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An External Body in Protected Area

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Abstract: In practice, often there is a need for modelling systems for cancelling the Earth electrostatic field. For this purpose, a linear circular loop can be used. The realized protection is as better as the used ring is thicker. In practical applications, a system of coaxial linear loops is used instead of one thick ring. In order to find the influence of protected object shape and volume to the electrostatic protection efficiency, a protected object is modelled as a half spherical electrode, placed with its flat side on the ground. According to the theoretical analysis, a general numerical program has been developed and numerical results are shown graphically.

Keywords: Electrostatic protection, toroidal primary cell, half sphere protected object.

1 Introduction

THE problems of electric and magnetic field synthesis are of a great importance in many theoretical applications, where it is necessary to generate the field with a high accuracy and of required features. One original analytical method for toroidal symmetrical systems modelling for homogeneous electric field generation, is developed in [1]. A system for producing a highly homogeneous, variable, and directable magnetic field is described in [2]. This system, which was used in gyromagnetic ratio experiments, was directed against the Earth's magnetic field to obtain very nearly a free space field.

In addition to the need to make a space of homogeneous electric field, very often there is a need for space in which there is no field. In that sense, specially generated electric fields, [1], can be used to neutralize some external field, for example the Earth electrostatic field. In that way, the intensity of external field is so decreased

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that its influence is practically equal to zero. Thus, a protected space without electric field can be obtained on the Earth. It is very important because special physical conditions in satellites, that differ a lot from the Earth's conditions, can be realized. In that way, the investigation of ordinary life and many technological processes in satellite conditions can be done on the Earth.

In order to protect the space from external electrostatic fields, as a starting element in modelling procedure, a primary cell is used. It consists of one loop of zero potential, placed parallel to the Earth surface. Complex protection systems consist of N toroidal electrodes, of zero potential, earthed using a conducting wire of negligible thickness. Since the loops are earthed, charges on the loops inevitably occur due to the Earth electrostatic field. These charges produce secondary component of the field, which is, in the protected space, of opposite direction regarding to the Earth field, so the resulting field is reduced. The larger the number of primary cells used, the closer the field to the external field, so the external field elimination is better.

In this paper, the influence of external body size to the achieved space protection will be observed.

2 Mathematical Background

2.1 Optimal design of protected area

Firstly, the system for electrostatic protection of space without the external body is observed, Fig. 1. Place coordinate system so that its axis coincides with the vector of external electric field, E_0. The total potential consists of two parts: the first one corresponds to the potential of external field E_0 and the second one is a consequence of the charges induced on primary cells electrodes.

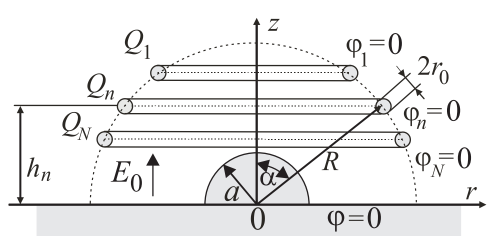

Fig. 1. A system for electrostatic protection and a half sphere external body.

In the modelling procedure of the system for electrostatic protection of space, the potential function along the z axis is expanded into a descending series, which contains only odd powers of variable z. In order to obtain the resulting field equal to zero in the central area, it is necessary for resulting potential to be as lower as possible. For this requirement implementation, it is necessary to annul as many dominant terms. Primary cell dimensions of N^{th} order are obtained by equalizing the coefficient of z^{2N+1} to zero. The larger the number of cells used, the better elimination of the external field.

Systems of different number of primary cells are observed in this paper. The external sphere object of different sizes is analyzed, too. Based on the procedure presented above, dimensions of optimal systems, which consist of one to five primary cells, are obtained and given in Table 1.

Table 1. Optimal system dimensions for N^{th} order primary cell.

	d_5/R	d_4/R	d_3/R	d_2/R	d_1/R	
N	0.963	0.855	0.683	0.462	0.208	5
1	0.775	0.946	0.790	0.549	0.250	4
2	0.906	0.538	0.914	0.671	0.315	3
3	0.949	0.742	0.406	0.843	0.423	2
4	0.968	0.836	0.613	0.324	0.632	1
5	0.978	0.887	0.730	0.519	0.270	N
	h_1/R	h_2/R	h_3/R	h_4/R	h_5/R	

2.2 Charge calculation on the loops

In order to examine the influence on the realized protection quality with the smallest mathematical difficulties, the external body is modelled as conducting half sphere and placed into the protection area, Fig 1. Its centre coincides with the coordinate origin. Taking into account the image theorem into the sphere and flat mirror, a potential distribution is expressed as:

$$\varphi = -E_0\left(\sqrt{r^2+z^2} - \frac{a^3}{r^2+z^2}\right)\frac{z}{\sqrt{r^2+z^2}} + \frac{1}{2\pi^2\varepsilon}\sum_{n=1}^{N}\sum_{m=1}^{4} Q_{nm}\frac{K(\pi/2,k_{nm})}{R_{nm}}, \quad (1)$$

where the first term corresponds to the Earth electric field and the second one corresponds to the electric field of the charges induced on conducting rings, their images into the sphere and flat mirror.

$K(\pi/2,k_{nm})$ is the complete Elliptic integral of the first kind of moduli:

$$k_{n1}^2 = \frac{4d_n r}{(d_n+r)^2+(z-h_n)^2}, \qquad k_{n2}^2 = \frac{4d_n r}{(d_n+r)^2+(z+h_n)^2},$$

$$k_{n3}^2 = \frac{4a^2 d_n r}{R^2\left[\left(\frac{a^2}{R^2}d_n+r\right)^2+\left(z-\frac{a^2}{R^2}h_n\right)^2\right]}, \quad k_{n4}^2 = \frac{4a^2 d_n r}{R^2\left[\left(\frac{a^2}{R^2}d_n+r\right)^2+\left(z+\frac{a^2}{R^2}h_n\right)^2\right]}.$$

$Q_{n1} = Q_n$ are induced charges on the ring electrodes, $Q_{n2} = -Q_n$ are the charges of their images into the flat mirror and $Q_{n3} = -Q_{n4} = -(a/R)Q_n$ are the charges of their images into the sphere mirror.

Using the condition that the toroidal electrodes are of zero potential, their unknown charges can be determined by solving the following system of linear equations:

$$E_0\left(R - \frac{a^3}{R^2}\right)\cos\alpha_p = \frac{1}{2\pi^2\varepsilon}\sum_{n=1}^{N}\sum_{m=1}^{4} Q_{nm}\frac{K(\pi/2, k_{pnm})}{R_{pnm}}, \tag{2}$$

where

$$\cos\alpha_p = \arctan\frac{d_p}{h_p} \tag{3}$$

is the angle marked in Fig.1 and defined for each electrode of the primary cell as in Table 1.

3 Numerical Results

In accordance with the analysis presented above, a general numerical program has been developed using program package Mathematica 7.0. The same problem is modelled using the program package Femm, [3]. The ratio of electric field strength along the system axis z and the value of external electric field, E/E_0, for different number of primary cells N and $a/R = 0.2$, by application of both Mathematica and Femm, is presented in Fig. 2. Equipotential lines for $a/R = 0.2$ and $a/R = 0.5$ and different number of primary cells, $N = 1$ and $N = 3$, are shown in Fig. 3 and Fig. 4, respectively.

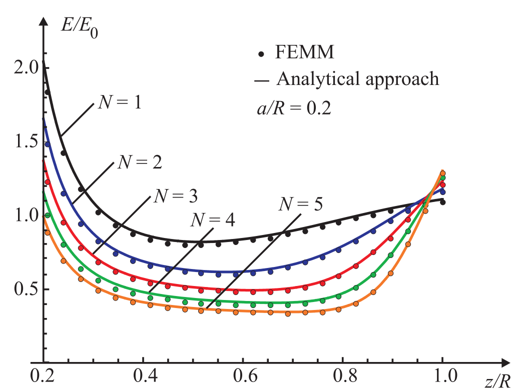

Fig. 2. Ratio of electric field strength E along z axis and the external electric field, E_0, for different number of primary cells N and $a/R = 0.2$.

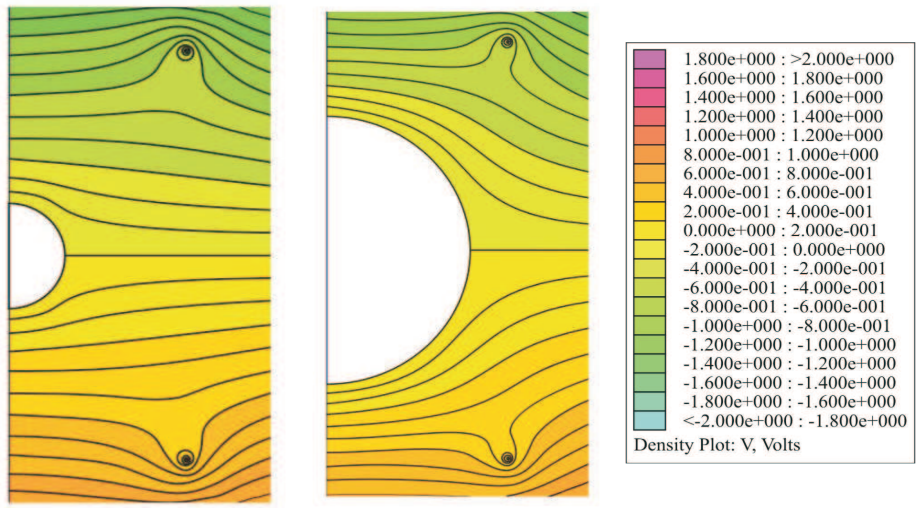

Fig. 3. Equipotential lines for $N = 1$ and $a/R = 0.2$ (a) and $a/R = 0.5$ (b).

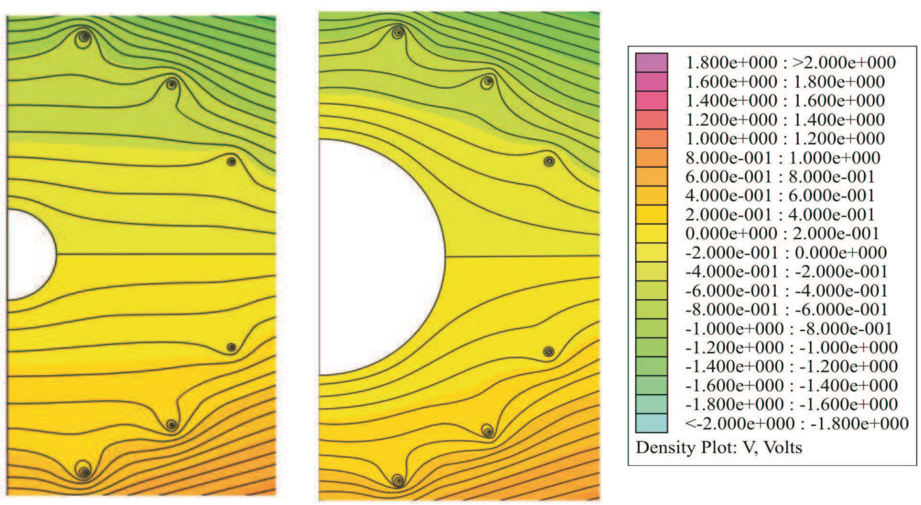

Fig. 4. Equipotential lines for $N = 3$ and $a/R = 0.2$ (a) and $a/R = 0.5$ (b).

In order to achieve a better protection of space, with a smaller number of electrodes, the recommended number of primary cells is $N = 3$. Keeping this in mind, the influence of the external object volume on the ratio of the electric field intensity along the z axis and the external field, by application both Mathematica and Femm, is presented in Fig. 5.

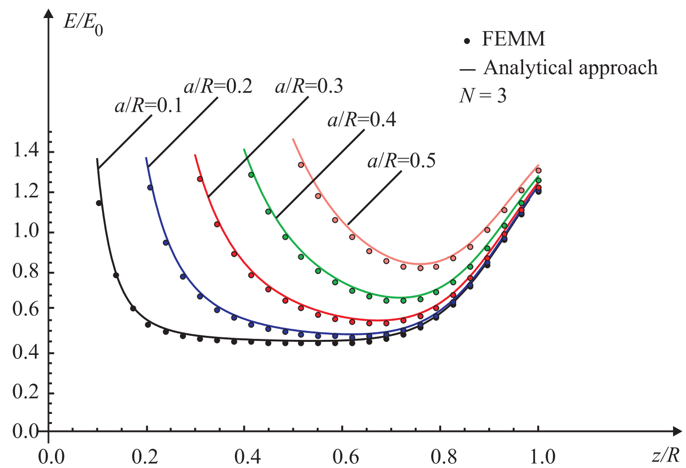

Fig. 5. Ratio E/E_0 along the system axis z axis for different external body sizes and $N = 3$.

4 Conclusion

For the electrostatic protection against the Earth's electrostatic field, a system of linear toroidal electrodes has been used. Toroidal loops are so dimensioned that each of them, with its image into the flat mirror, makes a Helmholtz pair of loops [4]. A procedure for optimal system design is based on the fact that the resulting potential has to be as low and homogeneous as possible. An electrostatic protection improvement is attained using primary cells of higher order. The electrostatic system that has to satisfy these electrostatic demands, has to be optimal in the view of simplicity and production economy, as well. Keeping this in mind, the recommended number of primary cells is $N = 3$.

In order to determine the influence of external object on electrostatic protection efficiency, the object is modelled as a half sphere and placed in the protected area. Obtained numerical results, presented graphically, elucidate that small external object does not influence strongly on the realized electrostatic protection. There is a very good agreement of the results obtained analytically and using the program package Femm.

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