Shape Optimization of Multistage Depressed Collectors by Parallel Evolutionary Algorithm

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Abstract: In this paper is presented a novel parallel meta-heuristic algorithm called MeTEO, which can be used to optimize the performance of multistage collectors. The collectors and electron guns are simulated by means of a FEM based simulator (COLLGUN), whereas the optimization is performed by a hybrid algorithm (MeTEO) composed by three different heuristics based on artificial life: FSO (Flock of Starlings Optimization), PSO (Particle Swarm Optimization), and BCA (Bacterial Chemotaxis Algorithm). MeTEO allows a parallel implementation.

I. INTRODUCTION

Specialized 3-D simulators are required by TWT multistage depressed collector (MDC) designers to help them to analyze and test new and arbitrarily shaped geometries for high efficiency TWTs. To perform such a task a Finite Element (FE) approach can be pursued, since it allows a very flexible meshing and gives the possibility of using irregular meshes to fit properly the MDC's geometry; in such a way complex geometries can be accurately simulated [1]. Unfortunately, the use of optimization techniques in the design process of these devices is rarely used [2][3][4], because of the high computational cost of efficiency evaluation (the fitness function), which requires the simulation of the device and of the high number of parameters from which it depends. In fact the performance of this kind of device is mainly related to the geometry of the electrodes, to their voltages and to applied focusing magnetic field. While voltages and applied fields can be modified also after the realization of the device during the calibration phase, the choice of a functional geometry is a much more complicated task. In this paper the authors present the application of a meta-heuristics technique developed at Roma Tre University, called MeTEO (**Me**tric- **T**opological-**E**volutionary-**O**ptimization), to optimize the geometrical parameters of multistage collectors, simulated by means of Finite element collector and electron gun simulator COLLGUN [5], a package which includes a parametric geometric descriptor, an unstructured mesh generator and a 3-D FE-based Vlasov solver, developed at University of Catania. MeTEO is a hybrid algorithm composed by three different heuristics: FSO (Flock of Starlings Optimization), PSO (Particle Swarm Optimization), and BCA (Bacterial Chemotaxis Algorithm). It performs optimization by using both topological (FSO) as metric (PSO) rules used for simulating the collective behavior present in such heuristics based on Swarm Intelligence. In fact, the mentioned heuristics shown a different performance when they are working alone. In particular, FSO presents a high degree of exploration, and a good capability to escape from local_minima, whereas PSO, and BCA show high capability to perform convergence. As it will be shown, MeTEO is intrinsically an algorithm devoted to parallelization.

II. TWT MDC SHAPE OPTIMIZATION ALGORITHM

The shape optimization algorithms requires the combination and the interaction between several modules: the preprocessor for the geometry description and the mesh generation the FE coupled problem solver, the postprocessor for the collector efficiency evaluation (the fitness function), and clearly the optimization MeTEO code. Some details about the functionality of these modules is presented in the following.

A. Geometry description and mesh generation

In order to ensure the proper functioning of the process of identifying optimal innovative, but also functional and feasible, geometries, we must be considered on one hand the geometric constraints and on the other the procedures of geometry description which reduces the dimensionality of the problem, theoretically infinite. To overcome this problem we make use of simple geometric primitives for the description of each stage, which constitutes the entire device. In doing so, the geometry is obtained by composing simple primitives, such as cylinder, cone, truncated cone, etc., as shown in fig. 1, and the optimization parameters are directly individuated by the primitives' parameters which constitute each stage.

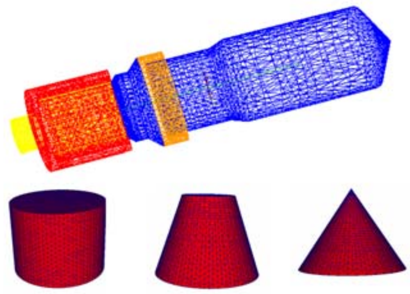

Fig. 1. Some primitives used for geometrical description and an example of two stage collector obtained by combining these primitives

B. FE coupled problem steady state solver

The coupled electromagnetic-motional problem inside collector region is governed by the so called Vlasov equation, coupled with Maxwell equations. Since the charge and current distribution are not known a priori, the numerical solution of the above complete set of equations can be conveniently performed by following an iterative scheme, based on the three steps shown in fig. 2, which are repeated until convergence is reached, i.e. when the "distance" between two consecutive solutions is less than a user-specified end-iteration tolerance.

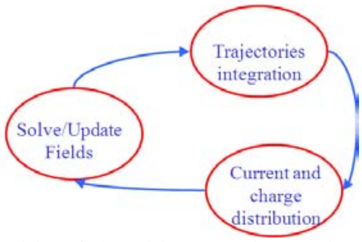

Fig. 2. Phases of the solution of the FE steady-state electro-dynamical coupled problem.

C. Optimization by MeTEO

The proposed algorithm has been called MeTEO for point out its Metric-Topological and Evolutionary inspiration. In fact, it is based on a hybridization of two heuristics coming from swarm intelligence: FSO (topological swarm) and the standard Particle Swarm Optimization (metric swarm) and a third evolutionary heuristic, the (BCA) that has no collective behavior. In particular, FSO has been firstly described as a modification of the well known PSO by adding topological rules to the metric rules that are typical of the PSO. The FSO is inspired to recent naturalistic observation about the real starling flight. FSO is particularly suitable for exploration and multimodal analysis [6],[7]. The BCA is based on the emulation of the motion of a real bacterium looking for food (i.e. fitness function). It is a heuristic that shows its better performances in local search. The present approach uses the FSO to explore the solution space, the PSO to investigate subspaces in which the global optimum could be present and finally, the BCA is used for refining solutions. Moreover, a parallel strategy is implemented in which the FSO is permanently running, and any time it found a possible solution, the PSO is lunched. Successively, it is transformed in BCA, and so on. In addition, in order to improve this parallel search a sort of penalty (or barrier) method has been introduced. It consists of changing the fitness function (fitness modification - FM) any time the FSO decides to lunch PSO-BCA on a subspace. To implement this framework a cluster of 20 CPU has been used.

III. VALIDATION

In order to validate this framework some tests have been done. In particular hereafter a preliminary result is presented, regarding the optimal design of the electrodes' geometry of a typical two stage TWT MDC, obtained by using a limited set of parameter: the length, the inner and the outer diameters of the first stage. The beam entering in the collector has reference energy of 4.8 kV a current of 53.2 mA, and a radius of 0.63 mm [5]. The cross section of electron beam was modeled assuming that the current is radially distributed in 25 rings, each of them divided in 10 macro-electrons. The voltages of the two electrodes were assigned to ½ and ¾ of the reference energy of the beam, i.e. 2.4kV and 3.6kV respectively. For each fitness function evaluation (collector efficiency) an irregular mesh of first order tetrahedra was generated, using a more refined mesh in the inter-electrode regions, where a more intense non-uniform electric field is expected. The typical FE simulation data for the steady-state coupled problem solved by COLLGUN are summarized in table I. Starting from an initial geometry with an efficiency value equal to 72%, with 300 MeTEO iterations (100 FSO, 100 PSO, 100 BCA) we obtain a geometry, shown in fig. 3 together with trajectories, with an efficiency equal to 83.6%. The computational time employed to perform this task is about 24 hours. Furthermore it is worth noticing that by optimizing the electrodes' voltages this geometry can do efficiency value until to 88%.

TABLE I
FINITE ELEMENT SIMULATION DATA

Number of meshes' tetrahedra	20000 ÷ 100000
Number of meshes' points	6000 ÷ 35000
Number of trajectories used	250
End-iteration tolerance	0.1%
Number of iteration carried out	4 ÷ 6
Time elapsed for each fitness function evaluation (mesh generation and FE problem solution)	2'00" ÷ 5'00"

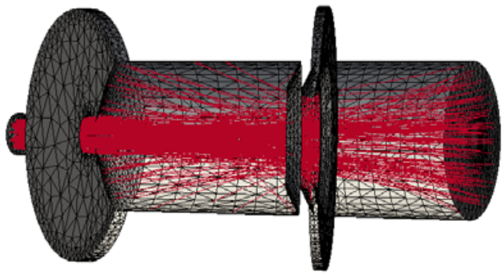
Fig. 3. Plot of trajectories in optimized MDC geometry

IV. REFERENCES

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