Commissioning the Rutherford Appleton Laboratory (RAL) Scaled Penning Surface Plasma Source

Dan Faircloth

Low Energy Beams Group Leader

Scott Lawrie, Theo Rutter, Mark Whitehead, Trevor Wood, Vadim Dudnikov
Motivation for a Scaled Source

1. Front End Test Stand (FETS)
   To fulfil the full 2 ms 50 Hz requirements

2. ISIS Spallation Neutron Source
   Reduce power density > reduce sputtering >
   increase lifetime
What is FETS?

A test stand to demonstrate a perfectly chopped 60 mA H⁻, 3 MeV, 2 ms, 50 Hz beam.
What is FETS?

High brightness H⁻ ion source
- 60 mA, 0.25 π mm mrad beam
- 2 ms, 50 Hz pulsed operation

Radio Frequency Quadrupole
- four-vane, 324 MHz, 3 MeV
- 4 m bolted construction

Low Energy Beam Transport
- 3 solenoids

Medium Energy Beam Transport
- 9 quadrupoles
- 3 re-bunching cavities
- novel ‘fast-slow’ perfect chopping

Diagnostics
- non-interceptive
- BPM’s
- CT’s
- laser-based

Beam dumps
- defocussing quads
- water cooled pure Al cones
FETS Status

- High brightness H⁻ ion source
- Radio Frequency Quadrupole
- Beam dumps

Low Energy Beam Transport
- Fully commissioned

Medium Energy Beam Transport
- 9 quadrupoles – complete

Diagnostics
Quadrupoles

7 short

2 long
FETS Status

High brightness H⁻ ion source

Radio Frequency Quadrupole

Low Energy Beam Transport
Fully commissioned

Medium Energy Beam Transport
• 9 quadrupoles - complete
• Re-bunching cavities – in manufacture
• Chopper- final components in manufacture

Diagnostics
Tested at CERN
BPM’s calibrated

Beam dumps
Delivered

Infrastructure
Infrastructure

Shielding
Power
Cooling plant
RF
Interlocks
Controls
FETS Status

High brightness H⁻ ion source

Radio Frequency Quadrupole
3 sections complete...

Low Energy Beam Transport
Fully commissioned

Medium Energy Beam Transport
- 9 quadrupoles - complete
- Re-bunching cavities – in manufacture
- Chopper- final components in manufacture

Diagnostics
Tested at CERN BPM’s calibrated

Beam dumps
Delivered

Infrastructure
Shielding
Power
Cooling plant
RF
Interlocks
Controls

Delivered

Science & Technology Facilities Council
ISIS
RFQ Construction

Sections made of 2 major and 2 minor vanes

4 x 1 m long sections bolted together

3D o-ring

Vanes bolted together to make 1 m sections
Errors in minor vanes

![Graph showing errors in minor vanes along the distance along RFQ (mm)]
Error in field flatness can be compensated using existing tuners.

Change in transmission by simulating the minor vane errors is <1%.

Final machining of section 4 now underway.
FETS Status

High brightness H⁻ ion source
Fully commissioned at half duty cycle requirement

Radio Frequency Quadrupole
3 sections complete…

Low Energy Beam Transport
Fully commissioned

Medium Energy Beam Transport
- 9 quadrupoles - complete
- Re-bunching cavities – in manufacture
- Chopper- final components in manufacture

Diagnostics
Tested at CERN BPM’s calibrated

Beam dumps
Delivered

Infrastructure
- Shielding
- Power
- Cooling plant
- RF
- Interlocks
- Controls
Limit of the present source

either

60 mA 1 ms 50 Hz

or

60 mA 2 ms 25 Hz

Droop is unavoidable at 50 Hz 2 ms
Duty factor limited by the ability to maintain optimum Cs coverage.

Cs coverage is strongly influenced by electrode surface temperature...

1. TRANSIENT PROBLEM
   Temperature rise during the pulse
   \[ \Delta T^\circ = 160^\circ C \]

   **SOLUTION**
   Reduce plasma power density by increasing surface area
   <0.2 mm

2. STEADY STATE PROBLEM
   The cooling system’s ability to maintain the average electrode surface temperatures

   **SOLUTION**
   Improve cooling

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600-800°C
Mechanical Design

CFD cooling simulations

See Theo Rutter’s Poster TuePE27

Air

Water

2.2 ms 50 Hz operation

Cathode heater system

arbitrarily low duty cycles + easier start up
RAL x2 Scaled Source

- permanent magnet
- Penning field
- extraction electrode
- support insulators
- caesium shields
RAL x2 Scaled Source

- cathode
- plasma volume
- caesium feed
- hydrogen feed
- hollow anode
- air cooling
RAL x2 Scaled Source

140 mm diameter flange
RAL Standard Source Plasma Chamber

Penning field

0.6 mm

3.5 mm

0.75 mm

10 mm

10 mm

2.1 mm

sectional views
RAL x2 Scaled Source Plasma Chamber

sectional views

10 mm

8.5 mm

0.75 mm

20 mm

4.2 mm
RAL Double Depth Scaled Source Plasma Chamber

sectional views
RAL Double Width Scaled Source Plasma Chamber

sectional views
Extraction Aperture

- Slit and circular

- 10-20 mm
- 0.6 - 1.2 mm
- 2.8 - 5.5 mm diameter
Components:
- moly aperture plate
- shapal aperture plate insulator
- moly anode
- moly cathode
- macor cathode spacer
- cathode heater block
- macor insulator
- Penning magnet holders
- extraction electrode, support and insulators
- cathode heaters

Parts:
- Penning magnet holders
- Extraction electrode, support and insulators
- Cathode heaters
Source body – delivery due 1st week of August

#fail
Source will be installed on VESPA test stand

VESPA = VEssel for Source Plasma Analysis
Detailed Optical Plasma Study

See Scott Lawrie’s Poster TuePE19

- Density measurements
  - Atom Density = 9 \times 10^{11} \cdot l_{arc}^{-0.5}
  - Electron Density = 2 \times 10^{18} \cdot l_{arc}^{0.5}

- Temperature measurements
  - Atoms
  - Electrons

- Perveance measurements
  - Using a high resolution monochromator
  - Argon admixture experiments
  - Calibrated power measurements
Lifetime

- Maximising lifetime is important for ISIS operations
- Lifetime limited by electrode sputtering
- Other electrode materials to be investigated
Refractory Metals

<table>
<thead>
<tr>
<th>Melting point °C</th>
<th>2623</th>
<th>3422</th>
<th>3186</th>
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<tbody>
<tr>
<td>Density g.cm(^{-3})</td>
<td>10.28</td>
<td>19.25</td>
<td>21.02</td>
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<tr>
<td>Vickers hardness MPa</td>
<td>1530</td>
<td>3430</td>
<td>2450</td>
</tr>
</tbody>
</table>
ISIS Operation Source Electrode Erosion Database

Over 140 sources

Number of days running

5 9 14 20 24 30 36
Improvements on ISIS

- Minimise low energy beam loss
Improved extraction system
Improvements on ISIS

- Minimise low energy beam loss
- Minimise medium energy beam loss
ISIS Pre-injector Reconfiguration

ISIS currently has no MEBT and loses ~30% beam

DTL Tank 1

3.2 m available for MEBT

RFQ

Walls removed, new floor built, crane extended

See Trevor Wood’s Poster TuePE37
Improvements on ISIS

- Minimise low energy beam loss
- Minimise medium energy beam loss
- Source can be run at lower discharge currents
- Reduced sputtering damage
- Longer lifetimes
Thank you for your attention

Questions, Comments?