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The method of relocation of boundary condition for the problem of electromagnetic wave scattering by perfectly conducting thin objects

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ABSTRACT

A three-dimensional problem of monochromatic electromagnetic wave scattering by perfectly conducting body of small thickness is considered. The numerical method for the solution of this problem, based on the relocation of the boundary condition to the median surface is developed. In this method we state a new boundary value problem in the domain outside this surface. The original shape of the body is taken into account due to the boundary conditions. Further, the resulting problem reduces to a system of two integro-differential equations on the median surface. A numerical scheme for solving these equations is developed. This scheme does not degenerate when the body thickness tends to zero. The developed method has been tested by the example of the problem of electromagnetic wave scattering by the body in the form of a rectangular wing.

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1. Introduction

The classical problem of monochromatic electromagnetic wave scattering by a perfectly conducting body, based on Maxwell equations, is considered. For the numerical solution of such problem the high-efficiency approach which based on the method of boundary integral equations is used. The main idea of this method is based on writing the integral expression for the solution with integrals over the boundary of domain wherein the problem is being solved. In case of the problem of electromagnetic wave scattering by the object placed in the homogeneous external medium, the expression for the electric field in terms of the surface currents is used. At that, the equations of electrodynamics outside the body and boundary conditions at infinity are fulfilled automatically. For finding the unknown surface currents, it is necessary to write the integral equation that ensures the fulfillment of boundary condition on the body surface (refer, for example, [1], [2], [3], [4]).

In comparison with the grid-based methods that suppose the discretization of spatial domain surrounding the objects, here the computational grid is build only on the surface of irradiated bodies. At that, the conditions at infinity are fulfilled automatically and the issue of enlargement of the domain, covered by the spatial grid, for the correct consideration of these conditions is eliminated. In the problems of diffraction the latter issue is particularly acute because the step of spatial discretization is defined not only by the complexity of geometry but by the length of wave as well (the step of discretization

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should be considerably less than the wave length). The limitation imposed by the wave length on the grid step is often determinative and does not allow employment of the non-uniform grids as is done, for example, in the exterior problems of computational aerohydrodynamics.

In case when the method of boundary integral equations is used for solving the problems of diffraction by the bodies of small thickness, certain difficulties appear. By the term "the bodies of small thickness" we mean the bodies where one of the overall dimensions is much smaller than the others. The example of such body is the rectangular wing of a finite span with a small airfoil thickness ratio. The integral equations, written on the closed surface limiting the body, degenerate when the body thickness tends to zero. When the integral equation is solved numerically by the methods that suppose the discretization of boundary surface, one has to use the partition of surface into the big number of cells – the grid step should be less than the body thickness. Low accuracies are observed near the body edges. Note that the issue of numerical solution of boundary value problems outside the bodies of small thickness is typical for the method of boundary integral equations (it appears not only in the problems of diffraction).

The problems of solving the boundary integral equations of electromagnetic wave scattering by perfectly conducting bodies of small thickness, in particular, are described in [5], [6]. Note that in the last article, the authors propose an approach to the solution of scattering by thin body problem, based on application of combined field integral equation (CFIE), which is written on the surface of the body. In [6], the authors also point out that standard numerical algorithms for solving boundary integral equations which work well for thick bodies, require fine mesh in case of bodies of small thickness.

In case of the numerical solution of boundary integral equations, the problem is reduced to the system of linear algebraic equations with dense matrix. The number of equations of such a system is determined by the number of cells of the partition of the boundary surfaces. A significant increase in the number of cells of the partition used for the solution can be achieved by applying special methods for compressing dense matrices and fast matrix algorithms. Such methods are widely used in problems of electrodynamics, allowing to significantly increase the computational complexity of the problems being solved [7], [8], [9], [10], [11], [12], [13], [14], [15], [16].

For the sake of simplicity, the problem of diffraction by the body of small thickness is often substituted by the problem of diffraction by the thin screen that approximates this body. However, the simple substitution of a bodily object by a screen not always enables to obtain correctly all of the necessary physical characteristics. Thus, the shape of the edges and boundaries of perfectly conducting bodies has a significant influence on the calculated radar cross section (RCS). This property of electromagnetic scattering is reflected in the methods of the physical theory of diffraction, which are applicable to the case of short waves [17], [18].

In the present article, in order to solve the problem of electromagnetic wave diffraction by the perfectly conducting body of small thickness, we develop the approximation approach based on the relocation of boundary condition to the median surface of the body. Our main idea is the following.

We assume that the whole original surface of the body consists of two components, that have a small distance between each other. Each point z^+ of one of these components uniquely corresponds to the point z^- of the other component. We also assume that there is a median surface, formed by the midpoints of segments with ends at the corresponding points z^+ and z^- of the mentioned surface components.

The original problem for the electromagnetic field is imposed in the region outside the initial surface of the body, where the condition of orthogonality of the electric field to the normal vector to the surface is required.

The idea of our approach is to consider the new boundary value problem for the electromagnetic field in the region outside the median surface instead of considering the original boundary-value problem. Here we set the condition that on the positive side of the median surface the electric field is orthogonal to the vector, which is the normal to the original surface in the corresponding point z^+. Similarly, on the negative side of the median surface the condition of orthogonality between the electric field and the normal vector to the original surface at the corresponding point z^- is set. The numerical scheme for such a boundary value problem is based on the reduction of the problem to the boundary integral equations that are then solved numerically.

Our achieved goal was to develop a numerical method that does not degenerate as the distance between the specified components decreases. If the distance between these components becomes equal to zero our numerical scheme transforms to the known numerical scheme for solving the problem of electromagnetic wave scattering by a perfectly conducting screen.

Comment. *One can say that in our method a thin body is replaced by a screen and on each side of the screen the condition of the orthogonality between the electric field and the normal vector transferred from the real surface is imposed. Such an approach could be called a method "over-surface boundary condition". However, we do not use such a name, since it causes associations with the name of a completely different existing method – the method of the "on surface radiation conditions" (OSRC) [19], [20]. In this method an integral representation of the solution of scattering problem is written using surface integrals. The densities in such integrals are sought approximately using the concordance between asymptotic expansion of the electric field at the infinity and the radiation conditions. Unlike our method, the OSRC method is a method for simulating high-frequency electromagnetic wave scattering.*

The one of the goals of OSRC method is to obtain the approximation of the solution bypassing the process of solving the boundary integral equation. Moreover, the articles [19] describe an integral representation of the solution for plane problems on the original surface of the body. This representation which is fundamentally based on the fact that the body is bounded by a closed curve and degenerates as the thickness of the body tends to zero. The main feature of our method is an approximation for bodies of small thickness using of an auxiliary surface.

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