On the simulation of the Iron Calorimeter Magnet for INO

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Introduction

The Iron Calorimeter (ICAL) detector at the India-based Neutrino Observatory (INO) aims to make precision measurements of neutrino (ν) parameters using atmospheric νs. This involves measuring the direction, momentum and the sign of the electric charge of the charged particles such as muons, pions and kaons in interactions of neutrinos with the target nucleons of the iron in the ICAL. The magnetic field in the magnetized iron will in conjunction with the fast tracking detectors, be used to measure the sign of the electric charge and momentum of charged particles produced in neutrino-iron interactions.

The design of the ICAL magnet is similar to that in the MONOLITH proposal [1]. Preliminary results of simulations have been presented in the INO Report [2]. This contribution presents some investigations, using finite element simulations of the ICAL magnet, aimed at finding the optimal slot configuration (through which pass the copper coils energizing ICAL), tiling of plates and the study of magnetic field strengths and uniformity for the standard design and the effect of various kinds of departure from this design. These studies should help in obtaining the desired piecewise uniformity of as high a magnetic field as possible for the lowest power dissipation in the coil.

ICAL Magnet Geometry

The baseline ICAL magnet configuration for one 16 kton module consists of about 140 layers of low carbon steel of nominal thickness 56 mm alternated with gaps of 40 mm in which will be placed active detectors to measure the charged particles produced in ν interactions with iron. Each iron layer has a dimension of 16m × 16m assembled from 2m × 4m tiles. Copper coils carrying DC current with cross section 62.5 cm × 8 cm having a length of 14m and width 7.8m are used to magnetize the low carbon steel plates. The calorimeter will be magnetized with a piecewise uniform magnetic field (1-1.3 T) to distinguish the μ^+ and μ^- events from the opposite curvature of their tracks in the presence of a magnetic field.

Simulation results

The simulation has been carried out using the finite element method based commercial software Magnet 6.26 from Infolytica, Canada. The parameters varied in the magnet simulation were the gaps between successive tiles of 2m × 4m used to form each of the 140 layers of steel, different types of slots, iron plate thickness etc.

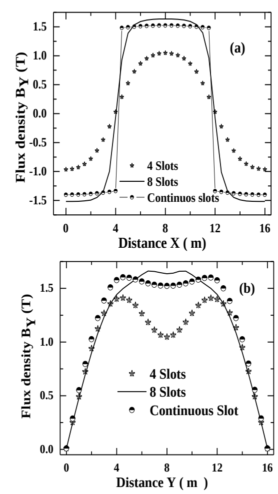

Figure: 1 Flux density variation with distance for different slot models at total current of 20 kA-turn, (a) X versus B_Y, (b) Y versus B_Y.

Simulation has been done for 1 layer of steel plate with 4, 8 and continuous slots having 2, 4 and 2 coils respectively carrying total current of 1-50 kA-turn. Fig. 1(a) and (b) show the variation of magnetic flux density (B_Y) along X and Y direction for each types of slot in the material at the middle of the plate. The 8-slot plate gives the maximum B_Y in both the direction compared to other two due to more number of coils with minimum separation. Plate with 4 slots shows a lower B_Y as the magnetic lines of force go around the coil due to minimum reluctance path. The variation of B_Y along Y direction shows maximum in B_Y at distance of 4 and 12 m due to proximity to the coils. The continuous slot, on the other hand, gives a uniformity over a much larger area as compared to 4 slots (29.5%) and 8 slots (61.5%) over a length of 8 m with variation in $\Delta B/B \leq 5\%$ along both directions.

The effect of tiling each of the 16m × 16m layers for 4 different configurations C-1, C-2, C-3 and C-4 shown in Fig. 2, on the magnetic field has been studied. This is shown in Fig. 3

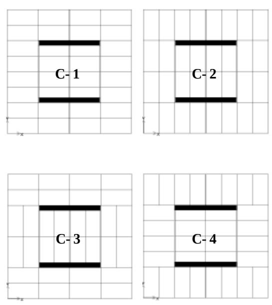

Figure: 2 Top views of four different arrangements of tiles with continuous slots. Deep black line shows the coils position.

Fig.3 shows that configurations C-1 and C-4 are giving same B_Y at all Ampere-turns and it is similar for C-2 and C-3. C-2 gives more B_Y (~6% and ~1.5% at total current of 25 and 50 kA-turn respectively) as compared to C-1. This is due to minimum number of gaps have been seen by magnetic lines of force which results in less leakage of flux.

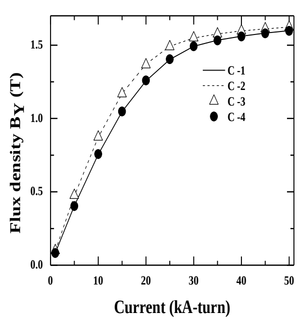

Figure: 3 Comparisons of flux density variation with current with different configurations at tiles with 2 mm gap.

So considering configuration C-2, the effect of air gap on the magnitude of flux density variation inside the material is shown in Fig. 4 for 2, 4, 5 and 6 mm gaps. The flux density inside the material decreases as the leakage flux increases with increase of air gap.

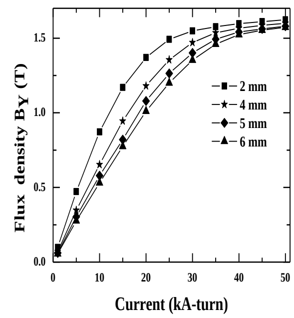

Figure: 4 Comparisons of flux density variation with gaps using configuration C-2.

In addition, the variation of B_Y inside the material has been studied for single layer (C-2, tiles with 5mm gap) steel plate allowing a variation in tile thickness of ±2 mm. It has been found that 54 mm thick tiles give ~ 0.7% and 2% more B_Y as compared to 56 and 58 mm respectively at total current of 20 kA-turn. It has also been seen that if the thickness of tiles is varied within 1 mm of a mean of 55 mm the calculated field for a 3 layer configuration shows a maximum field strength variation of < ±2%.

Summary

The ICAL magnet having 8-slots gives more flux density and continuous slots give more uniformity. The tile configurations for magnet layers corresponding to C-2 and C-3 are more efficient than other two configurations at lower values of Ampere-turns. Tiles of 54 mm thickness give more flux density as compared to those with thickness of 56 and 58 mm.

References

[1] N. Y. Agafonova et al., MONOLITH: A massive magnetized iron detector for neutrino oscillation studies, LNGS-P26-2000

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