Acceleration of evolution-based algorithms by relation preconditioning of optimization parameters

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A modified genetic algorithm is proposed for optimization of low-dimensional systems of mathematical models described by partial differential equations. The paper explains its principle, benefits and illustrates its utilization for the simple size optimization of the plunger of a bearingless electromagnetic actuator, whose goal is to maximize the force acting on the plunger during its operation. The algorithm is implemented in the framework OptiLab that represents a part of application Agros2D developed by the authors.

***Index Terms*—genetic algorithms, design optimization, finite element analysis, electromagnetic fields, electromagnetic forces, machine components, valve**

I. Introduction

GENETIC ALGORITHMS (GAs) represent efficient tools for finding optimal solution from a large amount of possible solutions [1]. For this reason, they are also frequently used for the optimization of various electrical devices, such as electric machines or actuators [2], [3]. Full utilization of GAs for optimization of real devices is conditioned by a correct and accurate formulation of the task. This holds even for the shape optimization that is often uneasy to define (complicated geometrical shapes, possibility of manufacturing, technological restrictions, solvability of the task, mutual relations among particular optimized parameters and so forth).

The paper presents a modified, efficient GA whose power was tested on several strongly nonlinear tasks. The principal aim of the paper is to show the application of the technology of preconditioning the parameters based on their mutual relations, which leads to a simplified formulation of the constrained optimization problem and considerably accelerates the process of finding the optimum solution.

II. Proposed Genetic Algorithm

The described implementation of GA for single and multi-criteria optimization starts from the classic concept of GA, but it contains a number of techniques that are very practical for the optimization, where computation of every individual is performed by the finite element method, which is time demanding. These techniques include for example application of discrete and continuous optimized parameters, implementation of sensitivity analysis in optimization cycles or defining mutual relations among the parameters. And just the last item makes the formulation of the task much easier (because it is not necessary to define limits of particular parameters) and leads to a considerable reduction of the time of computation.

With respect to the fact that finding the parameters during optimization represents a random process, a great attention has to be paid to the selection of their limits and constraints to avoid their unacceptable combinations and satisfy the conditions of fabricability. This is reached by applying the relations among particular parameters (the difference between the constraints and relations consisting mainly in their algorithmic representation). Figure 1 shows the simplified process of optimization based on the implemented algorithm.

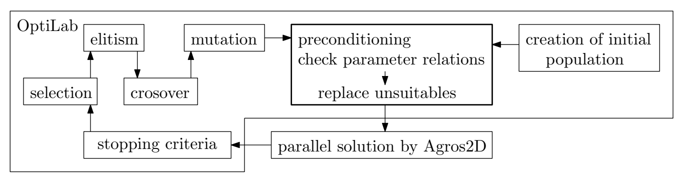

Fig. 1. Block diagram of optimization process by genetic algorithms

All individuals in population are checked and inadequate individuals are excluded and replaced by new ones. With respect to the nature of the problem, a model with unsuitable parameters is excluded already before its solution. This results in an improvement of the initial population and substantial acceleration of the process.

III. Illustrative Example

Using of the proposed GA is illustrated with a simple size optimization of the plunger shape of a bearingless linear electromagnetic actuator. A novel type of this device was designed in [4]. The actuator is supposed to work as a valve for electrically non-conductive liquids and its principal advantages are a very small number of mechanical parts, high operation reliability and low operation time.

The actuator consists of the nonlinear magnetic core, hollow movable plunger, permanent magnet (PM) and field coil. The NdFeB permanent magnet and field coil represent the sources of magnetic force acting on the plunger. When the field coil is switched off, the PM closes the valve. The principal arrangement of the device is shown in Fig. 2.

The static characteristic (dependence of the axial force acting on the plunger on its position) is given by one equation describing the distribution of magnetic field (in terms of magnetic vector potential $\boldsymbol{A}$) in the system and one integral expression.

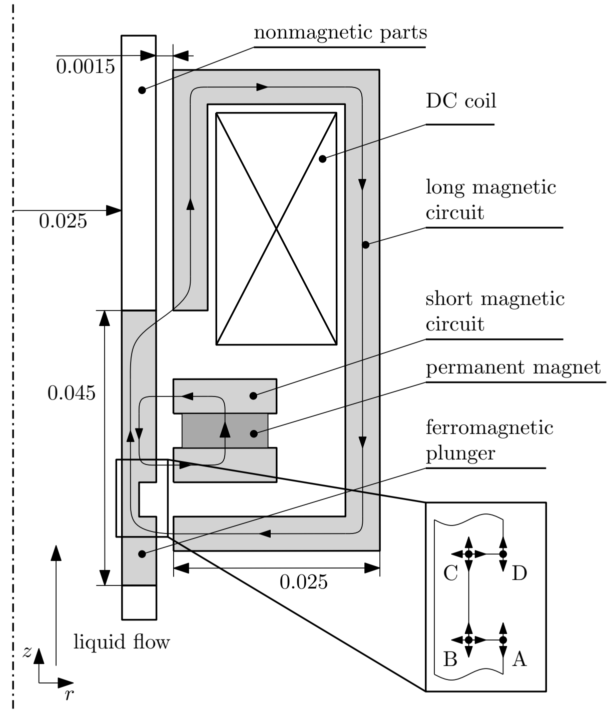

Fig. 2. Arrangement of bearingless electromagnetic actuator

This continuous model reads

$$\mathrm{curl}\ \left(\mu(\boldsymbol{B})^{-1}\mathrm{curl}\ \boldsymbol{A} - \boldsymbol{H}_{\mathrm{c}}\right) = \boldsymbol{J}_{\mathrm{ext}}\,, \tag{1}$$

and

$$\boldsymbol{F}_{\mathrm{m}} = \oint_S \boldsymbol{T}_{\mathrm{m}}\,\mathrm{d}\boldsymbol{S}\,;\quad \boldsymbol{T}_{\mathrm{m}} = \boldsymbol{H}\otimes\boldsymbol{B} - \frac{1}{2}(\boldsymbol{H}\cdot\boldsymbol{B})\,\boldsymbol{I}\,. \tag{2}$$

Here, μ is the magnetic permeability, $\boldsymbol{B}$ denotes the magnetic flux density, $\boldsymbol{H}_{\mathrm{c}}$ stands for the coercive force, $\boldsymbol{J}_{\mathrm{ext}}$ is the external current density in the field coil, $\boldsymbol{F}_{\mathrm{m}}$ is the vector of the magnetic force, $\boldsymbol{T}_{\mathrm{m}}$ denotes the magnetic stress tensor, $\boldsymbol{H}$ is the magnetic field strength, S represents the surface of the plunger, $\boldsymbol{I}$ is the unit matrix and symbol $\otimes$ denotes the dyadic product.

During its operation, the plunger moves in the direction of $\pm z$ axis. The closing static characteristic $F(\delta)$ (δ describes plunger position) of the actuator is the subject of the optimization. It was found that it strongly depends on the shape of the gap in the plunger that is characterized by four points (Fig.2).

The position of points A, B, C, D may change. Points A and D can move only in the direction z. Points B and C can move in both directions. This means altogether 6 parameters. For these parameters, just rough limits are determined together with their mutual relations

$$B_z < C_z\,;\ A_z \leq B_z\,;\ D_z \geq C_z\,,$$

that are checked and must be satisfied for every individual during the optimization. The objective function is defined as the average value F_{avg} of the closing static characteristic. The optimization problem is defined as

$$\text{maximize } F_{\mathrm{avg}}(P)\,,\quad P = (A_z, B_r, B_z, C_r, C_z, D_z)\,. \tag{3}$$

IV. Results

The evolution of the objective function can be seen in Fig. 3 (left part). The process gradually increased the average value of the force F_{avg} to 55 N. Figure 3 (right part) depicts the evolution of optimization of the device. Visible is the total number of individuals, number of individuals that did not satisfy the criteria and time of computation of every population.

With respect to the fact that computation of every individual represents several solutions of strongly nonlinear PDE (1) (computation of the static characteristic is carried out sequentially), the numerical experiments shows that the precondition leads to huge savings in the time of computation (while the solution time of every individual is about 30 s, computational time with the preconditioned parameters is six times lower).

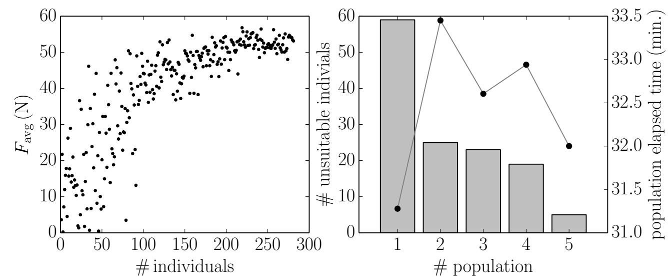

Fig. 3. Evolution of the objective function and number of unsuitable individuals (bar chart) together with population elapsed time (line chart)

V. Conclusion

The goal of the work was to improve the existing implementation of GAs and include there a possibility of defining mutual relations among particular optimized parameters. Based on a lot of tests with standard testing functions and results of the illustrative example it is obvious that a relatively simple modification of the classic algorithm makes the formulation of the problem easier and leads to a considerable acceleration of computations. The full paper will contain a discussion of the fabricability conditions based on preconditioning.

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