Perturbation cluster method for anisotropy modeling

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Abstract. The paper gives a detailed description of created algorithm, that can be effectively used in the setting of anisotropic medium for electrodynamics CAD implementation. In fact, the developed program provides itself the numerical apparatus for material perturbation analysis. The cluster method approach presented as the finished model in the wide area of applicability. This paper presented the formulation of the problem in the terms of electromagnetic propagation.

1. Introduction

Modeling the anisotropic medium in modern electrodynamics CAD’s systems can be implemented by several ways. First, specifying the multilayer structure, with different electro physical parameters (analogue of decomposition approach). Second, by tensor method. Randomly inhomogeneous medium often described by the coordinate method.

Regarding to analytical approach, the anisotropic medium can act as the propagation environment only for simple shaped objects. This theme particularly interesting, in the case of plasma effects investigation [1]. For complex-shaped target solution obtaining strict theory gives the necessary analytical boundaries to initial verification.

Suppose that the initial state of medium (unperturbed) known and isotropic. Perturbation of the medium determines the anisotropic behavior. Saving the physical sense in the process of reconstruction of the propagation medium, allows to realize the cluster analysis of that system. Cluster decomposition widely used in propagation prediction, but applies in space splitting without calculation of status of each element. This formulation describes, for example in [2].

Perturbation cluster method can be used to describe the medium with heat flows and heat transfer, any transfer of the substance, described by the analytical functions, reconstruction of the environment associated with the mechanical action, or with any movement of the system (rotation for example). This method can also be used successfully for the description of the antenna lens (Luneburg lens, as well).

2. Generalities

The defining equation for describing the state of perturbation cluster is following (first order only) [3]:

$$A = A_0 + \beta A_1, \tag{1}$$

where A – current state of cluster, A_0 – state of unperturbed cluster (isotropic medium) and β – first order factor (coupling coefficient). Strictly, in form (1) can be described any physical processes that changing the parameters of medium. The apparent simplicity of the formula in most cases not justifiable. The main problem is to establish the coupling coefficient, suchwise, that it most accurately described the physical statement.

Implementing the cluster approach, the decomposition rules setting is necessary. On fig.1 presented some possible morphology of space, condition of which determines by value A in (1). Perturbation direction is the initial data, and it can be represented as a curved path. The geometry is divided into equal parts which are the clusters. The serial number – n is assign to each cluster. First cluster statement is constant and equal to A_0. Pervasive perturbation described by magnitude A_1, and transition function $\beta(n)$. This formulation can be expand to two-dimensional, three-dimensional or even four-dimensional (with time axis) space decomposition.

3. Software algorithms

The developed software, allows to setup the specific anisotropy for the space in view of its morphology. Only axially symmetric shapes considered. This condition is a goal of obtaining the unique cluster transmission function that should be determined at input parameters.

Consider the program with a simple example. Take known characteristic dependence of water permittivity versus temperature of medium ($\varepsilon(temp)$) [4], as a description of the anisotropy behavior. Heat transfer between layers of water is a physical rationale of the disturbance process. As mentioned above the processes occurring in time require 4-D decomposition algorithm. First of all, it is necessary to install this time frame. Instant system time – t_0 – time of transition between adjacent clusters. Relaxation time – τ – the time that single cluster will take to return to unperturbed condition (the inertia of the system to specific perturbation). The velocity of internal processes does not exceed the velocity of relaxation of the system. Equilibration time – T – the time that whole system require to equilibrate (all layers are equally perturbed). Time – t – interval for which the solution will be obtaining.

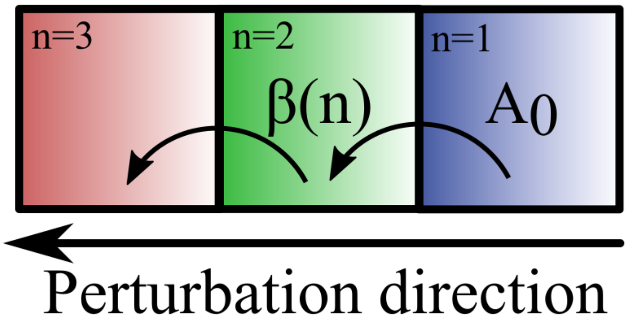

Figure 1. One-dimensional cluster decomposition.

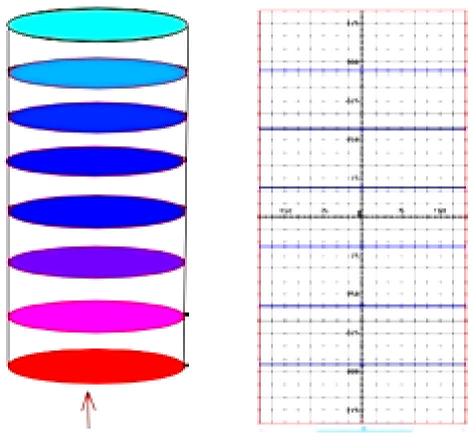

Figure 2. Cylinder cluster decomposition.

$$\begin{cases} t_0 N = t, \\ \tau N = T, \Rightarrow t_0 N < \tau N \Rightarrow t_0 < \tau, \\ t < T. \end{cases} \tag{2}$$

where, N – the number of system clusters.

Set of equations (2) must be must be complimented by the criterion of equality cluster thickness ($h_1 = h_2 = \ldots h_n$). This condition is necessary for immutability of transition function. Decomposition method with different cluster thickness is also used, but in fact correct time frame strongly correlate with this value (basically different thickness provides equal time intervals in system and vice versa).

In order to, adjacent cluster with vary perturbation did not have time to equilibrate (equal perturbation), during to t, inequality (2) should become more strict:

$$t < 2\tau \Rightarrow t_0 < \frac{2\tau}{N}. \tag{3}$$

Finally, to exclude any noticeable changing in cluster state, during the moving of perturbation along the whole system, inequality (2) reconstruct to the fastest time frame:

$$t_0 < \frac{2(\Delta\tau)}{N}, \tag{4}$$

where, $\Delta\tau$ – the maximum period of time, during the cluster relaxation, in which the changing of cluster statement remains negligible.

On fig. 2 presented the cylinder with formed clusters to describe the problem. Colors of clusters correspond to the temperature disturbance. From (4) it is possible to obtain the cluster thickness (and the number of clusters in decomposition). t_0 – determines only by physical initial parameters. This paper will not proved the heat transfer calculation by the reason of inadequate subject, however this procedure may be initializing also for dissipative systems. $\Delta\tau$ – value determine by confidential interval of system analysis. In general this interval given explicitly by (1), where first order factor priory gives the accuracy of perturbation calculation. The number of clusters is given by the user as the input parameter.

Following fig. 2 there are seven clusters in the system ($N = 7$). Relaxation time of water physically is also describes by heat exchange with the surrounding medium. In this case set the A_0 in (1) to 20°C (normal conditions). It makes no sense to describe all other physical effects that can be taken into account. In general, confidential interval put mutually and then checked the t_0 value in (4). In this value corresponds to real situation the decomposition method considered acceptable. If not, confidential interval should be specified.

In the case of not dissipative system, to this cylinder morphology, transition function have a linear behavior: $\beta(n) = -kn$, where k – coefficient that corresponds to velocity of perturbation ($k \sim t_0$).

After each cluster receiver it's perturbed condition, temperature correlated with tabular data for permittivity and medium get the anisotropic description for future electrodynamics analysis.

4. Time independent systems

Most of electrodynamics problems that describes in terms of propagation in anisotropic medium, occurs as time independent perturbation cluster method. List below presents some possible formulations in this case.

Moving medium. If the medium parameters is constant in time, this situation described the relativistics effects of noninetrial frames of references.

Dielectric lenses. All variety of lenses with functionaly changing of layers permittivity, may be described by the cluster decomposition method, with step by step transition coefficient.

Any time dependent processes with $\Delta\tau > t_0$. Time frame condition (2) can be checked for specify problem to determine necessity of introducing the 4D decompostion. Any slow processes can be solved without time axis, but with the account of introduced assumption.

The developed software may be used effectively in conjunction with other electrodynamics CADs. Host system takes all numerical calculation of fields, and perturbation cluster system determines the anisotropic medium setting.

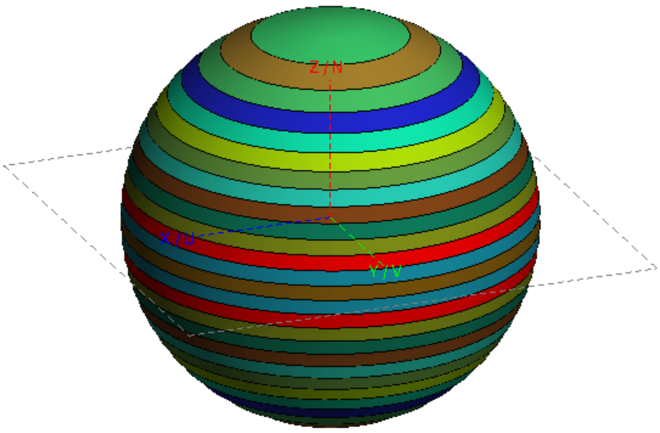

Figure 3. Experiment results.

Fig. 3 stands for example of cluster decomposition in FEKO to solve the scattering by rotating sphere problem. Non inertial medium formed in the terms of perturbation theory. None of the commercially available CADs, has not such a mathematical apparatus to anisotropic medium setting. In this case the distributed modeling may significantly increase the effectiveness of simulating.

5. Conclusion

Described in this paper software gives the formulation of perturbation cluster algorithm. Presented an example of 4D decomposition in time domain to adequate setting of anisotropic medium. The permissible time frame was given. Listed the electrodynamics problem that can be applied to the decomposition algorithm without time axis. Shortly shown the benefits of distributed modeling together with the created software.

In general, proposed method proved it’s effectiveness in number of situation and can be used in wide range of possible applications (eg, [6] – [8]).

6. References

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