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PERFORMANCE OF THE H^- ION SOURCE DEVELOPMENT RIG AT RAL

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Abstract

A dedicated ion source development rig (ISDR) has been constructed at Rutherford Appleton Laboratory (RAL) to fully characterise the ISIS ion source and then produce sources with enhanced performances suitable for next generation projects such as the European Spallation Source (ESS). The ISDR has been designed to replicate the beam transport configurations on both the present ISIS pre-injector and the ISIS RFQ. Experiments will be described which investigate the intrinsic differences between these two configurations. Initial results from the ISDR have shown that space charge neutralisation in the accelerated H^- beam is sub-optimal due to the relatively low residual gas pressure in the diagnostics chamber. The effect of introducing buffer gas atoms in order to artificially raise the residual pressure and increase space charge neutralisation will be detailed.

1 INTRODUCTION

The ISDR at RAL is now being operated with an ion source identical to that used on ISIS. This is a surface plasma ion source of the Penning type, and on ISIS routinely produces 35 mA of H^- ions during a 200 µs pulse at 50 Hz for uninterrupted periods of up to 50 days[1, 2].

The commissioning of the ISDR has been described in detail[3]. The ISDR is intended to reproduce, as closely as possible, the beam conditions on either ISIS or the ISIS RFQ test stand[4], producing an H^- beam at 35 keV in each case.

Recent experiments on the ISIS RFQ test stand have shown that of the ≈ 48 mA of current measured immediately after the ion source, ≈ 36 mA is transmitted to the end of the low energy beam transport (LEBT) system[5]. It is possible that the initial beam current measurement is artificially high because of the inclusion of electrons accelerated in the 35 kV gap, which are then removed in the LEBT. Alternatively it may be the case that the efficiency of the LEBT is less than was assumed. Further investigation of this effect has been impracticable on the ISIS RFQ test stand because of diagnostic space constraints, but the ISDR has now been re-equipped for this purpose.

Initial experimental results on the ISDR indicated that the beam emittance was larger than expected, with the beam expanding to a larger area than that of the slit plate and scintillator detector being used[3]. This was probably due to ineffective space-charge neutralisation in the diagnostics chamber. For this reason the ISDR has been fitted with an improved scintillator detector, and now has the capability to introduce a suitable buffer gas directly into the diagnostics chamber in order to increase space-charge neutralisation.

2 BEAM DIAGNOSTICS

Figure 1 shows a plan view of the ISDR diagnostics chamber. The configuration of the ‘front end’ of the apparatus (magnet flange, ion source assembly, cold box, PEEK and nylon insulators, diaphragm plate, ‘ISIS’ optics and toroid) is identical to that previously described[3], with the ‘ISIS’ optics being readily interchangeable with an ‘RFQ’ optics equivalent.

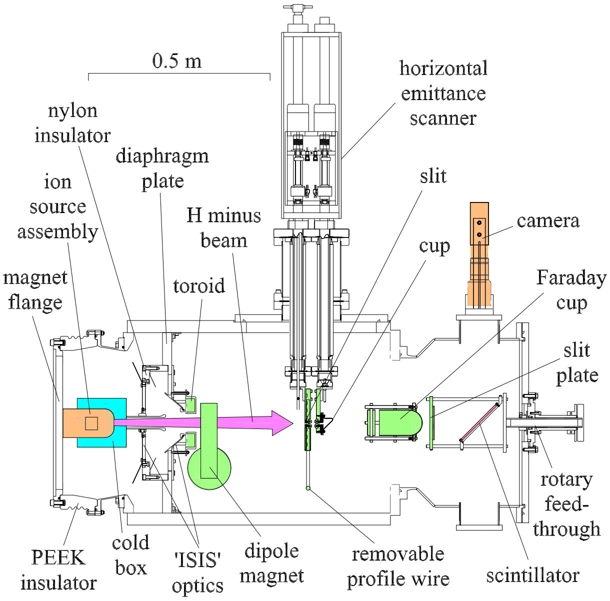

Figure 1. Schematic plan view of the ISDR diagnostics layout, configured for ‘ISIS’ optics.

Inside the diagnostics chamber, directly after the toroid, is a small, high-vacuum compatible dipole electromagnet, producing a field of up to 0.025 T over an area 50 mm × 50 mm. A field strength of only 0.0065 T should be sufficient to separate even 35 keV electrons out of the H^- beam by ≈ 200 mm in the horizontal plane at the position of the emittance scanners. The H^- beam and any electron beam can be characterised using the ‘slit and cup’ horizontal emittance scanner shown in figure 1. An additional, removable profile wire can be mounted on the end of the horizontal scanner, to enable rapid profile measurements to be made without the need to integrate cup measurements at each slit position. A second emittance scanner, in the vertical plane, is also included in the diagnostics suite. The operation of these scanners, which are identical to those used on the ISIS RFQ test stand, is discussed fully elsewhere[3, 6].

The diagnostics chamber has been extended to accommodate an improved scintillator detector. This consists of a 127 mm × 127 mm 'chromox' amorphous scintillator, at 45° to the beam axis, mounted 50 – 100 mm behind a 127 mm × 90 mm slit plate, which has 61 slits of 0.125 mm width on 2 mm centres. This replaces a similar device based on a 50 mm × 50 mm scintillator, with the increase in area having been determined by modelling the beam using the electromagnetic computer aided design programme MAFIA, assuming no space-charge neutralisation. The resultant image on the scintillator is captured with a charge coupled device camera, mounted outside the vacuum on a glass viewing port. The image produced can then be processed to obtain the emittance. In figure 1 the orientation for measuring vertical emittance is shown, but by rotating the entire scintillator and slit plate assembly through 90° using a rotary feed-through, the horizontal emittance can also be measured, using a second camera mounted in the vertical plane. A Faraday cup can act as a beam stop to protect the scintillator, which is only intended for H^- beams at low repetition rate (< 50/4 Hz), and also provides independent beam current measurements. The Faraday cup can be moved into and out of the beam via a second rotary feed-through mounted on the end flange.

3 OPERATION

Typical oscilloscope traces (100 µs per division) for the ion source running on the ISDR with the 'RFQ' optics are shown in figure 2. Those shown, and their steady values, are arc current (I_D, ≈ 52 A), extract voltage (V_E, ≈ 17.6 kV), extract current (I_E, ≈ 200 mA) and beam current (I_B, ≈ 54 mA).

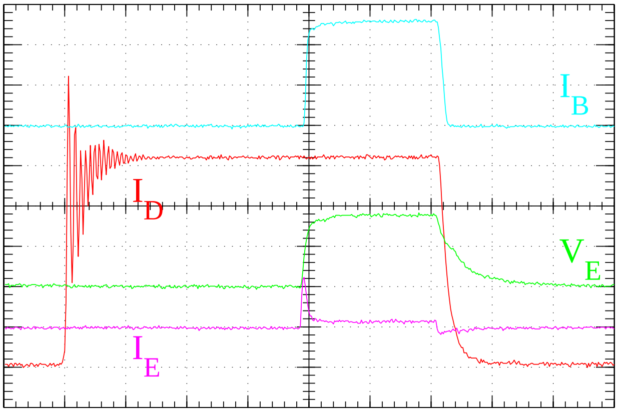

Figure 2. Typical oscilloscope traces.

The ringing during the first 100 µs of the arc current pulse appears to be a characteristic of the IGBT system used on the Danfysik pulsed arc power supply for the ISDR, but does not affect the extracted beam. The beam current is measured with the toroid immediately after the acceleration optics, and compares well with the values measured on the RFQ test stand[5].

For similar source conditions, but using the 'ISIS' optics, I_B ≈ 40 mA. This is simply explained by the fact that the 'ISIS' optics accelerates the beam after it has passed through a 120 mm long × 30 mm diameter tube, which eliminates the possibility of caesium from the ion source reaching the acceleration gap, but also collimates the beam. In the 'RFQ' optics, however, the beam passes through a 30 mm diameter hole in the front of the cold box, and then a 47.5 mm diameter hole in the grounded plate after the acceleration gap, which allows for a greater throughput of current. Beam measurements using the profile wire, 490 mm downstream from the cold box face, show that the horizontal beam width is ≈ 63 mm for the 'ISIS' optics and ≈ 91 mm for the 'RFQ' optics, which demonstrates that some of the additional current may not be commensurate with high brightness.

4 ELECTRON BEAM INVESTIGATIONS

Three different experiments were conducted in order to detect any electron beam associated with the 'RFQ' optics, as discussed in section 1. The first of these involved setting the dipole magnet to ≈ 0.005 T, which should deflect any 35 keV electrons by ≈ 120 mm at the position of the emittance scanners, thus entirely separating them from the H^- beam. Any lower energy electrons will be deflected by more than this. The profile wire was then moved out from the centre of the diagnostics chamber to its maximum extension at 220 mm in order to measure the profile of the H^- beam and any electrons present.

In the second instance the profile wire was set at a position 54 mm from the centre of the diagnostics chamber, ≈ 8.5 mm from the edge of the H^- beam. The dipole magnet field was then increased from zero up to the level where the edge of the H^- beam itself was deflected onto the profile wire (≈ 0.007 T), ensuring that any electrons would be detected at intermediate field levels.

Finally the profile wire was positioned at the centre of the diagnostics chamber, and the current was measured with the magnet switched off, giving the total of the H^- and electron beams at this point. When the magnet is switched on at 0.005 T this current should drop according to the fraction of electrons present in the beam. As a check of field levels in the dipole magnet this method was also used to measure the deflection of the centre of the 35 keV H^- beam, which was ≈ 3mm at 0.005 T, in full agreement with theory.

None of the experiments outlined above showed any evidence of electrons being included in the H^- beam when using the 'RFQ' optics. This was also true of the 'ISIS' optics. Therefore the conclusion must be that the loss of H^- current in the ISIS RFQ test stand LEBT is a real effect, which may be the result of stripping by residual gas molecules or collisions with the beam pipe walls.

5 THE EFFECT OF BUFFER GAS

Figure 3 shows the effect of buffer gas on the beam current measured using the profile wire positioned at the centre of the beam. This diagnostic tool does not discriminate between particle energies, and so gives a good indication of the relative numbers of H^- ions in the beam and positively charged buffer ions in its vicinity during the beam pulse. It is assumed that any electrons formed will be rapidly ejected from the H^- beam because of their high mobility. The curves shown are for the 'RFQ' optics, and begin at the base pressure in the diagnostics chamber for this configuration (1.6×10^{-5} mbar), determined by the flow of H_2 from the ion source under normal operating conditions. At this pressure $\approx$ 40% space-charge compensation can be seen after $\approx$ 75 µs. Increasing the H_2 pressure to 2.0×10^{-5} mbar by feeding excess H_2 gas into the ion source increases the compensation to $\approx$ 80%. Feeding Kr gas (which has a relatively large ionisation cross-section and low ionisation potential) directly into the diagnostics vessel in order to raise the pressure to 1.8×10^{-5} mbar from the H_2 base pressure leads to $\approx$ 100% compensation, whereas Kr at 5.3×10^{-5} mbar gives $\approx$ 70% over-compensation.

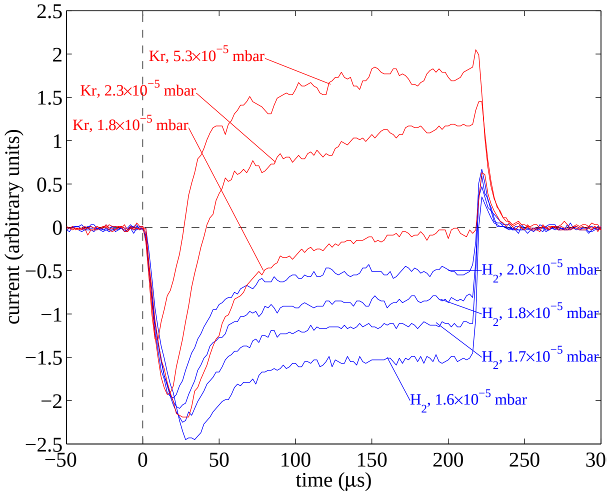

Figure 3. Space-charge neutralisation.

For the 'ISIS' optics, the base pressure in the diagnostics vessel is only 8.0×10^{-6} mbar, and there is virtually no space charge compensation. The introduction of Kr gives similar results to those shown in figure 3.

Preliminary emittance plots, taken using the emittance scanners with the 'ISIS' optics are shown in figure 4. These are both vertical emittances, taken at base pressure and then with Kr introduced to raise the pressure to 2.0×10^{-5} mbar. The effects of the buffer gas are immediately obvious. The normalised rms emittance value falls from $\varepsilon_V = 0.52\ \pi$ mm mrad to $\varepsilon_V = 0.46\ \pi$ mm mrad, the vertical extent of the beam is reduced, the divergence of the beam is lessened and more current is concentrated at the centre of the beam. Similar results were also obtained for the horizontal emittance. Whilst these effects are less dramatic than may have been expected given the degree of space-charge compensation demonstrated earlier in this section, the addition of Kr appears to be entirely beneficial. The emittance values are higher than those measured on the ISIS RFQ test stand, and this probably indicates that the part of the beam being lost in the LEBT on the ISIS RFQ test stand is that which is causing the relatively larger emittances on the ISDR.

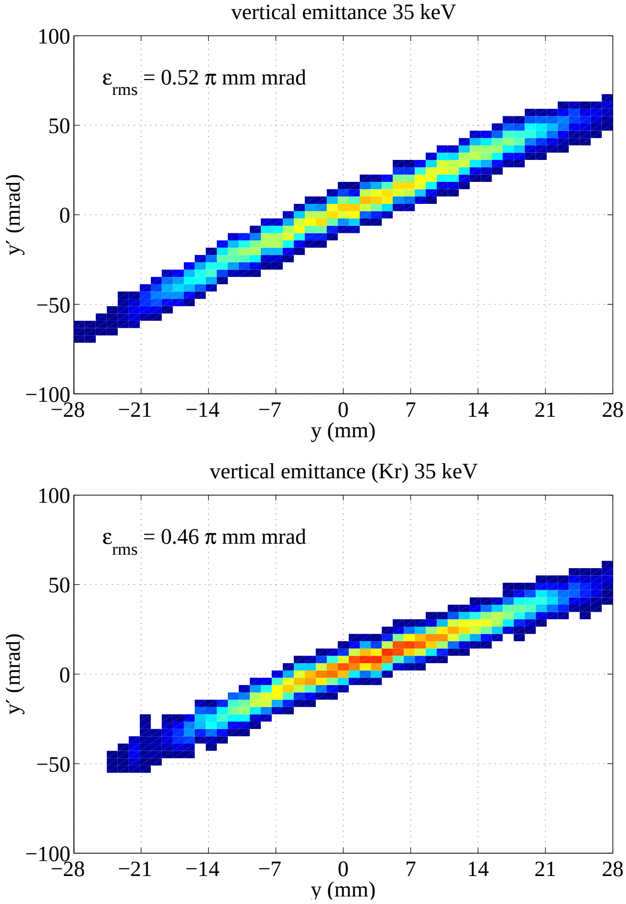

Figure 4. ISDR vertical emittance plots without and with krypton.

6 ACKNOWLEDGMENTS

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