
Scope of Machine Protection at ESS

Machine Protection (MP) needs to reliably:

- **protect** the “machine” **from damage**, be it beam-induced or resulting from any other source,
- **protect** the “machine” **from unnecessary beam-induced activation**.

Machine protection will be implemented in a way to:

- **minimize** unnecessary down-time due to **spurious trips**,
- provide optimal **support** for **failure localization**,
- **support** all **operational modes** of the facility,
- **avoid wrong configuration** of equipment,
- **support** operation in **degraded mode**.
Functional MP Architecture Concept

Machine Protection

- Proton Beam Monitoring Systems
- Local Protection Systems Accelerator
- Local Protection Systems Target
- Local Protection Systems Neutron Science

Beam Interlock System

Beam Switch-Off Actuation Systems

Proton Beam State

Higher-Level Operation Safety Critical Systems
BIS Concept (adapted from CERN)

Local Protection Systems, Beam Monitoring Systems (BCMs, BLMs, BPMs)

Beam Interlock System

Input Device

Driver

Driver

Interface Module

Master Module

Master of Masters

Actuator Interface

Actuator Interface

Actuator Interface

Actuator Interface

Proton Source

LEBT Chopper

MEBT Chopper

RFQ

Actuators
Top Level Requirements

Based on risk analysis (IEC61508, IEC61511)

Protection Integrity Level 2
\((10^{-6} - 10^{-7}/h)\)

- 35% of PIL2
  \(3.5 \times 10^{-7} - 3.5 \times 10^{-8}/h\)
- 15% of PIL2
  \(1.5 \times 10^{-7} - 1.5 \times 10^{-8}/h\)
- 50% of PIL2
  \(5 \times 10^{-7} - 5 \times 10^{-8}/h\)

Input System: 1 µs
Beam Interlock System: 2 - 3 µs
Actuators: 1 µs

4 - 5 µs

Requirements which are not trivial.

Two independent and diverse redundant beam interlock systems:

- Fast Beam Interlock FBI System/ FPGA based
- Slow Beam Interlock SBI System/ PLC based
First Prototype of the FBI System

See MOPGF138 from A. Monera Martinez for more details
Initial Results from FMEDA of the FBIS Prototype

See R. Andersson MOPGF126
The challenge is not only to build a Beam Interlock System, but to make sure the systems connected to it provide sufficient protection integrity.

Traceability of requirements and standardized documentation of all systems relevant for Machine Protection is very important.
## Governance of Machine Protection

### Machine Protection Committee: Take on responsibility and take decisions

**MPC domain/responsibilities:**
- Approval of concept, overall scope,
- Coordination of hazard risk analysis,
- Approval of overall machine protection requirements,
- Coordination of machine protection requirements allocation.

### Stakeholder Requirements

<table>
<thead>
<tr>
<th>Operations</th>
<th>Accelerator</th>
<th>Controls</th>
<th>Target</th>
<th>CF</th>
<th>NSS</th>
<th>PSS</th>
<th>TSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Requirements on work procedures, checklists, training for personnel - ...</td>
<td>- Provide systems suitable for allocated machine protection functions - ...</td>
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<td>- Provide systems suitable for machine protection functions,</td>
<td>XY, .....</td>
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<td>Provide run permit signal according to MP interface specification</td>
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### System Requirements

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### System Requirements

- Specification of signal, cable, connector type
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(Corresponding to analysis part of IEC61508)
Presented scope and concept for ESS Machine Protection.

Different concept ideas for the BIS are currently under investigation.

First prototyping started.

A decision making body is helpful when implementing Machine Protection at a complex facility like ESS.

Special thanks to the CERN team (R. Schmidt et al.) and the ZHAW team (C. Hilbes et al.).