Passive magnetic shielding calculation for the photodetectors of RICH2

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Abstract

With the help of a software package for solving Maxwell equations, MAFIA, a design of the magnetic shielding of the photodetectors array of RICH2 is proposed.

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1 Introduction

The photodetectors proposed for the RICH detector of LHCb (either HPD’s or Multi Anodes PM’s) are sensitive to magnetic field.

In the region of RICH2 the B field will be in the order of 100 gauss. The support of the photodetectors must therefore provide an effective magnetic shielding.

A work to find an optimal solution for the photodetectors housing of RICH2, has been carried out with the help of MAFIA[1].

2 Tools

Computations of the magnetic shielding propriety of different photodetectors housing has been performed with MAFIA. MAFIA is a software package furnished from the Computer Simulation Technique, for which at CERN there are 12 license units available.

MAFIA solves Maxwell’s equation in integral form, resulting in a set of matrix equations, each of which is the discrete re-formulation of one of the original Maxwell equations. This approach is called Finite Integration Theory and can be applied to static, harmonic and time dependent fields.

Before the computer aided analysis, an analytical approach was considered [2].

Differential equation coming from magnetic shielding problems can be solved analytically only for geometry with a high degrees of symmetry, like spheres or infinite cylinders, and for material with linear relative magnetic permeability. This is not the case considered in the present work. Nevertheless some results about magnetic shielding optimisation obtained in [2] have direct implication on this work.

1) Although the thicker the shell becomes, the better the shielding effect is, the deflection of magnetic flux is greater for a thin shell. It is therefore unwise to make the thickness large in order to achieve a high shielding effect. Judging from the fact that the bending of magnetic flux is most pronounced along the inner boundary of the shield, one may see that more efficient shielding can be achieved by making use of multiple shells.

2) Once one has decided to use multiple shells, one has to optimise the thickness of the shells with respect to the interspace between them. In fig. 1 is shown the shielding ratio \( \frac{B_{\text{residual}}}{B_{\text{external}}} \) as a function of the ratio of the thickness of the shells and the space between them for two different relative magnetic permeabilities \( \mu_r=100 \) and \( \mu_r=1000 \). The shield is in that case a multi-sphere with innermost radius 5 cm and outermost radius 15 cm. This result has been extrapolated to our case for the the following reason:
   - the symmetry of the problem leads to assume that, in average, this is the best solution.
   - the range of the relative magnetic permeability of the material we have chosen for our shielding (soft iron) varies from \( \mu_r=300 \) to \( \mu_r=4000 \), which is not far away from the value used in this computation.

3) in order to better direct the field flux, we should avoid layers perpendicular to the field direction.
Figure 1: Shielding ratio ($B_{residual}/B_{external}$) vs. the ratio of the thickness of the shells and the space between them, computed for 3 concentric sphere with innermost radius 5 cm and outermost radius 15 cm. The shielding effect is computed for $\mu_r=100$ and $\mu_r=1000$. 
The whole detector of LHCb is shown in fig. 2. A first tentative design of the photodetector housing is included in the technical proposal and shown in fig. 3\textsuperscript{1).} The material we have chosen is soft iron.

The dipole magnet produces a field in the $y$ direction, therefore for symmetry reason the field must be perpendicular to $y$ in the plane $y = 0$. The B field predicted in that region from the magnet group is in the order of 100 gauss. We impose an external B field of 150 gauss along $y$ and we tested the final project with a field of 50 gauss along $x$ and $z$.

The result of the first computation are in fig. 4 and 5. In fig. 4 the logarithm of the B field is shown with arrows. It can be seen that the field at $y=1.15$, near the roof, has changed direction. The field flux has to escape from the material near $x = 0$. Some of the flux escape from the top, some from the bottom.

The flux escaping from the bottom has opposite direction to the external field, therefore there is a region, near the roof, where the field is very low. This is shown in fig. 5. In that figure has been plotted the value of B (in gauss) versus $y$ for six different rows of photodetectors. It is possible to see that at $y = .8$ m the field goes down (the photodetectors should be installed up to $y = .60$ m).

This is a very unstable solution.

\footnote{Unfortunately the references axis we chose are different from the axis used in the official design. To get it: $x_{\text{used}} = -z_{\text{official}}, z_{\text{used}} = x_{\text{official}}$.}
The first optimisation was the number of shells to use. We tested housing with 2, 3 and 5 shells instead of the 2 of the original design. The more robust shielding is achieved for 3 shells.

After that the shape of the box was changed as in fig. 6. Each of the 90° edges has been substitute from two 45° edges. The box has been extended 1 meter in the z direction. An additional wall near the photodetectors has been added. The results of the simulation are shown in fig. 7 (without the additional wall) and fig. 8 (with the additional wall). The shielding effect is stronger and more uniform.

The additional wall is necessary to get a shielded field to less than 20 gauss for the most external row of photodetectors as well.

The last set-up is shown in fig. 9. The flat roof perpendicular to the external field has been substituted by a 45° oblique triangular roof. That allows an optimal funnelling of the magnetic field.

The residual B field is shown in fig. 10. This is a uniform and stable solution with a reduction factor of 15.

The main characteristics of the different design are in table 1.

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Table 1: Property of different photodetector housing.

The computation for the shielding effect on 50 G transverse field has been performed. The residual B field is shown in fig. 11 for an external field along x (parallel to the beam axis) and in fig. 12 for an external field along z (perpendicular to the beam axis). The shielding is very good for B parallel to x (the residual field goes from 1 to 3 gauss). It is not as satisfactory for B parallel to z (the residual field goes from 6 to 25 gauss). Therefore a further study has to be carried out in case the z-component of the magnetic field in the detector will result in greater then 20 gauss.

5 Conclusion

Fig. 13 summarise the evolution of the models, showing for each design the range of the residual B field in the region of the photodetectors plane for an external field of 150 gauss along y. The optimal solution is clearly the last design (fig. 9). A study of the mechanical feasibility of this project will be carried out.
Figure 3: The original design. The external B field, of 150 gauss, is along y. On blue (gray) is the photodetector housing, on red (black) the photodetection plane.

Figure 4: Residual B field distribution in the original design (fig. 3). The plane of the section is perpendicular to z and intersect in the middle the photodetector plane. The external field is of 150 gauss along y.
Figure 5: Residual B field vs. $y$ for different rows of photodetectors calculated for the original design (fig. 3). The external field is of 150 gauss along $y$.

Figure 6: Box extended for 1 meter along $z$, 90° edges substituted by 45° edges. Wall in front added.
Figure 7: Residual B field vs. $y$ for different rows of photodetectors in the box of fig. 6 without the wall in front. The external field is of 150 gauss along $y$.

Figure 8: Residual B field vs. $y$ for different rows of photodetectors in the box of fig. 6. The external field is of 150 gauss along $y$. 
Figure 9: House-shaped box (last project)

Figure 10: Residual B field vs. $y$ for the box of fig. 9. The external field is of 150 gauss along $y$. 
Figure 11: Residual B field (different scale) vs. $y$ for the box of fig. 9. External field of 50 gauss along $x$.

Figure 12: Residual B field vs. $y$ for the box of fig. 9. External field of 50 gauss along $z$. 
Figure 13: Evolution of the models. Range of variation of the residual B field in the region of the photodetector plane. The external field is of 150 gauss along the y direction.

1 → fig. 3, 2 → fig. 6 (without wall in front), 3 → fig. 6, 4 → fig. 9.

References
