SNS Credited Beam Power Limit System

Preliminary Design

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Abstract

The Controls Section at the Spallation Neutron Source (SNS) is designing a programmable signal processor based credited safety control\(^i\) that calculates pulsed beam power based on beam kinetic energy and charge. The system must reliably shut off the beam if the average power exceeds 2.145 MW averaged over 60 seconds. This paper discusses architecture and design choices needed to develop the system under the auspices of a programmable radiation-safety credit control.

\(^i\) A credited control is a documented and approved means to mitigate hazards to people or environmental.
SNS Overview: Short Pulse Neutron Source

The linac accelerates a 26 mA, ~1 msec long H⁺ beam

The accumulator ring compresses the pulse to ~700 nsec

@ 60 Hz, this represents a 1.4 MW proton beam power

Slide from N. Evans, SNS. 2021
SNS Proton Power Upgrade (PPU) upgrade power can exceed target power rating

- PPU doubles SNS proton beam capability from 1.4 MW to **2.8 MW**
  - 30% energy increase, 50% current increase
  - 2 MW target
  - Largely an extension of existing accelerator technology
  - Leverages built-in upgrade provisions

<table>
<thead>
<tr>
<th>Key performance parameter</th>
<th>Threshold</th>
<th>Objective</th>
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<tbody>
<tr>
<td>Beam power on target (MW)</td>
<td>1.7</td>
<td>2.0</td>
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<tr>
<td>Beam energy (GeV)</td>
<td>1.25</td>
<td>1.3</td>
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<tr>
<td>Target operation without failure (hours)</td>
<td>1250 × 1.7 MW</td>
<td>1250 × 2.0 MW</td>
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<tr>
<td>Stored beam in ring (ppp)</td>
<td>1.6 × 10^{14} at 1.25 GeV</td>
<td>2.24 × 10^{14} at 1.3 GeV</td>
</tr>
<tr>
<td>Number of installed PPU cryomodules</td>
<td>6</td>
<td>7</td>
</tr>
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BPLS is critical to safely meeting KPP Objectives

Slide from N. Evans, SNS. 2021
Beam Power Limiting System (BPLS) Calculates Both PPS and MPS Thresholds Based on Measured Beam Energy and Charge

\[ P = R_{rate} E_b \int_{t_o}^{t_o+w} I(t) dt \]

\[ E_b = \sqrt{E_0^2 + \left( \frac{cBL(I)}{\theta} \right)^2} - E_0 \]

\[ C_i = \max \{ t_j \in cycle \} \left( \int_{t_j}^{t_j+T_{pulse}} dt \ I(t) \right) \]

\[ P_{ave}^{PPS} = \frac{1}{60} \sum_{m=0}^{3599} E_b C_i, \quad \text{Accelerator Safety Envelope} \]

\[ P_{ave}^{MPS} = \frac{1}{10} \sum_{m=0}^{599} E_b C_i, \quad \text{Operations Envelope} \]
Requirements are for a credited system that...

- Provides highly reliable and accurate means to measure beam power
- Shuts off the proton beam through the PPS if beam power exceeds 2 MW for one minute
- Shuts off the proton beam through the MPS if the beam power exceeds 2 MW for 10 seconds [not part of the credited system]
- Incorporates self test, diagnostics, and modes for calibration
- Uses commercial off the shelf technology where possible
Credited Control Requires Design Pedigree Traceable to Standards

- **BPLS**
- **System**
  - Mechanical
  - Analog
  - Calibration
  - Digital
  - Safety PLC

**Standards**:
- IEC 15288
- IEC 61508
- Reqtracer
  - SRD
  - sSRD
  - DCM

**Other Standards**:
- IEEE Std 299.1-2013
- ISO/IEC 17025
- IEC 17025
- DO-254
- IEC 61508
BPLS Test FCM Installed in proton beam line

Installed FCT

Temporary spool to permit initial installation of a single FCT

D. Willis
BPLS Components Installed

- BPLS Stand w/ Covers
- New Bellows
- New Spool Pieces

D. Willis
DCCT Supports and Covers in SNS-8550, RTBT Support Building

1002 voting scheme. 2x3 DCCTs measured with the safety PLC to calculate beam energy
Test-stand progress

Beam Simulator

Safety PLC

MicroTCA and FPGA
The design and test are progressing well

• Status
  – System and subsystem requirements complete – making revisions after preliminary design review (PDR)
  – One FCM installed and tested with beam
  – One set of DCCTs are installed and accurately calculating beam energy
  – Micro-TCA based FPGA detail design in process
  – Integrated test stand incorporating analog, digital, and PLC hardware installed