H⁻ Injection into the ISIS Synchrotron

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Content

• Who, what, where is ISIS?
• Injection scheme
• In-house foil manufacturing
• Beam measurements and simulations
• Upgrade plans
ISIS

- World leading spallation neutron source
- 30 years of operation
- 2000 users, 750 experiments/year
- 4 or 5 user runs per year
  - 24hr operation for 35-40 days
  - Around 90% beam availability
**ISIS**

**Ion Source:** 50mA peak, 200 μs, 50 pps
**RFQ:** 4-rod, 665 keV, H⁻
**Linac:** 70 MeV H⁻, 202.5 MHz, 25 mA

**Synchrotron:** 800 MeV protons, 3.0x10^{13} ppp max Q_{(h,v)} = 4.31, 3.83

Ten superperiods
- Doublet, Singlet, CF Dipole
- 20 Trim Quads & 13 Steerers
- No multipoles

RF -
- Six h=2 (1.3-3.1 MHz)
- Four h=4

~£35M/year operating budget
~350 staff - 150 in accelerator division
Synchrotron Hall

The 7GeV proton synchrotron
Acceleration Cycle

Injection:
~ 200 μs pulse
3x10^{13} ppp over ~ 135 Turns
~ 97-99% Efficient

Trapping and acceleration:
70 – 800 MeV in 10 ms
~ 95-98% Efficient

Fast Vertical Extraction:
~100% Efficient
ISIS Injection

- Four 12kA dipoles
- 65mm bump
- ~200 ug/cm² Al₂O₃ foil
- Vertical ‘sweeper’ magnet
- Horizontal painting achieved by closed orbit movement
Injection Timing

Injection Dipole

Vertical Sweeper

B Field

Ring Intensity

Dispersion Closed Orbit

Vertical Sweep Amplitude
Injection Dump

40mm long
Water cooled graphite
200W waste beam
ISIS Foil

Make foil template from 99.9% Al foil 0.15mm thick
Anneal in vacuum furnace – 360°C, 8 hrs
Anodise to thicken Al₂O₃ layer – 180V, 10 min
Anneal again
ISIS Foil

Scour one side of foil
Etch in Bromine solution
Rinse in Acetone
ISIS Foil

Coat both sides with 0.25um Al
Shelf life ~ 6 months
Diagnostics

- 39 Argon filled ionisation chamber Beam Loss Monitors (BLMs)
Diagnostics

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Diagnostics

• 30 split cylinder electrode Position Monitors (BPMs)
Diagnostics

0ms

10ms
Diagnostics

- 5 residual gas ionisation profile monitors – 2 multi-channel
Beam Distribution
Diagnostics

- 2 Toroidal intensity monitors
Orbit Correction

- Turn-by-turn DAQ of full cycle in 1 plane
- IDL front-end to MAD-X lattice model
- RMS orbit deviations reduced to 2-3mm in both planes.
Painting Measurement

\[ y_n = A.e^{-\left(\frac{(\pi n \delta Q)^2}{2}\right)} \times \cos\left(2\pi n\left[Q_0 + \frac{n\Delta Q}{2}\right] + 2\pi \phi\right) + n\Delta R + R_0 \]

- \( y_n \): Position of nth turn
- \( \delta Q \): Q spread
- \( A \): Initial betatron amplitude
- \( \phi \): Initial betatron phase/2\pi
- \( Q_0 \): Initial Q value
- \( \Delta Q \): Change in Q per turn
- \( R_0 \): Initial closed orbit
- \( \Delta R \): Change in R per turn

- Measured betatron amplitude
- Measured closed orbit
- Calculated betatron amplitude
- Calculated closed orbit
### Painting Measurement

\[ y_n = A_e^{\left(\frac{\pi n \delta Q}{2}\right)} \times \cos\left(2\pi n \left[ Q_0 + \frac{n \Delta Q}{2} \right] + 2\pi \phi \right) + n \Delta R + R_0 \]

- \( y_n \): Position of the \( n \)th turn
- \( A \): Initial betatron amplitude
- \( \phi \): Initial betatron phase/2\( \pi \)
- \( Q_0 \): Initial Q value
- \( \Delta Q \): Change in Q per turn
- \( R_0 \): Initial closed orbit
- \( \Delta R \): Change in R per turn

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**Graphs:**
- Measured betatron amplitude
- Measured closed orbit
- Calculated betatron amplitude
- Calculated closed orbit

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**Equation Breakdown:**
- \( y_n \) represents the position of the \( n \)th turn.
- \( A \) is the initial betatron amplitude.
- \( \phi \) is the initial betatron phase divided by \( 2\pi \).
- \( Q_0 \) is the initial Q value.
- \( \Delta Q \) is the change in Q per turn.
- \( R_0 \) is the initial closed orbit.
- \( \Delta R \) is the change in R per turn.

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**Graph Details:**
- The graphs show the measured and calculated behavior of betatron amplitude and closed orbit over time.
- The measured data is represented by solid lines, while the calculated data is represented by dashed lines.
- The graphs provide a visual comparison between the measured and calculated values over time.
Simulation in ORBIT

**Horizontal**

- $2.5 \times 10^{12}$ ppp
- $2.5 \times 10^{13}$ ppp
- $2.5 \times 10^{12}$ ppp
- $2.5 \times 10^{13}$ ppp
- $-0.3$ ms
- $-0.2$ ms
- $-0.1$ ms

**Vertical**

- $2.5 \times 10^{12}$ ppp
- $2.5 \times 10^{13}$ ppp
- $2.5 \times 10^{12}$ ppp
- $2.5 \times 10^{13}$ ppp
- $-0.3$ ms
- $-0.2$ ms
- $-0.1$ ms

**Simulation in ORBIT**

- Horizontal and Vertical graphs showing intensity profiles and ORBIT profiles.
Beam Loss Studies of the ISIS Synchrotron Using ORBIT – DJ Adams – IPAC’12

Upgrade plans

• Injection Dipole Power Supply
  – Individual magnets, achieve design current

• New foil change mechanism
  – New viewing port, multiple foils

• Tests of alternative foils
  – Collaboration with CSNS/JParc
### 180 MeV Injector

<table>
<thead>
<tr>
<th></th>
<th>Present</th>
<th>Upgrade</th>
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<tbody>
<tr>
<td><strong>Magnet Field</strong></td>
<td>Sinusoidal</td>
<td>Sinusoidal</td>
</tr>
<tr>
<td><strong>Energy Range</strong></td>
<td>70–800 MeV</td>
<td>180–800 MeV</td>
</tr>
<tr>
<td><strong>Intensity</strong></td>
<td>2.5–3.0x10^{13} ppp</td>
<td>~ 8.0x10^{13} ppp</td>
</tr>
<tr>
<td><strong>Mean Power</strong></td>
<td>160–200 kW</td>
<td>~ 500 kW</td>
</tr>
<tr>
<td><strong>Injection</strong></td>
<td>H^+, inside</td>
<td>H^+, outside</td>
</tr>
<tr>
<td><strong>Longitud Trapping</strong></td>
<td>“adiabatic capture”</td>
<td>chopped beam</td>
</tr>
<tr>
<td><strong>RF System DHRF:</strong></td>
<td>( f_2 = 1.3–3.1 \text{ MHz} )</td>
<td>( f_2 = 2.0–3.1 \text{ MHz} )</td>
</tr>
<tr>
<td>( h = 2, 4 )</td>
<td>( V_{pk} = 80, 160 \text{ kV} )</td>
<td>( V_{pk} = 80, 160 \text{ kV} )</td>
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Questions?