THE EFFECT OF EXTRACTION GEOMETRY ON THE MEASURED ISIS H^- ION SOURCE BEAM

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Abstract

Recent Finite Element Analysis (FEA) electromagnetic modelling of the extraction region of the ISIS H^- ion source has suggested that the present set up of extraction electrode and 90° sector magnet is sub-optimal, with the result that the beam profile is asymmetric, the beam is strongly divergent in the horizontal plane and there is severe aberration in the focusing in the vertical plane. The FEA model of the beam optics has demonstrated that relatively simple changes to the system should produce a dramatic improvement in performance. These changes have been incorporated on the Ion Source Development Rig (ISDR) at Rutherford Appleton Laboratory (RAL), and their effects on the H^- beam are presented here.

INTRODUCTION

A recent paper[1] has described MAFIA modelling of the extraction region of the ISIS H^- ion source[2,3]. This demonstrated that optimisation of the beam optics should result in a significant improvement in the measured emittance of the source. The design incorporates new pole pieces for the 90° sector magnet, and a "maximag" magnet steel tube (internal diameter 30 mm, wall thickness 5 mm) extending from 3 mm in front of the 90° plane to flush with the cold box exit. Together these should deal with fringe fields of the 90° sector magnet more effectively. In addition two new extraction geometries were specified: one a terminated version of the standard ISIS extraction geometry and the other a Pierce geometry[4].

Figure 1. Extraction electrodes and aperture plates for the ISIS standard geometry (centre), terminated standard geometry (left) and Pierce geometry (right).

All of these new components have now been manufactured and tested on the ISDR. The extract electrodes and aperture plates used are shown in Figure 1.

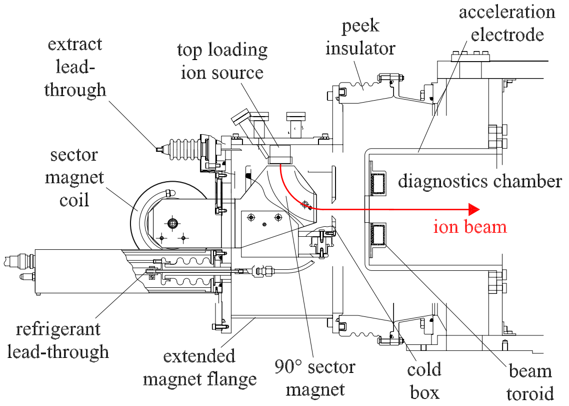

Figure 2. Schematic of the top loading ion source and extended magnet flange on the ISDR.

THE TOP LOADING ION SOURCE

The configuration of the ion source and magnet flange for the ISDR[5] has now been changed so that the ion source assembly can be loaded from the top, rather than the back of the magnet flange, as shown in Figure 2. This will allow greater flexibility for future source developments, where additional space for scaling of source components or more aggressive cooling strategies can be provided by inserting a spacer ring between the ion source flange and the magnet flange. The penalty for this innovation, however, is that the source has had to be moved back by about 200 mm from its original position. The emittance scanners on the ISDR were designed for use with the ISIS RFQ test stand[6], and were only required to scan over ±30 mm to cover the maximum extent of the Low Energy Beam Transport beampipe. This means that, with the distance from the cold box front plate to the emittance scanners now increased to 685 mm (56 mm of acceleration gap and 629 mm of drift), the extent of the divergent ion beam would be larger than the range of the scanners. This problem has been addressed by modifying the scanners so that two or more separate scans can be taken and then merged to create a single scan over a range of ±78 mm.

RESULTS

Emittance scans were taken for four combinations of extract electrode geometry and pole pieces: ISIS standard geometry with old pole pieces, ISIS standard geometry

Table 1. Emittance values for the four combinations of extract electrode and pole pieces with varying pressures of Kr in the diagnostics chamber. All values are for normalised rms emittance in π mm mrad during a 10 µs interval 150 µs into the 250 µs pulse, with an extract voltage of 17 kV, beam energy of 35 keV and a beam current of between 45 and 55 mA.

	H_2 (1.7×10^{-5} mbar)	H_2+Kr (2.2×10^{-5} mbar)	H_2+Kr (4.0×10^{-5} mbar)	H_2+Kr (1.0×10^{-4} mbar)
Standard Geometry Old Pole Pieces	$\varepsilon_H = 0.97$ $\varepsilon_V = 0.94$	$\varepsilon_H = 0.99$ $\varepsilon_V = 0.84$	ε_H no measurement $\varepsilon_V = 0.91$	no measurements
Standard Geometry New Pole Pieces	$\varepsilon_H = 0.97$ $\varepsilon_V = 0.90$	$\varepsilon_H = 0.91$ $\varepsilon_V = 0.92$	$\varepsilon_H = 0.92$ $\varepsilon_V = 0.90$	$\varepsilon_H = 0.83$ $\varepsilon_V = 0.72$
Terminated Standard New Pole Pieces	$\varepsilon_H = 0.91$ $\varepsilon_V = 0.98$	$\varepsilon_H = 0.85$ $\varepsilon_V = 0.97$	$\varepsilon_H = 0.82$ $\varepsilon_V = 1.06$	$\varepsilon_H = 0.77$ $\varepsilon_V = 0.97$
Pierce New Pole Pieces	$\varepsilon_H = 0.73$ $\varepsilon_V = 0.80$	$\varepsilon_H = 0.72$ $\varepsilon_V = 0.83$	$\varepsilon_H = 0.71$ $\varepsilon_V = 0.79$	$\varepsilon_H = 0.62$ $\varepsilon_V = 0.73$

with new pole pieces, terminated standard geometry with new pole pieces and Pierce geometry with new pole pieces. In each case the source parameters were kept as constant as possible, with an extract voltage of 17 kV, a beam energy of 35 keV, a pulse width of 250 µs and a beam current of between 45 and 55 mA.

Previous experiments on the ISDR[5] have shown that there is very little space charge compensation in the diagnostics chamber when the pressure (of ≈1.7×10^{-5} mbar) is determined solely by the transmission of H_2 from the ion source chamber. The introduction of Kr as a buffer gas has been shown to provide space charge compensation and improve the emittance measurements. To investigate this effect further in the present measurements Kr was introduced into the diagnostics chamber to raise the combined pressure of H_2 and Kr to levels of 2.2×10^{-5} mbar, 4.0×10^{-5} mbar and 1.0×10^{-4} mbar.

The results are shown in Table 1, where all values are for the normalised rms emittance in π mm mrad. The emittances in both planes display the general trend that the values get smaller with each successive geometry refinement and the introduction of more Kr, but this is not always the case. For instance replacing the ISIS standard geometry extraction electrode with the terminated standard leads to an increase in the vertical emittance values. However, it can be seen that overall the worst values are those for the ISIS standard geometry and old pole pieces with no introduction of Kr (worst case, shaded orange in Table 1) and the best values are those for the Pierce geometry and new pole pieces with Kr introduced to 1.0×10^{-4} mbar (best case, shaded green in Table 1).

Figure 3 shows the worst case. It is immediately obvious that the spatial extents of ≈±50 mm in both the horizontal and vertical planes justify the modification of the emittance scanners to scan over a wider range. Indeed there is evidence that previous emittance measurements quoted for the ISDR[5] may have been too small because the edges of the beam were being missed. The horizontal emittance plot is fairly uniform and symmetrical, whereas the vertical plot is more asymmetric. The emittance values are higher than those typically measured on the ISIS RFQ using the same source configuration[7] ($\varepsilon_H = 0.64$, $\varepsilon_V = 0.48$ π mm mrad), but for the RFQ only ≈34 mA of beam is delivered through the Low Energy Beam Transport (LEBT). This probably indicates that the part of the beam being lost in the LEBT on the RFQ is that which is causing the relatively larger emittances on the ISDR.

Figure 4 shows the best case. The spatial extent of the beam in the horizontal plane has been reduced to ≈±30 mm, and in this plane the beam displays three distinct peaks. This structure is evident in all of the scans taken with the Pierce geometry, irrespective of the amount of Kr, and is taken to be indicative of a slight over-focusing in the horizontal plane of the extract electrode. This will be investigated at a later date by reducing the angle of the recess in the Pierce geometry aperture plate (see Figure 1). In the vertical plane the beam is asymmetric, and has been positioned to maximise the charge on axis, but again covers a range of ≈60 mm. The asymmetry of the vertical profiles in both the best and worst cases may be evidence that there is not an even distribution of charge across the slit in the aperture plate when the ions are extracted. Examination of many used ion source cathodes has shown erosion concentrated towards the area where Cs is fed through the anode into the source. If this is a consequence of the plasma being localised near the Cs feed this could well result in an asymmetry in the vertical plane. A new Cs delivery system, which should give a more even plasma distribution has been designed and manufactured, and awaits testing on the ISDR.

Although the changes in normalised rms emittance values (from $\varepsilon_H = 0.97$, $\varepsilon_V = 0.94$ π mm mrad in the worst case to $\varepsilon_H = 0.62$, $\varepsilon_V = 0.73$ π mm mrad in the best case) are not as dramatic as those predicted by MAFIA modelling[1], there is still a marked improvement in both the horizontal and vertical planes as a result of the Pierce geometry, new pole pieces and the introduction of Kr. It is hoped that future refinements of the extraction geometry and Cs delivery system will improve the situation still further.

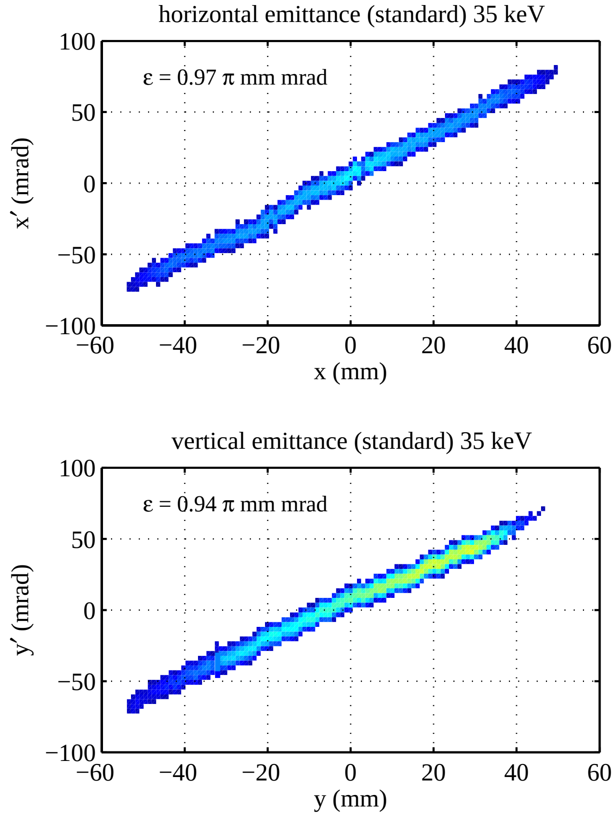

Figure 3. ISDR horizontal and vertical emittance plots for the ISIS standard geometry and old pole pieces with no introduction of Kr.

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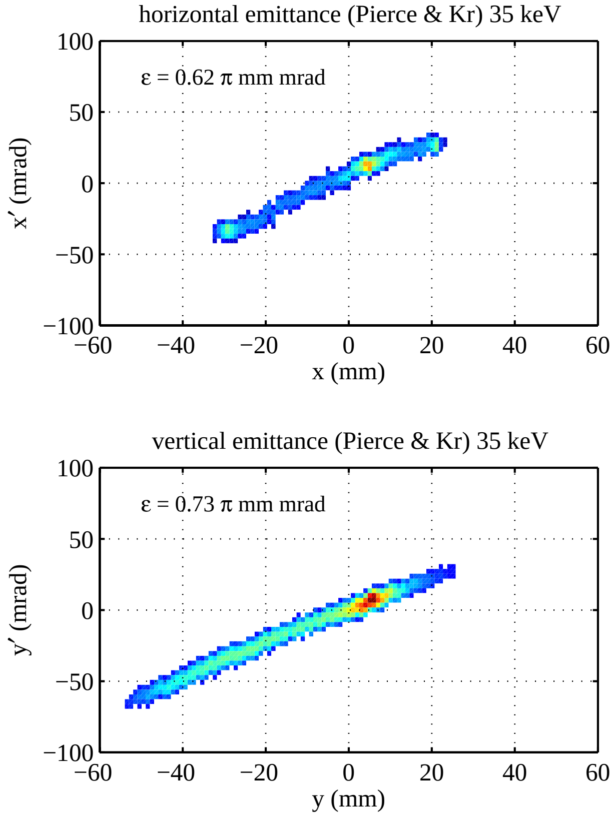

Figure 4. ISDR horizontal and vertical emittance plots for the Pierce geometry and new pole pieces with Kr introduced to raise the diagnostics chamber pressure to 1.0×10^{-4} mbar.

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