объединенный
институт
ядерных
исследований
дубна

E9-94-479

M.Nessi*, F.Bergsma*, S.B.Vorozhtsov, O.N.Borisov,
O.V.Lomakina, G.A.Karamysheva, J.A.Budagov

LARGE TileCal MAGNETIC FIELD SIMULATION

Submitted to «XIV Meeting on Charged Particle Accelerators»,
Protvino, 1994

---

*CERN, Geneva, Switzerland

1994

Несси М. и др. E9-94-479

Моделирование магнитного поля в TileCal

Сделана оценка магнитного поля эксперимента АТЛАС в области адронного калориметра. Такая оценка важна с точки зрения выяснения условий экранирования фотоумножителей и влияния магнитного поля на световой выход сцинтилляторов и связанной с этим калибровкой сцинтилляторов. Магнитное поле в области адронного калориметра создается за счет центрального соленоида и 8 сверхпроводящих тороидальных обмоток. В результате расчетов оказалось, что магнитное поле на сцинтилляторах не превышает 6 мТ, а в зоне фотоумножителей, после надлежащей экранировки, 0.6 мТ. Была выполнена также оценка пондеромоторных усилий в системе. Для расчетов применялись программы VF OPERA-TOSCA и CERN POISCR.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1994

Nessi M. et al. E9-94-479

Large TileCal Magnetic Field Simulation

The ATLAS magnetic field map has been estimated in the presence of the hadron tile calorimeter. This is an important issue in order to quantify the needs for individual PMT shielding, the effect on the scintillator light yield and its implications on the calibration. The field source is based on a central solenoid and 8 superconducting air-core toroid coils. The maximum induction value in the scintillating tiles does not exceed 6 mT. When an iron plate is used to close the open drawer window the field inside the PMT near to the extended barrel edge does not exceed 0.6 mT. Estimation of pondermotive force distribution, acting on individual units of the system was performed. VF electromagnetic software OPERA-TOSCA and CERN POISCR code were used for the field simulation of the system.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1994

1 Formulation of the problem

- Calculation of the ATLAS space map for the field inside the magnet and for fringe fields outside the magnet [1]. Submitting calculated field map into various simulation programs.
- Calculation of the magnetic field of scintillating tile calorimeter in order to quantify the PMT shielding and the B-field effect on scintillator [2].
- Study of uniformity distortions arising from the geometric effects:
  - Calculation of the effect of field flux distortion in the feet region of TileCal.
  - Calculation of the effect of field disturbances due to studies in the tile zone.
- Estimation of pondermotive force distribution, acting on individual units of the system:
  - The force between Barrel and Extended Barrel [2].
  - The attractive forces between end-cap toroids and Barrel toroids through the yoke [3].
  - Mechanical tolerances/forces arising from asymmetries [1]?

2 The adopted ATLAS simulation model

Schematically various aspects of system are shown in Figs 2.1÷2.3. In these Figures there are identified the only elements of the detector which are field sources or magnetized media. ATLAS coil system constructed with the help of the preprocessor OPERA-3D [4] is shown in Fig. 2.1. One can see the solenoid in the very centre, 8-coil Barrel toroid around the solenoid and on both sides of the system - very simplified images of the end-cap toroids. Minimal part of iron needed for calculations is shown in Fig. 2.2 and Fig. 2.3. Only half of the TileCal iron along the Z-axis (Fig. 2.2) and only 4 sectors along the φ-coordinate (Fig. 2.3) were taken into consideration. Proper boundary conditions reflecting the symmetry of the system were assigned at the enclosure of the region of calculation. Periodical along φ -coordinate symmetry condition has been taken into consideration. The active section should be replaced by iron with a suitable packing factor = 0.76 and anisotropic properties taking into account the slots for tiles (but it still has not been done up to now). Magnetic characteristic for steel 08 was taken from [5,6].

3 Magnetic field in the scintillators

3.1 Simplified model representation results

Calculation with the 2D code POISCR [7] for the system configuration in the polar R-Z coordinates was used for the simplified model [8]. No stray field from coil toroids is included

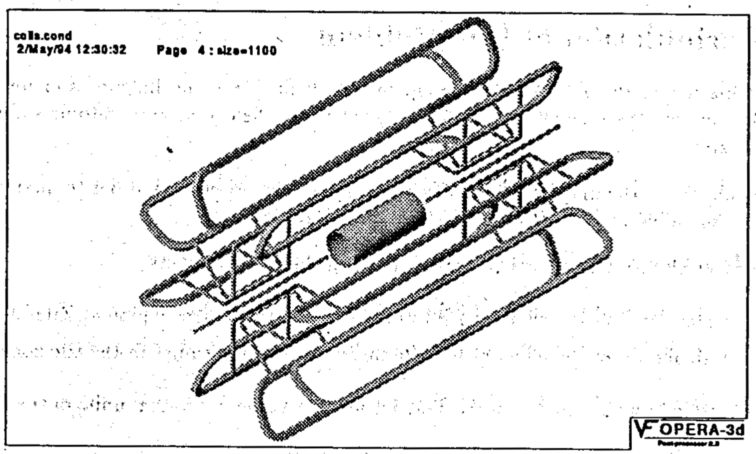

Figure 2.1: ATLAS coil system

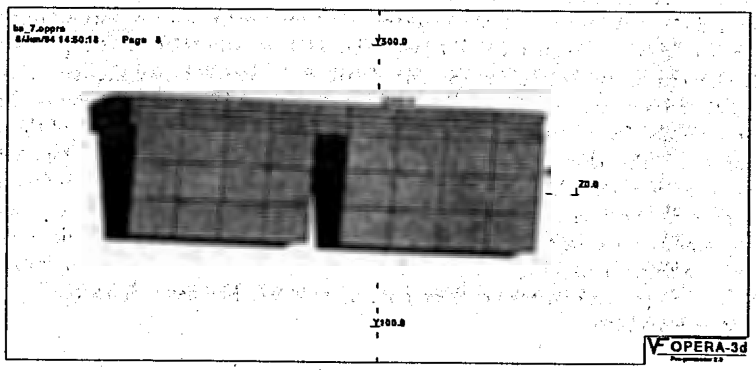

Figure 2.2: 3D iron model for TOSCA calculations

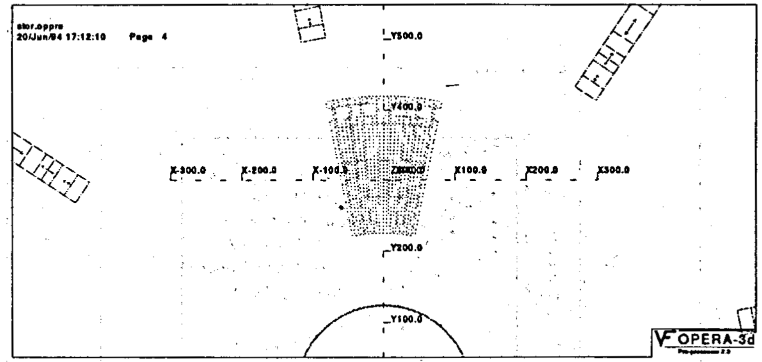

Figure 2.3: Barrel and Extended Barrel 4 sectors cross-section in XOY plane

into calculation. We need this model to get an impression of the flux line distribution and to find out where there are places within TileCal absorber with the maximum field values. This would give us the most critical points as far as the field lines penetration into tile region concerned. From these calculations one can see that such points are situated along the border, namely, at the corners of Barrel and Extended Barrel contour.

We can make an estimation for the lower limit of the field in the TileCal assuming that the total flux coming out of solenoid is uniformly distributed over Barrel and Extended Barrel cylindrical surface at the R_{min}. Then we shall get $B_{average} \approx 0.13$ T at this TileCal surface. This rather low value as compared with solenoid field 2 T reflects a geometrical factor connected with the much larger cross-section area for the flux in the TileCal in relation to the cross-section of solenoid. This can be compared with the Barrel field value for R_{min}, Z_{min} which is equal to 0.4 T.

3.2 Results with a more realistic tile structure

It is constructed as the previous model but with inserting the real tile structure regions into the most critical points with the maximum induction value in the TileCal iron. These points have been found out in the previous model. The purpose of the model is to get a feeling what the maximum field value would be inside the tile regions of the TileCal.

Firstly the real tile structure area was introduced at the Barrel corner with the R_{min} and Z_{max} values. In Fig.3.1 field values along the 1st from the Barrel edge (Z= 2.9275 m) and

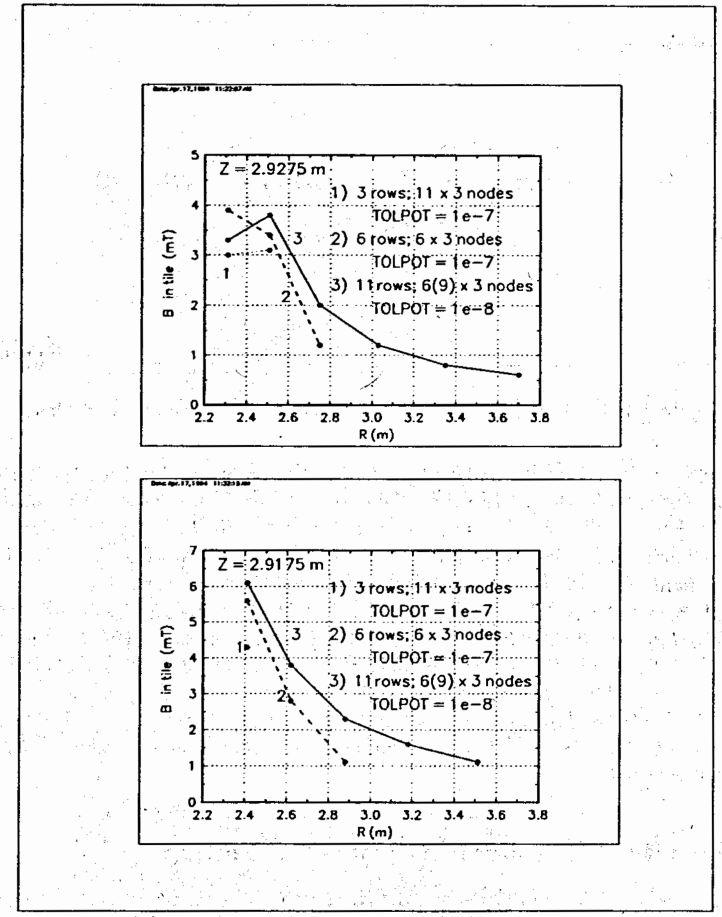

Figure 3.1: Field inside tile regions for various number of rows with the real tile structure

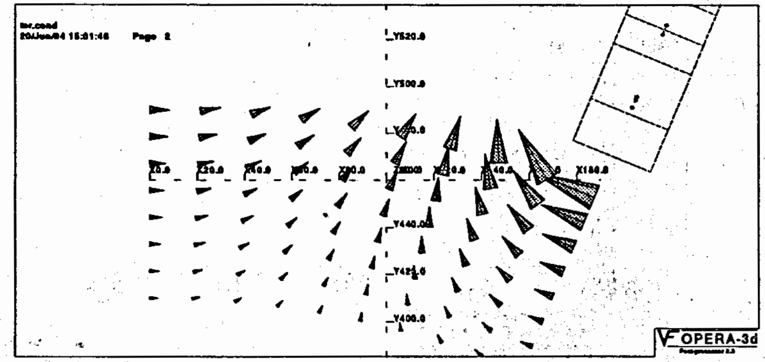

Figure 4.1: Barrel toroid stray field pattern near the TileCal support part

the 2-nd (Z=2.9175 m) R-columns are given. One can notice that for the region with the maximum iron field 1.6 T the maximum induction value in tiles does not exceed 6 mT±2mT which is safely below desired limit 10 mT.

One could also expect the tile field increase with radius in the vicinity of the Barrel corner with (R_{max}, Z_{max}). But in this region situation differs from the corner with (R_{min}, Z_{max}) as there is thick solid return flux iron connecting Extended Barrel and Barrel along Z-axis and safely screening tile slots from the magnetic flux penetration.

2D calculations near Z ≡ 0 show that the flux lines are ≈ parallel to the Z-axis and the tile field is also no more than 6 mT.

4 Magnetic field at the PMT location

Here we mainly shall consider the three–dimensional model (3D) of the TileCal magnetic field distribution [9] with the help of the VF software TOSCA [4].

4.1 Central (Z ≡ 0) TileCal barrel plane

This set of calculations was done with the only Barrel toroid coils with the nonzero current. The rest of the ATLAS coil system was without current at all.

In Fig. 4.1 one can observe that the toroid stray field shows 16 - poles behavior in the region between the Barrel toroid and the TileCal, R = 4.2 m ÷ 5.0 m. In this Figure the

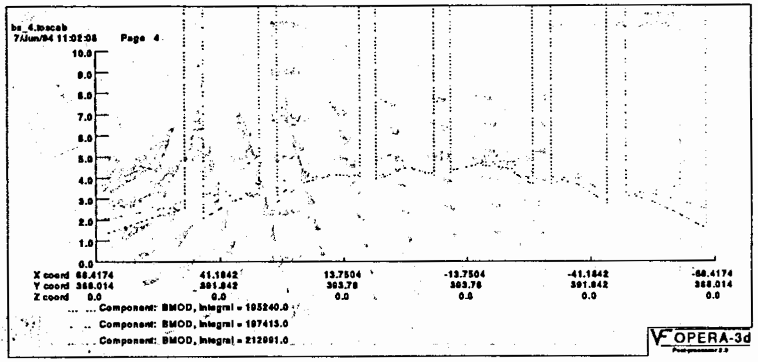

Figure 4.2: PMT location field distribution in Z $\equiv$ 0 plane

length of vectors represents in relative units an induction value at the point. There is only toroid in the system (no iron, no other coils). In the support part the toroid stray field varies from 80 mT at R=380 cm to 200 mT at R=420 cm.

On the outer surface of iron exposed to the toroid stray field the maximum field value is $\approx$ 0.8 T. The maximum field occurs at the azimuth of the toroid coil and in between the two toroid coils.

Field at the PMT location is not more than 0.4 mT for the Z $\equiv$ 0 plane (4 gauss in Fig. 4.2). In this Figure three curves correspond to the low (394 cm), middle (400 cm) and upper (408 cm) radii within the radial range of the PMT location windows. The maximum PMT location field is at the middle azimuthal position of the iron taken for calculation which could be explained by the normal induction component penetration into the PMT region from the outer support part. So low PMT field level could not be of any surprise because at the given iron field level the relative permeability of iron is very high for steel-08 ($\approx$ 3000). This calculation also confirms the result of the 2D POISCR calculations with the PMT region field of $\approx$ 0.15 mT.

Now we have the field level of more than two orders of magnitude less than it has been estimated $\approx$ one year ago and reported at the TileCal collaboration meeting (31-01-94 and 2-02-94) [2]. The reason for this dramatic change in the field level is modifications of the parameters and probably some methodological improvements in conducting the calculations.

4.2 Edge of the end-cap (Z_{max}-plane)

On the outer surface of iron exposed to the toroid stray field the maximum field value is $\approx$ 1.5 T. This is $\approx$ twice higher field level than in the middle of the Barrel part which could be explained by the Barrel toroid stray field flux lines attracting to the TileCal iron.

Due to the open PMT window at the edge of the Extended Barrel the rather large outside toroid field of $\approx$ 120 mT gradually decreases from the edge (Z=614.6 cm) down along Z-axis inside the TileCal PMT windows.

4.3 Shielding at the edge of the end-cap

Having in mind the result of section 4.2 one should probably foresee some extra set-up for the PMT shielding at the Extended Barrel edge where there occurs the highest flux penetration to the PMT location.

Naturally, one can use the same 10 cm thick iron plate to close the open PMT window as it was successfully used for the outer radius of the support part. On the left side of Fig. 2.2 one can notice the proposed shielding ring separating the PMT windows from the toroid stray field.

Of course, the plate would be substantially magnetized ($\approx$ 2 T) but the field inside the PMT window near the Extended Barrel edge became no more than 0.6 mT (6 gauss) now.

5 The return flux field map

Now we switch on the current only for the solenoid with the rest of the ATLAS coil system without the current at all.

The iron surface maximum field value is in the support part inside the so-called crack region [10] between the Barrel and Extended Barrel part of the TileCal. On the inner surface of the support the field is 1 T and on the outer surface $\approx$ 0.6 T. This happens due to the return flux of the solenoid and was already observed in the previous calculations with the help of the POISCR code [7].

Near the crack region (Z = 294.7 cm $\div$ 344.7 cm) the PMT location field is not more than 0.3 mT due to the support magnetization from the solenoid return flux.

Although this field is $\approx$ an order of magnitude of one obtained with Barrel toroid the combined magnetization of the support part from the toroid and solenoid could give a rapid rise in the PMT field in this area because of nonlinear effects in ferromagnetic material.

As toroid and solenoid induction vectors have always a 90° angle between them, in the worst case one could expect $\approx$ 50% of the total field level increase due to geometrical but not algebraic addition of the induction vectors in this region. In this case an approximate value of the maximum field value could be $\approx$ 1.5 T in iron. This field level seems to be still tolerable as the relative permeability of steel-08 at this induction is still high ($\approx$ 1000).

The situation also is a bit simplified due to the fact that the upper part of the support (in Fig. 2.3) shields the PMT from the toroid stray field and the lower part conducts the solenoid return flux (separated-functions device).

At the April 1994 ATLAS week there was discussion concerning the problem of the crack region between the Barrel and the Extended Barrel of the end-cap region [10]. Presently a gap of 50 cm is foreseen, bridged only partially by the structure connecting the flux returns at the outer radius. The tile calorimeter community brought up the question if this gap should be "plugged" with calorimetry, leaving of course sufficient space for services, cables and electronics for the detectors inside the tile calorimeter. Filling the gap would also be helpful to reduce neutron backgrounds to the muon chambers and the above-mentioned problem with the PMT location field would be completely solved.

One could also insert more iron for the support part in the crack region. In the limiting case of filling the whole crack region with iron our calculation shows only 0.2 T magnetization of iron near PMT location (5 times less than in the previous case). But in this case tile field can increase somewhat and some intermediate solution should be adopted then.

Due to results obtained here the problem of the individual PMT shielding is considerably simplified and the drawers mechanics getting much simpler. Substantial saving of the material cost and manpower for R&D will take place. The decision could be taken to abandon the expensive high magnetic permeability material (μ-metal) for the PMT shielding.

References

[1] F. Dydak and P. Jenni. Questions to LHCC Magnet Expert Panel, 10 Nov 1992.

[2] M. Nessi. Status of B-field calculations and return flux design. Presentation to the TileCal - collaboration meeting (31-01-94 and 2-02-94).

[3] W. Kozanecki (MUO-TR-180). Report on the highlights of the Toroid meeting held at CERN on 27 January 1994. (see also minutes of the Toroid meeting held at Saclay on 27. Jan. 1994). In: Minutes of the Muon Working Group Meeting 2 February 1994.

[4] Tosca User Guide. Version 6.3. 1993.

[5] S.B.Vorozhtsov et al. Permeability Measurements with the Systematic Error Correction by Calculation of Stand Magnets. April 3, 1993. SDC-93-486.

[6] V.V.Kukhtin. Measurements of a Magnetization Curve for the Iron Samples. CERN/EP/NA-4 Note, August 21, 1984.

[7] CERN Program Library Writeup T602.

[8] M.Nessi et al. Computer Models for the TileCal Magnetic Field Distributions. ATLAS Internal Note TileCal-NO-012, 9 May 1994.

[9] M.Nessi et al. TileCal Magnetic Field Simulation. ATLAS Internal Note TileCal-NO-018, 24 June 1994.

[10] M.Nessi. Summary of the recent activities of the Tile calorimeter detector unit. In: Minutes of the ATLAS Plenary Meeting held on 21 and 22 April 1994.

Received by Publishing Department
on December 13, 1994.