MODIFICATIONS TO THE ANALYSING MAGNET IN THE ISIS PENNING ION SOURCE

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Abstract

A full 3D electromagnetic finite element analysis and particle tracking study has been undertaken of the ISIS Penning surface plasma ion source using CST Particle Studio 2008. The existing 90° analysing magnet is found to have a sub-optimal magnetic field index, causing beam divergence and contributing to beam loss. Different magnet pole piece geometries are modelled and the effect of space charge investigated. Based on this modelling, three new sets of poles are manufactured and tested on the Ion Source Development Rig.

INTRODUCTION

The design of the ISIS H^- ion source has previously been described in detail [1]. One important aspect of the system is the 90° sector magnet housed inside the cold box. These components remove extracted electrons, neutral hydrogen and caesium, leaving a very pure H^- beam. Beam profile studies [2] conducted on the Ion Source Development Rig (ISDR) at various extraction potentials found that the beam has an asymmetric, elongated 'cobra-head' profile. At the standard operational extraction potential of 17 kV, the asymmetric beam expands and collimates resulting in a reduced beam current of approximately 50 mA. Circular extraction apertures at different positions along the standard slit aperture also exhibit this same 'cobra-head' profile [3]. This result proves that the irregular beam profile is caused by the analysing magnetic field rather than asymmetries in the plasma or extraction system.

The Front End Test Stand (FETS) [4] being constructed at ISIS requires 70 mA of beam current. To achieve this, the extraction potential will be increased to 25 kV. However, because of beam collimation, the desired current may not be achievable with the present sector magnet poles.

To study the effect of the magnetic field on beam transport, a full 3D finite element analysis (FEA) model has been developed in CST Studio Suite 2008.

FINITE ELEMENT MODELLING

Present ISDR setup

To model beam transport effectively, both the electric and magnetic fields must be solved accurately. A regular hexahedral mesh is required for particle tracking, and hence more mesh cells were needed to solve the electromagnetic fields than would be sufficient using an irregular tetrahedral mesh. With 4 GB of computer memory, a total of approximately 4.3×10^6 mesh cells were available. Therefore a careful balance was needed to distribute cells between various parts of the model whilst solving all fields accurately. Because of the vast difference in scales between the extraction electrodes and the magnetic field pole tips, mesh cell densities varied between 1.6×10^{12} m^{-3} in the extraction region and 2.5×10^{8} m^{-3} in the sector magnet dipole gap. The 3D structure of the model is shown in Figure 1. A drift space of 700 mm was included in the model in order to compare the predicted beam with measurements using the slit-slit emittance scanners on the ISDR. Additionally, profile and emittance monitors were positioned where the laser diagnostics tank and solenoids will be in FETS to ensure that the beam was not further collimated downstream.

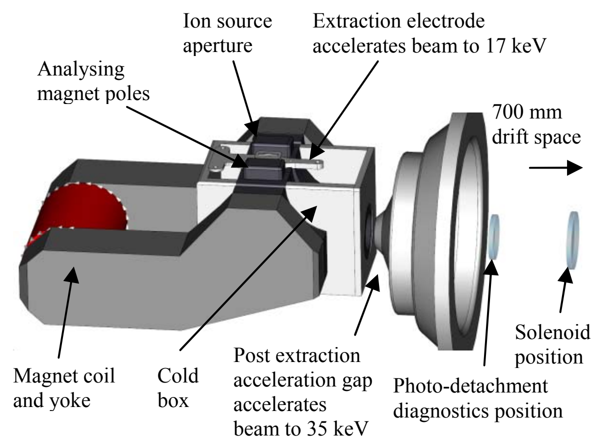

Figure 1: CST Studio Suite 2008 model of the ISDR ion source. Extra drift space omitted for clarity.

Analysing Magnet Geometry

Figure 2 shows the geometry of the present analysing magnet poles. After extraction, the H^- beam follows an 80 mm radius arc through the dipole.

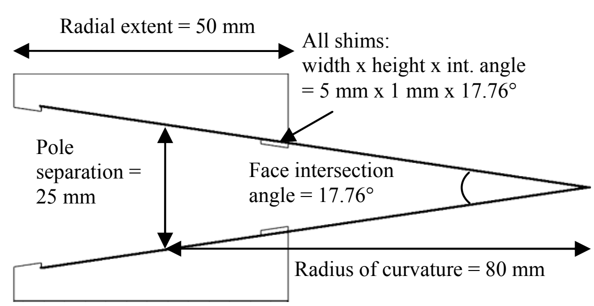

Figure 2: Plan view of present pole tip geometry.

The beam may be focused in the radial direction by the magnetic field. A measure of how good the variance of the magnetic field B is with radius R is the magnetic field index, n

$$n = -\frac{R}{B}\frac{dB}{dR}$$

To ensure parallel beam transport along the dipole arc, n must equal 1. If n > 1, the field is too strong at small radii and too weak at large radii, so the beam undergoes radial defocusing. Conversely, an n < 1 field yields radial focusing. The area where n is uniform and of the magnitude desired is the "good-field region".

The field indices of both the present and new poles (see below) are plotted as a function of radial position at the median plane in Figure 3. The present pole faces intersect an angle of 17.76° and are separated by 25 mm. This geometry causes an average magnetic field index of n = 1.35. Therefore this geometry may indeed generate the vertically defocused 'cobra-head' beam profile.

Interesting effects happen off centre, however, so a new method of viewing magnetic field indices is used in Figure 4. This plots a 2D histogram of n as a function of both radial and transverse position, allowing one to study the uniformity of the field index across the entire gap.

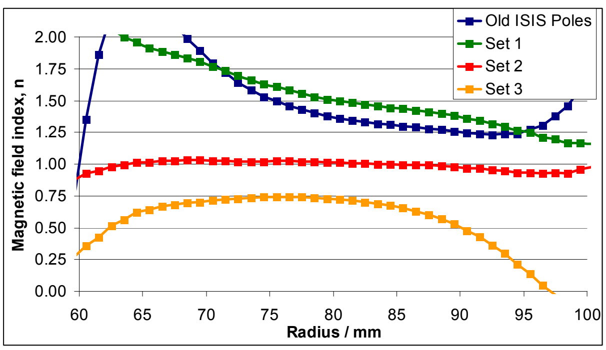

Figure 3: Comparison of the magnetic field index for all sets of magnet poles designed.

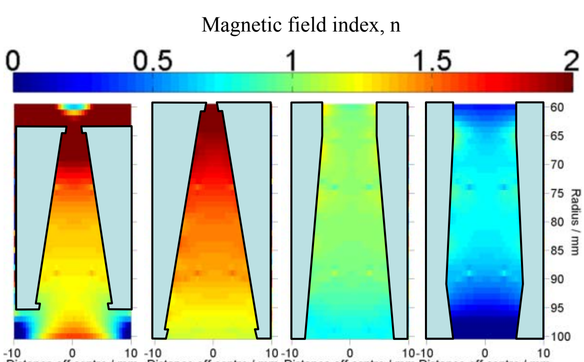

Figure 4: 2D histograms of n for the different magnet designs. From left: Old ISIS poles, Set 1, Set 2, Set 3.

The good field region of the present poles is rather small because of the narrow radial extent of 50 mm. Hence an immediate improvement for the poles was to widen them in the radial direction in order to increase the size of the good field region. The maximum radial extent for magnet poles that can fit in the cold box is 74 mm.

MANUFACTURED POLES

By modifying the pole separation and face angles, the field index was varied to give focus to the beam. To experiment with this effect on the ISDR, three new pole geometries were chosen for manufacture to perform different tasks. All have a radial extent of 74 mm. The pole geometries are summarised in Table 1.

Set 1, being identical to the old poles except for the increased radial extent, tests the effect of fringe fields. Set 2 has an extremely uniform n = 1 field due to carefully chosen face angle and shims. Set 3 vertically focuses the beam with its low field index and overly large rear shim.

Table 1: Geometries of the new poles.

Pole Set	**1**	**2**	**3**
Separation	25 mm	29 mm	29 mm
Intersection Angle	17.76°	14°	12°
Field index	n = 1.35	n = 1.0	n = 0.75
Front Shims			
Width	5 mm	10 mm	10 mm
Height	1 mm	0 mm	0 mm
Int. angle	17.76°	0°	0°
Rear Shims			
Width	5 mm	0 mm	20 mm
Height	1 mm	0 mm	0 mm
Int. angle	17.76°	14°	-12°

The negative intersection angle for the rear shims on Set 3 means that they intersect to the left of Figure 2. The field index maps of the new poles are compared with the present poles in Figures 3 and 4.

BEAM TRANSPORT STUDY

Downstream Steering

For the implementation of the new pole pieces on the FETS, the beam produced from the ion source must be correctly aligned to enter the three-solenoid low energy beam transport (LEBT) as parallel and on axis as possible.

A small residual field from the 90° analysing magnet continued to exist a substantial distance downstream from the cold box and was enough to over-steer the beam, meaning poor entry into the LEBT. To compensate for this, the vertical cut-off from a full 90° bend has been increased from 3 mm to 14 mm in the new poles.

Space Charge Compensation

Particle trajectories were calculated for the present ISDR pole pieces. With 100% space charge compensation throughout the entire path, the beam maintained the rectangular shape it had when leaving the slit aperture, but expanded somewhat in the transverse direction by the extraction electrode. Thus by the time the beam reached the LEBT, it had dimensions approximately 10 mm x 10 mm. The real beam in the ISDR collimates to a diameter of 80mm and has a shape far removed from a rectangle. Therefore space charge must be included at some point in the beam path to expand and alter the beam's shape.

No space charge compensation occurs in the extraction or acceleration gaps as neutralising particles are swept away soon after forming by the accelerating potentials. However substantial compensation occurs in the drift space of the sector magnet due to high gas pressures in the cold box [5].

By solving the particle trajectories in these regions separately, a good agreement was found between the beam current, profile and emittance predicted in the model and those measured on the ISDR, as shown in Figures 5. In particular, the anomalous 'cobra-head' beam profile has been successfully simulated. Additionally, focussing effects due to different acceleration voltages have been replicated in simulations, as seen in Figure 6.

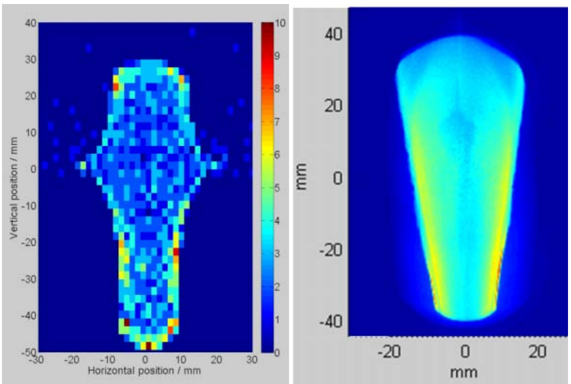

Figure 5: Comparison of beams at 17kV extraction potential. Simulated beam (left) and real beam (right).

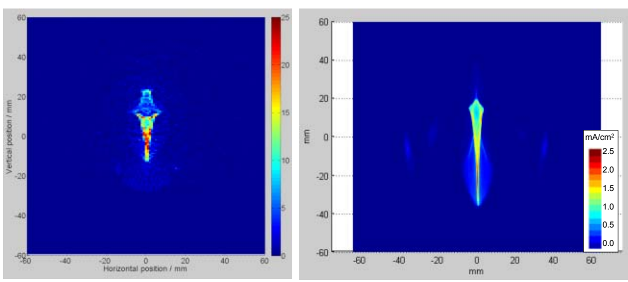

Figure 6: Comparison of beams at 10kV extraction potential. Simulated beam (left) and real beam (right). Note the faint "wings" either side of the sharp "tail" at the bottom of the beam in both cases.

Successfully simulating the present beam increases the credibility of results obtained when particle tracking through the new poles. The predicted beam profiles are shown in Figures 7 and 8. Set 2 creates the roundest beam and highest current, whereas Set 3 causes the beam to expand transversely due to its strong radial focussing, resulting in a slight loss of current. The new poles have been manufactured and are being tested presently.

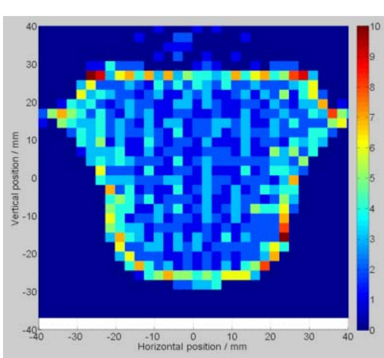

Figure 7: Predicted beam produced from pole set 2.

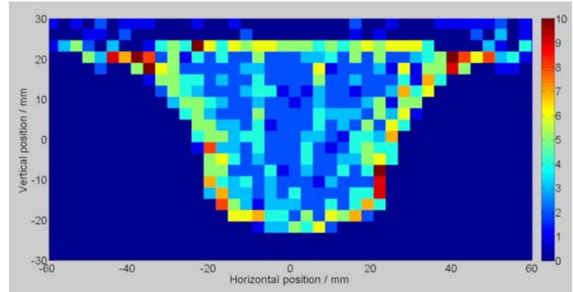

Figure 8: Predicted beam produced from pole set 3.

PRELIMINARY RESULTS

Replacing the analysing magnet poles in the ISDR takes considerable time so only pole set 2 has been tested so far. Nevertheless preliminary results are encouraging. With the standard extraction and platform voltages of 17 and 35 kV respectively, the beam profile shown in Figure 9 compares well with the predicted beam in Figure 7. Detailed calculations have not been completed yet, but Figure 10 shows a qualitative reduction in vertical emittance, indicating that the new magnet poles will allow the beam requirements needed for FETS to be reached.

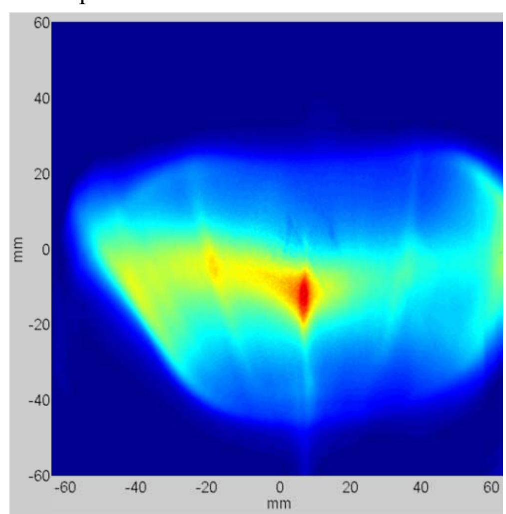

Figure 9: Profile of the beam after passing through set 2.

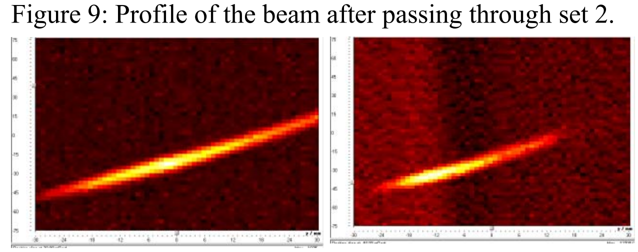

Figure 10: Vertical emittance of the beam with the old poles (left) and with pole set 2 (right).

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