Fabrication and testing of the magnet of the prototype Iron Calorimetric detector

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Introduction

A 50 kton iron calorimetric (ICAL) detector is proposed to be set up at an underground laboratory [1] to make a precision measurement of neutrino (ν) parameters using atmospheric νs. As a first step a prototype 35 ton ICAL detector will be set up over ground to track cosmic muons. Experience with the prototype will be very useful in planning for the much bigger ICAL. This prototype will provide an active volume of about 1 m^3. The present paper discusses only the electromagnet and not the detector and electronics (see contributions to this symposium).

INO Magnet

The geometry and structure of INO magnet is largely fixed by the principle of ICAL detector. Its twofold purpose; providing target nucleons for neutrino interactions and also a medium in which secondary charged p[articles can be separated on the basis of their magnetic rigidity. As the prototype magnet detects muons, only the second function is required. Since the prototype was expected to provide data on practical inefficiencies (not reflected in the computer simulation), the overall design of prototype magnet was kept as close to the conceived design of the full scale INO magnet. This structure takes the form of a multilayered sandwich of large dimensions (Figure 1). The gap in between two magnetized plates is to be filled with large area gas ionization detectors (resistive plate detectors or RPCs).

Fig. 1. INO prototype magnet structure

Prototype Magnet Optimisation

To carryout design optimizations a software was needed (finite element method or FEM based) on which such simulations and design evaluations could be carried out. After detailed comparison, we zeroed on the code Magnet 6.0 by M/s Infolytica, Canada on its superior features in regard to ease of simulation and data post-simulation data analysis and presentation.

The design variables were; iron plate thickness, gap between two layers, material used for magnetic path, iron to copper ratio, coil location, and dimensions of the magnetic circuit. Not all of these were explored as the aim was to have the proto-detector in place in the least time and with minimal cost and not minimum electrical input. For example, with a proposal that magnet steel needed for this can be made available by dismantling an old MHD magnet, we immediately accepted and implemented this idea.

The simulations with Magnet 6.0 were done assuming C10 as the magnetic material. The design was assumed to ideal; that is no air gaps or misalignment between the plates that constitute a single layer. For this idealized design a figure of 2500 Amp-turns was expected to provide a field strength of ~ 1T in the iron plates. As the actual material in this case was not C10 departures from design values was expected in the experimental trials. Further, the actual gaps and surface irregularities would add to uncertainties in the Ampere-turn requirements and the highest attainable field in this proto-magnet.

Magnet Fabrication and Testing

The iron plates necessary for this work were obtained from the iron blocks of MHD magnet which had some internal gaps and slots. Hence, a lot of patchwork and at times reduction/ alteration of dimensions of plates with regard to design had to be accepted. The plate thickness was 50 mm (-4mm, +1mm) and were not entirely planar after hot working necessary to remove them from thick blocks of iron. Gas cutting was used to obtain pieces that were then joined by tack welding to form a ‘T’ and a ‘C’ shaped plate. A single layer can be made from joining a T and a C plate. The gap left in between along the leg of T plate is used for locating the coils which are slipped in before joining T and C plates. The iron plates after cutting were not machined to even out mating surfaces as this is expected to be the case in 50 kton ICAL magnet where such machining is expected to involve a high cost. Spacers made out of stainless steel were welded at appropriate locations on the bottom surface of T and C plates to ensure a uniform gap of 50 mm (+3mm -0 mm) between any two stacks of iron plates. Finally to even out the loading of the magnet on the floor, a stainless steel tray filled with cement was designed to provide the base for the magnet.

The coils were made from electrolytic copper conductor tubing that has a central bore for flowing low conductivity water. The power supply for the magnet coils is a thyrister controlled three phase low voltage constant current type and has a stabilized reference to regulate the current.

Using standard software packages, the FEM based analysis of mechanical loading/ stress analysis and deformations was carried out to ascertain the suitability of location of spacers between plates.

At 2500 and 3750 Amp-turns the magnetic field B in the central portion of the T plate was measured to be 0.8 and 1.2 Tesla, respectively. Since the existing power supply had reached the limit, the saturation B field was measured with the same supply and a single smaller 0.5m × 0.5m C- and T-section. This magnet excitation curve is shown in Fig.2. The uniformity of field was measured by introducing a small gap in one of the plates and moving the probe along the plate edge. The uniformity was seen to be in the range of 5% and reduces as we move to higher fields close to the saturation value.

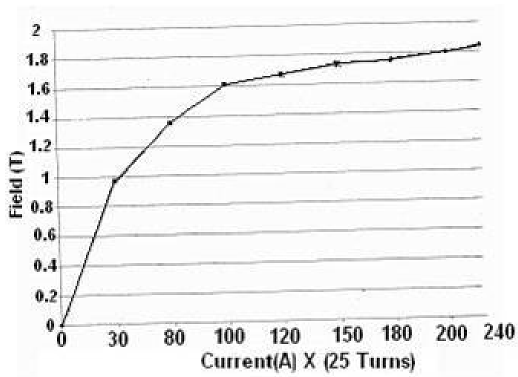

Fig. 2. B-H curve for a smaller magnet sample

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References

[1] V.M. Datar, invited talk at DAE Symp. On Nucl.Phys. **51** (2006) 173 and INO Report May 2006 at www.imsc.res.in/~ino.