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Influence of Cylindrical Shield Dimensions on Shielding Effectiveness

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Abstract

Study of dimensional parameters' influence on shielding properties of cylindrical shields will allow to optimise the fusion process, as well as to reduce production costs by reducing the material used. The purpose of this work was to compare results of theoretical calculation of shielding effectiveness of an infinite cylindrical shield with the data obtained in real conditions.

A cylindrical Ni-Fe shield was synthesised by electrochemical deposition with length of 32 cm, diameter of 4.5 cm and shielding thickness of ≈ 100 µm. The cylinder length was then reduced from 32 cm to 6 cm in 4 cm increments and for each cylinder length shielding effectiveness was measured using three-coordinate Helmholtz field-forming system.

The measurement results show that the calculation of shielding effectiveness of infinite cylindrical shield is valid for cylinder lengths $l \geq 18$–20 cm. Shielding effectiveness is markedly reduced at values of $l < 15$ cm.

Analysis of data obtained allowed to conclude that it is necessary to determine the correction factor when calculating a cylindrical screen shielding efficiency.

Keywords: shielding, magnetostatic fields, cylindrical shields.

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Влияние габаритных параметров цилиндрического экрана на эффективность экранирования

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Изучение влияния габаритных параметров на экранирующие свойства цилиндрических экранов позволит оптимизировать процесс синтеза, а также снизить затраты на производство, за счёт уменьшения используемого материала. Целью данной работы было сравнение результатов теоретического расчёта эффективности экранирования бесконечного цилиндрического экрана и данных, полученных в реальных условиях.

Методом электрохимического осаждения был синтезирован цилиндрический экран Ni-Fe, длина которого составила 32 см, диаметр 4,5 см, толщина экранирующего покрытия составила ≈ 100 мкм. Затем длина цилиндра уменьшалась от 30 до 6 см с шагом в 4 см, для каждой длины цилиндра была измерена эффективность экранирования с помощью полеобразующей системы трёхкоординатных катушек Гельмгольца.

Результаты измерений показали, что расчёт эффективности экранирования бесконечного цилиндрического экрана справедлив при длине цилиндра $l \geq 18$–20 см. При значениях $l < 15$ см эффективность экранирования заметно снижается.

Анализ полученных данных позволил сделать вывод о необходимости определения поправочного коэффициента при расчётах эффективности экранирования цилиндрического экрана.

Ключевые слова: экранирование, магнитостатические поля, цилиндрические экраны.

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Introduction

Global electrification along with the undeniable benefits poses many threats, of which electromagnetic radiation is the most significant. One of the particularly difficult cases of protection from the impact of external electromagnetic fields is shielding of static magnetic fields.

This type of magnetic fields can have a negative impact on the human body, disable devices and their elements and is also widely used in the military industry [1, 2]. To minimize the effects of magnetostatic fields magnetically soft materials (steel, permalloy, amorphous metal alloys are usually used). Study of magnetostatic shielding is based on the principle of magnetic field shunting by a ferromagnetic material [3, 4]. The basis of this principle is the closure of the field lines through the material with low resistance to magnetic flux which means that the shielding efficiency is directly proportional to the value of magnetic permeability (μ) of the shielding material and inversely proportional to the area of its cross section. However we have previously shown [5, 6] that a number of experimental results on the magnetostatic shielding does not agree with the provisions of the shunt principle.

Thus the purpose of this work was to investigate the shielding effectiveness of the cylindrical shield and to find out the effect of the cylinder length changing on shielding effectiveness. This will reduce the error in theoretical calculations which in turn will have a positive impact on the quality of development of highly effective protection of devices and equipment for a wide range of applications.

Measurement technique

An aluminum cylinder with a single layer Ni shielding coating $Ni_{80}Fe_{20}$ with a copper underlayer was made as the test sample with the following parameters: 32 cm long, diameter is 4.5 cm. The average thickness of the coating was 132 μm.

The aluminum surface preparation process was carried out in several stages such as trichloroethylene treatment degreasing with Vienna lime, chemical etching, chemical galvanizing and copper undercoating was then applied to increase of adhesion.

The shielding coating was synthesised by electrochemical deposition using nickel anodes at 35–40 °C. The current density was 25 mA/cm^2. The composition of the electrolyte solution is shown in Table.

Table

The composition of the electrolyte solution

№	Reactive	Content, *g/l*
1	$NiSO_4 \cdot 6H_2O$	210
2	$NiCl_2 \cdot 6H_2O$	20
3	$FeSO_4 \cdot 7H_2O$	15
4	$KNaC_4H_4O_6 \cdot 4H_2O$	30
5	$MgSO_4$	60
6	H_3BO_3	30
7	Saccharine	2
8	Ascorbic acid	2

The thickness of the resulting shielding coating was ≈ 100 μm.

From the resulting cylinder with the shielding coating, 4 cm were cut off (Figure 1), then at each length, the shielding effectiveness was measured.

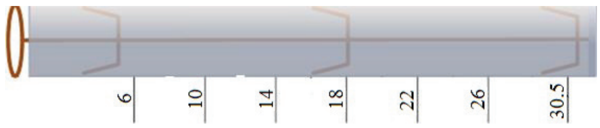

Figure 1 – Schematic representation of the test sample

The efficiency of the shielding was measured by means of a three-coordinate Helmholtz field-forming system.

Results and discussion

The most complex case of shielding against external sources of electromagnetic radiation is that of static magnetic fields [5]. Usually when considering magnetostatic shielding the principle of the magnetic field shunting with a ferromagnetic material is used. The basic essence of this principle is to short circuit the field lines through a material with low resistance to magnetic flux. According to this approach the effectiveness of the shielding is constant and directly proportional to the magnetic permeability of the shield material and inversely proportional to its cross-sectional area [7, 8]. For an infinite cylindrical shield, the calculation of the shielding effectiveness is carried out according to the formula:

$$Oe_{cyl.} = 0.57\mu d/r,$$

where μ is the magnetic constant, *d* is shield thickness [mm]; *r* is outer radius [mm].

As we know [9], in theoretical calculations of shielding efficiency usually use ideal geometric shapes of samples (infinite plane and infinite cylinder, sphere). In real conditions the situation is much more complicated – bodies, blocks to be shielded have finite dimensions, irregular shape and may contain holes and apertures. Therefore, for practical purposes, it is important to know how the screen size affects such characteristics as the maximum screening efficiency Oe_{max} and the magnetic field strength corresponding to the maximum screening efficiency HOe_{max}.

To check the validity of the above formula, the shielding effectiveness was measured at cylinder lengths l = 6–30 cm, in 4 cm increments. Figure 2 shows the obtained results of shielding efficiency depending on the length of the cylinder. It can be seen that reducing the cylinder length to 14 cm does not result in a significant change in shielding effectiveness. When the cylinder length is further reduced from 14 cm to 6 cm, there is a sharp decrease in shielding effectiveness.

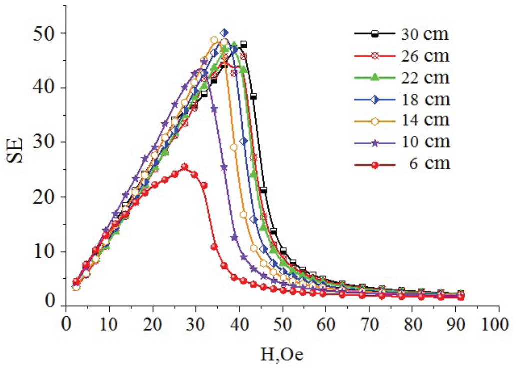

Figure 2 – Shielding efficiency depending on the length of the cylinder

Figure 3 shows the dependencies of Oe_{max} and HOe_{max} on the length of the cylindrical shield.

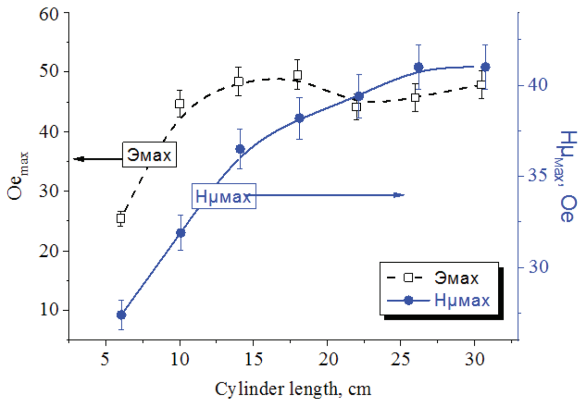

Figure 3 – Changing the position of the maximum shielding efficiency depending on the length of the cylinder

It can be seen, the parameters Oe_{max} and HOe_{max} become very stable at values of $l \geq$ 18–20 cm. At values of $l <$ 15 cm, the shielding efficiency decreases markedly. For example, the Oe_{max} values of a 6 cm long sample are 2 times lower than those of a 26–30 cm long sample. At the same time, the HOe_{max} shifts to a lower field region from 44 to 26 Oe.

Conclusion

Studies have been carried out on the shielding effectiveness of an aluminum cylinder with Ni-Fe shielding.

It is found that the theoretical calculations of shielding efficiency differ from the data obtained under real conditions. Parameters as the maximum screening efficiency Oe_{max} and the magnetic field strength corresponding to the maximum screening efficiency HOe_{max} are stable at values $l \geq$ 18–20 cm, so maximum shielding efficiency of the obtained sample holds within 45–50 times. Reducing the length of the cylinder to a value of $l <$ 15 cm leads to a significant decrease in the maximum shielding efficiency from 42 to 25 times. At the same time the HOe_{max} shifts to a lower field region.

This result is due to the effect of the magnetic field flowing into the open sample of finite size. Thus in order to reduce the influence of the dimensional effect of cylindrical and close-shaped shields the l/r ratio must be $\geq$ 8–9.

Further it is planned to extend the research range to obtain a correction factor to calculate the shielding effectiveness of real cylindrical shields.

The findings are to be used in the manufacture of shields to protect sensitive components of various kinds of devices.

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