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# THE INFLUENCE OF THE SHAPE AND POSITION OF A MAGNETIC SCREEN FOR A DC SEPTUM MAGNET

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# 1. Introduction

Septum magnets are used to inject or extract particle beams in circular accelerators. These magnets bend these particle beams without affecting the circulating or orbiting beams within the circular accelerator. Therefore a homogeneous dipole field is necessary in the gap of the septum magnet, while next to the magnet the leak field, also called fringe field, needs to be small as not to disturb the circulating beam.

To obtain more insight in the effectiveness of different magnetic shield geometry's, simulations have been done on an eight-turn DC septum magnet configuration, using a two-dimensional finite element program called Flux2d. This note does not pretend to be exhaustive nor will it serve ready to apply recipes for shielding, since the fringe field of a septum magnet is dependent on more things than the shield geometry only. However it does provide the possibility to compare different shield geometry's with each other. A septum magnet designer can then choose geometry and refine the final design of his magnet with the relative performance of the chosen shield geometry in mind.

# 2. Septum magnet fringe field

In principle a basic septum magnet without any further magnetic shield produces a fringe field much smaller than the gap field. In this note the fringe field will always be discussed on the symmetry plane, as indicated in figure 1, unless indicated otherwise.

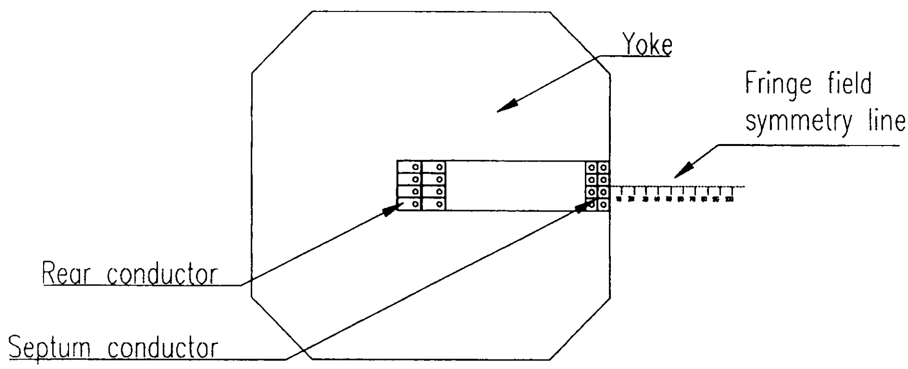



Figure 1: The septum magnet cross for which the calculations have been done. On the right the scale on which the fringe field is calculated, indicating the distance from the septum conductor.

The fringe field close to the septum conductor (roughly less than a gap height's distance from the septum conductor) is influenced by mainly two factors:

- septum conductor related factors, such as play between septum conductor and yoke, and current density uniformity within the septum conductor itself (non uniformity can be caused by water cooling circuits or insulation between turns)
- yoke related factors, such as yoke material (permeability) and less important the yoke shape

Further away from the septum conductor the septum related factor becomes less significant and the yoke related factor becomes the primary cause. It is of great importance to understand the cause of the fringe field, as to improve the magnet design on the right point, when a reduction in fringe field is sought after.

Neglecting the effect of leak fluxes caused by the septum conductor configuration, an electric equivalent circuit can be drawn up for the flux distribution in the septum magnet and its surroundings as is indicated in figure 2. The coils produce a Voltage V egual to the current times the number of turn (n). The current that can be calculated in the equivalent electrical circuit, describes the magnetic flux.

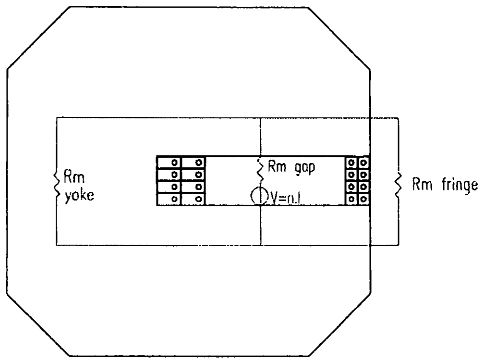



Figure 2: An equivalent electrical circuit of the magnetic fluxes in the septum magnet yoke and the leak flux.

Each resistance can be calculated as:

$$Rm = \frac{l_m}{A.\mu_0 \mu_r}$$

Where $l_m$ represents the average path length, A the average sectional area of the path, and $\mu_0$ and $\mu_r$ stand for the permeability of vacuum and the relative permeability respectively. The magnetic resistance of the gap is very important, since its path length is relatively long, while $\mu_r$ equals 1. The magnetic resistance of the yoke is far smaller than the gap resistance mainly due to the $\mu_r >> 1$. The fringe field magnetic resistance is even bigger than the gap resistance. From this on it can be seen that the gap field is mainly determined by the gap and yoke resistances, while the fringe field resistance, only causes a leak flux, but has little impact on the other fluxes. Magnetic shielding close to the septum conductor, in this equivalent circuit, comes down to adding a low resistance parallel to the high fringe field resistance, as to deviate as much as possible of the leak flux as to where it does not affect the orbiting beam.

## 3. Different magnetic screen shapes

As to reduce the fringe field, many approaches are possible. More often than not they are determined by the space available, and the trouble one accepts to go through to build these. First of all, by choosing the steel of the yoke, and therefore its permeability, already a great difference in fringe field can be obtained. In this note a non-linear steel, corresponding to the ARMCO B-H curve has been used. Also one can vary the thickness of the screens or the distances between screens and magnet. To allow for fair comparison between the different shapes neither of these factors have been changed between the different geometry's. Keeping this in mind, several shapes for magnetic screens have been compared, and the are described below.

1. Small screen
A Ferro-nickel screen at 1-mm distance of the septum blade of 1-mm thickness as to provide a screen for the septum conductor based causes of fringe field. Since the septum magnet under study is a multi-turn magnet with 0.4 mm of insulation between winding, the current density of far from uniform in the septum conductor region. The screen height is slightly taller than the magnet gap, as to cover properly the small gap between the yoke and septum. One could vary the thickness and the distance of the screen, and given the available space an optimal configuration could be found. For all the other following geometry's the screens distance from the septum conductor and its thickness will be the same as to this configuration, to allow comparison of the different solutions.

2. Tall screen
Another approach is to increase the small screen in height as to 'drain' away the leak flux, coming out of the side of the magnet yoke. This method does not bring much relief, since now, the magnetic screen works as a second back leg for the flux, and since it is very thin, it saturates, and flux leaks out again.

3. Small screen with orbiting beam screen
The orbiting beam is often guided for RF purposes within a non-magnetic beam screen. It can be imagined that this screen would be made of a magnetic material. This screen is independent of the magnet, and a gap exists between the septum magnet and the screen, as to allow the magnet to be movable, without being attached to the screen. This solution gives a much lower fringe field than the previous solutions, but evidently the gap between beam screen and magnet allows some leak flux to pass, explaining the increased fringe field near this gap. Further into the beam screen the field drops very rapidly.

4. Tall screen at a distance
A tall screen could be used, if the parts next to the yoke are a certain distance, in the order of a gap height. Close to the magnet gap the screen closes in at 45 degrees to the septum conductor as not to increase the effective septum thickness. This solution gives much greater reduction in the fringe field than the solutions discussed before, but may not be as easy to build.

5. Magnet in screened off in a box
Continuing on geometry 3, it could be imagined to 'wrap' the entire septum magnet in a box like screen, at a distance from the magnet yoke. The result with respect to geometry 4 is less efficient at distances close to the septum, probably because the increased flux capture, which makes the screen saturate. Further off the septum, the field is slightly lower.

6. Closed orbiting beam tube
When screening off the source of the leak flux, the septum magnet, doesn't achieve the required low fringe field, a tube can be attached to the little beam screen, as to create a sort of Faraday cage for the orbiting beam. Very effective, since the lowest fringe field value were calculated for this version. This solution could be used in an area where not many other sources for leak fields exist, and where the septum does not need to be movable. Typically this could be used for a DC magnet outside vacuum, with a big gap opening.

7. Movable orbiting beam tube
When the magnet is movable, solution number 6 is not practical to use. Another variation would be to combine the orbiting beam screen and add to a small screen next to the septum conductor wing, overlapping the beam screen. This way, the overlap will allow the septum magnet to be moved, without creating a space between the beam screen and the septum screen, thus keeping the Faraday cage idea. This solution is due to the overlapping screens close to the septum magnet even slightly

better close to the septum magnet, and gives in some effectiveness at greater distance from the septum when compared to the closed orbiting beam tube.

Figure 3 shows the calculated relative fringe field values of the 7 solutions, plus a solution without a beam screen for comparison. In Appendix 1, the mechanical dimensions and model details of the septum magnet are shown. In appendix 2 the layout of the different magnetic screen shapes as described above, is graphically shown. In appendix 3, figure 3 is repeated, but for comparison three curves are added: one curve shows the fringe field of a simulated pulsed single turn magnet, one curve shows the fringe field as measured on magnet smv20.2, a 5 mm single turn septum magnet. Another curve shows the measured fringe field of BESMH, a 3 mm single turn septum magnet, where a little screen is used.

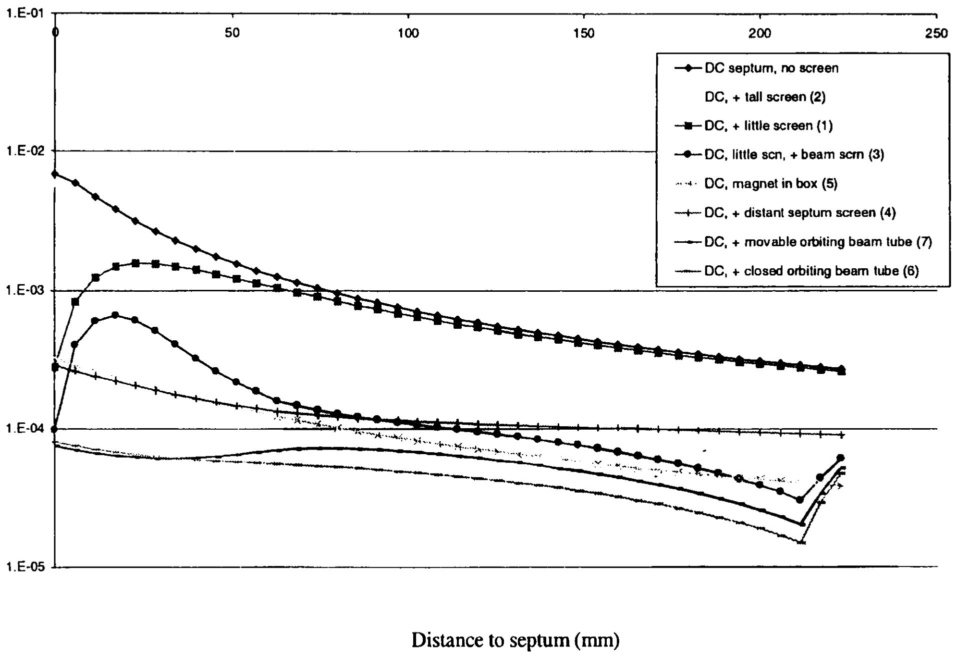



Figure 3: The relative fringe field as function as the distance towards the septum conductor for the different magnetic screen shapes, as simulated

# 4. Magnetic screen position and thickness influence

Starting with the little screen geometry (described earlier under geometry number 1), a few calculations were done to review the influence of the distance between the screen and septum conductor and the thickness of the screen. In figure 4 the results are shown, and the further the screen can be moved away from the septum, the better the smaller the fringe field next to it. This is obvious, since when the screen is moved away, it will automatically saturate less. However for the distances that can be considered acceptable for septum construction, of around 1 mm, the gain that can be achieved is far less than by optimising the screen shape.

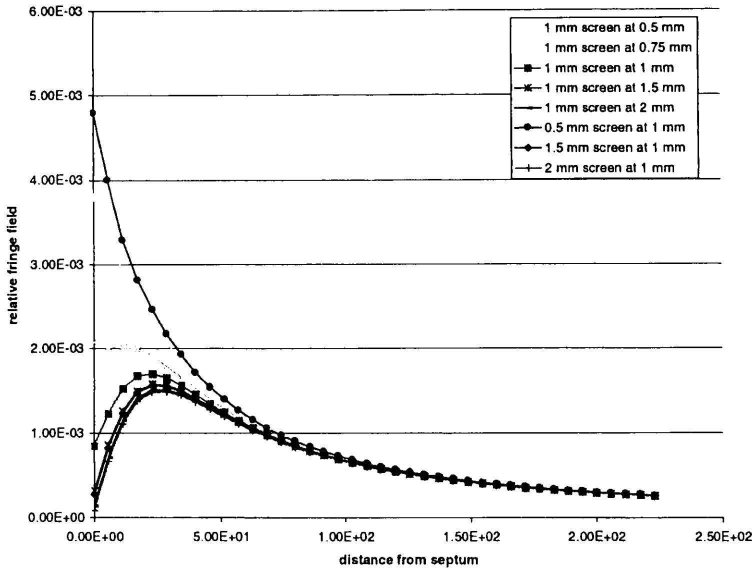



Figure 4: the relative fringe field, with a little magnetic screen (geometry 1), as several distances from the septum conductor.

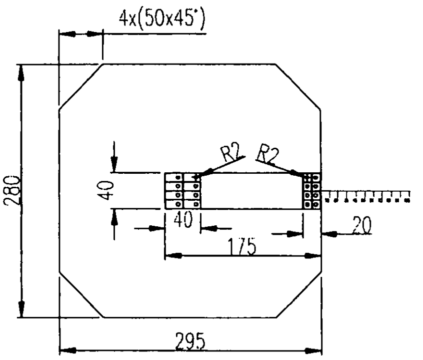
## 5. Conclusion

Several magnetic screens shapes have been evaluated, and their performance to reduce the fringe field of septum magnets has been compared, for a given eight turn DC septum magnet. A small screen just covering the septum conductor and overlapping the gap between septum conductor and yoke just a little bit proves a useful easy to implement method. If even lower fringe fields are needed, a magnetic orbiting beam screen, attached to the septum magnet or just overlapping with the magnetic screen next to the septum conductor, can achieve extremely good results. Fringe fields down to 1/10000 times the gap field are achievable, but at the expense of a higher technical complexity to build.

The results of the calculations performed, are to be interpreted with care. Many variables as shield thickness and space between septum conductor and shield were kept fixed. They only cover a 2 dimensional cross section, whereas a considerable part of the fringe field is caused by the magnet extremities. Further study of each septum design in detail is left to the designer.

## Appendix 1: Septum magnet model.

The different magnetic screen shapes as evaluated in this report. The number between brackets corresponds with the geometry description in this note. The comparison was done with a 1 Tesla 8 turn DC magnet model with 0.4 mm insulation between the turns and between coil and yoke. Each winding has a 4 mm diameter water cooling hole. The layout and overall dimensions of the magnet model are shown below.




As B-H curve for the yoke steel, an Armco steel equivalent curve was used, for the Ferro/Nickel screen a 50/50% compound curve was used. Below their curve descriptions as used in Flux2d are shown.

MATERIAL DATA BASE VERSION 89

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 9 isotropic relative magnetic permeability scalar splines
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ARMCO : armco u=1057 a H=1200;u=2048 a H=40 7

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last modification made on 2/08/99 10:13:25 by borburgh

11 isotropic relative magnetic permeability scalar analytic saturation plot

last modification made on 2/08/99 10:13:25 by borburgh

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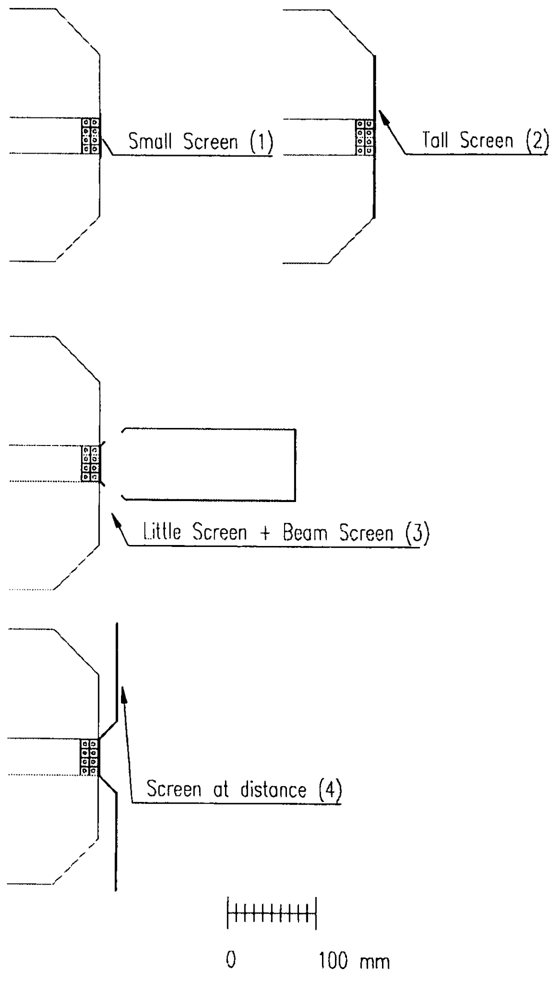
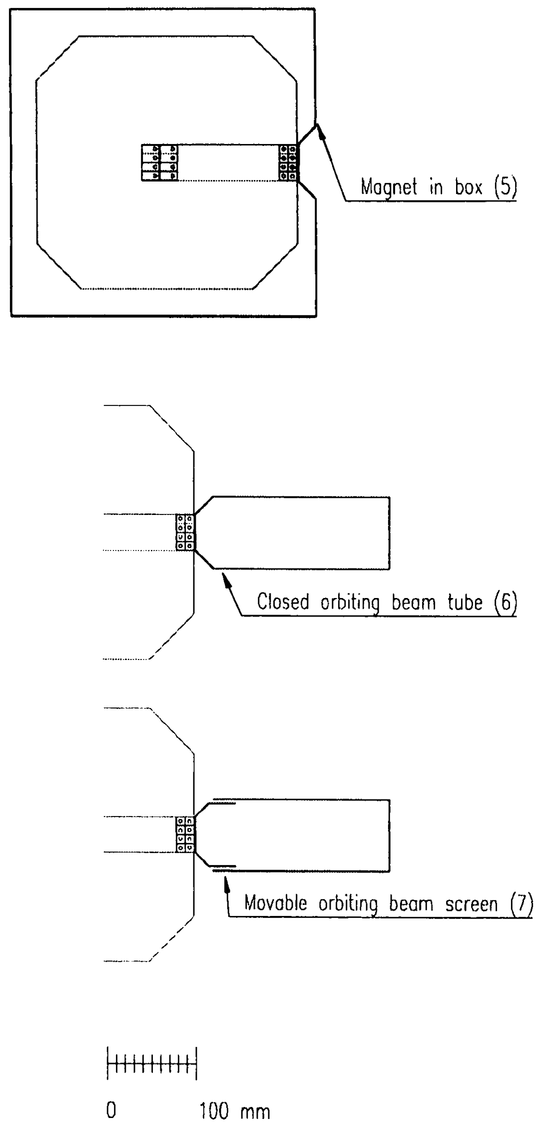
# Appendix 2: Magnetic screen shapes

All drawings on scale.





Magnet in box (5)
Closed orbiting beam tube (6)
Movable orbiting beam screen (7)
0
100 mm

# Appendix 3: More fringe field curves

The relative fringe field as simulated as function of the distance to the septum. Added in this figure are three curves: one curve shows the fringe field of a simulated pulsed single turn magnet, one curve shows the fringe field as measured on magnet smv20.2, a 5 mm single turn septum magnet. Another curve shows the measured fringe field of BESMH, a 3 mm single turn septum magnet, where a little screen is used.