PENETRATION OF ELECTROSTATIC FIELD THROUGH FARADAY SHIELD OF ICRH STRAP ANTENNA

V.E. Moiseenko

Institute of Plasma Physics, NSC KIPT, Kharkov, Ukraine

The penetration of electrostatic field outside the shield at the part the antenna faced to plasma is studied in the framework of two-dimensional numerical model. It is shown that single-layer Faraday shield does not have satisfactory shielding properties. The shielding can be improved sufficiently using overlaying two-layer shield.

PACS: 52.50.Qt

INTRODUCTION

To protect antenna from the direct contact to plasma and to prevent penetration of the electrostatic field induced by antenna, the Faraday shield is used. Ideally, it should be made from anisotropic substance with high conductivity in one direction and low conductivity in others. Since such substance does not exist the shield is normally made from discrete metallic elements. For the reason of discreteness of the shield, a portion of electrostatic field can penetrate outside the volume surrounded by it. Outside the antenna box, both parallel and perpendicular to the steady magnetic field components of the electrostatic field cause strong oscillatory motion of ions and electrons of scrape-off-layer low-density plasma that normally exists in the shield vicinity. If the energy of oscillatory motion of ions exceeds the energy threshold of sputtering the sputtered material of the shield goes into the plasma increasing the concentration of impurities.

Another unfavorable effect that is caused by the penetration of electrostatic field through Faraday shield is the excitation of waves in plasma by the electrostatic mechanism [1]. Both slow and fast wave could be excited with it. While fast wave excitation does not cause problems, the slow wave excitation is adverse [2].

The electrostatic field penetrates through the shield at all its surface. The part of the shield faced to plasma is of primary interest.

DESCRIPTION OF MODEL

We consider the Faraday shield consisting of similar bended strap elements placed periodically at the same distance each from other (see Fig.1). We assume that the period of the shield is much smaller than the wavelength and than the every size of antenna. The first assumption allows us to introduce the electric potential φ and use the Laplas equation to describe electric field in small-scale area near the shield. The second assumption makes it possible to ignore the dependence of potential from z -coordinate. Because of the periodicity of the shield in y direction one could expect that the dependence of the potential along this coordinate is also periodical with slowly varying amplitude. In our consideration the last variation is neglected because it is of the same order as the already neglected variation of the potential in z -coordinate. Thus, the problem could be considered at a single period of the shield accounting periodic boundary conditions in y direction. At the period, there is a reflection symmetry. For this reason the domain for Laplas equation in y direction is chosen as a half of period.

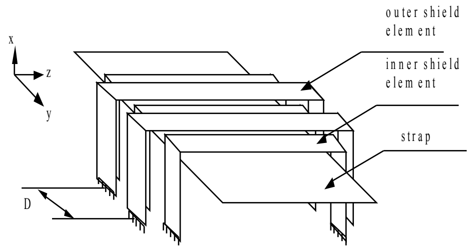

Fig.1. A fragment of strap antenna covered by two-layer Faraday shield

To operate with dimensionless quantities and variables we scale the coordinates by the shield half-period $\tilde{x}=2x/D$, $\tilde{y}=2y/D$ and the potential by the potential at the strap surface $\tilde{\varphi}=\varphi/\varphi_s$. The Laplas equation reads:

$$\tilde{\nabla}^2\tilde{\varphi}=0 \quad . \qquad (1)$$

The boundary conditions are the following. The condition $\tilde{\varphi}|_{\tilde{x}=0}=1$ determines the potential at the strap. The condition $\frac{\partial\tilde{\varphi}}{\partial\tilde{x}}|_{\tilde{x}=\infty}=0$ nullifies the electric field at the infinity. Owing to the reflection symmetry and periodicity, the boundary conditions for potential in y direction become Neumann's ones: $\frac{\partial\tilde{\varphi}}{\partial\tilde{y}}|_{\tilde{y}=0}=0$ and $\frac{\partial\tilde{\varphi}}{\partial\tilde{y}}|_{\tilde{y}=1}=0$. There is also the internal boundary conditions $\tilde{\varphi}|_{\tilde{x}=\delta_i,\ \tilde{y}\in(0,d_i)}=0$ and $\tilde{\varphi}|_{\tilde{x}=\delta_e,\ \tilde{y}\in(1-d_e,1)}=0$ nullifying the potential at the shield elements. Here δ is the normalized distance between antenna strap and shield element in x direction; d is the normalized half-width of the shield element; indices i and e denote inner and outer shield elements.

The equation (1) with the above mentioned boundary conditions is solved numerically using finite difference method. The boundary condition at $\tilde{x}=\infty$ is substituted by the same condition at finite value of $\tilde{x}$: $\tilde{x}=x_{\inf}^{\sim}$.

This value is chosen large enough in order not to influence on the solution.

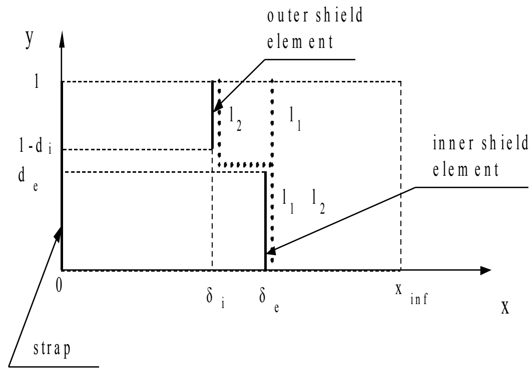

Fig.2. The domain of boundary problem for Laplas equation

Besides the calculation of potential, two average values of electric field strength $\bar{E}_i=\sqrt{\frac{1}{l_i}\int_{l_i}\left(E_x^2+E_y^2\right)dl}$ are calculated. The first contour l_1 along which the averaging is performed (see Fig.2) represents the nearest to the front of the shield plane from the outer side. The second contour l_2 is the projection of the outer surface of the shield to the plane $(\tilde{x},\tilde{y})$.

CALCULATION RESULTS

First the single-layer shield is analyzed. The contours of the distribution of the potential in the case $d_e=0.8$ and $\delta_e=1$ are shown in Fig.3.

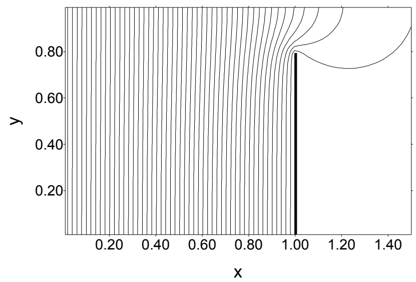

Fig.3. Contours of the distribution of potential in the case $d_e=0.8$ and $\delta_e=1$. Shield element is shown by bold line.

One can see there that the electric field penetrates outside the shield through the slots between the shield elements. The dependences of average electric field strength $\bar{E}_1$ on the width of the shield element d_e and on the distance between the strap and the shield element δ_e are displayed in Figs. 4 and 5. The dependences are apparent: the electric field strength outside the shield decreases with decrease of the shield transparency $T=1-d_e$ and with increase of the distance δ_e between shield and strap. However, even for low shield transparency, it is order of the electric field strength inside the shield.

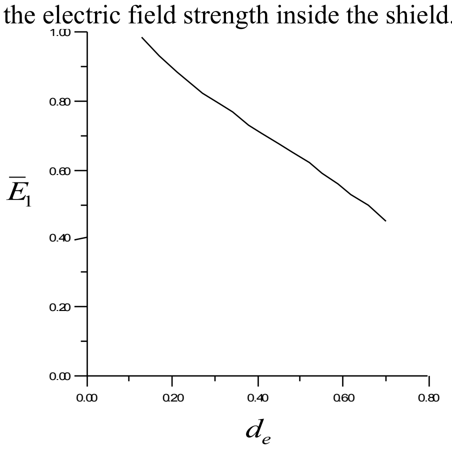

Fig.4. Dependence of average electric field strength $\bar{E}_1$ from the width of the shield element d_e

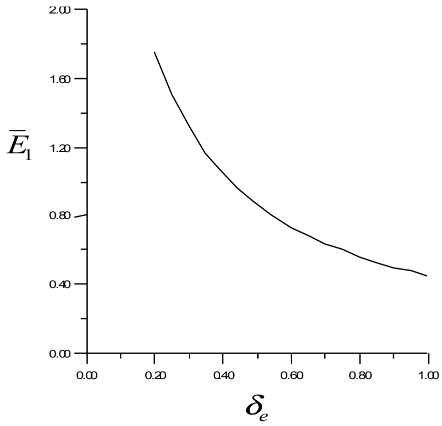

Fig.5. Dependence of average electric field strength $\bar{E}_1$ from the distance δ_e between shield element and strap

For double-layer shield the transparency $T=1-d_e-d_i$ could both positive and negative. The second case relates to the situation when the inner and outer shields overlay. The distribution of potential in the second case is shown in Fig.6.

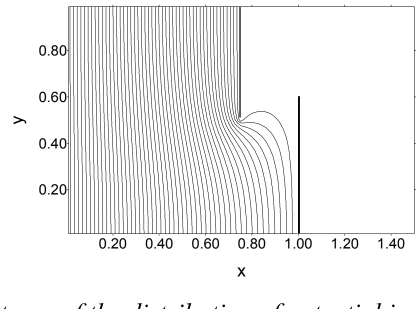

Fig.6. Contours of the distribution of potential in the case $d_e=0.6$, $d_i=0.5$, $\delta_e=1$ and $\delta_i=0.75$

In this case the penetration of the potential outside the shield is less than in the case of single-layer shield.

The dependences of electric field strengths $\bar{E}_1$ and $\bar{E}_2$ on the width d_e of outer shield element are displayed in Fig.7. Since the contour l_2 is closer to the shield than the contour l_1 the strength $\bar{E}_2$ is always stronger than $\bar{E}_1$.

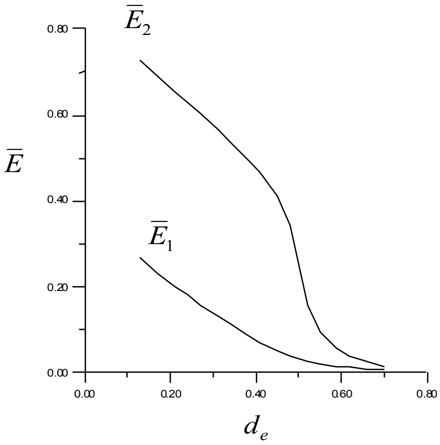

Fig.7. Dependences of average electric field strengths from the width of the outer shield element d_e *the case* $d_i = 0.5$, $\delta_e = 1$ *and* $\delta_i = 0.75$

Both strengths decrease with d_e . For $\bar{E}_2$, the decrement becomes stronger near the point where the shield transparency T changes sign.

SUMMARY AND DISCUSSIONS

The calculations of the distribution of electrostatic fields in the vicinity of Faraday shield show that the field penetrates outside the shield both in the case of single-layer and double-layer shields. The fields outside the shield rapidly decrease with the distance from the shield with characteristic space scale order of the shield period D . In this respect the shield with smaller period is preferable because the volume occupied by the electrostatic field is smaller. Moreover, the Fourier spectrum of the electrostatic field strength in y direction starts from the minimum value $k_{y\,\min} = 2\pi / D$ that increases with decrease of shield period. For fine shield the cut-off zone for slow wave is wider and the excitation of this wave is less effective.

For the single-layer shield, the electric field strength at the outer surface of the shield is order of that one between the shield and the strap. It decreases with decrease of the shield transparency and with increase of the distance between the shield and antenna strap. However, even for shields with low transparency its value remains unacceptably high. If plasma ions are present in the vicinity of the shield, their energy of motion in the electrostatic field could exceed the threshold of sputtering.

In the case of overlaying the double-layer shield fully protects the strap antenna from the fluxes of particles. The electrostatic field outside this shield is more than order less strong than the field inside the shield. Thus, the criterion of non-sputtering could be met. The obvious disadvantage of the double-layer shield is low transparency for the electromagnetic field. However, the last one could be increased keeping the small space between two layers in the front part of the shield and enlarging it at the side parts.

ACKNOWLEGEMENT

The author is thankful to Prof. K.N. Stepanov for stimulating discussions and support and to Dr. A.I.Lyssoivan for discussion of the calculation results and of practical aspects of electrostatic shielding.

REFERENCES

1. C. Riccardi, E. Agostini, M. Fontanesi. Measurements of plasma loading in the presence of electrostatic waves// *Phys. Plasmas*, 1995, Vol.2, pp. 3588-3594.
2. V.E. Moiseenko A Fast Wave Antenna for ICRF Plasma Heating// *Transactions of Fusion Technology*, 2001, Vol. 39, pp. 65-72.

ПРОНИКНОВЕНИЕ ЭЛЕКТРОСТАТИЧЕСКИХ ПОЛЕЙ СКВОЗЬ ФАРАДЕЕВСКИЙ ЭКРАН ПОЛУВИТКОВОЙ ВЧ АНТЕННЫ

В.Е.Моисеенко

В рамках двумерной численной модели изучено проникновение электростатических полей сквозь экран на его участке, обращенном к плазме. Показано, что однослойный Фарадеевский экран не обеспечивает экранирование на приемлемом уровне. С использованием двухслойного экрана экранирование может быть существенно улучшено.

ПРОНИКНЕННЯ ЕЛЕКТРОСТАТИЧНИХ ПОЛІВ КРІЗЬ ФАРАДЕЇВСЬКИЙ ЕКРАН НАПІВВИТКОВОЇ ВЧ АНТЕНИ

В.Є. Моісеєнко

У рамках двовимірної числової моделі вивчено проникнення електростатичних полів крізь екран на його частині, що звернена до плазми. Показано, що одношаровий Фарадеївський екран не забезпечує екранування на прийнятному рівні. З використанням двошарового екрану екранування може бути суттєво поліпшене.