BEAM LOSS CONTROL IN THE ISIS ACCELERATOR FACILITY

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Facility Overview

- H- Ion Source: ~50 mA, 300 µs pulse length.
- 665 KeV RFQ.
- 70 MeV Linac.
- 70 MeV injection line (HEDS).
- 800 MeV Synchrotron, 50 Hz, H- charge exchange injection, accelerating up to $3 \times 10^{13}$ protons per pulse, 200 KW.
- EPB1 delivers beam to Target station 1 at 40 pps.
- EPB2 delivers beam to Target station 2 at 10 pps.

A loss limited high intensity machine
Beam Loss Diagnostics

- **ISIS Beam Loss Monitors**
  (3 m, coaxial ionisation chambers)
  - BLM Sensitivity
    ~1x10^9 protons @ 70 MeV,
    ~7x10^6 protons @ 800 MeV

- **ISIS Intensity Monitor**
  (transformer)

- **Scintillator Loss Monitor**
  (plastic BD408)

- **Intesity monitor sensitivity**
  ±3x10^{10} ppp
Beam Diagnostic Layout

- Loss levels from these diagnostics are monitored every 50 Hz pulse
- The protection system response depends on severity and longevity of the beam loss and associated hazard
- Ranging from switching beam off, inhibiting for a few pulses, to issuing warnings

<table>
<thead>
<tr>
<th>Component</th>
<th>Intensity Monitor</th>
<th>Beam Loss Monitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Source</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>RFQ</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Linac</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>HEDS</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Synchrotron</td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td>EPB1</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>EPB2</td>
<td>5</td>
<td>15</td>
</tr>
</tbody>
</table>
Injector Operation

- Beam loss optimised using:
  - Ion source extract volts
  - LEDS solenoids
  - RFQ and linac phases
  - Tank and HEDS quadrupoles.

- Dominant loss is Tank 1: 70-80 % transmission.

0.1 Vs is equivalent to $2.3 \times 10^9$ lost H$^-$ particles.
Injector Operation: Simulation and Possible Upgrade

From: C Plostinar, C Prior, G Rees, A Mitchell, A Letchford, “Modelling the ISIS 70 MeV Linac”, p3859, THPPP052, IPAC12

- Improve Matching between RFQ and Linac tank 1 with the addition of 4 quads and 2 buncher cavities.
- Simulations suggest almost lossless transmission.
Ring Operation: Injection

- H\(^+\) charge exchange injection over \(\sim 130\) turns accumulating \(\sim 3\times10^{13}\) protons with efficiency >98\%. Anti-correlated painting.

- Foil stripping efficiency \(\sim 98\%\). Un-stripped beam transported to dump producing BLM signal R0BLM3.

- Un-tunable increases in R0BLM3 give indication of foil failure.

- \(\sim 30\) foil re-circulations for each injected proton result in scattering and losses.
  - These are localised mostly in the injection and collector straight.

- Beam loss optimisations include 6D phase space control in both injection line and ring. Use: HEDS quads, dipoles, linac RF, ring RF, and transverse injection painting parameters.
Ring Operation: Trapping and Acceleration

- Beam trapped and accelerated from 70-800 MeV in 10 ms
- Addition of dual harmonic RF system increased operating trapping efficiency (0.0-2.5ms) from >90% to >95%
- Acceleration losses (2.5-10.0 ms) <1%
- Longitudinal losses driven by fast trapping of unbunched (non-chopped) injected beam
- Transverse losses driven by high intensity effects mostly mitigated by betatron tune variation.
- Losses localised to super period 1 and 2 by the use of collectors
Ring Operation: Collectors

Side View of Collimator Straight

View of ISIS Collectors

Output from Scintillator BLMs (in ISIS main dipole after collectors)

Beam Damage!
Ring Operation: Extraction

- Ring extraction: Vertical closed orbit bump and single turn fast extraction using 3 kickers.
- Originally operated with 12 µVs loss.

- Vertical beam emittance $283\pm20 \, \pi \, \text{mm mrad}$ (measurements using orbit bumps and BLMs)

- Engineering vacuum vessel apertures show acceptance on extracted turn is $220 \, \pi \, \text{mm mrad}$. (acceptance limited by quad doublet and septum)

- New larger aperture septum and new vertical bump increases acceptance to $280 \, \pi \, \text{mm mrad}$. (new elements installed in 2000)

Vertical beam loss on near-by blm reduced from 12 µVs to <1 µVs.
Beam Optimisation

- Many key parameters require time dependent control
- Use in-house arbitrary waveform “function generators”
  Typically optimise at 20 points during 50 Hz cycle
  e.g.
  Vertical sweeper (injection painting)
  Trim quadrupoles (betatron Q’s)
  Steering magnets (closed orbits)
  RF volts, phase, loops (longitudinal params)

- For many of these there are two sets of generators
  *Normal* (~50 Hz) and *Experimental* (< 1.6 Hz)
  Allow online optimisations during user runs.

- Beam loss management strategy is to push all losses
  onto collector straight in sp1.
Ring Beam Loss Simulations

• ORBIT simulations of ISIS RCS include
  Injection and Acceleration (3D space charge)
  Injection painting, foil scattering, …
  Corrected RF (close agreement in longitudinal)
  Collimators and vacuum vessel apertures
  (D J Adams, IPAC12, THPPP088, p3942)

• Total Beam Loss
  Simulated 3%, Measured 7%

• Time structure - reasonable agreement

• Beam loss on H&V collimators
  About 50% on each as measured

• Very valuable tool
  Doesn’t include all effects (errors, instabilities …)
  Shows we still have much to understand!
800 MeV Transport

3.5 V signal on BLM number ten equivalent to \(1.2 \times 10^{12}\) lost protons. Produced by 10 mm thick graphite target used for muon production.

Low loss achieved by setting beam line aperture at 100% emittance + 20 mm.
Summary

• We have outlined the diagnostics, methods and systems used to operate ISIS – a loss limited high intensity machine

• These systems have allowed reliable operation with well controlled dose rates and minimal machine damage over ~28 years

• We expect use of very similar systems and ideas for proposed ISIS upgrades