Different coil systems used for magnetometers calibration - a comparative analysis

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Abstract

In this study we address some aspects of the theoretical model, configuration and requirements to practical realization of coil systems, utilized to create a homogeneous magnetic field used for magnetometers calibration. This analysis is applied to two different types of discrete magnetic coil systems with two (Helmholtz coils), three and four coils, with round and square shapes. It is also applied to solenoids with a different number of windings and a different diameter-to-the-length ratio. Monte Carlo methods have been used for varying mechanical parameters of the coil systems and analyzing uniformity of the magnetic field in a three-dimensional central zone with different sizes. It is shown that the achievement of the magnetic field with extremely high homogeneity ($>10^5$) depends not only on coil system configuration (number of coils, size and current ratio), but is especially sensitive to the mechanical precision of specific implementention design.

Introduction

Producing of magnetic fields with a high homogeneity in a given volume of space is related to many problems in different scientific areas. Solenoids, usually cylindrical in shape, or systems of discrete coils are used in generation of such fields [1] [2] [3]. The analysis of the homogeneity of the field was made by a number of authors [3] [4] [6] and the common between their works is purely theoretical approach covering only idealized coil systems with exact parameter values. Based on the fact that the construction of such a system is involved with overcoming of many difficulties of mechanical and structural nature, it is important to study the sensitivity of such systems to the mechanical precision and the ability of achieving fields with predetermined degree of homogeneity in a 3D region of space. One possible solution to the above problem is demonstrated in this work. The results presented here are connected to particular application of such coil systems, namely their use in the calibration of magnetometers.

Method description

Using the analytical solution for the components of the magnetic field vector in the case of circular current loop [6] and square current loop [7], we construct a numerical model of the distribution of the magnetic field in the three-dimensional central zone, defined in the case of a circular coil system as a cylinder coaxial to the axis of symmetry with a diameter equal to its height and as a cube in the case of square coil system. As a measure of the field homogeneity in the central zone we take the reciprocal of the maximum relative deviation of the magnetic vector in that zone. The deviation value is determined by calculating the difference in magnitude of the magnetic vector in 1000 different points, distributed uniformly throughout the whole zone with that in the central point of symmetry and divided by the same central point magnitude. Finally, we take the maximum of these 1000 values. The next step consists in finding the relationship between the homogeneity of the field and the mechanical precision of the coil system parameters using Monte Carlo simulation. The dimensions of the individual coils and the distance between them is varied within certain limits by addition of the normally distributed random variables with a given dispersion to the exact system parameters values and finding the homogeneity of the field in the central zone. All calculations are made using C# programming language.

Results

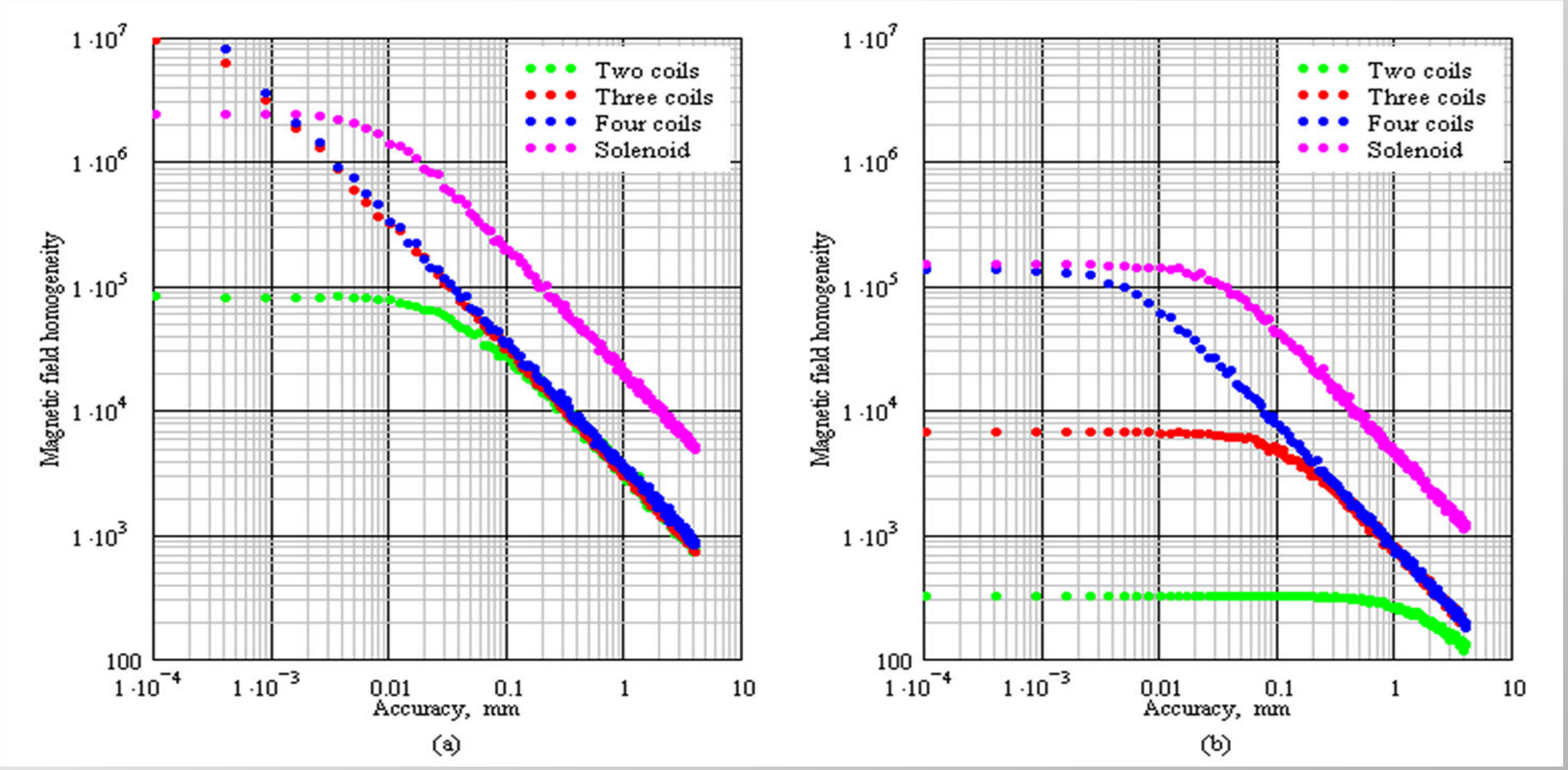

Fig. 1. Magnetic field homogeneity in the central cylindrical zone as a function of the mechanical accuracy in the case of circular coils with 500 mm diameter and 1000 windings solenoid with diameter-to-the-length ratio of 1:10 and 500 mm diameter. Zone size is 25 mm (a) and 100 mm (b) respectively.

Results

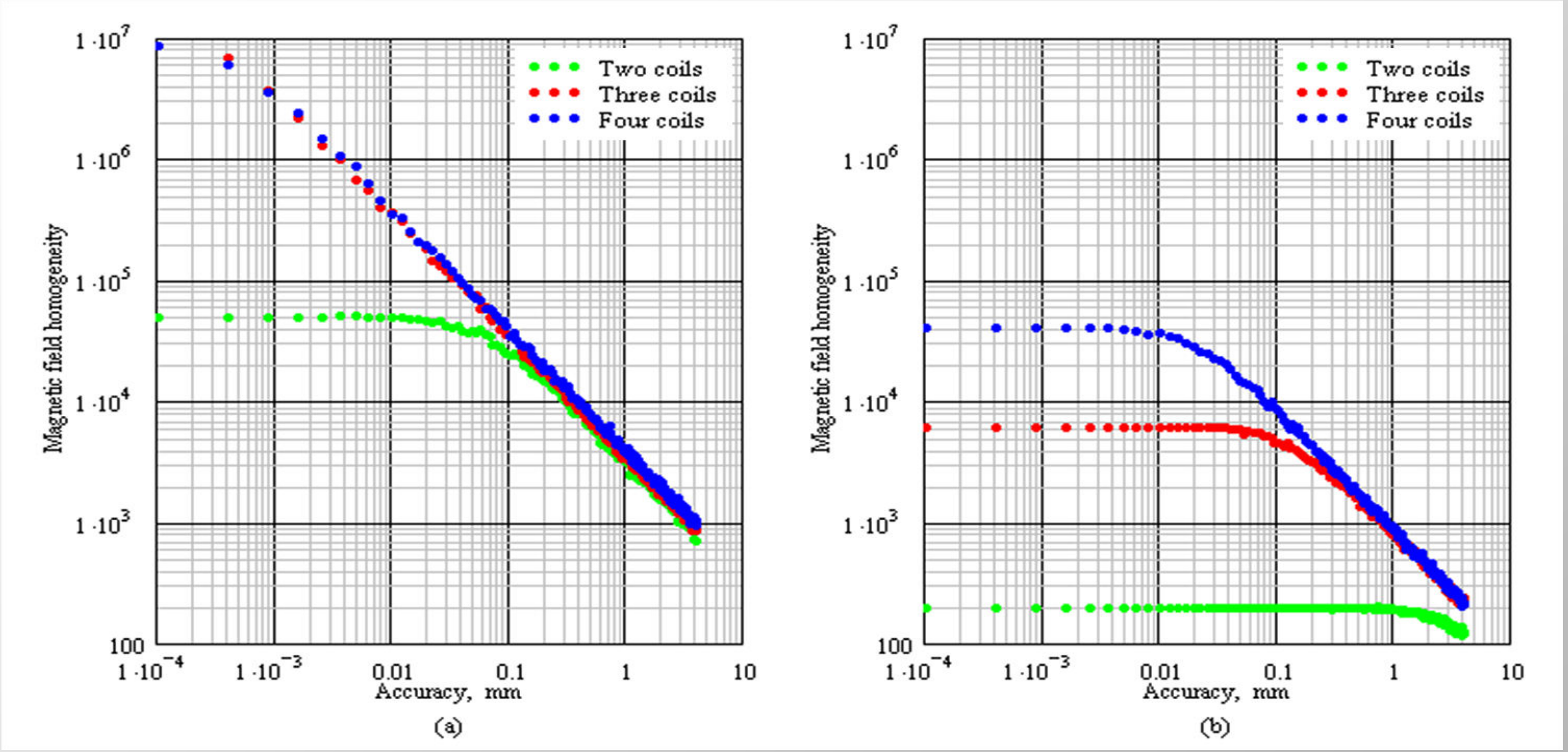

Fig. 2. Magnetic field homogeneity as a function of the mechanical accuracy in the case of square coils with side length 500 mm, in the central cubic zone with size 25 mm (a) and 100 mm (b).

Results

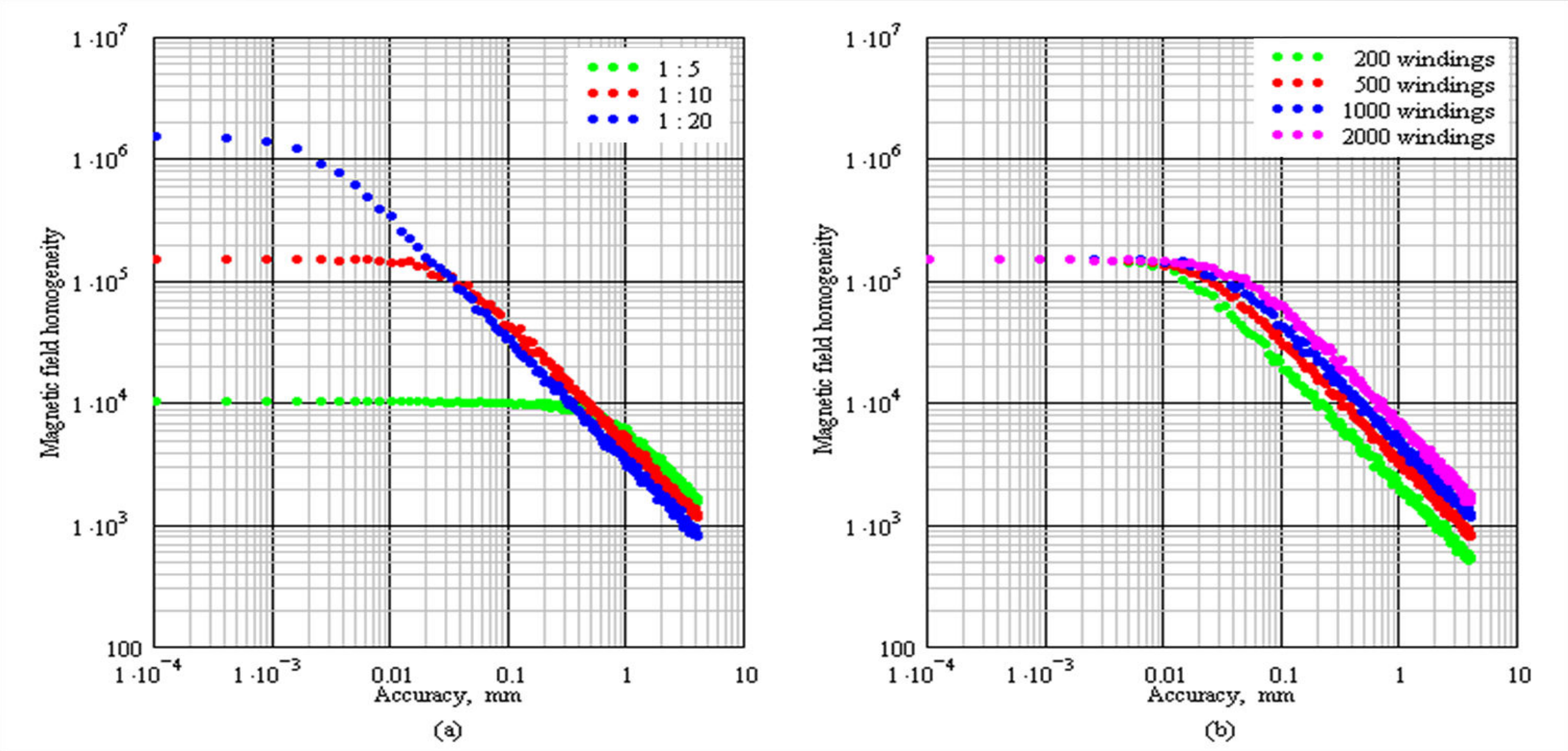

Fig. 3 Magnetic field homogeneity as a function of the mechanical accuracy in the case of circular solenoids with 1000 windings of 500 mm in diameter and different diameter-to-the-length ratio (a) and solenoids with diameter 500 mm, diameter-to-the-length ratio 1:10 and different number of windings (b). Zone size is 100 mm.

Discussion and conclusions

From the demonstrated results the following observations can be made:

- ❑ In the case of coil systems with dimensions about 1 m and with reasonably achievable mechanical accuracy of about 0.1 mm, when the size of the central zone is relatively small, the systems with three or more coils have not advantages over the classical two-component Helmholtz coil system. If the central zone is larger, three and four component systems are an order of magnitude better than that of Helmholtz. Moreover, a four-component system does not have big advantages over the systems with three coils.
- ❑ Using the solenoid with diameter-to-the-length ratio of at least 1:10 gives results one order of magnitude better than discrete coil systems under the same conditions.
- ❑ The homogeneity of the field generated by the solenoid is highly dependent on the diameter-to-the-length ratio (for achieving a field homogeneity of 10^5 and more, it should be at least 1:10) than on the number of solenoid windings.

As a final conclusion we can state that absolute calibration of the magnetometer with accuracy <1 nT requires magnetic fields with a high degree of homogeneity ($>10^5$) and using a solenoid with diameter-to-the-length ratio at least of 1:10 provides result of the order of magnitude more accurate compared to the discrete coil systems case. Nevertheless, the calibration of the magnetometers with such a high degree of accuracy is a really challenging task.

References

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