Multiobjective Geometry Optimization of a SPMSM Using an Evolutionary Algorithm

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***Abstract*—This paper presents a methodology for the optimization of a Surface mounted Permanent Magnet Synchronous Motor (SPMSM) with 4 poles and 24 slots. In particular, it is focused on a multiobjective optimization using a genetic algorithm developed in Matlab with Optimization Toolbox that is coupled with Maxwell 14. The first one has been used for the optimization and the post-processing of the data, the second one for the Finite Element (FE) analysis and for the geometry creation. Aim of the optimization was to maximize the nominal torque and minimize the mass of a motor.**

***Keywords*—PMSM, optizmization, evolutionary algorithm, Pareto front**

INTRODUCTION

Nowadays it became clear that the shape design of electromagnetic devices has to fulfill multiple objectives concurrently. The objectives of the optimization are not always the same because they vary with the application in which the device is used. In a multi-criteria optimization (MCO) the general solution is represented by the Pareto front of non-dominated solutions. This represents the list of all the designs that allow to reach the objectives of the optimization. Only one of these solutions will be selected, thanks to the experience and the personal evaluations of the designer that may consider further mechanical and thermal constraints. In the last decade, in many fields of engineering, evolutionary algorithms have been developed in order to find properly the Pareto front [2].

Increasing capabilities of nowadays tools and packages connected with greater performance of computers allowed to successfully achieve good results in optimization of electrical machines with a computational cost compatible with the industrial processes.

DESIGN PROBLEM

A. SPMSM

The case of study is represented by a SPMSM, with a rated speed of 1500 rpm, rated power of 550 W and rated voltage of 230V. Design variables are presented in Table 1.

Design Variables	x_2 [mm] Rotor Outer Diameter	x_2 [mm] Rotor Inner Diameter	x_3 [mm] Stator Outer Diameter	x_4 [mm] Magnet Thickness
Prototype	74	26	120	3.5

B. Multiobjective optimization

The inverse problem consists of identifying the feasible geometries of the machine in order to maximize the torque and minimize the mass. This set of objectives is of a great interest in all the problems of optimization of modern motors applied in electrical vehicles, where maximum torque provides the maximum acceleration, while minimum weight is necessary in order to lighten cars and lower the price of a hybrid or electric vehicle. The following objective functions are defined:

$$f_1(x) = \int_\Omega \rho(x)^2 \, d\Omega \tag{1}$$

$$f_2(x) = T(x), \tag{2}$$

where ρ is the density of materials and T is the torque.

The first equation represents the mass of the motor that has to be minimized, while the second one represents the nominal torque that has to be maximized. With regard to the time consumption for the evaluation of the functions, the first one is a geometry dependent function and the cost for its calculation is almost inexpensive, while the torque is field-dependent and needs many runs of nonlinear FE analysis. As mentioned in the introduction, there may exist multiple solutions to this problem. After solving the MCO problem a set of optimal non-dominated solutions is generated and the Pareto Front is determined. With the information provided by the Pareto Front, the motor designer may select the proper geometry, according to his designing experience. The direct problem has been solved using a 2D FE model of the motor, calculating the torque with the virtual works principle. Even if the shape of the motor changes and the mesh changes for every model, the number of elements of the mesh it's almost the same in every model.

In the solver's options it's possible to customize the settings for the mesh, such as the maximum elements size or the maximum number of elements for each region of the motor. It is of great importance to select the proper settings in order to get a high resolution and a low computation time.

The mesh of all models generated during the genetic algorithm had approximately about 2000 elements, while the mesh used in the final comparison between the optimized motor and the prototype had 60000 elements.

This work was supported by the Ministry of Education and Science, Poland, under grant N N510 5080406

MATLAB AND MAXWELL

Linking Matlab with Maxwell is a good way to solve optimization problems regarding the electrical machines. In fact, Matlab is a powerful software for numerical analysis that allows, thanks to the ActiveX controls, to command other software and to exchange data with them. All of the calculations, optimization and post-processing are carried out by Matlab, while all the geometry variations, model meshing and FE calculations are carried out by Maxwell. Starting from one of the SPMSM sample models that are present in Maxwell, Matlab begins the optimization and changes all the design variables values following the Genetic Algorithm rules. When the algorithm reaches the stopping criteria (e.g. maximum generations number, maximum computation time, etc.) Matlab closes Maxwell and plots the Pareto front.

RESULTS AND CONCLUSIONS

A connection between Matlab and Maxwell 14 has been successfully implemented. Varying 4 simple design variables, it has been possible to improve the performances of a given motor. In particular it was possible to maximize the average torque value, while reducing the cogging torque, torque ripple and the weight of the motor. Figure 1 shows the Pareto front obtained during the optimization process.

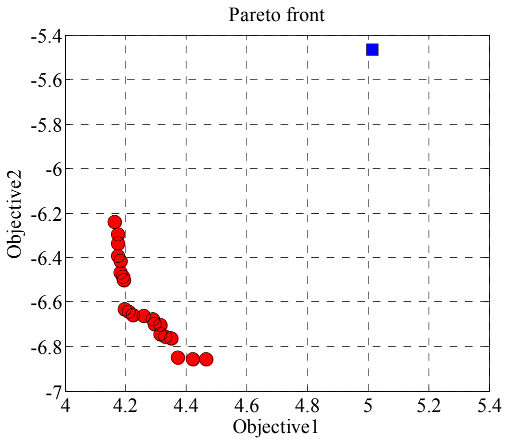

Fig. 1. Pareto Front: In blue, the prototype model, in red, the Pareto Front

Next figures show torque ripple (Fig. 2) for different geometries and cogging torque (Fig. 3) for different optimized geometries.

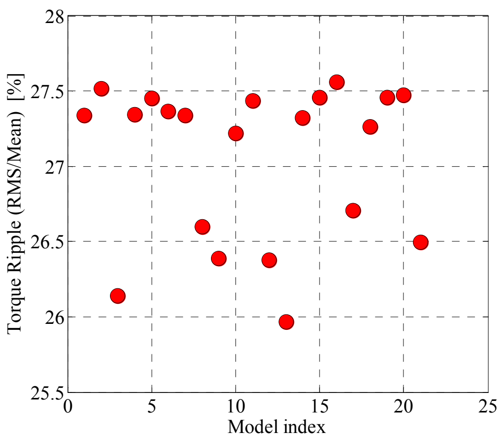

Fig. 2. Torque ripple for each model

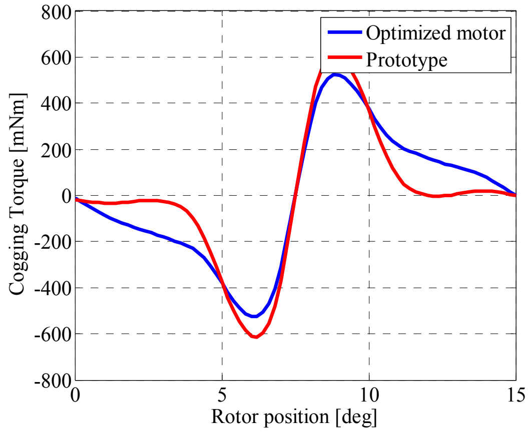

Fig. 3. Cogging torque

Figure 4 illustrates the cross section of pre- and post-optimized geometries.

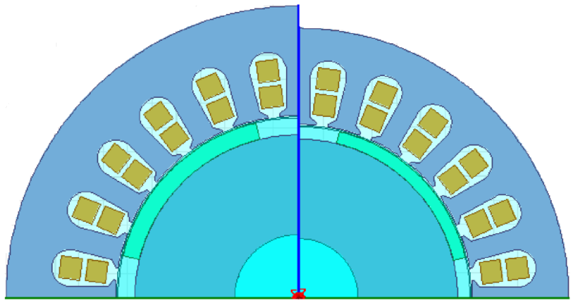

Fig. 4. Geometries comparison: Prototype motor (left), optimized motor (right).

The improvement of motor performance is significant. The simulation points out the benefits of the optimization using a genetic algorithm. In fact, if such improvement has been possible with just 4 design variables, certainly, even better performances improvement will be achieved using more design variables, selected properly according to the design needs (e.g. if cogging torque reduction is of interest, design variables could be the polar shoes shape, the skewing of the magnets, etc).

In particular, Matlab is very helpful for its capability in different kind of optimizations and in post processing the data; Maxwell, instead, is a well-known software for the design and the analysis of electrical machines via FEM. It is needless to say that Maxwell can be also connected with Simplorer, thus whole performance of a drive system may be evaluated. Increasing performance of new computers affect the design process of electrical machines. Integration between optimization tools such as Matlab and FEM packages is of great interest all over the world.

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