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STATIC MAGNETIC FORCES AND TORQUES IN ATLAS

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Пондеромоторные силы и моменты сил в детекторе ATLAS

Целью данной работы является расчет пондеромоторных сил и моментов сил, действующих в детекторе ATLAS (LHC, CERN). Полученная информация может быть использована для оптимизации различных элементов системы в процессе их проектирования. Результаты расчета сил могут также служить в качестве дополнительного критерия при замене магнитных материалов, используемых при изготовлении различных структур, на немагнитные.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Static Magnetic Forces and Torques in ATLAS

The magnetic forces acting on the various metallic objects around the ATLAS detector, are the subject of the given paper. A system designer could use the information on global forces and torque acting on various components, obtained in this report, to optimize them. The results of force calculations could also serve as additional criteria for the replacement of the magnetic baseline material of various structures by nonmagnetic ones.

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

Communication of the Joint Institute for Nuclear Research. Dubna, 1997

Problem formulation

In the previous report on the ATLAS B-field determination the first estimation of the magnetic field perturbation, caused by the various metallic objects around the ATLAS detector, was performed[1]. The magnetic forces acting on the objects are the subject of the given paper.

The general formulation of the problem is given below. Most of the points were mentioned during the ***ATLAS B-field worshop*** (June 20-21, 1997, Dubna)[2 3] and were agreed upon at the ***Meeting on field computations*** (August 26,1997, CERN)[4].

TileCal

- Making a new summary (taking into account the latest information) of magnetic forces acting on various parts of the TileCal (the whole TileCal, active zones, girder, Barrel, Extended Barrel, front plates, end plates, crack region, forward shielding disk etc.).
    - *The 2D computer model with the only solenoid on to estimate forces on the TileCal Barrel and the Extended Barrel (active part with and without girder)*
    - *Torque due to the axial components of the force.*
    - *Estimation of the forces and torques when both the solenoid and the toroid are on. It requires a truly 3D computer model of the system.*
    - *Coupling forces between the barrel and the extended barrel*
    - *Although the axial force component in the barrel vanishes because of the symmetrical configuration, any misalignments will cause a net axial force there. To have an idea of the force magnitude for this case one can make its estimation for only half the barrel.*
    - *Detailed distribution of forces along the border of various parts of the system is valuable for understanding the mechanics of system performance.*
    - *What is the force exerted on the extended tile calorimeter if it is shifted from its nominal position by ±10 mm along the "x" or "y" axis?*
    - *The same question for the extended tile calorimeter tilted around "x" or "y" axis by an angle up to 1 mrad.*
- Estimation of the asymmetry forces and torques because of B-H and air stacking effects for various TileCal parts.

Toroids

- What is the force exerted on the toroid endcap magnet if it is shifted from its nominal position by ±10 mm along the "x" or "y" axis?
- The same question for the toroid endcap magnet tilted around "x" or "y" axis by an angle up to 1 mrad.

Large metallic (& partially magnetic) structures

- structure around the Barrel Toroid
- neutron shielding
- detector feet (A-frame)
- "green support" (between concrete floor & detector feet)

- what is the typical force range on a ferromagnetic object of the size of a pair of pliers or a screwdriver in the Barrel Toroid fully switched on?

These computations must be carried out

- under nominal running conditions
- with any combination of magnets off/on (i.e. BT on, ECT off)
- with regard for mechanical / geometrical imperfections (unbalanced forces)
- for the worst-case toroid fault scenario (different currents in different coils)
- mechanical design is better understood

Software and Cross-check

- Using different methods and different codes (POISCR, Tosca, Gfun3D, MafcoD, etc.) to ensure the highest reliability of the results
    - *Maxwell stresses*
    - *Virtual displacements*
    - *Energy variation principle*
- Comparing the results with the existing 2D (POISCR)[5] and 3D (MAFIA)[6] force estimations

Computer models

To have an idea of the field distribution in the vicinity of the objects under consideration the existing ***3D Tosca field model*** of the detector was used[7]. This model implies an ideal detector magnetic system (without any additional metallic objects). This information was used to have an idea of the field value producing the magnetization of the metallic objects around the detector, and also to calculate the field distribution at the iron-air interface surfaces for estimating the forces acting on various parts of the TileCal.

As the first step in the magnetic force evaluation, by the IE method, ***the constant magnetization*** approach was applied[8]. The magnetization level of the metallic structures considered was defined on the basis of the external field value, knowledge of saturation magnetization for the given material of the object, and the analytical formula of the demagnetization factor, depending on the specific form of the object. In order to compute the magnetic forces acting on the ferromagnetic bars, they were represented by a set of current sheets. The density of current along the cross section of the sheets was chosen in accordance with the magnetization of the bars. Then the resulting force acting on the object could be calculated by the simple integration. The cross-check with the 3D PDE method (OPERA-3D) showed a sufficient accuracy of the approach in many cases.

The well-known ***2D POISCR program*** was also used[9]. This approach could be applied to consistency cross-check of the 3D IE and 3D PDE (OPERA-3D) methods.

The summary of the calculations is given below. The detailed explanation of the so far obtained results can be found in the accompanying reports [10], [11], [12].

TileCal forces

The applied force distribution obtained with the help of the 3D Tosca model is given in Figure 1. The results were cross-checked against the 2D PDE and 3D IE model. All of the coils (solenoid, BT and ECTs) are on. As was predicted in Ref. [13] the maximum force was applied to the girder surface and directed to the BT. The total radial force on the girder part, corresponding to the BT coil, would be about 1700 kN/coil. The value is in good agreement (for this type of calculations) with the value 1350 kN/coil predicted in Ref. [6,13].

As a consequence of the azimuthal variation of the force density on the outer girder surface, the maximum force applied to some of the TileCal Barrel modules is of the order of 180 kN, and for Extended Barrel modules it is 80 kN. The linear density of this force along the girder length is of the order of 34 kN/m.

The forces applied to the external TileCal surfaces (BT side of girder and ECT side of shielding disks) are largely defined by the fringe field of the toroids. Thus, they are close to zero when the toroids are off. Similarly, the forces applied to the internal surfaces are defined by the solenoid field and would be zero when the solenoid is off.

The total coupling force between the Barrel and the Extended Barrel, pushing the finger region from the Extended Barrel side in the direction of the Barrel (along the Z-axis), is of the order of $\approx$ 500 kN. This force is connected with the solenoidal field to a large extent. The force density has some azimuthal variation due to different girder magnetization from the BT side.

Estimation of the decentering forces due to a change in the TileCal geometrical position with relation to the solenoid shows the same order of the effects (see Table 1) as was already calculated in Ref. [14]. For the BT and TileCal displacement the most pronounced effect would be for the girder. In all cases the forces act upon TileCal in such a way as to increase the displacement (unstable equilibrium).

Table 1 TileCal

Structure element	Displacement	Radial force kN	Axial force kN
Solenoid	radial shift by 1 mm	2.5	-
Solenoid	axial shift by 1 mm	-	1.8
Solenoid	axial tilt by 1 mrad	3	1
BT	radial shift by 1 mm	12	-

One can find more about these calculations in Ref. [10,11].

Toroid forces

In this report only decentering forces due to changing ECT geometrical position with relation to the BT are given (see Table 2). Only the major effect is shown there. The radial shift and tilt in relation to the X or Y axis produce a very small force and torque. For the forces in the ideal toroid geometry see Ref.[15].

Table 2

Displacement	Torque kN×m	Equilibrium
Z-axis tilt by 1 mrad	520	stable

One can find more about these calculations in Ref.[12]

Metallic structure forces

The description of the metallic objects is given in Ref.[1].

The structure around the Barrel Toroid consists of such elements as racks and arcs. The forces acting on each rack are of the order of its weight (about 30 kN/m length along Z-axis) and are directed towards the detector Z-axis. The forces at arcs are directed towards the detector Z axis too. Their maximal value does not exceed 4 kN/m of the arc azimuthal length.

The typical force on a ferromagnetic object of the size of a pair of pliers or a screw driver in the Barrel Toroid fully switched on varies in a wide range and can reach 100 N in the vicinity of the ECT conductor.

No estimation of the force on the detector feet (A-frame) has been attempted so far. It is unlikely that any substantial effect would be there due to the nonmagnetic material of the structure.

There is still no answer as to force values at the neutron shielding: the real 3D software (TOSCA or GFUN3D) is needed to get a reliable result in this case. The force at the "green support" (between concrete floor & detector feet) is also under estimation.

One can find more about these calculations in Ref. [12]

Conclusions

- A system designer could use the information on global forces and torque acting on various components, obtained in this report, to optimize them.

- The results of force calculations could also serve as additional criteria for the replacement of the magnetic baseline material of various structures by nonmagnetic ones.
- Consideration of some of the objects is not yet finished. The incomplete information on their design and lack of the appropriate 3D software are the main problems to be overcome there.

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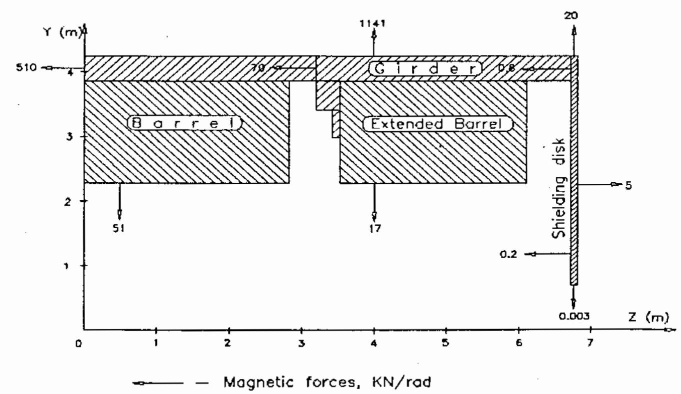

Figure 1 TileCal magnetic force distribution

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