Optimization of the Magnetic Field Homogeneity Area for Solenoid Type Magnets

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Abstract. Homogeneous magnetic fields are important requisites in modern physics research. In this paper we discuss the problem of magnetic field homogeneity area maximization for solenoid magnets. We discuss A-model and B-model, which are basic types of solenoid magnets used to provide a homogeneous field, and methods for their optimization. We propose C-model which can be used for the NICA project. We have also carried out a cross-check of the C-model with the parameters stated for the CLEO II detector.

1 Introduction

Detectors such as CMS CERN, ATLAS CERN, MPD NICA and FCC in Berlin use solenoid magnets under severe tolerance limits on the homogeneity of the magnetic field. The main problem in constructing these systems is the maximization of the homogeneous field area with adequate accuracy inside the detector. In this work we discuss two basic solenoid magnets models, ways of optimizing of these models and our new model within the designated problem. For comparing the models we selected parameters which provide the same magnetic field at the center of each model $B_{\text{center}} = 0.5$ T. Computations were performed (using TOSCA software) by the finite element method on tetrahedral mesh, which had been specially generated taking into account the structural features of the detectors [1].

2 Ways to increase the magnetic field homogeneity area

2.1 A-model

This is the reference model for our study. We got geometry and dimensions of the model (Fig. 1) and made calculations in order to assess whether any part of it needs improvement, and, if so, to establish a benchmark for our work. The model parameters: current density $J = 1.89767173 \cdot 10^6$ A/m^2, coil cross section $S = 0.212 \cdot 4.2$ m^2, full current $I = 1.68968691 \cdot 10^6$ A.

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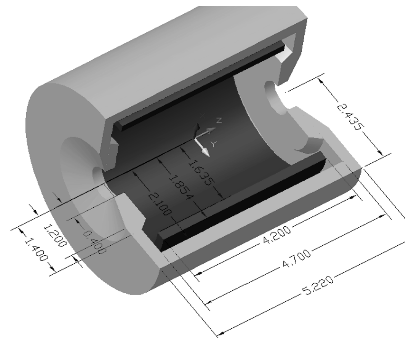
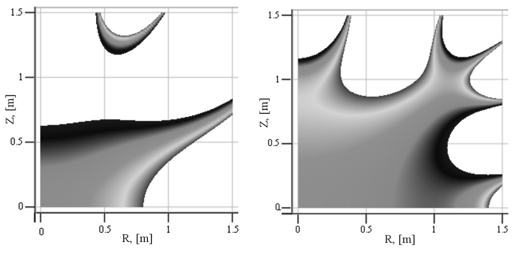


Figure 1. A-model geometry



(a) initial **(b)** optimized

Figure 2. A-model area of field homogeneity

We pay particular attention to providing a broad area of magnetic field homogeneity with accuracy ±0.1%, a tolerance often required for real detectors. Figure 2a shows that the magnetic field homogeneity area isn't big enough (on this figure and further figures mapping field homogeneity, we represent the distribution of the homogeneous field on a given plane inside the detector given its symmetry; gray-scale gradient shows variation of the field within range 0.5±0.005 T). It occupied less than 1/4 of working space inside the detector. So, the model needs optimization.

2.2 A-model optimization

We used four coils (three double and one single) with different currents, instead of one single unified coil (Fig. 3). We supposed that the final field homogeneity map of all coils would be given by overlapping the contribution of each coil separately in accordance with Root Mean Square (Fig. 4). This assumption is valid for small magnetic fields. Figure 2b shows the area of field homogeneity

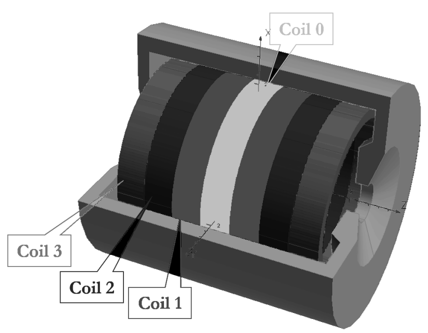


Figure 3. Optimized A-model geometry

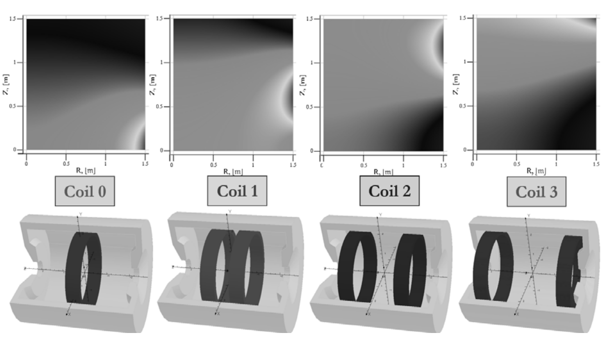


Figure 4. RMS optimization

after optimization with accuracy ±0.1%. The homogeneity area coverage increases 1.76 times in comparison with that of the initial model.

2.3 B-model

The B-model geometry is shown in Fig. 5. Figure 6a shows the field homogeneity map with accuracy ±0.1% for the B-model.

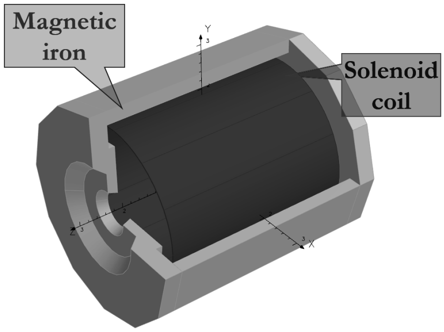
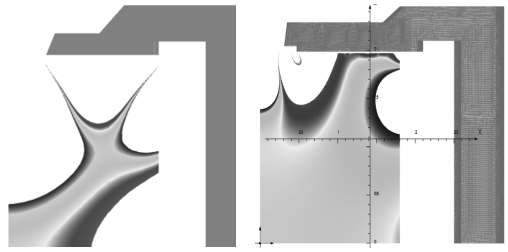


Figure 5. B-model geometry



(a) initial **(b)** optimized

Figure 6. B-model area of field homogeneity

2.4 B-model optimization

It is possible to improve the characteristics of the B-model by adding two coils to each side of the detector (Fig. 7). We select the appropriate current density for each coil in order to provide enough homogeneity field coverage: $J_{\text{main}} = 1.047247 \cdot 10^7$ A/m^2, $J_{\text{add1}} = 6.293004 \cdot 10^6$ A/m^2 and $J_{\text{add2}} = 1.255567 \cdot 10^6$ A/m^2. Figure 6b shows the map of the field homogeneity for the optimized B-model with the same level of accuracy ±0.1%.

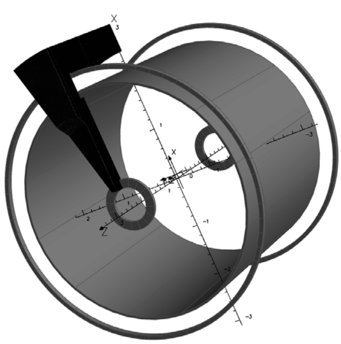


Figure 7. Optimized B-model geometry

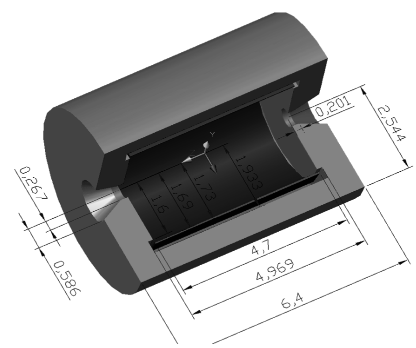


Figure 8. C-model geometry

2.5 C-model

We created the model with a single coil striving for construction simplicity. The dimensions and geometry of the model are given in Fig. 8. It is worth noting that the magnetic field distribution is sensitive to the size of the gap, or, in other words, how deeply the coil goes into the ferromagnetic on the edges of the model. The model parameters: current density $J = 9.956410099 \cdot 10^6$ A/m^2, coil cross section $S = 0.04 \cdot 4.7$ m^2, full current $I = 1.871805098 \cdot 10^6$ A. Figure 9 shows the area of field homogeneity obtained for the C-model.

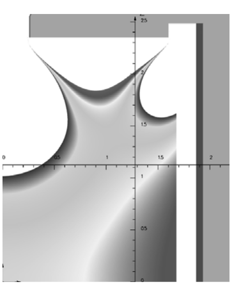


Figure 9. C-model area of field homogeneity

Table 1. Comparison of models

Model	**Area**, m^2	η, %	**Num. coils**
A	0.799	35.5	1
(optimization)	1.439	64	4
B	1.089	48.4	1
(optimization)	2.258	98.4	3
C	2.057	91.4	1

3 Comparison of models

The comparison of the main features of models, presented in Table 1, points to data obtained for a square area $S = 1.5 \cdot 1.5$ m^2 and corresponds with a homogeneity level of $\pm 0.1\%$. In all cases the models characteristics could be improved in different ways to get further optimization.

4 CLEO II cross-check

We conducted a cross-check of the C-model by creating a prototype satisfying the requirements for the CLEO II detector [2]. It is asked to provide a magnetic field 1.5 T with uniformity $\pm 0.2\%$ over 95% of the drift chamber volume.

The model geometry is represented in Figure 10. Figure 11 shows the map of field homogeneity obtained. The result of the simulation satisfies all the formulated requirements.

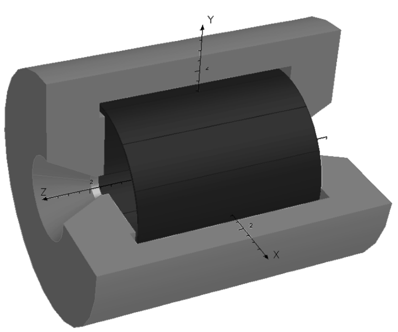


Figure 10. Model geometry for cross-check

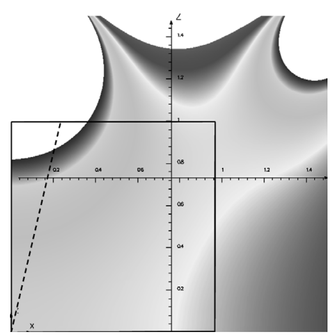


Figure 11. Map of field homogeneity for cross-check

5 Conclusion

1. Optimization algorithms for increasing the homogeneity area have been suggested.
2. A new model of the magnet detector has been proposed.
3. The new model has satisfied the requirements asked for the CLEO II detector.

References

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[2] Kubota, Yuichi, et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **320**, 1–2, 66–113 (1992)