OPERATIONAL EXPERIENCE AND FUTURE PLANS AT ISIS

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Contents

• Brief overview of ISIS
• Beam performance
• Main Accelerator Upgrades
• Operations and Accelerator R&D
• Future Projects
IScIS Facility

- Neutron and Muon source used for condensed matter research by 3000 users.
- H- ion source (55 mA)
- 665 keV RFQ (35 mA)
- 70 MeV linac (26 mA)
- 800 MeV 50 Hz, RCS ($2.8 \times 10^{13}$ ppp)
- Target 1 + Muon target (140 kW)
- Target 2 (36 kW)
Beam Performance

- First Beam in 1984, user operation in 1985, achieving full design current 160 kW (2.5x10^{13} ppp) in 1992.

- Operation is beam loss limited to facilitate hands on maintenance.
Super Period 1 upgrade (2002)

- Up to 10% Trapping and Acceleration loss managed on collimation systems to prevent machine damage and activation.

- Collimators upgrades in 2002
  13 Copper and Graphite water cooled blocks intercept ~ 2 KW.

- Energy capture range extended from 100-300 MeV
Pre-Injector Upgrade (2004)

- Replace aging Cockcroft Walton 665 keV injector with an RFQ
- Improved linac current from 19 mA to 26 mA allowing more ring power.
- 18 month offline test, internal cleaning for RF conditioning only issue.
• Ring RF, 6 cavities (h=2), 160 kV/turn 200 μA operation with 9% ring losses

• Add 4 cavities, h=4, 80 kV/turn, increased RF bucket acceptance and better bunching factors, 200 μA operation with 3 % loss.

• Achieved 230μA operationally and 250 μA during machine physics.
EPB1 Upgrades (2006-2015)

Muon Target (10 mm graphite) scatters proton beam to:
collimators 1.4 %
uncontrolled 0.47 % (quads+B)

Reduce collimator acceptance
Larger quads, 2 extra (optic flex)
Uncontrolled 0.06% @ B

Quad inserts for additional steering.
Main operating issues are managing Ring beam loss.

<table>
<thead>
<tr>
<th>Injection (−0.4–0 ms) 1% loss</th>
<th>Strip efficiency &gt; 99 %, scattering loss, ~30 recirculation</th>
<th>Painting emittance Amps, Tune, Transverse Optics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration (0–10 ms) ~3% Loss</td>
<td><strong>Transverse:</strong> ΔQ_{inc} &gt; −0.5 @ 0.4 ms. Machine Error. Vertical Head Tail @ 2 ms</td>
<td>Painting Amps, Tune, Envelopes Orbits, Bunching Factor. Ring RF.</td>
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<tr>
<td></td>
<td><strong>Longitudinal:</strong> Non-adiabatic trapping loss.</td>
<td>Injected ΔE/E, debuncher Φ, V Ring RF bucket V_{1}, V2, Φ, freq</td>
</tr>
<tr>
<td>Extraction &lt;0.1 %</td>
<td>Horizontal and vertical Halo scraped</td>
<td>Extract position, envelope</td>
</tr>
</tbody>
</table>
• Operation with 4 % beam loss

• Correct machine orbits and envelopes errors then empirically tune on beam loss.

• 20 quads, 13 dipoles, Time dependant functions, ~20 steps in 10 ms.

• Strategy: Move beam loss to collimators and then minimise overall loss.
• Ring Diagnostics: Intensity, beam loss, profile, position.

• Make more use of these by utilising developments to DAQ and CPU power: More acquired signals, data visualisation and comparison, automated measurements, model fitting and corrections.

• Fast measurements (< 1s) make machine tuning/error diagnosis, parameter rather than signal lead.

• FPGA technologies, 50 Hz is possible.
Synchrotron Operating Limit

• In current configuration machine capable of accelerating $3.15 \times 10^{13}$ with 9 % loss equivalent to 250 µA operation (200 kW)

• Limited by:
  - machine acceptance (collimated to 75 %)
  - (beam control/alignment)
  - Head Tail Instability

• Operated at 1.6 Hz only

Beam Loss Sum

- 198 uA, 2 cavities jun 2012
- 250 uA, 3 cavities jun 2013
- 245 uA, 4 cavities june 2016
• Beam damage inside dipole caused by small uncontrolled loss from collimation straight.

• Normal BLM’s outside dipole yoke shielded from loss.

• New non-metallic scintillator based BLM positioned inside rapid cycling dipole field to detect losses.

• Scintillators allow collimator and beam tuning setup without hitting dipole

• All ring dipoles will have scintillators by 2017
Multi Channel Profile Monitor

- Accurate transverse profile measurements key to machine setup and R&D topics.

- Residual Ionisation Profile monitors in development:
  - 40 channeletrons,
  - Non destructive

- Accurate reconstructed profiles require understanding effects of ion trajectory from
  - Guide fields
  - Space charge field
  - Channeletron response
Head-Tail Instability

- Driven by impedances
  Resistive wall (?),
  R Williamson MOPR031
  Operation:
    Vertical Q ramp
    Asymmetric bunches
- Damper system in development, 2018 operation

Normal beam
  Low loss

Normal beam + $\Theta$ shift
  Large loss!

ISIS Beam Bunches at ~ 2 ms

Sum signal

Difference signal

Beam Loss vs Time 0-5 ms

Loss!
Bunch Compression

Why shorten bunch?
- To improve frequency response of muon instruments
- Maintain low beam loss and good beam quality

Machine setup
- Ramp RF voltage down slowly before rapidly increasing ~0.2ms before extraction
- Step frequency law trim in final 0.2ms
- Switch off bunch length and phase loops in final 0.2ms
- Tweak extraction to reduce loss

Plans
- Test at higher repetition rates
- Further extraction beam loss reduction
- Different methods of bunch compression

Final turn FWHM reduction of >50%

Compressed
Uncompressed

R E Williamson, R J Mathieson, D J Adams, et al
Goal: Understand ring loss dynamics.

ORBIT model: fitted to measured transverse and longitudinal profiles.

Predict losses and visualise dynamics for machine tuning.

Measured 2% Loss  Simulated 0.5% loss

Implementing non linear magnets at moment
FLUKA Studies – ISIS Collectors

- SP1 collector straight modelled in FLUKA
- ORBIT beam loss input
- 170 mSv/hr measured, 415 mSv/hr simulated
- Total simulated power deposition 663 W, operationally 500–1500 W
• One of the main loss mechanism on ISIS

• Measured and simulated with ISIS in storage ring mode.

• Lobe behaviour acts as expected as a function of driving term and tune.

• Mathematical description in development with promising results. (Chris Warsop, MOPR030, HB2016)
• Effects of space charge and image forces from ISIS conformal rectangular vacuum vessels under study with in house SET3D code.

• Closed orbit errors generating sextupole resonances.

• Large deviations from design tune lead to reductions in machine acceptance and non linear driving terms.
MEBT upgrade

Improve Matching between RFQ and Linac tank 1

Currently loose ~ 25 % beam.

Install MEBT to match into Linac Tank 1

7 Quads and 2 buncher cavities, 96 % transmission

Increase linac transmission current from 26 mA to 36 mA

Installation in 2019
• ISIS RCS has 200 µs injection interval (133 turns). Dispersive horizontal painting 10-140 π mm mrad, Non adiabatic RF capture losses ~ 3 %

• MEBT chopper, 61 % chopping factor, ± 55° degrees RF in ring, variable timing. Inj time: 26 mA ~300μs , 36 mA ~ 200 µs

• H⁻ Paint changes with pulse length, Peak space charge moves from 80 to 70 MeV. Studied in ORBIT to see impact on losses.
Future Upgrades

- Future upgrade paths under study, taking into account ISIS Instrument, Neutronics, Target and Accelerator groups.

- Accelerators options under consideration:
  - Increase ISIS injection energy to 180 MeV with upgraded linac, 0.5 MW
  - Multi MW Synchrotron or FFAG
    (C. Prior WEAM6X01 talk tomorrow)

- Front End Test Stand (FETS): 60 mA, H⁻, 3 MeV technology demonstrator for next gen facilities. First RFQ beams this year.
  - Could be used to feed a new low energy FFAG, necessary for high power FFAG R&D.
Conclusion

• Since first operation in 1984 ISIS has continued to improve in operating intensity and beam control maintaining its position as a world class neutron facility.

• Numerous hardware upgrades and Accelerator R&D have provided extensive experience on how to operate a machine for nearly 4 decades and how to manage operations working near a realistic intensity limit.

• A future ISIS-II is under study to best utilise our experience as well as knowledge gained from the operation of other high power facilities.