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КОМПЬЮТЕРНЫЕ ТЕХНОЛОГИИ В ФИЗИКЕ

MATHEMATICAL MODELING OF DIFFRACTION ELECTROMAGNETIC WAVES BY CURVILINEAR PERIODIC STRUCTURES

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The problem of diffraction H-polarized plane waves by an ideally conducting infinite cylinder has been investigated. The numerical experiments, based on solving integral equations by the method of auxiliary spline currents, show that it is possible to reduce the integral radar cross section of the cylinder by modulating its directrix. There is evidence of similarity between the results obtained and a well-known natural phenomenon.

Представлено исследование проблемы дифракции H-поляризованных плоских волн идеально проводящим бесконечным цилиндром. Вычислительные эксперименты, основанные на решении интегральных уравнений методом вспомогательных сплайн-токов, показывают, что интегральное радарное сечение цилиндра можно уменьшить, модулируя его направляющую. Существует доказательство, что представленные результаты сходны с хорошо известным реальным явлением.

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INTRODUCTION

Periodic structures are widely used in various fields of physics and technology. Their properties are being studied intensively. However, the vast majority of published works are concerned with periodic structures having rectilinear directrix (plane structures). As for curvilinear periodic structures, they are poorly understood. However, in some cases, for a variety of reasons dictated by operating conditions, periodic structures need to be located on a curvilinear surface. Besides, curvilinear periodic structures have some properties substantially more pronounced than that of similar plane structures. So, for example, curvilinear structures are significantly more effective in applications for antenna decoupling or for minimizing the scattering cross section. The mathematical simulation of curvilinear periodic structures is somewhat more complicated since in this case Floquet theorem cannot be used.

1. PROBLEM FORMULATION

Let us assume that a plane monochromatic electromagnetic wave

$$U_0 = \mathrm{e}^{i(w_0 x - v_0 y)}\mathrm{e}^{-i\omega t}$$

impinges on an ideally conducting infinite cylinder whose generatrix is parallel with the Oz-axis and directrix is given in polar coordinates (r, φ) $(z = 0)$ by

$$r(\varphi) = a(1 + \tau \cos{(q\varphi)}).$$

Here $w_0 = k\sin\varphi_0$; $v_0 = k\cos\varphi_0$; $k = 2\pi/\lambda$; λ is the wavelength; φ_0 is the angle of incidence; $a = a^* - d/2$; $\tau = d/2a$ (see Fig. 1). We determine the integrated scattering cross section σ of this cylinder.

Assume that the magnetic field vector is parallel with the generatrix of the cylinder and perpendicular to the plane of incidence; that is, U_0 is the z-component of magnetic vector of the H-polarized incident plane wave. Then, as is shown in [1], the z-component of magnetic vector of the total field U on the boundary of the cylinder will satisfy the integral equation

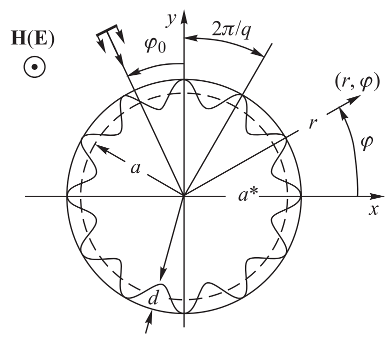

Fig. 1

$$\frac{1}{2}U(x(\varphi),y(\varphi)) = U_0(x(\varphi),y(\varphi)) + \frac{ik}{4}\int_0^{2\pi} H_1^{(1)}(kR(\varphi,\varphi'))\frac{1}{R(\varphi,\varphi')}\left((x(\varphi')-x(\varphi))\frac{dy(\varphi')}{d\varphi'} - (y(\varphi')-y(\varphi))\frac{dx(\varphi')}{d\varphi'}\right)U(x(\varphi'),y(\varphi'))d\varphi', \quad \varphi\in[0,2\pi], \quad (1)$$

where $x(\psi) = r(\psi)\cos\psi$, $y(\psi) = r(\psi)\sin\psi$, $\psi = \varphi,\varphi'$;

$$R(\varphi,\varphi') = \sqrt{(x(\varphi)-x(\varphi'))^2 + (y(\varphi)-y(\varphi'))^2},$$

and the expression for the integrated cross section can be written as

$$\sigma = \frac{2}{\pi k}\int_0^{2\pi}|f(\varphi)|^2 d\varphi,$$

where the scattering pattern $f(\varphi)$ is of the form

$$f(\varphi) = \frac{ik}{4}e^{-i\frac{\pi}{2}}\int_0^{2\pi} e^{-ik(x(\varphi')\cos(\varphi)+y(\varphi')\sin(\varphi))} \times \left(\frac{dx(\varphi')}{d\varphi'}\sin\varphi - \frac{dy(\varphi')}{d\varphi'}\cos\varphi\right)U(x(\varphi'),y(\varphi'))d\varphi'.$$

2. PROBLEM SOLUTION

The issue related to the behavior of the kernel of Fredholm integral equation of second kind as well as to the peculiarities of numerical solution to this equation are discussed in [2], so we concentrate on the results of the numerical experiments whose correctness was checked in accordance with the optical theorem.

Figure 2 shows the integrated scattering cross section σ as a function of depth of modulation $\gamma = d/\lambda$ of the directrix of the cylinder under consideration (for $a/\lambda = 1$ and $q = 24$).

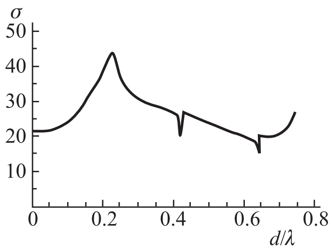

Fig. 2

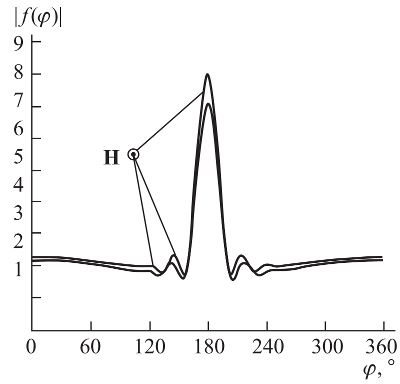

Fig. 3

As is easy to see, with an increase of γ the theoretically predicted rise of σ is stopped due to the formation of the so-called surface wave [3] which, according to hydro-aerodynamic terminology, «flows around» the cylinder, reducing its «turbulence» effect. Therefore, the subsequent increase in γ goes along with a decrease in σ down to values smaller than that for the integrated scattering cross section of the smooth cylinder. Still further, the surface wave «breaks away» («gets loose») [3], resulting in an increase of σ with increasing γ.

Figure 3 demonstrates relative scattering pattern amplitudes versus polar angle φ for E- and H-polarized incident plane waves (for $a/\lambda = 1$, $q = 24$, $\varphi_0 = -\pi/2$, and $\gamma = 0.3$). In the case of E-polarization, the calculations were carried out according to the methodology outlined in [4].

CONCLUSIONS

The preceding suggests that we are confronted with the situation similar to that when dolphins reduce the turbulence of their profiles due to modulation of skin integument and move faster than it is allowable from the point of view of their hydro-aerodynamic characteristics.

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REFERENCES

1. *Henl H., Maue A. W., Westpfall K.* Diffraction Theory. M.: Mir, 1964 (Russian translation).
2. *Galishnikova T. N., Il'insky A. S.* Numerical Methods for Diffraction Problems. M.: MGU, 1987 (in Russian).
3. *Vaganov R. B., Katsenelenbaum B. Z.* Fundamentals of Diffraction Theory. M.: Nauka, 1972 (in Russian).
4. *Kyurkchan A. G., Sukov A. I.* // Dokl. Ros. Akad. Nauk. 2000. V. 372. P. 480 (in Russian).