# LIMITS IN THE DESIGN OF SHORT SOLENOIDS FOR INTO MATCHING TO RFQS

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*Abstract*

An examination of the limits of solenoid length to bore ratio for a practical solenoid design is described, with reference to the linear matrix representation. Tracking of a four dimensional particle distribution through a finite element model of a solenoid design is compared with the matrix transform of the phase space ellipses describing the distribution. A design is presented based on these results for the solenoid matching system between the ion source and RFQ for the new ISIS preinjector.

## 1 INTRODUCTION

The ISIS ion source is an asymmetric slit source and as shown by Planner[1], three or four solenoids are required to match the ion source to the RFQ. There is a restriction on space available for the solenoids on ISIS, and this paper describes the calculations carried out to optimise the design of solenoids within the available space, particularly for determining the minimum acceptable length/bore ratio which is here shown to be ~3.0 - 3.5.

## 2 PARTICLE TRACKING THROUGH SOLENOIDS

The solenoids have been modelled with Vector Fields Opera2d, Opera3d and Tosca software. Particle tracking through single magnets and through matching systems was initially done in Opera2d. However to model the effects of tolerances in the manufacture of the solenoids it was necessary to model them in 3d.

In order to be able to track a large number of particles through the solenoids without spending excessive time, the magnetic fields computed by the Vector Fields software were represented by coarser meshes of points, and the particles were tracked through these coarser meshes. The magnetic system was assumed to be linear so that changes to the overall magnetic field strength were accommodated simply by linear scaling.

This procedure made it possible to model distributions containing many thousands of particles and hence produce a clearer picture of the aberrations generated in the system. Once the model of the required magnets has been produced it also makes it very simple to change the separation between magnets or the field strength in them.

The models of the magnets are calculated with the field level set just below the level at which the case material begins to saturate, in the models here using 6 $Amm^{-2}$ in the drive coils. This avoids any distortions in the fields caused by the saturation. However it does mean that saturation is not accounted for if the field is scaled to a higher level. Also the tracking currently does not include any space charge effects.

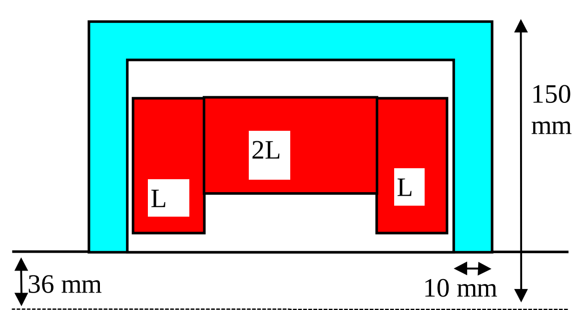
Checks on the calculations were made by carrying out complementary calculations based on the linear matrix representation of Larsen[2]. In this representation the solenoid is represented by a uniform field extending over the effective length together with ‘delta function’ end effects, and the particle distributions are represented by the usual elliptical boundaries. Comparisons between the finite element method and matrix method can be made anywhere except within the effective ends of the solenoids.

The effective length, of each magnet, is calculated by comparing the matrix ellipses and the tracked distribution. The ellipses are calculated for a test field level with an estimated effective length. The nominal level of the field distribution is set to a value such that the ∫Bdl over the estimated effective length is the same as that calculated along the axis of the finite element model. The length at which the highest fraction of tracked particles falls within both ellipses is used as the effective length.

The Trace computer code is used with this length to calculate the required field levels for the matching system. The beam is tracked through the whole system and the final distribution plotted to show any deviations from linear matrix match.

## 3 MAGNET DESIGN

The design of the solenoids uses an increased bore through the central part of the coils, based on a CERN design described in [3]. This improves the flatness of the field in the centre of the magnet and enhances the sharpness of the end fields, both of which reduce




Outline Solenoid design

aberrations. The model also includes the clearance between the outside of the coils and the casing which is required to accommodate the connections to the coils, but not the current in these connections nor the holes through the casing.

The coils, but not the case, are also slightly withdrawn from the beam pipe which puts the edges of the field outside the beam pipe. This is produces a slightly more uniform field than using the whole of a smaller bore

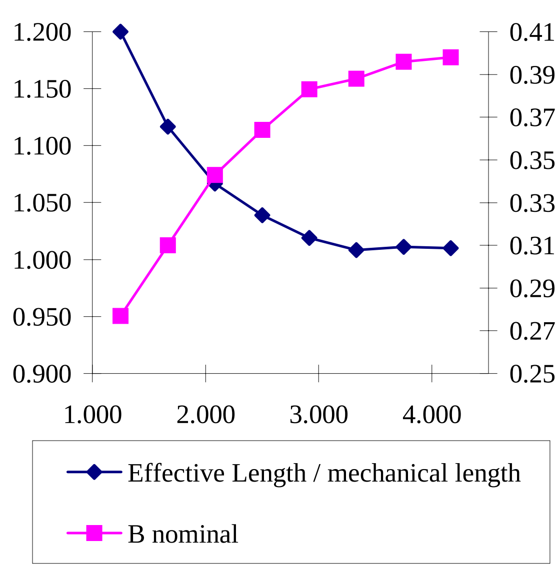
## 4 RESULTS

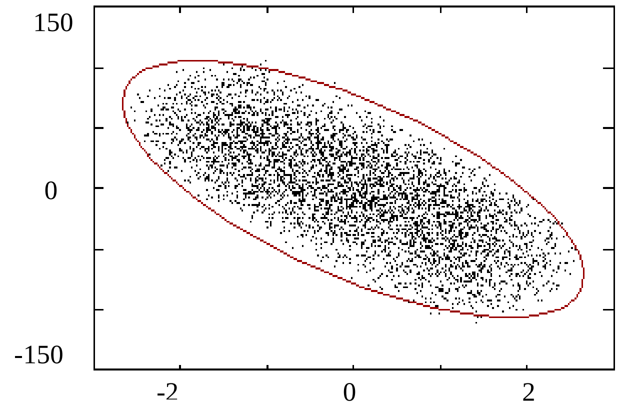
Finite element models have been run for solenoids ranging in length between 90 and 300 mm, all with a 72 mm bore and 10 mm thick end walls. An identical input beam is tracked through each solenoid.

The table below shows nominal field in each magnet, the variation in effective length/ mechanical length, and a qualitative description of the aberration after a single solenoid. The pictures opposite show the beam after a system of 3 solenoids, which in the matrix case enables a common match to be achieved, and shows the increase in aberration much more clearly than through a single magnet.

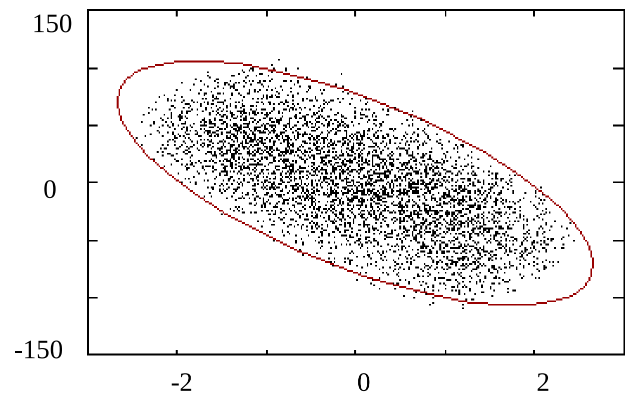
| length | length / bore | B nom | eff. length /mech. length | aberration |
|---|---|---|---|---|
| 90 | 1.25 | .277 | 1.200 | Very strong |
| 120 | 1.67 | .310 | 1.117 | significant |
| 150 | 2.08 | .343 | 1.067 | visible |
| 180 | 2.50 | .364 | 1.039 | just |
| 210 | 2.92 | .383 | 1.019 | just |
| 240 | 3.33 | .388 | 1.008 | no |
| 270 | 3.75 | .396 | 1.011 | no |
| 300 | 4.17 | .398 | 1.010 | no |

The plot shows the effective length/ mechanical length and the nominal field, as a function of length / bore..

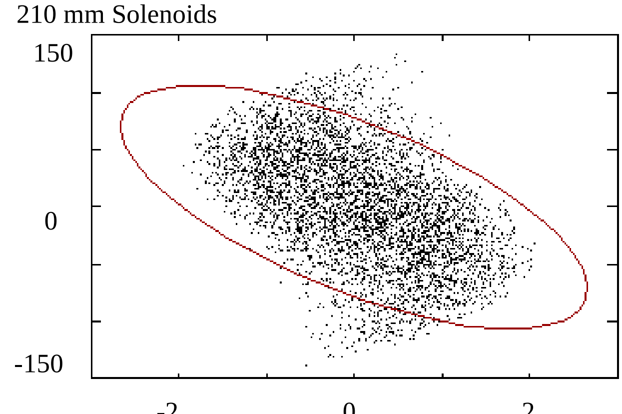


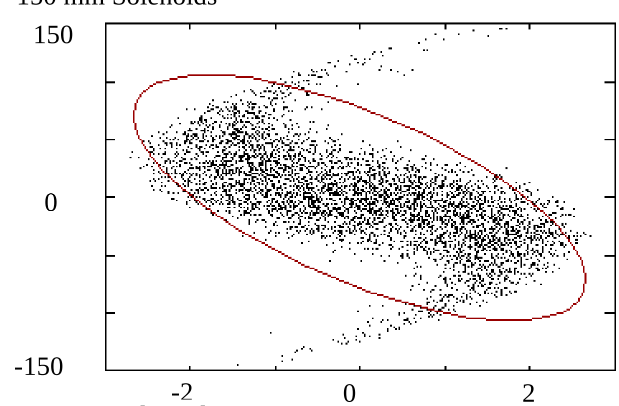

270 mm Solenoids




210 mm Solenoids




150 mm Solenoids




120 mm Solenoids

Increase in aberration through matching system with decreasing length of solenoid. x x' plot.

Ellipse $\alpha$=0.92 $\beta$=0.034 $\varepsilon$=208

In all cases at the effective length, after a single magnet over 95% of the particles are contained within the ellipses. This rises to 98% or more at length to bore ratios over 3. There is also visible S bending in the distributions up to 3 and some distortion from an ellipse just beyond. The plots of effective length / mechanical length and nominal field against length to bore, show turning points at around 3.5.

These effects all occurring in the same region suggest that 3.0-3.5 is a sensible limit to the minimum length to bore ratio of a low aberration solenoid.

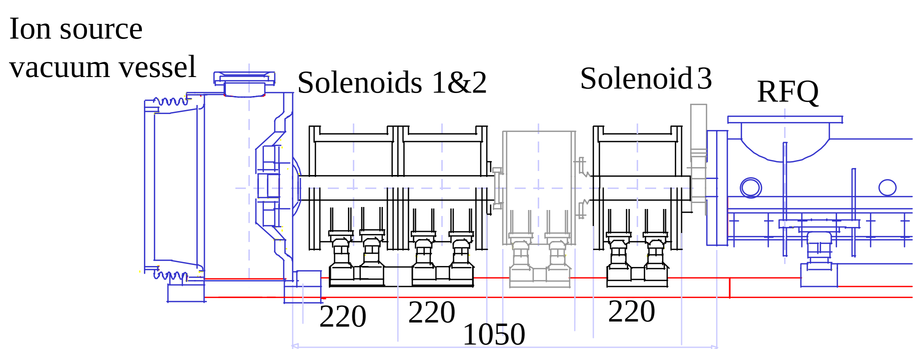
## 5 THE DESIGN FOR ISIS

The existing ISIS ion source is used with a single gap post accelerator to bring the beam energy to 35 keV. The system was initially designed using two solenoids with a length to bore ratio of 4 and due to the constrained length one low power solenoid with a length to bore ratio of 2.5. The first solenoid is mounted close to the ground electrode of the accelerating gap, and abuts the second low power solenoid. This gives the longest possible, gap to accommodate the required diagnostics, before the final solenoid which has to be positioned as close to the RFQ as possible.

The system is tightly length constrained to replace the existing LEDS equipment in the ISIS injector without preventing their reinstallation. However to gain the advantage of only designing and manufacturing a single type of magnet it was decided to make all three the same. This required the longer magnets to be shortened slightly, and together with an increase in the bore has reduced the ratio to 3. The net effect on the system aberrations is slightly beneficial.

The magnet design chosen differs from those modelled and presented here in that it has thicker end walls, which further reduce any effects of saturation in the casing. As a result the effective length is shorter than physical length.

The magnet and system designs have been checked using Trace2d including residual space charge up to 30 mA and using 3d tracking with zero space charge.



Ion source to RFQ low energy beam line for ISIS

## REFERENCES


[1] Matching unequal transverse emittances from an H- ion source into an RFQ. C.W.Planner Particle accelerators vol48 1995.

[2] Transport Matrices for a Magnetic solenoid. R.Larsen, Spear 107, 1971.

[3] Study of LEBT for RFQ2 G.Rossat, M.Weiss, PS/LI/note 85-1 , CERN 1985