OPTIMIZATION OF AN ELECTRIC APPARATUS USING GENETIC ALGORITHMS

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ABSTRACT

This article deals with the magnetic field optimization of an electric apparatus using genetic algorithms along with numerical modelling of electrodynamic forces, which is necessary for the objective function evaluation. Two little bit different genetic algorithms are programmed in computer program MATLAB. The program ANSYS in batch mode is used for the objective function evaluation using the finite element method. The purpose of the optimization process is to find the most convenient geometry configuration of the current-carrying conductor that satisfies prescribed criteria.

1 INTRODUCTION

The design of electric apparatus geometry often requires finding the solution that is the most convenient in terms of satisfying the prescribed criteria with respect to some other requirements and constraints. For this purpose many optimization methods have been developed. Each method has its advantages and disadvantages in terms of convergence rate, whether the method is appropriate for global or local problems, the different requirements on the objective function and so forth.

One of the recent optimization method that has been developed in conjunction with research of optimization processes in the nature is known as genetic algorithm. They have been used in many technical sciences including electromagnetism during last ten years. As it shows, they have many attributes that are appropriate for using in electric apparatus optimization:

- They are naturally stochastic, which means they belong to global optimization methods. This is convenient for solving unknown magnetic field distribution.
- The objective function does not have to be known as an analytic expression. It only has to be evaluateable. This is important feature for using this method along with numerical evaluation of the objective function based on the finite element method.

Unlike “traditional” optimization methods it has another feature. It does not use the only one solution but uses the whole group of possible solution (known as **population** in genetic algorithms speech). This is especially convenient in the electric apparatus design because you can subsequently choose the solution that is appropriate for other reasons and there is also a little uncertainty of magnetic field distribution due to unpredictable electric arc behaviour.

2 GENETIC ALGORITHMS FUNDAMENTALS

Genetic algorithms do not use explicitly expressed optimized parameters but the parameters are binary coded. Each of the parameter forms sequence of zeros and ones known as a gene. The row of genes forms a chromosome. Each parameter can be expressed in different bit depth. As stated above, the genetic algorithms use many individuals (each consists of one chromosome) and these form one population.

The optimization process proceeds the following steps:

1. The generation of the first population as random sequence of zeros and ones.
2. The evaluation of the objective function for each individual.
3. Selection – the purpose is to find better individuals.
4. Pairing – it means to pair the rest of the population to create the next generation.
5. Crossover – each pair generates two new individuals.
6. Mutation – random position in chromosome is inverted (important for good convergence).
7. Continue at step 2 as a new generation.

Two different ways of selection were used in the following example. Firstly, the decimation selection strategy was used. It is simply based on the better half of population selection. The second way is often used and is known as a tournament selection. The random subgroup of individuals is chosen and the individual with the best objective goes on to the next generation. This procedure is repeated until the number of individuals for next generation is achieved. The program enables to choose the number of individuals for tournament.

3 PROBLEM DESCRIPTION

The aim of the optimization process is to find the best configuration of the current-carrying conductor of the low voltage circuit-breaker. The best configuration is determined by the highest electrodynamic force in x direction acting on the electric arc between moving and fixed contact. This is important for the good extinguishing capability of the quenching chamber. Since the extinguishing process is also influenced by the moving contact movement due to electrodynamic forces [2], the objective function also takes this problem into account. The three objective functions were studied. First, only the force acting on the lowest third of the electric arc was taken into account. Secondly, the whole volume of the arc was studied. And lastly, the influence of the moving contact to the objective function was added.

The unchangeable part of the geometry is shown in Fig. 1. This part was prepared in AutoCAD as a 3D volume model. It consists of the fixed current-carrying conductor as well as iron (nonlinear permeable) plates of quenching chamber. It is automatically loaded to the

ANSYS program during optimization process using the *.sat file interface. Next the changeable part of the geometry is added in accordance with the current values of the optimized parameters. The changeable part and optimized parameters can be seen from Fig. 2.

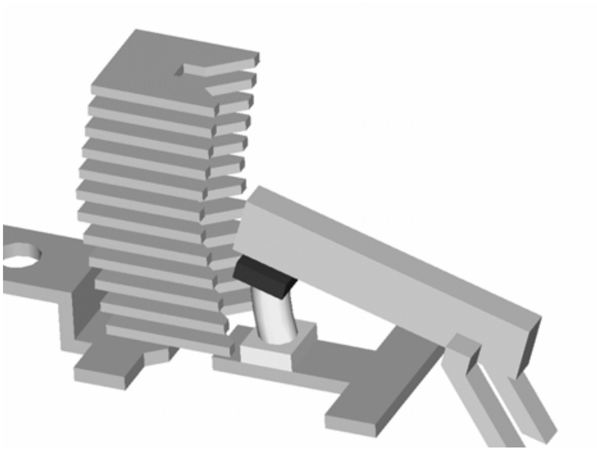

Fig. 1: *Fixed geometry*

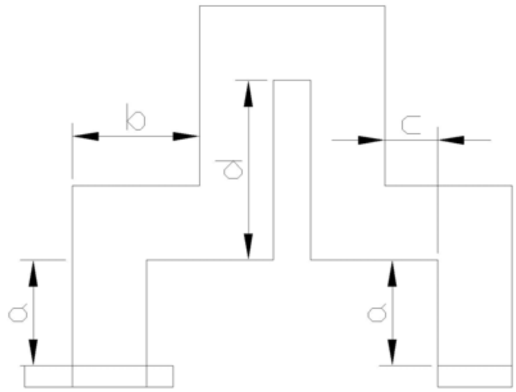

Fig. 2: *Changeable geometry*

The allowed range of parameters including bit depth is described in Tab. 1

Parameter	min. value	max. value	constraint	bit depth
a	1	36	no	3
b	-17	18	no	3
c	1	19	for b<=0	3
c	1	20-b	for b>0	3
d	0	24	no	2

Tab. 1: *Range of parameters*

3.1 OPTIMIZATION PROCESS

The whole optimization process is controlled by the program written in MATLAB. It is possible to control the number of generation, the number of individuals in population, the probability of crossover, the final probability of mutation and also the gradient of increase in the probability of the final mutation (the number of cycles before the final probability is reached).

The optimization process begins with generation of the first population. Then the program calls the ANSYS program to obtain the value of the objective function. The batch mode of ANSYS is used for evaluation in order to be automatic looping possible. All instructions for ANSYS are saved in *.dat file. The interface (necessary for parameters and values needed for objective function evaluation) between MATLAB and ANSYS is made as two ASCII text files. The fist file is generated by MATLAB and is used as an input to ANSYS and the second one creates ANSYS – the values needed for objective function evaluation are saved here. Since the computation in ANSYS is quite time-consuming and the calculations for the same parameter values are often repeated, there is a condition before calling ANSYS testing whether the objective function for the desired parameters has been calculated before. If so, then the objective function is taken from the previously saved auxiliary matrix. If not, then the ANSYS is called and the new objective function value is saved behind the last row of auxiliary matrix. As it showed, this saves a lot of time in optimization process.

When objective functions are evaluated for the whole population, the optimization process proceeds with selecting, pairing, crossovering and mutation. Then the whole optimization process continues from the step 2 until termination condition is met.

4 RESULTS

As it showed, the way of selection (decimation versus tournament) did not affect the final results and even did not affect the convergence rate for this example. The tournament way of selection was therefore used.

Five cases of the objective function were studied. The forces are divided by the volume of the relevant elements to be comparison of the influences of individual parts possible. The forms of the objective functions are shown in Tab. 2. Tab.3 shows the results obtained from the optimization process. The results are computed for current I = 10 000 A.

Case	Objective function
1	FX_DOL/VOLUDOL
2	FX_DOL/VOLU_DOL+0.8*FX_STR/VOLU_STR+0.6*FX_HOR/VOLU_DOL
3	1*FX_DOL/VOL_DOL+0.8*FX_STR/VOL_STR+0.6*FX_HOR/VOL_HOR-1.011*FY_KON/VOL_KON
4	1*FX_DOL/VOL_DOL+0.8*FX_STR/VOL_STR+0.6*FX_HOR/VOL_HOR-2*FY_KON/VOL_KON
5	1*FX_DOL/VOL_DOL+0.8*FX_STR/VOL_STR+0.6*FX_HOR/VOL_HOR-1.5*FY_KON/VOL_KON

Tab. 2: *Types of objective function*

Case	a	b	c	d	Value of objective function
1	11	-7	19	0	-9.6939E7
1	11	-7	19	8	-9.6939E7
1	11	-7	19	24	-9.6939E7
2	11	-7	19	0	4.2899E8
3	11	-7	19	0	-4.6275E8
4	16	-12	13.8571	0	-4.9762E8
5	11	-7	19	0	-4.7907E8

Tab. 3: *Optimized parameters*

It can be seen that for the first case there are three different possibilities of the geometry configuration for the same value of the objective function. But the other cases show that the most convenient geometry configuration is achieved when a = 11 mm and d = 0 mm.

Parameters b and c have no physical meaning when d = 0mm - see Fig. 2.

For the examples above, the 16 individuals in population and 30 generation were considered. It was determined that the number of generation should not decrease below 10 and number of individuals below 6. Calculated magnetic flux density in the electric arc and in moving contact is shown in Fig. 3. Fig. 4 shows vectors of forces acting on the lower part of the electric arc.

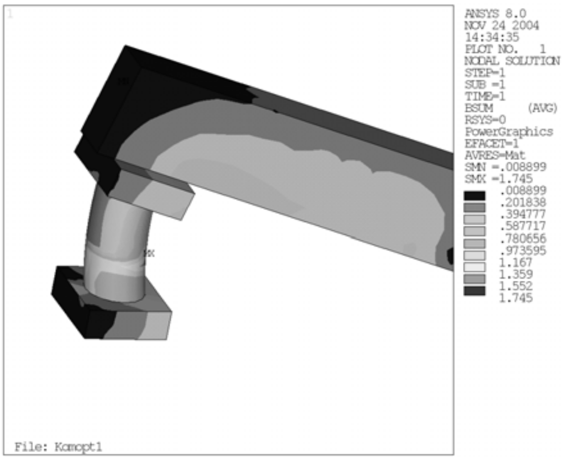

Fig. 3: *Magnetic flux density*

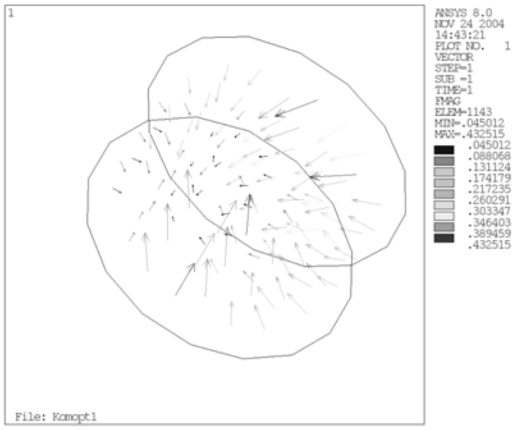

Fig. 4: *Vectors of forces*

5 CONCLUSION

This article describes the capability of the genetic algorithms used for the geometry optimization of low voltage circuit-breaker. It was shown that these algorithms are powerful and effective tools for solving similar problems. The aim of this work was to explore the possibilities of the genetic algorithms in the area of electric apparatus and to find out the requirements and settings for the next effective work. The obtained skills will be used for the following work that will focus on the magnetic field optimization of the geometry using the magnetohydrodynamic model of an electric arc in the quenching chamber.

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