Mitigation of the Torque Ripple of a Switched Reluctance Motor Through a Multi-Objective Optimization

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***Abstract* – A Multi-Objective Optimization analysis was carried out in order to mitigate the torque ripple of a 4:2 Switched Reluctance Motor. To accomplish this task the Pareto Archived Evolution Strategy was implemented jointly with the Kriging Method which replaced the surrogate function. The technique was applied on the optimization of some rotor geometrical parameters with the aid of Finite Element simulations to evaluate the approximation points for the Kriging model. The numerical results were compared to those issued from a prototype testing.**

I. Introduction

Due to its intrinsic geometrical characteristics, Switched Reluctance Motors (SRM) produce greater torque ripple when compared to traditional rotating motors. Such torque ripple is very troublesome because it generates vibration and audible noise [1]. Unfortunately, in most cases, the mitigation of the torque ripple implies in the degradation of other important features, such as the starting and the average torques. To deal with this antagonism multi-objective optimization techniques seem to be the most suitable approach.

This paper proposes the combination of a multi-objective technique with the Finite Element Method (FEM) for the optimization of some geometrical rotor parameters of a 4:2 SRM. This optimization will consider the mitigation of the torque ripple as well as the minimal degradations in the starting and average torques.

The multi-objective optimization approach is based on the use of the Pareto Archived Evolution Strategy (PAES) jointly with the Kriging Method, which replaces the surrogate function as objective-function.

The Finite Element simulations provided the static torque values within a pole pitch as approximation points for the Kriging model.

The optimized rotor was prototyped and the whole SRM was submitted to tests in order to verify the proposed features.

II. Switched Reluctance Motor Characteristics

The SRM considered in this work presents some unusual geometrical characteristics such as asymmetrical poles and a non-constant air-gap. This new design was conceived in order to improve the starting unidirectional torque in any rotor position [2].

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Fig. 1 depicts the main geometrical characteristics of the SRM and the details of the rotor.

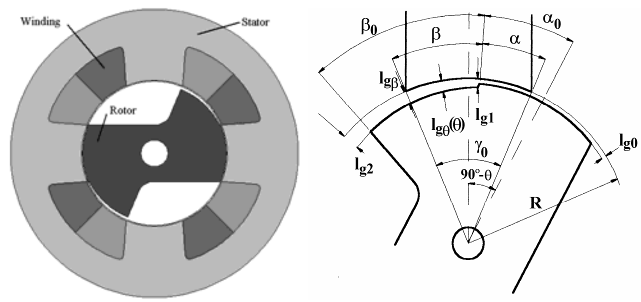

Fig. 1. SRM geometric characteristics and details of the rotor.

III. The multi-objective Optimization

As stated formerly, the main goal of the multi-objective optimization was to minimize the ripple torque taking into account a minimal degradation in the average and starting torques. Based on previous analytical evaluations of sensibility three rotor parameters were chosen, namely β_0, l_{g1} and l_{g2}, for the optimization procedure. Thus the task was to find the best combination of values for β_0, l_{g1} and l_{g2} to accomplish the task.

The mathematical expression used as objective-function is presented in (1), where $\overline{C}$ is the average torque, C(θ) the static torque at angular position θ, and $C(\theta_0)$ is the starting torque.

$$(P)\left\{\text{Min } f(\beta_0, l_{g1}, l_{g2}) = (\overline{C} - C(\theta_0)) + \sum_{i=1}^{n} \left|C(\theta_i) - \overline{C}\right| \right. \quad (1)$$

The variation domain for each parameter to be optimized is presented in Table I.

Table I. Parameters Variation Domain

Parameter	Reference Value	Minimum Value	Maximum Value
β_0	45°	30°	60°
l_{g1}	0.6 mm	0.4 mm	0.6 mm
l_{g2}	1.2 mm	0.6 mm	1.8 mm

A. Methodology

For every triple (β_0, l_{g1}, l_{g2}) and for θ ranging within one pole pitch, 2D nonlinear magnetostatic FEM simulations were carried out to obtain the torque values to be used in (1).

A multi-objective optimization was performed by using the PAES method on a kriging approach [4] of two surrogate functions : the first is defined by (1) and the average torque.

B. PAES - Pareto Archived Evolution Strategy

The algorithm proposed by Knowles and Corne [3] starts with the initialization of a single chromosome (the current solution), which is evaluated using the objective functions.

A mutation operator is applied to the current solution to obtain a copy. This new individual is evaluated and is called the new candidate solution.

Acceptance criterion is straightforward, when one solution dominates the other, but when there is no dominance between the solutions, the candidate is compared to a reference population, called the archive. On the acceptance criterion, the algorithm takes into account the location of the solution: there is a preference to solutions located in the least crowded regions. So the archive stores all the nondominated generated solutions and helps the accurate selection between the candidate and the current solution.

The result of this process is a front closer to the optimal solution and more diverse. This diversity is achieved thanks to a d-dimensional grid, where d is the number of objectives.

III. Tests

To validate the numerical results the torque ripple was obtained indirectly through the vibration-signal acquisition followed by a Fast Fourier Transform (FFT) analysis in the range of 400 Hz, which corresponds to the main component of the torque ripple.

IV Results

The multi-objective optimization provided the following values for the geometric parameters: $\beta_0 = 60°$, $l_{g1} = 0.5$ mm and $l_{g2} = 1.0$ mm. Fig. 1 presents the static torque measurements within a range of [-20° to 90°] for θ. The Table II summarizes the torque aspects for both curves.

Table II. Torque Characteristics

	Original Prototype	**Optimized Prototype**
Average Torque (N.m)	0.23	0.24
Starting Torque (N.m)	0.10	0.20

Fig. 2 presents the Pareto set issued from the multi-objective method.

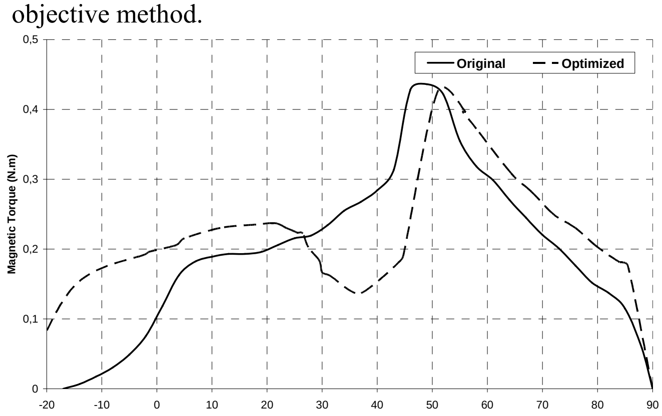

Fig. 1. Static torque measurements for both prototypes

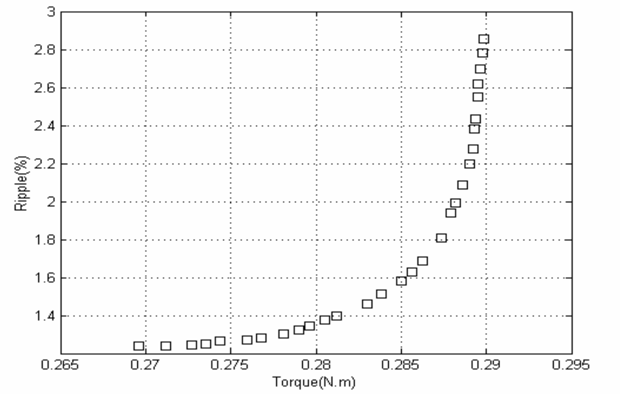

Fig. 2. Pareto set

Fig. 3 shows the vibration test results for both rotors.

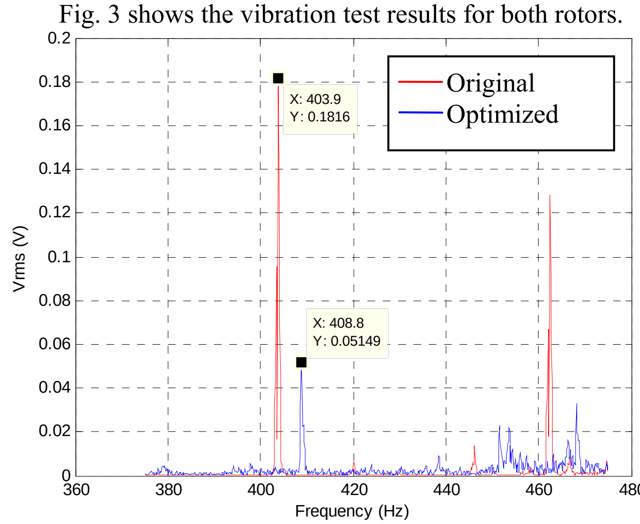

Fig. 3. Vibration analysis

Conclusions

A numerical optimization of the 4:2 SRM was performed and a new rotor geometry was obtained. The torque characteristic after optimization presents a higher starting torque, a slightly higher average torque and a lower ripple rate. As observed in Fig. 3, a significant reduction for the vibration when using the optimized rotor was achieved which confirms the numerical results.

In the full paper further optimization details and test results will be presented.

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