Ion Source Emittance Measurements at RAL

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Abstract
This report is a companion to the presentation given at the CARE workshop entitled “ABI Workshop on Transverse and Longitudinal Emittance Measurement in Hadron Accelerators”. The workshop was held in Bad Kreznach from 10 to 12 December, 2008. An overview of the three ion sources at RAL is presented, followed by a brief outline of the development work that lead to source design changes. Pepperpot emittance measurements for a beam propagating in a drift space are also shown. In addition to the author this paper contains the work of Scott Lawrie, Alan Letchford, Christoph Gabor, Mark Whitehead, Trevor Wood, Juergen Pozimski, Simon Jolly, Peter Savage, Mischa Woods and Virginie Papadopoulou.

INTRODUCTION
The ISIS H Penning Surface Plasma Source (SPS) has been a world leading operational H ion source for 20 years; it routinely produces 35 mA of H ions during a 200 us pulse at 50 Hz for uninterrupted periods of up to 50 days. Recently the source has been developed to increase its output and improve beam quality. Transverse emittances are a key measure of beam quality, this paper outlines the emittance measurements performed during the development program.

ION SOURCES AT RAL
There are three ion sources operating at RAL, all are based on the ISIS operational source with minor design modifications. The table summarizes the performance of the three sources.

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy keV</th>
<th>Current mA</th>
<th>Duty Cycle @ 50 Hz</th>
<th>Emittance πmm.mrad</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISIS Operational</td>
<td>35</td>
<td>35</td>
<td>200 μs</td>
<td>0.2</td>
</tr>
<tr>
<td>Ion Source Development Rig</td>
<td>35</td>
<td>Up to 80</td>
<td>200 μs –2 ms</td>
<td>0.1 - 1</td>
</tr>
<tr>
<td>FETS</td>
<td>65</td>
<td>60</td>
<td>2 ms</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The ISIS Operational H Source
The source is of the Penning Surface Plasma type, comprising a molybdenum anode and cathode between which a low pressure hydrogen discharge is struck. The basic construction is shown in figure 1. Hydrogen and cesium are fed into the discharge via holes in the anode. The anode and cathode are housed in the stainless steel source body. The anode is thermally and electrically connected to the body, whereas the cathode is isolated from the body by means of a ceramic spacer. The whole assembly is bolted to the ion source flange, separated by a thin layer of mica to provide electrical isolation for the cathode. The ions are extracted through the 0.6 x 10 mm extraction slit in the aperture plate.
Figure 1: The ISIS H⁻ ion source. The figure shows a cross section through the source.

After extraction the beam is bent through 90°, then further accelerated to 35 keV as shown in figure 2. The 90° bend analyzes out all the electrons and negatively charged molecular Hydrogen leaving only H⁻ ions. The analyzing magnet sits in a refrigerated box, this serves as a Cesium trap to prevent Cesium vapor entering the next stage of the accelerator. The magnet also enlarges the beam in the horizontal direction, so that the slit extracted beam is expanded to have an equal aspect ratio after post acceleration.

Figure 2: The 90° analyzing magnet and post acceleration system.
**Ion Source Development Rig Source**

A crucial part of the ion source development program is the ability to test sources off-line. The Ion Source Development Rig (ISDR) allows development to continue without compromising the operation of ISIS. The ISDR is basically a copy of the ISIS source but with two important modifications: the Penning field is provided by a separate magnetic circuit to allow the source to operate at different extraction voltages and Penning fields; and the source mounting has been modified to allow sources of different sizes to be tested.

The key to understanding beam behavior is a comprehensive set of diagnostics. The ISDR is equipped with a diagnostic vessel onto which various measurement devices can be mounted:

- A pair of X and Y slit-slit emittance scanners are permanently mounted on the sides of the diagnostic vessel and can be retracted without stopping the source.
- A pepperpot emittance device can be mounted on the rear of the vessel. The pepperpot can be moved along the axis of the beam and can be moved onto the same measurement plane as the slit-slit scanners whilst the beam is running.
- The head of the pepperpot can be replaced by a scintillator profile measurement head, allowing profile measurements along the axis of the beam.
- A retarding potential energy analyzer can be mounted on the rear of the vessel in the place of the moveable pepperpot/profile device.
- Beam current is measured via a torroid permanently mounted on the entrance to the diagnostics vessel.
- A buffer gas delivery system mounted directly after the beam current torroid allows for the controlled and measured introduction of various gasses to study the effect of space charge.
- A dipole magnet can be installed in the vessel to study the degree of stripping in the beam.

In addition there is pressure monitoring and a full set of ion source parameter monitoring; source temperatures, power supply voltage and current monitoring.

**FETS Source**

The aim of the Front End Test Stand is to develop a high power driver for generic applications including drivers for spallation neutron sources, neutrino factories, waste transmuters and tritium production facilities. FETS is currently being constructed at RAL. The installed ion source implements the designed modifications developed on the ISDR to allow it to work at longer duty cycles with improved emittance and increased output current.

The next section discusses the development work that lead to design modifications in three key areas: extraction, 90 degree analysing magnet and post acceleration.
DESIGN MODIFICATIONS AND EMITTANCE MEASUREMENTS

Modified Extraction Electrodes

Previous finite element modelling and particle tracking work[1] suggested that the vertical emittance could be improved by terminating the extraction jaws. It also suggested that the horizontal emittance could be improved by changing to electrodes with a Pierce profile. Figure 3 shows the three extraction electrodes that were tested on the ISDR.

![Extraction electrodes and aperture plates for the ISIS standard geometry (centre), terminated standard geometry (left) and Pierce geometry (right).](image)

As predicted the vertical emittance is reduced when using terminated extraction jaws, however the increased space charge density causes the horizontal emittance to increase slightly. When the terminated Pierce profile is employed, the horizontal emittance is reduced, but again because the beam profile is squeezed smaller space charge forces increase the emittance slightly in the vertical plane.
Modified 90 Degree Analysing Magnet Pole Pieces

Modelling work [2] has shown that the original design of the 90 degree analysing magnet pole pieces was not optimal: the poles had a field gradient index of 1.4 and the good field region was not large enough to transport the entire beam around the 90 degree sector dipole. Figure 5 shows the simulated results for the original design and three new pole pieces tested on the ISDR.

Figure 6 shows the results for the $n = 1.4$ and $n = 1.0$ field gradient index cases. The effect on beam aspect ratio can easily be seen. To get an equal aspect ratio beam a field gradient index of about $n = 1.2$ is required.
Figure 5: Finite element model results showing the field gradient index contours integrated around the sector of the analyzing dipole. The ISIS operational source pole tips are shown on the far left.

\[ n = -\frac{R_e}{B_e} \left( \frac{dB}{dR} \right) \]

Figure 6: Horizontal and Vertical emittance measurements for the \( n = 1.4 \) and 1.0 field gradient index pole pieces. Profiles are also shown.
**Modifying the Post Acceleration Gap**

Simulations [3] have shown that the optimum post acceleration field for minimum emittance growth is about 9 kVmm\(^{-1}\). Figure 7 shows the effect modifying the length of the post acceleration gap has on emittance and beam profile.

![Graphs showing emittance and profile measurements for different post acceleration gap settings](image)

**Figure 7:** Emittance and profile measurements for different post acceleration gap setting with a 25 kV post acceleration voltage.
MOVEABLE PEPPERPOT MEASUREMENTS

Using the movable pepperpot emittance device on the ISDR it is possible measure the beam’s propagation though a drift space. Figure 8 shows pepperpot measurements taken at three different positions downstream from the ground plane of the post acceleration gap.

11kV Standard Extract n = 1 Pole Pieces 35 mA beam

![Figure 8: Movable pepperpot emittance and profile measurements taken on a beam at three different positions along the path of the beam. The beam is propagating through a drift space.](image)

Phase shearing in the emittance plots can been seen, however the calculated emittance does not stay constant. This shows the limitations of the pepperpot measurement technique: it requires careful analysis and is susceptible to measurement and calculation error.

CONCLUSIONS

Emittance measurements are important when assessing source design changes.

Emittance measurements require careful analysis.
REFERENCES

