Importance and relevance of the scientific content

1. Introduction

One of the most utilized effects of the electromagnetic field is the mechanical one, with a great number of applications within techniques: electrons beams, magnetic and electric separation, electromechanical converters, and electromagnetic levitation (M. Younes, A. Tilmatine, K. Medles, M. Rahli, and L. Dascalescu, *Numerical Modeling of Conductive Particle Trajectories in Roll-Type Corona-Electrostatic Separators*, IEEE Trans. Industry Applications, 43, pp. 1130-1136 (2007); Z. Petres, P. Baranyi, P. Korondi, and H. Hashimoto, *Trajectory Tracking by TP Model Transformation: Case Study of a Benchmark Problem*,IEEE Trans Industrial Eleconics, 54, pp. 1654-1663 (2007); S. Park, R. Horowitz, S. K. Hong, and Y.Nam, *Trajectory-Switching Algorithm for a MEMS Gyroscope*, IEEE Trans. Instrumentation Measurements, 56, pp. 2561-2570 (2007)). Establishing the electromagnetic forces implies, firstly, to solve the problem of electromagnetic field. If the time evolution of positions and velocities of the bodies is known, then the electromagnetic field and forces can be determined. When the displacements of the bodies are not known, the electromagnetic filed problem is not completely formulated and the computation of forces, necessary to the trajectories determination, can not be done. New procedures dedicated to determination of electromagnetic field, forces and trajectories are necessary.

2. The state of the art

The electromagnetic field depends on the constitutive relations of the materials, on field sources and bodies positions, if the state is stationary, or on the positions and velocity if the state is quasi-stationary (the eddy currents appear). In the presence of ferromagnetic bodies and permanent magnets, the constitutive ***B-H*** relations can be non-linear.

For immobile media, the specialized literature offers a great number of important results regarding the determination of the electromagnetic field in stationary or quasi-stationary state, for linear or non-linear media. For moving media the results are more insignificant and their majority refers to the case when the velocity is known. The eddy currents and non-linear media can be considered. The most complicated problem appears when the electromagnetic problem is coupled with the motion one. The electromagnetic forces influence the displacements and the velocities of the bodies that influence as well the electromagnetic field, thus the values of the forces. The results found in the specialist literature are, in this case, poor and insignificant. Many times, even if the body is in motion, the forces can be calculated in the hypothesis of a stationary state (when eddy currents do not appear). This is the case of the electrons beams or insulating bodies. The problem becomes even more complicated if the positions of the moving bodies influence the field of eddy currents or the medium is non-linear. In Table 1 different computation methods for electromagnetic field and forces are appreciated, using marks from 1 to 10. This is done with respect to the possibilities of method application (PA) and the degree of development of the method (DZ). We take into consideration:

- Linear media (*L*), non-linear media (*N*);
- Immobile parts ($v = 0$), moving parts ($v \neq 0$, known trajectory) or moving parts with velocity v (trajectory) unknown;
- Problems without (F) or with eddy currents (C).

The Finite Elements Method (FEM), for example, is applied with difficulty for coupled problems (mark 4), having three great disadvantages: reconstruction of the mesh at the same time with bodies displacement along the trajectories (unknown), with the consequence of some errors appearance when calculating the forces; the mesh and the artificial boundaries introduce parasite forces; the stability of the trajectory can not be analyzed using FEM. Biot-Savard-Laplace (B-S-L) formulae can be applied only for the particular case of homogenous infinite media (mark 6) and it is very well developed (mark 10). For inhomogeneous linear media FEM method is more efficient then B-S-L, where the non-homogenous media are approached iteratively, like the non-linear ones. But for non-linear media the possibilities of application for B-S-L (within the integral equation with volume elements) are huge (I.Ciric, F.Hantila, M.Maricaru, and St.Marinescu, "Behavior of Syncronous Generators with Rotor Excentricity Evaluated by the Polarization Fixed Point Method", *ICEM2006*, September 2-5, 2006, Chania, Crete Island, Greece, p51). In the case of integral procedures, the problems without eddy currents are completely different treated in comparison with those with eddy currents: in the first case B-S-L formulae are applied, in the second one the integral equation for the current density is added (R.Albanese, F.Hantila, G.Preda, G.Rubinacci, " A Nonlinear Eddy-Current Integral Formulation for Moving Bodies", *IEEE Transaction on Magnetics* , sept., 1998, no.5, vol.34, p.2529-2534).

Table 1

		F E M		B E M		FEM + BEM		Integral procedures (volume elements)	
Velocity	Media	F PA/DZ	C PA/DZ	F PA/DZ	C PA/DZ	F PA/DZ	C PA/DZ	F (B-S-L)	C (eddy crt)
$v = 0$	L	9/10	9/10	9/9	8/6	10/9	10/9	6/10	9/7
	N	9/10	9/7	4/2	3/2	10/9	**9/5**	**9/5**	**9/4**
$v \neq 0$, given	L	8/9	8/8	**8/5**	**8/2**	**10/6**	**10/5**	7/9	**9/2**
	N	8/7	8/6	2/1	2/1	**10/5**	**10/3**	**9/5**	**9/1**
v not given	L	4/1	4/1	**7/1**	6/1	**9/1**	**9/1**	7/6	**10/1**
	N	4/1	4/1	2/1	2/1	**9/1**	**9/1**	**9/1**	**9/1**

Remarks:

a) In the Table 1, the cells associated to methods that should be developed are marked.

b) It is recommended that the research effort to be oriented towards the integral methods or the hybrid FEM-BEM methods.

c) In the case of the problems with moving bodies there are no important results. When B-S-L formulae can be used, mutual inductances can be calculated and the forces can be determined very fast. There are papers that report results in this field (H. Ohsaki, H. Deguchi, E. Masada - "*Dynamical Behaviour Analysis of the Superconducting Magnets for an EDS-LSM Maglev*", International Journal of Applied Electromagnetics in Materials, 2, 1991, p. 265-273.) In 1993, the paper M. Koizumi, T. Takahashi - "*An Integral Equation Method for Analysis of Three-Dimensional Magneto-Dynamics with Moving Objects*", (IEEE Transaction on Magnetics, vol. 2a, no. 2, March 1993, p. 1516-1519) is one of the first papers that treats the coupled problem for linear media. The integral equation for current density is used and the eddy-current produced by bodies' displacement are neglected. The equations of electromagnetic field are discretized in time and space and the matrix that determines the forces with respect to bodies' positions and velocities is calculated. Then the equation of dynamic equilibrium is solved. The computational effort is huge. We can remark the paper N. Esposito, A. Musolino, M. Rangi - "*Modelling of Three-Dimensional Nonlinear Eddy Currents Problems with Conductors in Motion by an Integral Formulation*", (COMPUMAG'95, Berlin, p. 122-123) where the integral equation of $\boldsymbol{J}$ for mobile non-linear media, with known velocity, is solved. The huge non-linear system is solved using Newton-Raphson procedure.

d) At COMPUMAG'95 conference opening session, the great specialist Prof. C.W. Trowbridge presents the papers of the conference and suggests the future research directions (C.W. Trowbridge - "*Computing Electromagnetic Field for Research and Industry: major achievements and future friends*:, COMPUMAG'95, Berlin, p. 50-51). The first asked direction is **the computation of the electromagnetic field within domains with rigid moving parts**. He appreciates that integral methods will be wanted (and parallel processing).