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Development of Finite Element Approach for the Electromagnetodynamic Problems

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I. SUMMARY OF THE STATE-OF-THE-ART

Our current interest concerning with the finite element approach for the electromagnetodynamic field problems is roughly classified into three major categories.

1. Dual Energy Finite Elements

The first is to exploit an ultimate efficient finite element method to obtain the highly accurate solutions as soon as possible. Previously, we proposed a locally orthogonal discretization method. This method is based on a geometrical duality between the Voronoi polygons and Delaunay triangles so that only one type of potential is required to implement the dual energy finite element approach [1]. Furthermore, we have proposed a Voronoi-Delaunay transformation method to implement the dual energy approach in an ultimate efficient manner. As a result, for example, we have succeeded that one hour computation can be reduced only few minutes by our Voronoi-Delaunay transformation method [2].

2. Finite Element Solution of the Open Boundary Problems

The second one is to apply the finite element method for the open boundary electromagnetodynamic field problems containing the nonlinear ferromagnetic materials. It is well known that the finite element method is difficult to apply the electromagnetic field problems having open boundary. In order to overcome this difficulty, we have proposed a strategic dual image method [3]. In our strategic dual image method, the rotational and divergence electromagnetic field components can be separated by imposing the images of rotational and divergence sources, respectively. The rotational and divergence field components are respectively evaluated by imposing the zero and symmetrical boundary conditions to a hypothetical boundary when the field is represented in terms of the vector potentials. Combination of both rotational and divergence field components yields the open boundary electromagnetic fields even if a nonlinear medium is contained in the problem region [4]. Thus, our strategic dual image method makes it possible to obtain the finite element solutions of the nonlinear open boundary electromagnetic field problems.

3. Constitutive Equation of the Ferromagnetic Materials

The third one is to work out a constitutive relation of the ferromagnetic materials taking into account the hysteresis and anomalous eddy currents between the magnetic domain walls. In order to evaluate the magnetic fields exactly, it is essentially required to take into account the characteristics of ferromagnetic materials. We proposed a Chua type magnetization model which was capable of representing the Rayleigh's relationship, after-effect and iron loss. Also, it has been clarified that a parameter concerning with hysteretic properties is closely related to a number of domain walls and is an important factor related to iron loss of soft magnetic materials [5]. Thus, the finite element solutions of electromagneto-dynamic field problems can be obtained taking into account the hysteresis and anomalous eddy currents between the magnetic domain walls.

II. REVIEW OF PROGRESS TO DATE

1. Dual Energy Finite Elements

The finite element method is one of the widely used numerical schemes for evaluating the various electromagnetic fields. To implement the finite element approach in an efficient manner, dual energy finite element method based on a complementary variational formulation was proposed [6]. This traditional dual energy finite element method requires to use the two distinct potentials, viz., vector and scalar, so that the method provides the improved functionals but however, it does not provide the improved local solutions. To overcome this deficiency, we have proposed a locally orthogonal discretization method. This method is based on a geometrical duality between the Voronoi polygons and Delaunay triangles. Thereby, by means of this locally orthogonal discretization method, only one type of potential is required to implement the dual energy approach. Even if a single type of potential is employed to implement the dual energy approach, our locally orthogonal discretization method is compelled to solve the two-systems, viz., primal and complementary systems. Afterward, we have exploited the Voronoi-Delaunay transformation method that the solution of Delaunay/primal system can be obtained by transforming the solution of Voronoi/complementary system. Thus, we have succeeded to evaluate the electromagnetodynamic fields in an ultimate efficient manner.

2. Finite Element Solution of the Open Boundary Problems

Because of its essential feature, it is difficult to obtain the finite element solution of the electromagnetodynamic field problems having open boundary. To remove this difficulty, various means have been proposed, so far such as the infinite element, ballooning and infinitesimal scaling methods. These existing methods are accompanied by some difficulties, e.g., parameter determination problem, king size matrix operation and nonlinear system equation. In order to obtain the open boundary solution in the extremely simple and exact procedures, we have proposed the strategic dual image method. By means of these strategic dual images, an open boundary field problem can be reduced into the zero and symmetrical boundary field problems. This leads to the extremely simple and exact finite element solution of the open boundary electromagnetodynamic field problems. Our strategic dual image method is based on the essential nature of vector fields, i.e., any vector fields are composed of the rotational and divergence field components. These rotational and divergence components are respectively obtained by imposing the images of rotational and divergence field source images. Furthermore, depending on the potential to be employed in the formulations, the evaluations or rotational and divergence field components are reduced to solve the zero or symmetrical boundary value problem. Thus, it is possible to obtain the finite element solution of the open boundary electromagnetodynamic field problems.

3. Constitutive Equation of the Ferromagnetic Materials

The models representing the magnetization characteristics may be classified into two types. One is a Preisach type model, which assumes that each of domains has a rectangular hysteresis loop, and interaction between domains can be introduced by examining local field acting on domains [7]. Even though the Preisach type model is based on such simple assumptions, it gives valuable results that are agreement with experimental results. There is an unstable problem for which the Preisach's function takes a different value depending on the previous path in the magnetization processes. The other is a Chua type model, which has been derived on the purely phenomenological behavior of ferromagnetic materials. The key concept of Chua type model is that a trajectory of flux linkage vs. current is uniquely determined by the last point at which the time derivative of flux linkage changes sign [8]. The Chua type model exhibits many important hysterectic properties, e.g. the presence of minor loops and an increase in area of the loop with frequency. Intensive investigations were carried out about the Chua type model. At first, it has been clarified that the Chua type model is closely related with the Preisach type model. Secondly, a modified Chua type model has been derived taking into account the reversible magnetization processes. Thereby, it has been shown that this modified Chua type model is capable of representing the Rayleigh's relationship in the weekly magnetized region. Thirdly, it has been revealed that one of the most important parameters of Chua type model is corresponding to a number of domain walls in the ferromagnetic materials. Finally, the experimental verifications of Chua type model have been carried out.

III. EMERGING FUTURE DIRECTIONS

1. Dual Energy Finite Elements

The Voronoi-Delaunay transformation method has been successfully applied to the two-dimensional electromagnetodynamic field problems. However, we have not attacked to work out the Voronoi-Delaunay transformation in three dimensions. When the three dimensional Voronoi-Delaunay transformation technique is available for the electromagnetodynamic fields, then most of the problems compelled to use the king size or super computers will be solved by the small computers.

2. Finite Element Solution of the Open Boundary Problems

Currently, our strategic dual image method requires to use the specific shapes of hypothetical boundary, such as the circle for two-dimension, sphere for three dimension and ellipsoid for axisymmetrical three dimension. This means that the current strategic dual image method is somewhat inefficient procedure to obtain the open boundary solution because it accompanies the extra nodal variables. Our strategic dual image method will be generalized to use an arbitrary shape of hypothetical boundary. Furthermore, combination of this improved strategic dual image and Voronoi-Delaunay transformation methods will become a powerful tool to obtain the open boundary electromagnetodynamic field solutions.

3. Constitutive Equation of the Ferromagnetic Materials

Our Chua type magnetization model is capable of representing the after-effect, minor loop, Rayleigh's relationship and anomalous eddy current so that most of the typical magnetization processes can be reproduced with the exception of anisotropic property. Also, the parameters of Chua type model are closely related with the physical conditions of magnetic domain walls. In other words, the Chua type model is a versatile model and is based on a firm physical background. This Chua type model will be introduced into the Maxwell's equations to derive a governing equation fully taking into account the magnetization characteristics of magnetic materials. Thus, further practical finite element solution of the magnetodynamic field problems will be obtained by means of our Chua type model.

4. Final Target

Final target of our works is to exploit the nondestructive testing devices for the medical and metal searching. These nondestructive testing devices essentially necessitate the solutions of inverse problem so that intensive research is now carried out to work out an inverse problem solver based on the sampled pattern matching and AI techniques. Currently, we have succeeded to find a position of magnetic field source caused by the human eye movements.

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