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ABOUT ONE MODEL OF TEACHING ELECTRODYNAMICS

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ABSTRACT

We propose the integrated course of learning of some theories of physics, mathematics and computer science, combining the well known and hot problems of electrodynamics. Each task selected is constructed of several modules: theory and methods of decision, specifics of problem, visualization of numerical results and analysis. We consider the electromagnetic waves diffraction on a circular cylinder of infinite length. Modifying the electric properties of system and grouping the tasks based on the skills and experience of participants gives possibility to work in team. To learn the physical systems by modeling and learn to modeling by means of physical systems is the approach applied in work.

Keywords: Electrodynamics, electromagnetic diffraction, dielectric bodies, modeling.

INTRODUCTION

The knowledge saved up in fundamental sciences is very important for the process of education. The main goal of teaching is to understand "what" and "why" to know. The traditional methods of education become attractive when students are actively involved in process of training. Participation in researching and modeling processes encourages the process of learning subjects difficult as physics and mathematics, helps students contribute ideas, novelty and observe variety.

We propose the integrated course of learning of some theories of physics, mathematics and computer science. To learn the physical systems by modeling and learn to modeling by means of physical systems is the approach applied in work. We combine the well known and hot problems of physics and study step by step a wide class of questions of physical tasks. Each task selected is complex enough and is constructed of several modules: formulation of problem, main themes of theory and methods of decision, specifics of problem, visualization of numerical results and analysis. Each completed module gives self-confidence, develops intuition and skills of students, so necessary for formation of professionals working with goal of development of engineering sciences on demand of the changeable global world.

Diffraction of electromagnetic (EM) waves on one-element systems, as cylinders and spheres was of great interest since 1950 because of its wide application in antennas technique, in radio physics and optics (King T'ai Tsun, 1959, Ueit, 1963, Richmond, 1965, Gildenberg et. al, 1967, Ivanov, 1968, Periacov, 1968, Orlov, 1974, Zabaronkova, 1976, Kevanishvili et al, 1978, Nikoloski, 1978, Alvarez-Estrada & Calvo, 1980, Vaganov & Katsenelenbaum, 1982 and Abushagur Mystafa & Nicholas, 1985).

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These systems remain still an object of research as the models for tasks and testing of complicated systems. Modifying the electric properties of system and grouping the tasks based on the skills and experience of participants gives possibility to work in team. In this paper is considered the electromagnetic (EM) waves diffraction on a circular cylinder of infinite length. The different methods of theoretical and numerical decision of these problems are known. We had chosen the method used in our scientific works.

FORMULATION OF PROBLEM

Let's consider E-polarized electromagnetic (EM) wave incident from the direction of positive x - axis on the cylinder with circular cross section (xoy plane). The fields are time-harmonic dependence with the factor $\exp(-i\omega t)$:

$$E_z^{in} = e^{-ik(x\cos\vartheta + y\sin\vartheta) - i\omega t} \quad . \tag{1}$$

Dielectric permittivity of cylinder is defined as:

$$\hat{\varepsilon} = \begin{cases} \overset{:}{\varepsilon}_1(r), & 0 \le r \le a \\ 1 \quad , & r \mathrm{\ f\ } a \end{cases} \quad , \tag{2}$$

Where $\overset{:}{\varepsilon}_1(r) = \varepsilon_1 - f(r)$. (3)

$\varepsilon_1 = \overset{:}{\varepsilon}_1(0) \mathrm{\ f\ } 0$ is the permittivity at the center of cylinder. a is the radius of cylinder, k wave-vector of an incident wave makes angle ϑ with the direction of x axis; $k = 2\pi/\lambda$; λ is the wavelength in vacuum; ω is the frequency; $f(r)$ is the function of radial variable r. We have to define the (EM) field scattered by cylinder, far-field and near-field characteristics of system.

MAIN THEMES OF THEORY AND METHODS OF DECISION

The electric vector of (EM) field inside and outside the area of cylinder satisfies the Helmholtz's equation (Nikoloski, 1978 and Vaganov & Katsenelenbaum, 1982):

$$\Delta E_z + k^2 \hat{\varepsilon} E_z = 0 \quad . \tag{4}$$

The field is finite inside the area of cylinder under the condition (Vaganov & Katsenelenbaum, 1982):

$$\left(E_z \cdot grad\, \hat{\varepsilon} \right) = 0 \tag{5}$$

and satisfies the radiation condition outside the area of cylinder (Vaganov & Katsenelenbaum, 1982). The rigorous solution of eq. (4) in the area [-a , a] is difficult for many cases. According the method of separation of variables [10, 12] eq. (4) is converted into the radial equation:

$$\xi^2 R''(\xi) + \xi R'(\xi) + \left(\xi^2 - m^2\right) R(\xi) = f(\xi/k_1)\xi^2 R(\xi) \ , \tag{6}$$

"/" - denotes the derivative with respect to an argument. $k_1 = k\sqrt{\varepsilon_1 \mu_1}$; magnetic permittivity $\mu_1 \approx 1$. For nonlinear radial dependence of permittivity, in a case $f(\xi / k_1) = \chi \left(\frac{r}{a}\right)^{2n}$, $(n = 1, 2, ...)$ solution of eq. (6) is given in works (Bzahlava, 1991 and Bzahlava et. al., 1991).

In a case of constant permittivity, $f(\xi / k_1) = 0$, from eq. (6) we get the Bessel equation:

$$\xi^2 R^{//}(\xi) + \xi R^{/}(\xi) + \left(\xi^2 - m^2\right) R(\xi) = 0 . \qquad (7)$$

Solutions of eq. (7) are known as Bessel functions. $J_m(\xi)$ is the Bessel function of the first kind, where m is a real constant, $J_m(\xi)$ is defined by: $J_m(\xi) = \left(\frac{\xi}{2}\right)^m \sum_{l=0}^{\infty} \frac{(-1)^l (\xi / 2)^{2l}}{l!(m+l)!}$. (8)

The Bessel functions are related to the Hankel functions also called Bessel functions of the third kind: $H_m^{(1)}(\xi) = J_m(\xi) + iY_m(\xi)$. (9)

where $Y_m(\xi)$ is Bessel function of the second kind, a second solution of Bessel's equation (7) linearly independent of $J_m(\xi)$, is defined by formula:

$$Y_m(\xi) = \frac{J_m(\xi)\cos m\pi - J_{-m}(\xi)}{\sin m\pi} . \qquad (10)$$

The (EM) field scattered by cylinder is presented as the sum of multiple fields with unknown multi-pole spectra coefficients $\{A_m\}$ and $\{B_m\}$, therefore the expressions are written for fields outside and inside the areas of cylinder, respectively:

$$E_z^{\,t} = e^{-ik(x\cos\vartheta + y\sin\vartheta) - i\omega t} + \sum_{m=-\infty}^{m=\infty} A_m H_m^{(1)}(kr) e^{im\varphi - i\omega t} \quad , a \le r < \infty \quad , \quad 0 \le \varphi \le 2\pi , \qquad (11)$$

$$\hat{E}_z = \sum_{m=-\infty}^{m=\infty} B_m R_m(k_1 r) e^{im\varphi - i\omega t} \quad , 0 \le r \le a \quad , \quad 0 \le \varphi \le 2\pi . \qquad (12)$$

The electric and magnetic vectors of (EM) field satisfy the boundary conditions:

$$E_z^{\,t} = \hat{E}_z , \quad H_\varphi^{\,t} = \hat{H}_\varphi , \quad \text{at} \quad r = a \quad , \quad 0 \le \varphi \le 2\pi . \qquad (13)$$

According to some ideas of orthogonality of diffraction modes (Zabaronkova, 1976) for arbitrary dependence of permittivity $\varepsilon_1(r)$, we easily find the required spectra coefficients $\{A_m\}$ and $\{B_m\}$:

$$A_m = -i^{-m} \frac{R_m(k_1 a) J'_m(ka) - W_1 R'_m(k_1 a) J_m(ka)}{R_m(k_1 a) H_m^{(1)/}(ka) - W_1 R'_m(k_1 a) H_m^{(1)}(ka)} , \qquad (14)$$

$$B_m = i^{-m} \frac{2i / \pi ka}{R_m(k_1 a) H_m^{(1)/}(ka) - W_1 R'_m(k_1 a) H_m^{(1)}(ka)} . \qquad (15)$$

We used for determining H_φ the relation: $H_\varphi = -\frac{1}{i\omega\mu_1\mu_0}\frac{\partial}{\partial r}E_z$; $W_1 = k_1/k$.

Function $R_m(\xi)$ is the solution of eq. (6). Replacing function $R_m(\xi)$ by $J_m(\xi)$ in formulas (12), (14), (15), we get the expressions for spectra coefficients in a case of constant permittivity.

Let's consider the scattered (EM) field in far zone ($kr \to \infty$) by using the asymptotic expression of Hankel function $H_m^{(1)}(\xi)$ (Nikoloski, 1978). The angular dependence of E_Z is defined as:

$$F(\varphi) = e^{-i\pi/4}\sqrt{2/\pi k}\cdot\Phi(\varphi) \quad . \tag{16}$$

The scattering characteristics of system for far zone from the cylinder boundary are called the scattering cross-sections: total σ_S and backward σ_B , respectively:

$$\sigma_s = \frac{4}{k}I \quad , \quad \sigma_B = 2\pi\left|F(0)\right|^2 \quad , \tag{17}$$

here $I = \frac{1}{2\pi}\int_0^{2\pi}\Phi(\varphi)\Phi^*(\varphi)d\varphi$. (18)

"*" denotes the complex conjugate of function. In a case of one cylinder we get the expressions for:

$$\Phi(\varphi) = \sum_{m=-\infty}^{m=\infty} i^{-m}A_m e^{im\varphi} \quad \text{and} \quad I = \sum_{m=-\infty}^{m=\infty}\left|A_m\right|^2 \quad . \tag{19}$$

The near (EM) field is determined by formulas: (11), (12), (14), and (15). We can present the lines of equal amplitudes E_z and equal phases by means of expression (Bzahlava et. al, 1991): $\varphi_E = arctg\frac{\operatorname{Im}E_Z}{\operatorname{Re}E_Z}$.

SPECIFICS OF PROBLEM

For numerical estimation and visualization we propose the programs based on Matlab v7.0.4. At first we have to consider the syntax of Bessel functions: J = besselj (m, ξ) computes the Bessel function of the first kind, for each element of the array ξ . The order m need not be an integer, but must be real. The argument ξ can be complex. The result is real where ξ is positive. H = besselh (m, k, ξ) computes the Hankel function, where k = 1 or 2, for each element of the complex array ξ . H = besselh (m, ξ) uses k = 1. The offered programs are designed so that they were simple and easily read, instead of elegant. Computing (EM) fields by formulas (11), (12) we determine the number m of terms of series with simultaneous research of convergence of algorithm within the given accuracy 10^{-6} . The number of terms of series may be determined by the empiric condition: $m \geq 2\left[\left(k_1 a\right)+1\right]$.

VIZUALIZATION

For constructing the complete picture of system we have to calculate and analyze the main scattering characteristics of system. In this paper we demonstrate only some of them for a case of normal wave incident $(\vartheta = 0^0)$. The scattering pattern of a system in a case of constant $(\varepsilon = \varepsilon_1 = 1.7)$ permittivity is described in Cartesian coordinate system (fig.1) and in polar coordinate system (fig.2); The near field is

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performed by the lines of equal amplitudes and equal phases in the area $(-\lambda/2, \lambda/2)$ along the axes x and y for nonlinear dependence of permittivity: $f(\xi/k_1) = \chi\left(\frac{r}{a}\right)^2$, $ka = 2$; $\varepsilon_1 = 1.7$; $\chi = 0.2$.

CONCLUSION

This paper demonstrates the possibility of integrated learning of some theories of physics, mathematics and computer programming by choosing the appropriate tasks of electrodynamics. We have considered the main modules of solving problems. Creating working groups of students for different tasks of each module we have tried to achieve the intended goals: to pass knowledge necessary for higher levels of education and to get complete physical picture of researched system. In this paper we concentrated on the problems of electrodynamics but its findings are applicable to other disciplines as well.

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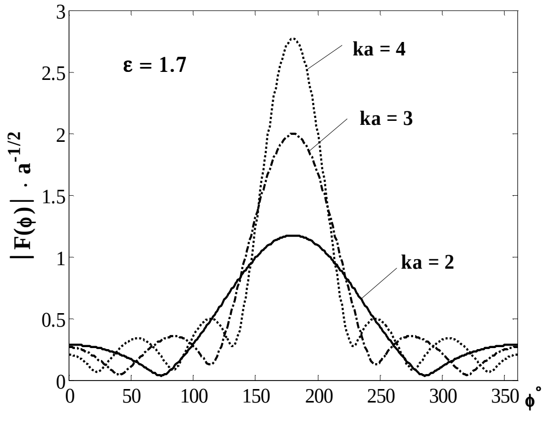

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Figure 1

Scattering pattern of cylinder in Cartesian coordinate system $\vartheta = 0^{\circ}$

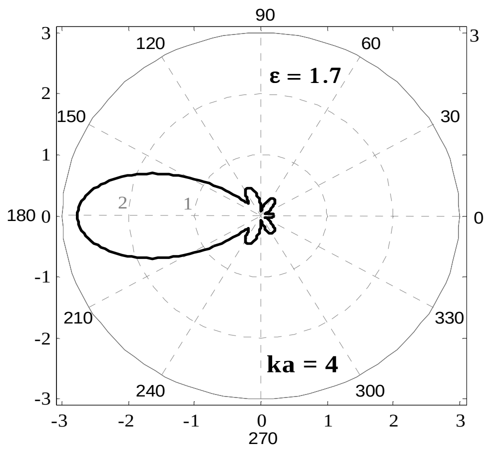

Figure 2

Scattering pattern of cylinder in polar coordinate system $\vartheta = 0^{\circ}$

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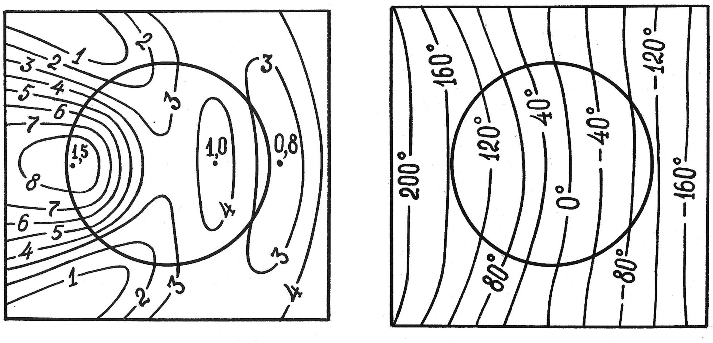

Figure 3
Lines of equal amplitudes (left), lines of equal phases (right)
$ka = 2; \quad \varepsilon_1 = 1.7; \quad \chi = 0.2$

