A CW radiofrequency ion source for production of negative hydrogen ion beams for cyclotrons

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Radiofrequency ion source RADIS

Presentation outline

• Introduction to the project
• Source and test stand
• Results
• Plans for future
 Ion source for the MCC30/15 cyclotron

Background

As a part of the compensation of the former Soviet Union debt to Finland, the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus manufactured and installed the MCC30/15 cyclotron at Jyväskylä.

The device produces 18–30 MeV H⁺ (200 µA) and 9–15 MeV D⁺ (60 µA) from negative ions with high-efficiency stripping extraction.
Ion source for the MCC30/15 cyclotron

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- Cyclotron was delivered in August 2009
- Accepted for use in April 2010
- Beams are used for medical isotope production and nuclear physics

Photograph © Ari Lehtiö 2009
The ion source delivered with the cyclotron is a conventional filament-driven multicusp source for H\(^-\) and D\(^-\) production.

- Problem: The filament lifetime with 1 mA output is about \(\sim 130\) h.
- Filament renewal is slow because the cyclotron vault cooldown after accelerator use can take up to 12 hours.
- Users require up to 350 h and longer experiments.
- A long-lifetime ion source is needed to replace the filament ion source.
The RADIS project was started in 2011.

- Experiments were made on existing TRIUMF multicusp chamber and extraction with flat spiral RF antenna.
Radiofrequency ion source for $\text{H}^-$ production

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  ![Diagram of a radiofrequency ion source](image)

- Achieved 210 $\mu$A of $\text{H}^-$ and 21 mA of $\text{e}^-$ with 1500 W RF input power.

- Based on the experience with the test source, a new plasma multicusp plasma chamber, extraction and test stand were built.
The extraction system

Extraction designed with IBSimu for 1 mA H⁻, up to 100 mA e⁻.
The extraction system

Extraction designed with IBSimu for 1 mA H\(^-\), up to 100 mA e\(^-\).
The test stand

Motorized impedance matching box

Plasma chamber

Permanent magnet deflector

Pepperpot emittance meter

FC1

FC2

Mirrors

Camera
Permanent magnet deflector

Any remaining electrons are blocked by deflector
Measured $H^-$ and $e^-$ currents

Result with TRIUMF-type chamber

$e^-/H^+$ ratio $21\pm10$
Measured $\text{H}^-$ current

$\text{H}^-$ content of FC1 signal $> 90\%$, verified with PM deflector before FC2
Pepperpot device

0.2 mm thick stainless steel mask with Ø0.5 mm holes

Vitrosil 077 quartz scintillator screen

Adjustable distance

Metal mirror
Pepperpot images
Pepperpot images
Pepperpot images
Pepperpot images
Emittance

Phase space plot for a 300 $\mu$A H$^-$ beam produced with 1 kW of RF power

$\epsilon_{n,rms} = 0.19 \pm 0.06$ mm mrad for a 590 $\mu$A H$^-$ beam
For higher resolution emittance measurements

- Smaller mask apertures and longer mask to scintillator distance
- Currently divergence resolution $\sigma = 3$ mrad
- Better separation of neutral component
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Best solution

- High quality bending magnet
- Working Allison scanner
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Future

- Emittance as a function of puller voltage and RF power
- Optimization of plasma electrode aperture
Revision of the front plate

Current front plate / plasma electrode

- 1 mA $\mathrm{H^-}$ produced at about 3 kW RF power
- Power efficiency needs to be improved to reach the performance goal persistently.
- Electromagnet front plate has poor confinement and therefore the plasma electrode bias adjusts the whole plasma potential
- Conical channel to the extraction aperture limits the flow of ro-vibrational molecules to the extraction region.
New front plate design

- Electron dump permanent magnets
- Biased plasma electrode
- Filter permanent magnet
Permanent magnet filter intensity was selected according to most common filter setting (5.5 A) corresponding to 23 mT peak field.
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Field topology

- Provides better plasma confinement at front plate
- Separates the biased plasma electrode from bulk plasma → allows adjustment of local plasma potential to optimize H\(^-\) production
Microwave RADIS

<table>
<thead>
<tr>
<th></th>
<th>RADIS RF</th>
<th>RADIS 2.45 GHz</th>
<th>LIISA filament</th>
<th>LIISA 2.45 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>H⁻ beam current</td>
<td>300</td>
<td>170</td>
<td>1500</td>
<td>500 μA</td>
</tr>
<tr>
<td>H⁻ current density</td>
<td>0.78</td>
<td>0.44</td>
<td>1.6</td>
<td>0.53 mA/cm²</td>
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<tr>
<td>e/H⁻</td>
<td>10–30</td>
<td>25–35</td>
<td>2–4</td>
<td>5–15 mA/cm²</td>
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<tr>
<td>Pressure</td>
<td>0.5–1</td>
<td>1</td>
<td>0.45</td>
<td>0.65 Pa</td>
</tr>
<tr>
<td>Plasma electrode</td>
<td>7–12</td>
<td>0</td>
<td>1–4</td>
<td>2–15 V</td>
</tr>
</tbody>
</table>

**Ignition thresholds**

- Pressure: \( \approx 4.5 \) Pa
- Power: \( \approx 1.0 \) kW
Roadmap

- Improvement of emittance measurement resolution
  → systematic emittance measurements

- Renew the front plate

- Optimization of plasma electrode aperture
  → beam current and emittance

- Durability test of source

- Modification of the injection line at MCC30/15 cyclotron to adapt to the different phase space properties of beam from RADIS source
Course on Ion optics with IBSimu

- August 5–14, 2015
- Part of 25th Jyväskylä Summer School
- More information at code website
  http://ibsimu.sourceforge.net/
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Thank you for your attention!