STUDY OF THE POST EXTRACTION ACCELERATION GAP IN THE ISIS H^- PENNING ION SOURCE *

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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 injection energy into the RFQ will be in the range of 60 to 70 keV whereas the standard ISIS H^- Penning ion source operates at 35 keV, therefore the post extraction acceleration voltage must be increased. In order to finalize the design of the FETS post extraction system, a study is being conducted on the Ion Source Development Rig (ISDR) at ISIS. This study shows how beam transport is affected by different post extraction acceleration voltages and gap lengths. Beam current and 4 dimensional profile measurements are presented along with theoretical calculations.

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 [1].

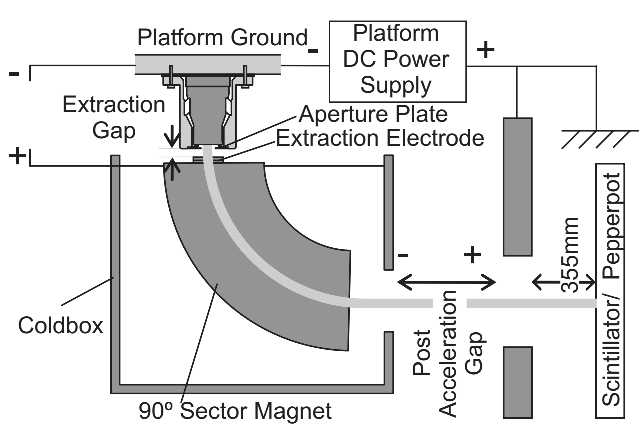

Figure 1: The ISIS ion source with the original configuration of a post acceleration with very low field gradient.

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When run in ‘standard conditions’ both the developmental ion source and the operational ion source suffer from very large emittances of about $\varepsilon_{100\%rms,\,norm.}$ = 0.9 πmm mrad.

For FETS the emittance has to be reduced and the beam parameters have to be improved in order to match the beam to the RFQ–acceptance and to prevent losses in the Low Energy Beam Transport (LEBT). The post acceleration gap is one reason for the low transmission through the standard ISIS–LEBT. The situation is compounded by non–uniform starting conditions caused by slit extraction and scraping caused by a combination of narrow apertures and sub–optimal design of the field in the sector magnet [3]. The other unknown aspect is the development of the space charge compensation. It is not only simulations that are restricted by these aspects but also measurements especially slit–slit emittance scans. Even with two transverse planes there is missing information. This has led to the development of a pepperpot emittance scanner [4], movable along the z–axis. By removing the pepperpot mask it is used as a profile monitor to gather the true spatial distribution $\rho(x,\,y)$. In all cases current is measured directly after the post acceleration gap.

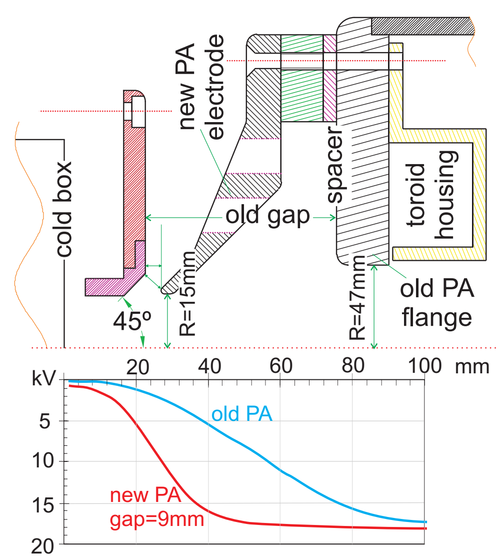

Figure 2: A schematic outline of the new introduced intermediate electrode between cold box and old post acceleration flange. Also shown, the variation of the beam axis by varying the gap length (from 55 mm to 9 mm).

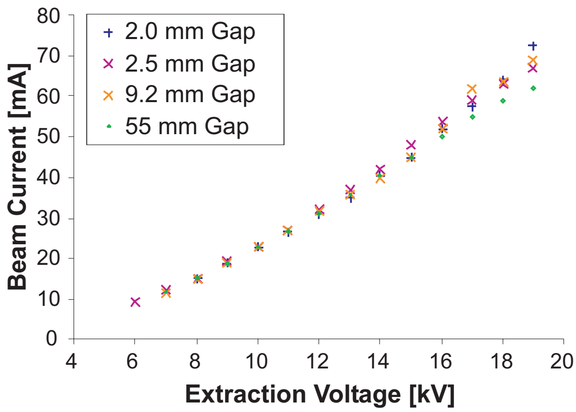

Figure 3: Beam current versus extraction voltage for different post acceleration gaps, measured after the old post acceleration flange. Post acceleration voltage kept constant at 18 kV

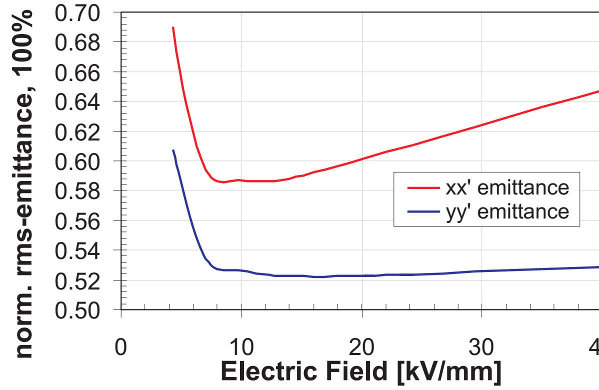

Figure 4: Variation of the electrical field by shortening the post acceleration gap keeping the total beam energy of 70 keV constant. Shown are xx' and yy' rms–emittances for 40 mA without any space charge compensation. A further so–called screening electrode introduced.

It would be very challenging to design the 70 keV post acceleration for FETS only with simulations. To combine both aims, increasing the voltage as well improving the beam transport through the gap, the remainder of the paper gives an overview of some experimental work performed on the ISDR at standard 35 keV beam energy. Simulations have been carried out for the standard ISIS beam energy and for the 70 keV case.

ION SOURCE AT 35 KEV BEAM ENERGY

The design of the ISIS H^- source (see Fig. 1) has previously been described in detail [2]. The source is of the Penning surface plasma type. The beam is extracted through an aperture plate, a +17 kV extraction voltage is used operationally. After extraction the beam is bent through a 90° sector magnet and then further accelerated by a 55 mm post acceleration gap from 17 to 35 keV total beam energy.

By introducing an additional electrode with spacers inside the original gap it is possible to reduce the gap length (see Fig. 2). The effect this has on the axis potential is also shown. Reducing the gap therefore a shorter drift with low energy and a high perveance.

Experimental results

The gap is varied in the range of 2 mm (⇒ 9.0 keV/ mm) up to 55 mm (⇒ 0.33 keV/ mm; the same as the operational ISIS ion source). The extraction voltage is then varied for each post acceleration gap setting. To maintain a constant post acceleration voltage of 18 kV the platform voltage must also be varied because the post acceleration voltage is the platform voltage minus the extraction voltage. Highest currents are achieved at $U_{ext} = 20$ keV (maximum of the power supply) and shortest gap length (highest electric field) I≈ 72 mA (see Fig. 3). At the highest extraction voltage, the largest increase of current ($\Delta \approx 10$ mA is achieved by increasing the electric field (reducing the gap).

This means the following:
(i)The current respective the plasma density is high enough to always deliver enough ions at increasing extraction voltage; (ii) it is possible to transport higher currents through the cold box; (iii) beam collimation is lower at higher electric fields (smaller emittance and smaller divergence angle) and allows higher beam output.

Fig. 5 shows beam profile measurements taken with the quartz scintillator positioned 355 mm downstream from the ground plane of the post acceleration gap. This is as close to the ground plane as the apparatus will allow. The pseudo–color images are proportional to the ion current density and all images are shown on the same color scale. Profile measurements are shown for different post acceleration voltages and different gap lengths. The calculated electric field in the gap is also shown. For all measurements a constant 10 kV extraction voltage is used which yields a ≈23 mA beam. A 10 kV rather than a 17 kV extraction voltage is used because the beam is smaller in width and height. For the 55 mm gap case it is clear that increasing the post acceleration voltage reduces the horizontal size of the beam, it focuses the beam. For shorter gap lengths the beam can be seen to actually go through a horizontal focus. For a constant 11 kV post acceleration voltage the same horizontal focusing effect is observed as the gap length is reduced, and at higher post acceleration voltages the beam actually goes though a horizontal focus as the gap length is reduced. The post acceleration gap is symmetrical so the focal strength is equal in both horizontal and vertical planes. A reduction in profile hight is only observed at high electrical fields, this shows that the beam is not symmetrical in the x and y planes.

THEORETICAL SIMULATIONS

Some of the problems of simulating the ISIS post–acceleration have already been discussed. Not knowing

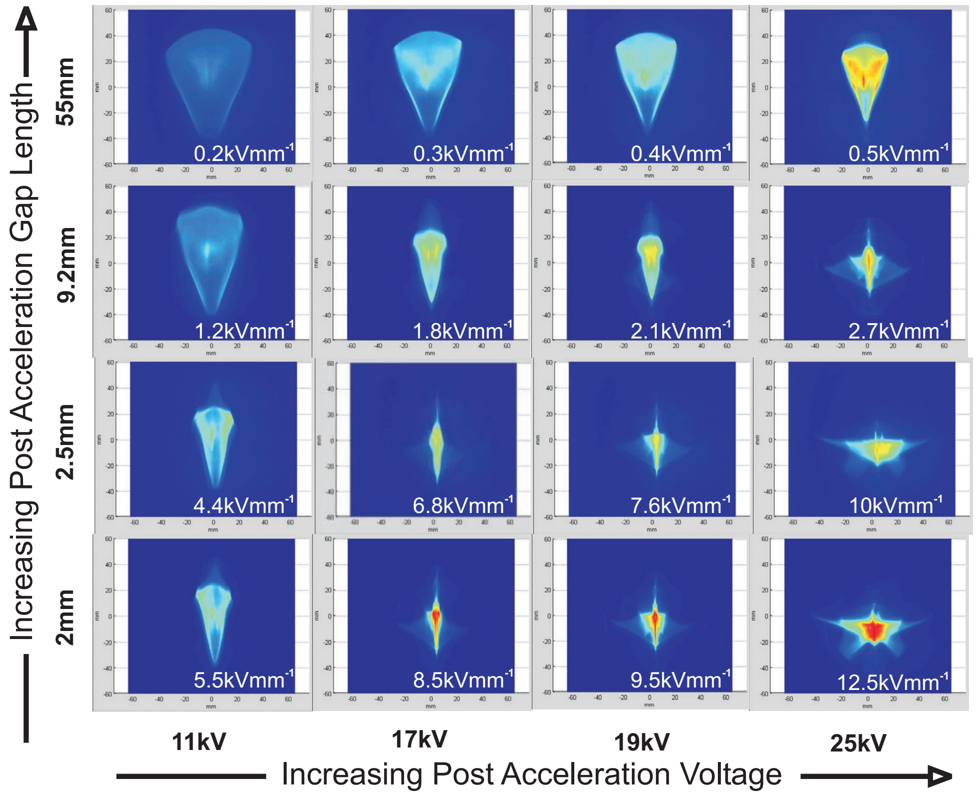

Figure 5: Variation of spatial distribution $\rho(x,\ y)$ versus gap length and total beam energy, measured 355 mm from ground plane of post acceleration gap. Constant 10 kV Extraction Voltage 23 mA H^- Beam Current.

the beam properties at the entrance of the post acceleration gap is a problem. However, using a homogeneous, cylinder–symmetric emittance distribution is it possible to show qualitatively similar effects as shown in Fig. 5. These focusing effects can be explained assuming the post acceleration gap as half a (decerlating) einzel–lens.

To investigate the circumstances for the 70 keV case further simulations have been performed. A realistic entrance distribution is found by tracking back particle distributions measured using the pepperpot emittance measurement device (see Fig.2). In order to keep beam collimation effects to a minimum a low extraction voltage of 13 keV (which gave a 40 mA ion beam current) was used for this measurement.

For a low emittance it is reasonable to chose an electric field in the region of 8. . . 10 keV/ mm. Technically the gap has to be slightly larger to reduce the probability for high voltage breakdowns and is more in the range of 4. . . 7 keV/ mm. The non–symmetric slit extraction causes different radii and therefore also different focal lengths. This yields the different emittance curves and minima. The considerable drop in emittance is a combination of different size of the beam in the post acceleration gap with its non–linear fringe field effects.

SUMMARY & OUTLOOK

The post acceleration with its applied electric field significantly influences beam parameters like radius, divergence and current. By reducing the gap a positive effect can be achieved, clearly seen as different focal points for the two different transverse planes. For FETS the electrical field should be in the range of 9 keV in order to benefit of the demonstrated effects. But this is limited for practical reasons (high voltage breakdowns) and the different behavior of the 2 different transverse planes (because of different radii).

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