Improvement of field uniformity in the ICAL magnet using air slots in the iron plates

P.R. Sarma* and Y.P. Viyogi
Variable Energy Cyclotron Centre, Block-AF, Bidhannagar, Kolkata-700064
** email: p.rudra.sarma@gmail.com*

Introduction

A large iron calorimeter ICAL is slated to be at the heart of the Indian Neutrino Observatory (INO) [1]. This will consist of a number of extremely large iron magnets. The total weight will be around 51000 ton. There will be 150 layers of iron plates of a thickness of 5.6 cm. The horizontal plates will be vertically separated by a distance of 4 cm. This space will be used for inserting RPC charged particle detectors.

In view of the enormous cost at which the observatory will be built, it is imperative that such a huge instrument should be utilized as effectively as possible. Effort should be made to use the total volume of iron in the calorimetric process. In other words, the magnetic field in the iron plates should be spread as uniformly as possible throughout the magnet volume.

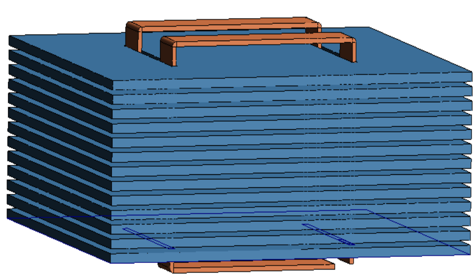

Fig.1. INO prototype magnet with a few layers (schematic) showing coils

Fig.1 shows the arrangement of the iron plates in the calorimeter along with the coils. The coils are placed in symmetrically cut air slots of cross-section 200cm×10cm. Fig.2 gives the plot of a 2D field calculation in a symmetric quarter portion of the plates. The flux lines go around the air slots to complete the magnetic circuit. As the horizontal plates consist of smaller plates (of size 2m×4m) small air gaps are bound to exist between them. To bring out the effect of these gaps we have assumed an effective gap of 4 mm in the magnetic circuit.

The lines of forces are nearly parallel to the coil slots in most of the iron volume. This implies that the magnetic field is uniform in that region. However, the flux lines bend around the corners, and therefore the magnitude of the field also changes rapidly at such regions. In the extreme corners of the plates the field falls to zero. Therefore the plate corners remain unutilized in the detection process.

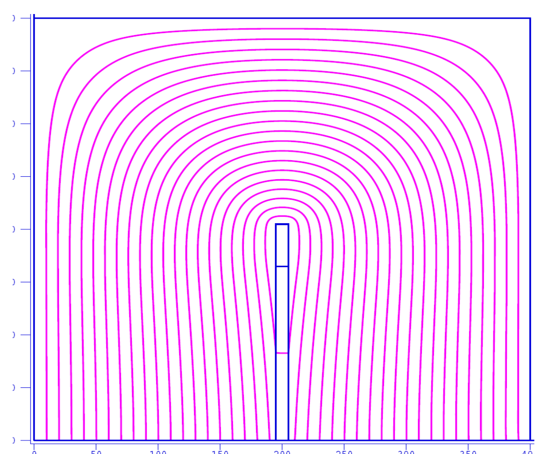

Fig.2. Field lines in a quarter of a magnet plate with no extra slot

In a previous work [2] we showed that the overall field uniformity can be improved if the width of the magnets are decreased in comparison with the length. However, this solution needs more number of magnet modules and consequently more number of coils. In the present work we offer a different solution where a single extra air slot improves the field quality.

Use of extra air slots

We have tried to increase the field in the corners by introducing extra air slots in the plates. Such slots will modify the field around them and try to push the flux lines towards the regions where the field is low. The length of the coil slots also have been optimized to make the field more uniform. Fig.3 shows the flux plot in such a plate magnet for 3000 amp-turn in a single coil. The extra slot is 2m in length, and is very narrow (2cm). The length has been kept to be 2m as the individual small plates are 2m in width and so the fabrication becomes easier.

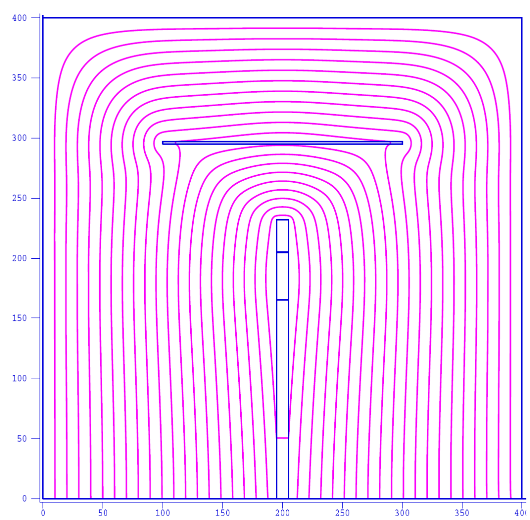

Fig.3. Field lines with an extra air slot.

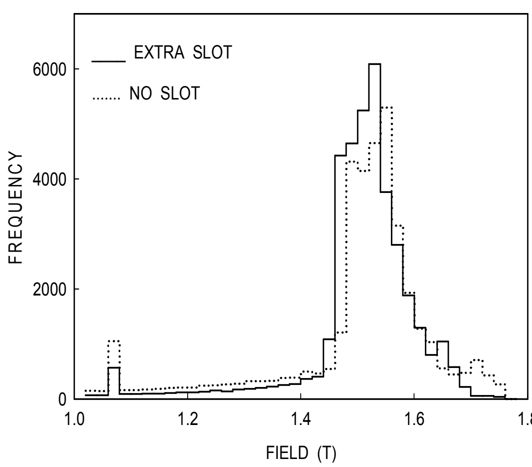

Fig.4. Field distribution without and with a slot.

A comparison of the figures shows that the flux lines are pushed to the corners and remain parallel to the slot in the upper portion of the plate. We have calculated the field in a matrix of 200×200 points (in a quarter plate of size 4m×4m). Fig.4 shows the histogram of the field within a 2cm×2cm cell over 4×10^4 cells for two cases - (a) no slot and (b) with straight slot. The average field |B| and the standard deviation σ/|B| of the field have been determined from this data.

We have tried slots of other shapes also (multiple slots and slanted slots). Fig.5 shows the flux lines in such arrangements. However, the slot shown in Fig.3 is preferred, as the arrangement is simple and mechanical fabrication is easier.

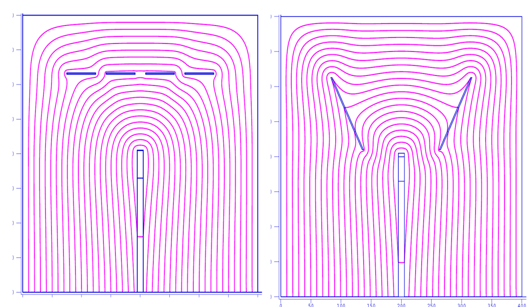

Fig.5. Field lines with various types of air slots.

Discussions

Table 1 gives the quantitative comparison of the plates with and without slots.

Table 1 : Average field |B| and width σ/|B| for various types of slots

Type of slot	|B| (Tesla)	σ/|B|
No slot	1.438	0.225
Single	1.475	0.178
Multiple	1.452	0.204
Slanted	1.411	0.176

The introduction of a simple narrow air slot, as shown in Fig.3, improves the field uniformity by about 20% over the normal case. Moreover, analysis shows that the average field also increases by about 2.6% in the case of extra slit. This is also beneficial to the calorimeter.

References

[1] INO Project Report, INO/2006/01, June 2006 (http://www.imsc.res.in/ino).

[2] Y.P. Viyogi and P.R. Sarma, DAE-BRNS Nucl. Phys. Symp. **56**, 1088 (2011).