MODELING OF INTERACTION OF ELECTROMAGNETIC RADIATION WITH TWO NON-UNIFORM CYLINDRICAL PARTICLES

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Abstract- Influence of monochromatic electromagnetic radiation on systems of the two-layer absorbing aerosol particles of a cylindrical form is considered. It was supposed that external and internal layers of each such cylindrical particle considerably differ on the absorbing ability. For the solution of this problem the bi-cylinder system of coordinates is used. It is supposed that radiuses of cylinders there is much less than a wavelength of the influencing radiation. In each layer distributions of density of the absorbed energy were calculated. Calculations of electric vectors at various values of dielectric permittivity were carried out (positive and negative). The method of approximate solutions for particles with dielectric permittivity depended on electric and magnetic vector is developed.

Keywords- Bi-cylinder system of coordinates, Electromagnetic radiation, Heating, Nonlinearity.

I. INTRODUCTION

Earlier in work [1] the two-layer aerosol cylindrical particles which are in an electromagnetic field were considered (for example, ice needle crystals in the atmosphere). As shown in work [2], the characteristic relation of diameter of needles (ice aerosols) to their length of d/L makes 0,04-0,2. When crystals are small so Reynolds number Re < 1, influence of the air environment on their orientation isn't enough and, probably, it is possible to consider orientation of such crystals chaotic. In process of integration of crystals and increase in Re the crystals of uniform density falling in quiet air are guided so that the environment resistance to their falling was maximum, and the speed of falling is therefore minimum. It means that needle crystals are guided mainly horizontally. Particles interact with each other even at the distances, in scores of times exceeding their sizes. In one cases of a needle and plates are guided when falling in parallel each other, in others – perpendicularly.

More detailed review of the works devoted to regularities of falling of crystals of various form can be found in work [3]. In this regard, we offered the following model of the aerosols of the extended form which are in an electromagnetic field: two parallel cylinders in the field of a flat monochromatic electromagnetic wave. On an ice needle the layer of so-called pollution can be formed (for example, a soot layer). Therefore in work [1] pairs of cylinders which two layers considerably differ on the properties were considered. It was supposed that cylinders absorb electromagnetic radiation. The vector of intensity of electric field is perpendicular to axes of cylinders. Radius of cylinders is much less, than the wavelength of the falling radiation. In this case for potentials of electric field out of and in cylinders it is possible to write down Laplace's equation.

$$\Delta\Phi = 0 \tag{1}$$

Solving Laplace's equation in bicylinder system of coordinates [4,5] it is possible to find the value of intensity of electric field in any point of the considered system.

In a point in bicylinder system of coordinates density of thermal sources decides on coordinates (σ, τ) as [6]

$$q_j = \frac{4\pi n_{rj} n_{ij} \left|\vec{E}\right|^2 I}{n_m \lambda \left|\vec{E}_0\right|^2} \tag{2}$$

where n_{rj} and n_{ij} – index of refraction and coefficient of absorption of substance particles with number j respectively, $\left|\vec{E}\right|^2$ - the module of a square of amplitude of an electric vector, I – intensity of the falling radiation, n_m – index of refraction of the environment, λ - the wavelength of the falling radiation, j = 1,2, E_0 – intensity of electric field in vacuum.

The following decisions for modules of a square of amplitude of an electric vector in layers of cylinders were received:

$$\left|\vec{E}\right|_1^2 = \frac{a^2}{(ch\tau - \cos\sigma)^2} \times$$
$$\times \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} n \cdot m (W_n W_m + V_n V_m) \times \tag{3}$$
$$\times \exp(-(n+m)\tau) \cos(n-m)\sigma$$

$$\left|\vec{E}\right|_2^2 = \frac{\left(a^1\right)^2}{\left(ch\tau^1 - \cos\sigma^1\right)^2} \times$$

$$\times \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} n \cdot m (W_n W_m + V_n V_m) \times \qquad (4)$$

$$\times \exp(-(n+m)\tau^1) \cos(n-m)\sigma^1$$

Here a – polar distance; σ, τ, z; σ^1, τ^1, z^1– bicylinder coordinates in external and inside layers, Wn and Vn – coefficients.

The offered method allows to find the relevant decisions for the module of a square of amplitude of an electric vector (and, respectively for density of thermal sources) for any values of indices of refraction and coefficients of absorption characterizing various layers of cylinders.

In the present work some model cases are considered.

II. NUMERICAL EXPERIMENTS AND DISCUSSION

SYSTEMS OF UNIFORM CYLINDERS WITH VARIOUS VALUES OF COMPLEX DIELECTRIC PERMITTIVITY OF SUBSTANCE OF A PARTICLE

1. At calculations the following values were used: λ=0,2 cm; ε_1 =1 (environment – air); n_2 = 1,78; m_2 = 0.0024; ε_2 = (n_2 +m_2·i) 1/2 (the given values correspond to ice at this wavelength and temperature 0^0C). It is known that $\varepsilon = \sqrt{n}$. In that case for ice $\varepsilon_2 = 1{,}33 - 0{,}0009i$

In fig. 1 dependences of the relation on the radius of a circle (Rx) in the section of the cylinder, perpendicular axes are constructed. Here φ - connected with the center of round section of the cylinder polar coordinate, changing along this section. The relation $\frac{|E|^2}{|E_0|^2}$ was in the points lying on these circles.

2. All parameters - the same, except model value of complex dielectric permittivity of substance of the cylinder:

$\varepsilon_2 = -1{,}6 - 0{,}0009i$

Follows from comparison that:
1) In the second case absorption in the area close to edge of the cylinder significantly decreases;
2) Area in which the absorption maximum, wider is observed (φ =110^0C - 250^0C); and the diagram of distribution in area is "platform" with approximately identical $\frac{|E|^2}{|E_0|^2}$ relation.

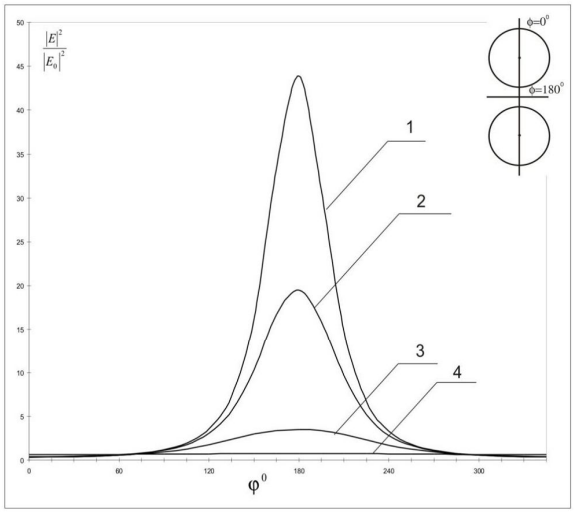


Fig. 1. The diagram of distribution $\frac{|E|^2}{|E_0|^2}$ in the micron R_0=1 cylinder at various radiuses of circles in the chosen section of 0.95 microns (1), 0,9 microns (2), 0,5 microns (3), 0,1 microns (4)

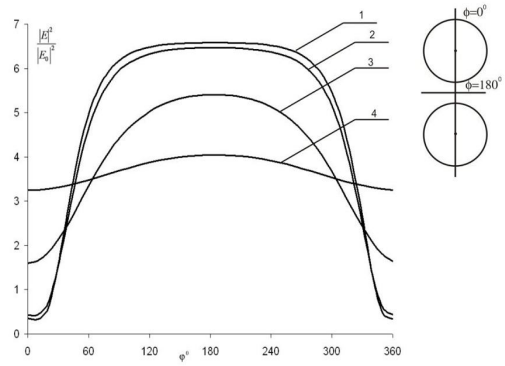


Fig. 2. The diagram of distribution $\frac{|E|^2}{|E_0|^2}$ in the micron R_0=1 cylinder at various radiuses of circles in the chosen section of 0.95 microns (1), 0,9 microns (2), 0,5 microns (3), 0,1 microns (4)

SYSTEMS OF NON-UNIFORM ON STRUCTURE CYLINDERS

Numerical computing experiments for various configurations of layers of the cylinder are made:

- Concentric layers;

- Not concentric layers (the inside layer represents structure with incidentally distributed radius depending on an angle on cylinder section).

Earlier in work [1] cylindrical particles with concentric layers were considered. In the present work model calculations for a case when the internal border of an external layer changes in a random way are carried out.

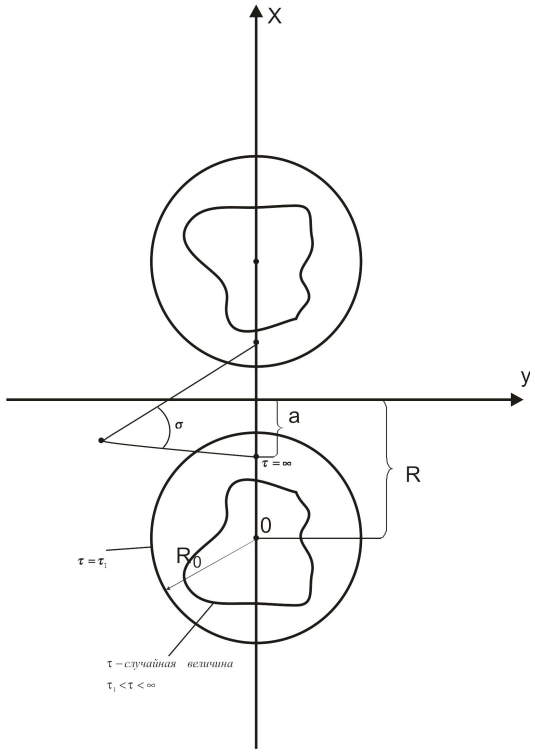


Fig. 3. Scheme of system of two two-layer cylinders (not concentric layers)

The decision considered in the present work is consolidated to the decision provided in work [1], but thus the radius of internal border is set anew for each considered point. In fact, in each point the boundary condition for the current radius (fig. 4) is applied.

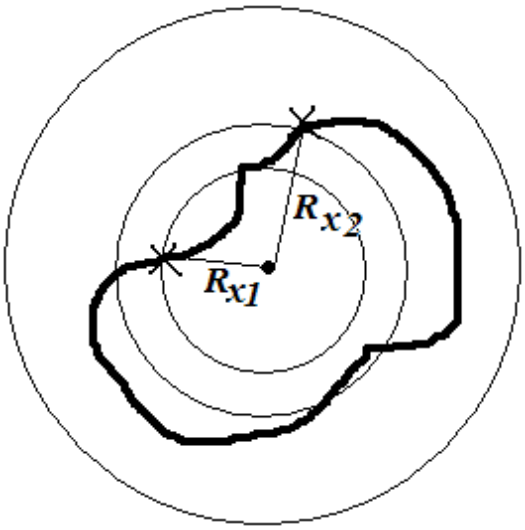
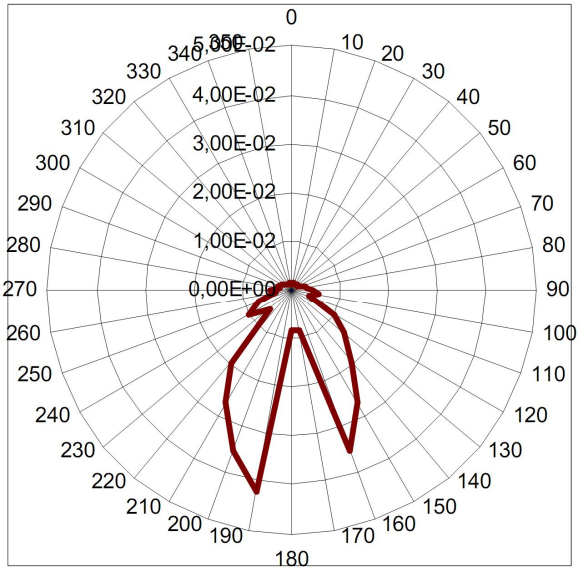
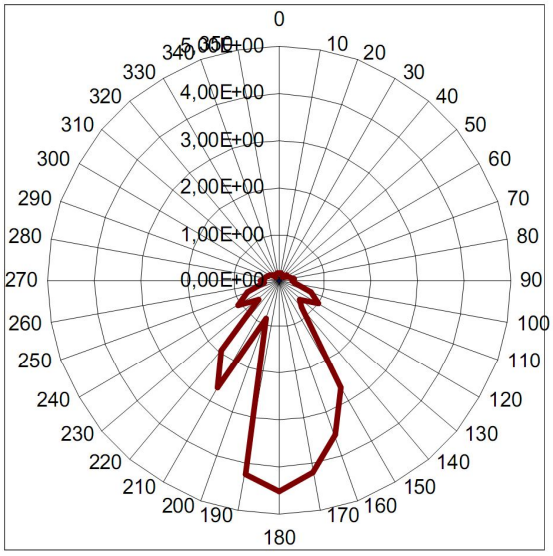


Fig. 4. To a method of calculation of absorption for casual distribution of internal border of an external layer.

Distributions $\frac{|E|^2}{|E_0|^2}$ in a cylindrical particle of the radius of R_0=1 microns at the radius of a circle of the chosen section of 0.95 microns with casual distribution of internal border of an external layer are found. In this case the point of a circle can belong to both an external, and inside layer. Values of complex dielectric permeability for an inside layer – ice (see the previous case), for external – the model values corresponding to strong absorption.



a)



b)

Fig. 5 (a,b). Distribution $\frac{|E|^2}{|E_0|^2}$ on cylinder section with incidentally distributed radius of an inside layer (a step 10^0).

Figures 5a and 5b correspond to various configurations of the internal border of an external layer chosen in a random way.

It is found that the type of distribution $\frac{|E|^2}{|E_0|^2}$ of the relation has the form depending on thickness of an external layer in the chosen point and is entered in the chart calculated for the radius of internal border of an external layer, the corresponding minimum thickness of an external layer.

The developed algorithms and program complex allow at a variation of various parameters of system (the sizes of particles, distances between them, properties of particles, etc.) to receive distribution of the heat sources initiated by electromagnetic radiation.

The developed method allows also in the second approach with use of iterations to solve a nonlinear problem with the dielectric permittivity depending on electric and magnetic vectors:

$\varepsilon = \varepsilon_0 + |\alpha| f(\vec{E}, \vec{H})$, where α – nonlinearity parameter. In this case it is possible to use a method of iterations: at the first stage to find a field with constant dielectric permittivity, and on the second – to specify the decision for the dielectric permittivity depending on a field.

Two options are possible. The first option assumes that a field in layers of the cylinder rather uniformly. Then the type of the equations does not change: in each layer this equation of Laplace, but with the new value of dielectric permittivity calculated for this nonlinear dependence on average values of electric and magnetic vectors in the corresponding layer. If function $f(\vec{E}, \vec{H})$ turns on only modules of vectors of intensity, the increase in dielectric permittivity leads to increase in electric field in this layer. If the function describing nonlinear character of an electromagnetic wave may contain directly vectors of intensity, then change of fields is more difficult as electric and magnetic vectors generally are complex.

In the second option when the field is strongly non-uniform in each layer, or in some one layer, the corresponding equation at the second stage will be transformed to the Poisson's equation. It can be solved by decomposition of the right part in a row on the same own functions which were received at the solution of the equation at the first stage (at rather simple nonlinear function, for example, square) or method of potentials. It is also possible to use a decision method for the Laplace's and the Helmholtz's differential equations on difficult structures (columns) which we develop in the works, based on ideas of the monograph [7].

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