REDESIGN OF THE 90° ANALYSING MAGNET OF THE ISIS H^- ION SOURCE USING FINITE ELEMENT MODELLING

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1 ABSTRACT

The magnetic field strength, uniformity, and stray components of the ISIS penning H^- ion source 90° bend magnet have been measured and modelled, both showing the intended steering is not achieved. If the field strength and particle energy are set to cause the particles to follow a constant radius, the resulting bend after passing through the fringe fields is 99°. Thus in use the energy and field strength are mismatched, in order to reduce the bend to 90°, which results in the beam following a path of increasing radius. This generates aberrations and causes the beam to be offset.

The design has been altered by shortening the pole pieces, and by adding a tube of high permeability material, to control the fringe fields along the beam path. The models of the new configurations show the beam can, after following a constant radius path through the magnet, be aligned. There is always a small offset but the magnet and source can be repositioned to take account of this. The position of the tube can be adjusted longitudinally which changes the overall bend angle.

2 DESCRIPTION

The ISIS ion source analysing magnet is designed to operate with a field index of n=1. [1,2] However, in order to achieve maximum extracted beam current, it is operated at a field level significantly lower than that required for n=1 operation at the ion source extraction voltage. A finite element model of the magnet, shown in figure 1, has been developed to investigate this effect using the Vector Fields Opera3d software. This model has shown that despite the original pole design being cut off at 80°, the beam is bent through ~99°, when the fields are set for n=1 operation. Thus the shortening is inadequate to control the effects of the fringe fields. The over steering is compensated by the reduced field level operation. The beam does not remain on constant radius as it would under n=1 conditions, but drifts wide, introducing aberrations. While it emerges close to parallel with the axis it is displaced below it, and consequently misaligned with the downstream elements of the beam line, risking further aberrations and steering. There are constraints on any modifications to address

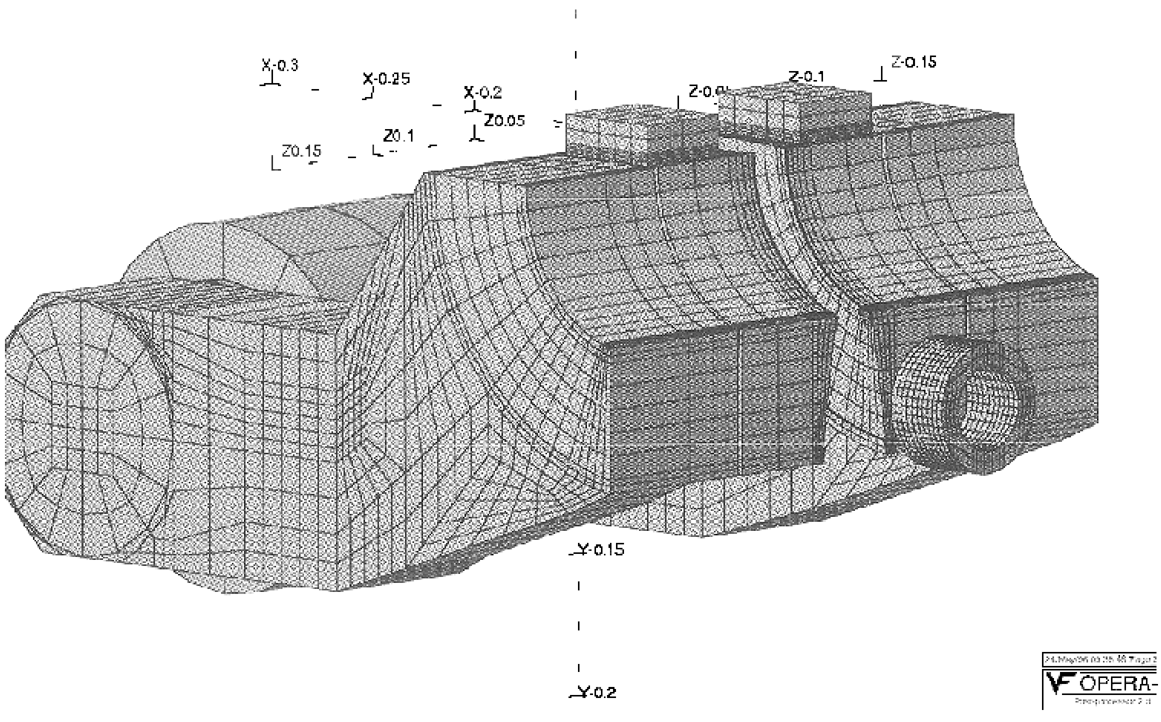

Figure 1 Magnet Model.

this problem. There is a requirement for a residual field, to sweep stripped electrons from the beam before the next components. The total length of the ion source and analysing magnet system is limited by space restrictions in its intended location.

2.1 Probe beam definitions

The steering produced by the magnet was investigated using the particle tracking code built into the software. Initially using single particles and ribbon beams with extent in only one phase plane. These simulations highlighted the steering problems but did not show aberrations. The more promising models were re-examined using a beam defined in both phase planes. This beam takes points around the bounding ellipse in one phase plane and at each of these takes an equal number of points on the bounding ellipse in the other plane. The beam is 20 mm by 20 mrad in the x-plane and 2 mm by 200 mrad in the y-plane. The beam size parameters are calculated by passing the tracking data to a mathcad program that converts from the position and axial velocities produced to conventional xx′ phase space. The accuracy of this process is limited by the need to find a suitable compromise between the number of particles and an acceptable processing time. A maximum of 225 particles has been used. The beam size is calculated by fitting an ellipse around all the tracked particles, after allowing for displacements from the axes.

2.2 Possible modifications investigated

The effects of changing the pole piece design and adding a shielding tube downstream of the poles have been modelled, and the effectiveness of these changes investigated using the particle tracking described earlier. Although it is possible to achieve correct alignment of the central trajectory solely by shortening the pole pieces to between 72° and 73°. This results in the beam traversing an extended region of fringe field, causing beam steering to vary across the magnet aperture.

Options using both shortened pole pieces and a tube, in the space available give too little steering. Unless the tube is so small it has almost no effect or the reduction in pole length is small.

2.3 Comparison of tube only solution with operational design.

The use of a tube, of high permeability material, and the original pole pieces is the most promising. The effects of varying the gap between the magnet and the tube have been modelled. The tube size used is 30 mm inside diameter, 8mm wall thickness and 25 mm long. The wall is sufficiently thick that it does not saturate and small enough that the reduction of the main field strength, within the magnet poles, is easily compensated. A simple tube has been chosen as it shields the beam adequately, eliminating the unwanted steering. The length of 25 mm is a compromise that allows the beam to exit into a region of suitable field for electron sweeping independent of the gap length. Using a constant main field strength the changes in the final alignment caused by varying the gap between the poles and the tube, are shown in table 1.

Table 1 Steering effects of gap length.

gap	resultant angle	displacement
31 mm	-5 mrad	-4 mm
36 mm	-1 mrad	0 mm
41 mm	10 mrad	-2 mm

Subsequent tests concentrated on the 36 mm gap as the improved design. Using the beam with both x and y extent. Figures 2, 3 and 4 show the results for the different models of calculations at the output for; a) The spot size, b) Horizontal emittance, c) Vertical emittance. The ellipse areas for each of these parameters are listed in table 2. The values for the 36 mm gap design, operating at n=1 field for 16 and 18 kV extracted beams, are compared with the operational design with the field level set for n=1 operation, ignoring the steering error, and with the field at the operating level.

Table 2 Beam sizes after magnet.

model	xy mm^2	xx′ mm mrad	yy′ mm mrad	y centre mm	y′ angle mrad
n=1 ignoring mis-steer (i)	174.1	188.9	177.9	1.8	85.1
Operational design (ii)	224.8	209.7	211.4	-10.2	-3.1
36 mm gap full field (iii)	173.7	209.3	181.7	0.0	-0.8
36 mm gap reduced field	177.8	197.8	184.9	-2.0	-1.8

Figure 2 shows the central trajectories for the first three cases listed in table 2. The steering correction in the improved design also causes the y-plane emittance to be closer to the level of the operational design at the unusable n=1 field level. The emittance in the x-plane seems to be related to the field level in the magnet rather than the path taken by the beam.

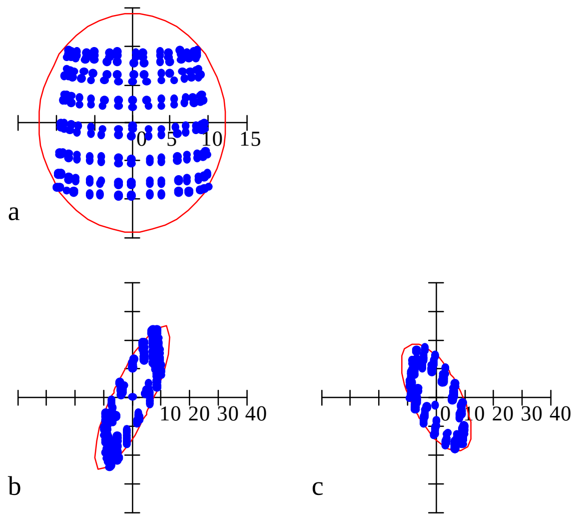

Figure 2 original specification

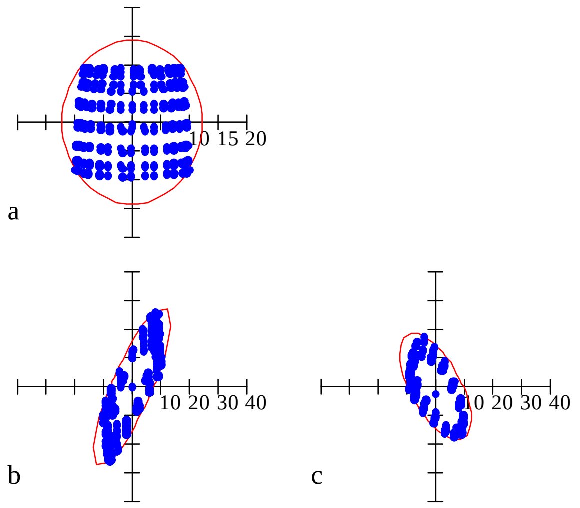

Figure 4 36 mm gap full field

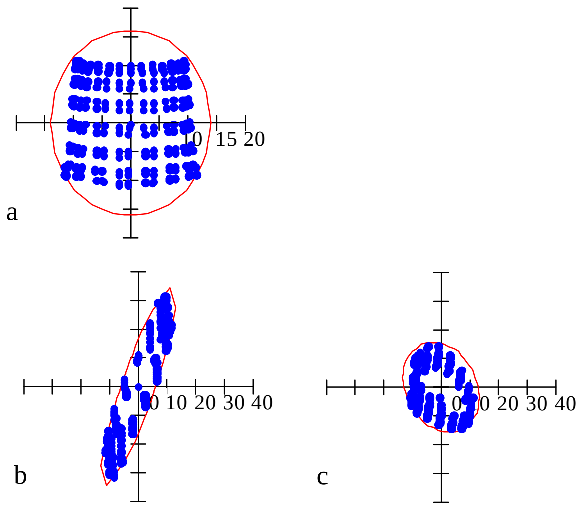

Figure 3 operating conditions.

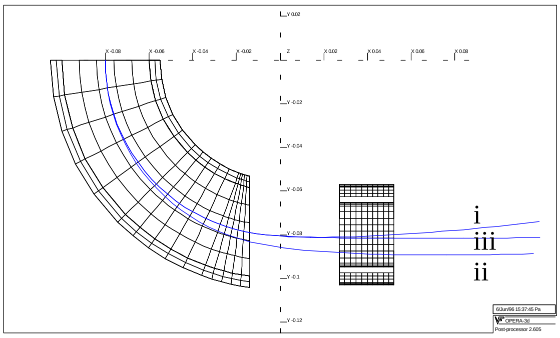

Figure 5 Alignment with different solutions

3 CONCLUSIONS

A finite element analysis of the ISIS H^- ion source analysing magnet has shown that with some design modifications a better alignment of the beam should be possible and the emittance benefits of operating at n=1 obtained. The design modifications requires the fitting of a 25 mm long tube separated from the pole by a gap of 36 mm ±5 mm and will be tested experimentally. There remains a residual offset which is greatly reduced by the tube arrangement. By allowing adjustment of the ion source in the vertical plane by ±2 mm it should be possible to align the source with the axis of downstream components. The combination of these two adjustments and the shielding effect of the tube should allow compensation for the mis-steering produced by the poles, without compromising the electron sweeping.

4 REFERENCES

1. Operational experience of Penning H^- Ion Sources at ISIS R.Sidlow this conference.
2. P.E.Gear and R.Sidlow Proc 2nd Inst Phys Conf Low Energy Ion Beams Bath 1980. Inst Phys Conf Ser No.54 P 284.

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