MULTI-BEAMLET STUDY OF BEAM TRANSPORT IN THE ISIS H^- ION SOURCE ANALYSING MAGNET

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Abstract

The RAL Front End Test Stand (FETS) is being constructed to demonstrate a chopped H^- beam of up to 60 mA at 3 MeV with 50 pps and sufficiently high beam quality for future high-power proton accelerators (HPPA). The existing 90° analysing magnet on the ISIS H^- Penning ion source does not perfectly transport the beam after extraction. The present ion source has a 10 mm x 0.6 mm slit extraction aperture. To understand how the beam is transported in the analysing magnet, new ion source aperture plates are manufactured with 5 individual holes instead of a slit. These holes produce separate beamlets that are used to study transport in the sector magnet. This paper details the experiments with the modified aperture plates on the Ion Source Development Rig (ISDR) at ISIS.

INTRODUCTION

An understanding of beam extraction and transport is essential when generating low emittance beams. The ISIS ion source is a world class H^- Penning surface plasma ion source with over 20 years of operational experience. It routinely delivers 50 mA of H^- ions with a 300 µs 50 Hz duty cycle for periods of up to 30 days. Developmental ion sources have produced beam currents up to 70 mA and duty cycles up to 1.5 ms at 50 Hz.

When run in 'standard conditions' both the developmental ion source and the operational ion source suffer from very large emittances of about 0.9 πmm-mRads rms normalized [1].

The beam from the operational ion source enters a magnetic LEBT and is collimated and focused by solenoids down to a 30 mA 0.5 πmm-mRads rms normalized beam for entry into an RFQ. There is still enough beam current for operational purposes so this large loss of beam in the LEBT is not a problem.

For future high intensity machines [2] this large loss of beam is not acceptable, this has motivated a study of beam extraction and transport.

ION SOURCE

The design of the ISIS H^- source has previously been described in detail [1]. The source is of the Penning type, comprising a molybdenum anode and cathode between which a low pressure hydrogen discharge is produced. A transverse magnetic Penning field is applied across the discharge. Hydrogen and Caesium are fed asymmetrically into the discharge via holes in the anode as shown in Figure 2. The anode and cathode are housed in a stainless steel source body.

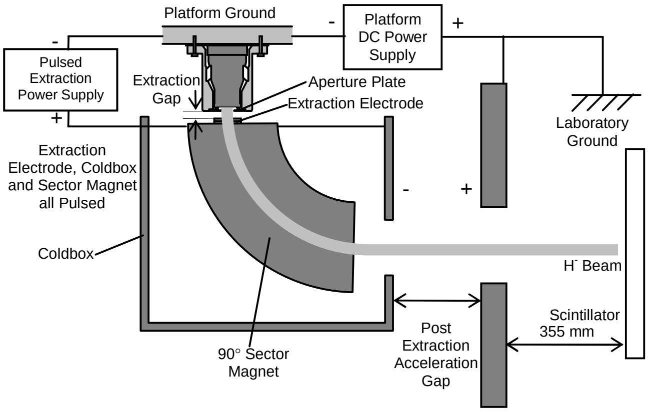


Figure 1: Schematic of the ISIS ion source extraction and post acceleration system.

The beam is extracted through an aperture plate (plasma electrode) using an extraction electrode. On the ISIS operational source the aperture is a 0.6 mm by 10 mm slit and the extraction electrode is of an open ended jaw design, with a jaw length of spacing of 2.1 mm and a separation from the aperture plate of 2.3 mm. A +17 kV extraction voltage is used operationally.

After extraction the beam is bent through a 90° sector magnet mounted in a refrigerated coldbox (Figure 1). The sector magnet has two main purposes; to analyze out the electrons extracted with the H^- ions, and to allow the coldbox to trap Caesium vapour escaping from the source.

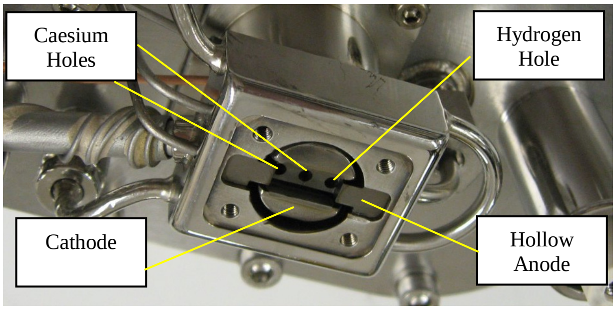


Figure 2: The discharge region of the ISIS ion source (Aperture plate removed). The position of the Cs and H_2 delivery holes are shown.

The H$^-$ beam emerges through a hole in the coldbox and is further accelerated by a 55 mm post acceleration gap. On the ISIS operational source this is an 18 kV post acceleration voltage giving a total beam energy of 35 keV.

EXPERIMENTS

To study how the beam transport varies at different radii within the sector magnet an aperture plate with five 1mm diameter holes is manufactured (Figure 3). The five holes are equally distributed along the 10 mm length of the original slit. Each of the 5 holes produces a separate beamlet which is extracted and transported. A standard ISIS extraction electrode is used. In addition to the aperture plate with 5 holes, three more aperture plates with a single 1 mm diameter hole in different positions are tested. By rotating these aperture plates by 180 degrees it is possible to produce an individual single beamlet in each of the hole positions of the 5 hole aperture plate. Each hole position is given a number as indicated in Figure 3: hole 1 is nearest the inside radius of the sector magnet, hole 5 nearest the outside radius. The asymmetric Hydrogen and Caesium feeds mean aperture plate holes 1 and 2 are below the Hydrogen feed hole in the hollow anode and holes 3, 4 and 5 are below the Caesium feed holes.

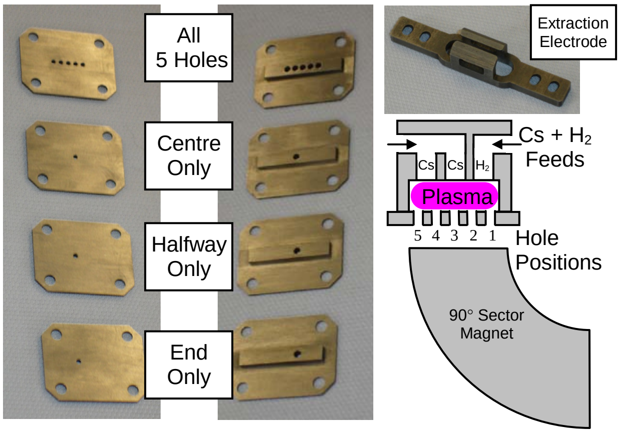


Figure 3: The round hole aperture plates and the hole positions relative to the sector magnet and Cs and H_2 feeds.

RESULTS

For each hole position the extraction voltage is varied whilst keeping the post acceleration voltage constant at the ISIS operational voltage of 18 kV. At each extraction voltage the sector magnet field is set to achieve on axis beam at the exit of the coldbox. The beam current is measured using a toriod. The beam current results are shown in Figure 5.

A quartz glass scintillator is positioned 355 mm downstream from the ground plane of the post acceleration gap. Figure 4 compares profile measurements between the standard slit and 5-hole aperture plate at 7 kV extraction voltage.

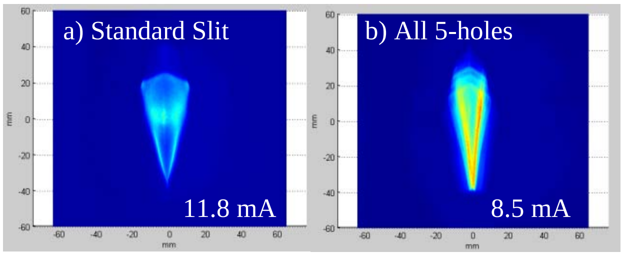


Figure 4: Profiles measured 355 mm downstream from ground plane of post acceleration gap. 7 kV Extraction Voltage 18 kV Post Acceleration Voltage.

The total aperture area of the 5 hole plate is 3.9 mm^2. This compares to 6 mm^2 for the standard slit.

Figure 6 shows the profile measurements for each of the individual hole positions at 8 and 17 kV extraction voltage.

DISCUSSION

It is clear from Figure 4b) and Figure 6 that the beam suffers from severe vertical defocusing: 1 mm diameter circular beamlets are stretched into tall thin beamlets. Historically the 90° sector magnet field gradient index was thought to be n = 1, however recent modelling work [3] has shown it to actually be n = 1.4. This is the cause of the vertical defocusing. New poles have been manufactured and are undergoing tests.

Comparing the standard slit aperture to the 5-hole version in Figure 4 shows the sector magnet deforms the beam into the same “cobra head” type profile. Each of the five beamlets from the 5-hole aperture plate are superimposed on top of each other. The beam currents for the two aperture plates are approximately in proportion to their areas.

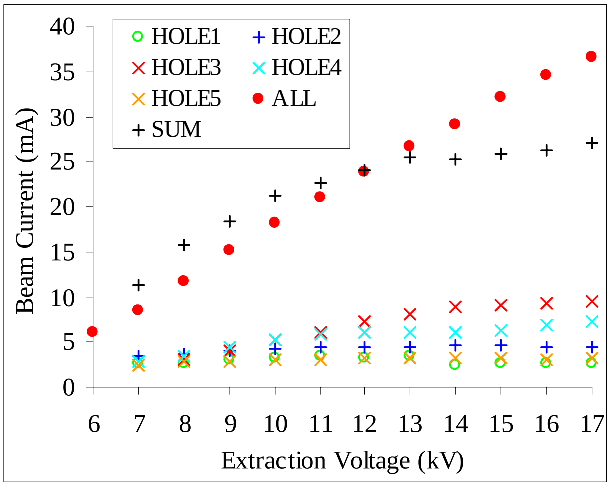
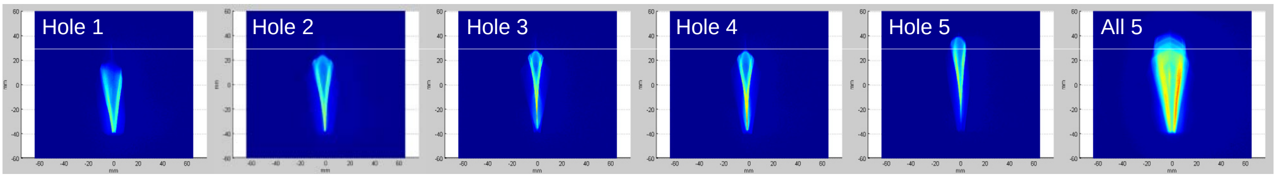


Figure 5: Beam current versus extraction voltage for each hole.

a) 8 kV Extraction Voltage



b) 17 kV Extraction Voltage

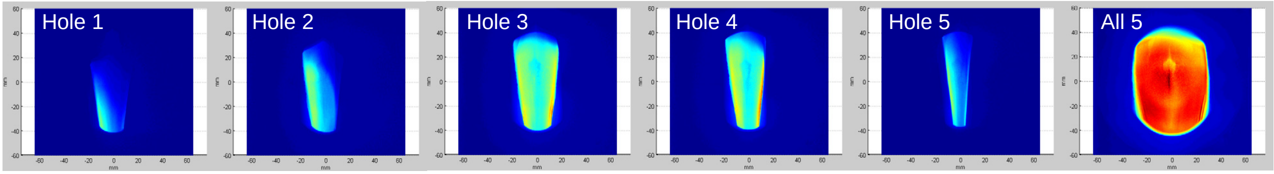


Figure 6: Beam profile measurements 355 mm downstream from ground plane of post acceleration gap with a standard 18 kV Post Acceleration Voltage.

Different beam currents are extracted from each hole (Figure 5). Hole 3 in the centre of the source emits the most current. Hole 4 nearest the Caesium feed (Figure 3) emits the next largest current. This implies that the plasma is asymmetric and H$^-$ production is greater nearest the Caesium feed, suggesting a symmetric Caesium feed into the plasma is required to produce a symmetric beam when a slit extraction system is used.

The sum of the beam current from the individual beamlets compared to the aperture plate with all 5 holes is shown in Figure 5. There is a transition at 12 kV extraction voltage: below 12 kV the sum of the individual beamlets is greater, above 12 kV the beam from the plate with all 5 holes is greater. This could be caused by beam being lost in the defocusing sector magnet combined with space charge effects.

If there is uniform extraction and transport the vertical order of the beamlets should be: hole 1 at the top through to hole 5 at the bottom. However Figure 6 shows this is not the case: hole 5 is actually at the top and hole 1 at the bottom with the others arranged in between.

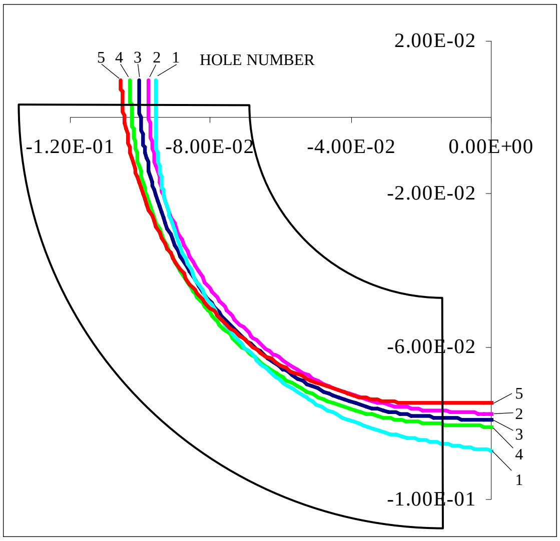


Figure 7: Simulation of particle trajectories.

The position of the beamlets on the scintillator screen can be explained using the results from finite element modelling. CST EM [4] studio is used to calculate the electric fields in the extraction region and GPT [5] to track the particles. The paths of single particles emitted from each hole are shown in Figure 7.

The fringe-field at either end of the extraction region focuses beamlets from hole 1 and hole 5 inwards. The weak defocusing from the n = 1.4 field gradient index sector magnet is not strong enough to defocus them and their trajectories cross over mid-way through the sector magnet. When they reach the scintillator the beamlet from hole 5 is at the top and hole 1 at the bottom.

This confirms that the good-field region of the extraction region needs to be enlarged. This can either be achieved by extending the length of the extraction electrode jaws and/or terminating them.

CONCLUSION

The 5-hole aperture plates have provided experimental proof that the sector magnet has a field gradient index greater than 1. They have also demonstrated focusing in the fringe field of the extraction region and information about plasma uniformity. The technique of separate beamlets will facilitate the evaluation of future plasma electrodes, extraction and transport systems.

REFERENCES

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