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Topology optimization considering magneto-elastic behavior

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Abstract. The present paper proposes a methodology based on topology optimization to design a synchro-reluctant motor considering magneto-elastic coupling. Stress on the rotor related to inertia forces and press-fitting effect on the stator are considered. The magneto-mechanical coupling is taken into account using a simplified magneto-elastic analytical model for the material behavior law. The objective is to maximize the machine's torque while considering an equality constraint on the volume. The topology optimization approach is based on a discrete BESO algorithm.

Keywords: Topology optimization, magneto-elastic coupling, synchro-reluctant machine.

INTRODUCTION

The design of electrical machines using topology optimization (TO) began as an alternative to classical parametric optimization methods. Various approaches have been applied to design electrical machines. These techniques fall into three categories: level-set, on-off and density penalization methods. Discrete on-off methods include the ESO and BESO evolutionary algorithms [1]. In [2], BESO was first used to design an electric machine structure, considering a magneto-mechanical problem. BESO algorithm eliminates or adds material to a set of elements to maximize an objective function. In this work, the saliency in the rotor is maximized; it is based on an energy method. Our interest is focused on the effects of stress on the electromagnetic design of the structure. The optimization problem focuses on the mean torque, with the objective function of improving the saliency. The originality of the approach is that the simulation is carried out by considering a material behavior law incorporating a coupled magneto-elastic model.

TOPOLOGY OPTIMIZATION

The machine to be designed is a 3-phases motor with 36 slots. The outer diameter is 130 mm, the rotor diameter is 75 mm, and the length is 100 mm. The optimization problem is formulated in equation 1, with V_e the elementary volume of a mesh element in the rotor, N_{iron} the total number of variables equal to the number of elements N_{mesh} . ρ_e is the optimization variable corresponding to the material density.

$$\begin{aligned} \max_{\rho_e} \quad & 1 - \frac{W_q}{W_d} \\ \text{s.c.} \quad & \sum_{i=1}^{N_{iron}} \rho_e \cdot V_e = V_{iron} \\ & \rho_e = 0 \text{ ou } 1 \quad e = 1 \cdots N_{mesh} \end{aligned} \tag{1}$$

Coupled problem resolution

2D magnetostatic and mechanical finite element models are used. In order to consider the effect of multiaxial stresses on the non-linear magnetic behavior, we introduce a coupling through a magneto-elastic behavior model [3]. Fig.1 gives the flowchart considering only inertia forces. The cases studied are initially limited to considering inertia forces on the rotor for speeds of 3000, 6000, and 20000 rpm. Subsequently, press-fitting radial forces are imposed on the stator. In this case, a 2D mechanical simulation is run before proceeding to the optimization described in the flowchart. It establishes the state of the residual stresses on the stator and modifies its energy contribution. Since each mesh element in the

rotor and stator has a different behavior law, the non-linear magnetostatic problem is solved using the fixed-point method.

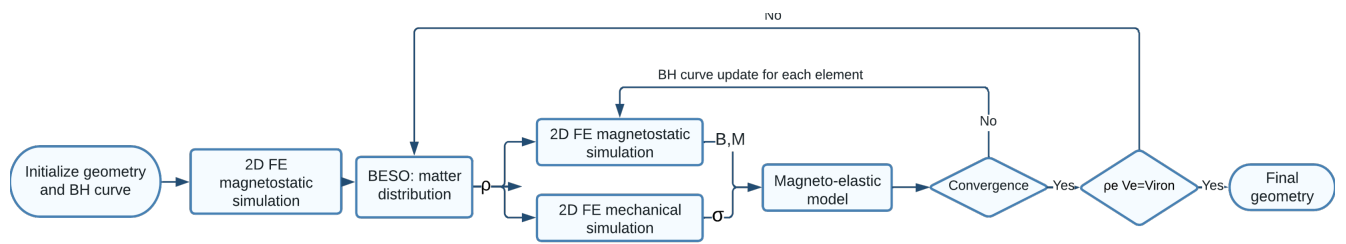


Figure 1: Chart of the coupled problem and topology optimization

Results and comparison

The objective function evolution for the three speeds is given in Fig.2a. Given the low inertia constraints, we observe the same behavior at low speeds. From 20000 rpm onwards, however, the optimization trajectory for the same BESO algorithm parameters changes. The volume constraint is increased to 57% when considering the stator stresses effect to obtain similar objective function convergence and avoid the asymmetry caused by lack of material. The algorithm tends to find the optimal saliency by modifying the material distribution in the rotor, but always with the same number of flux barriers. The representation of the machine’s saturation is given in figure 2c.

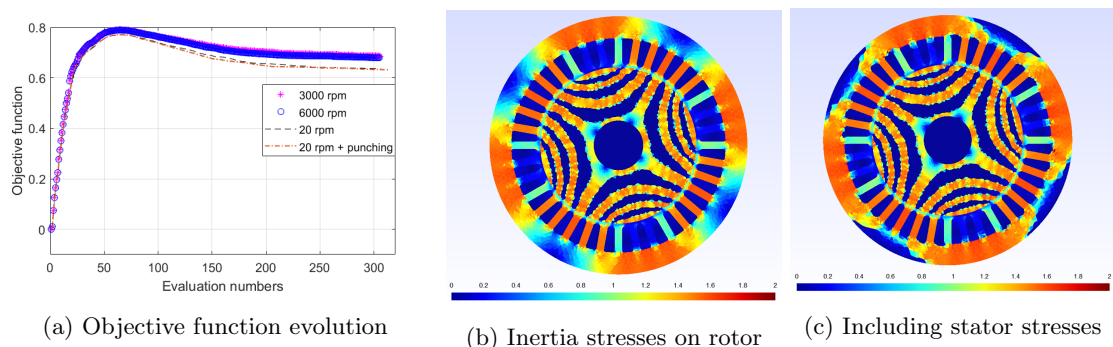


Figure 2: BESO evolution and first results (T)

CONCLUSIONS

When considering the rotor’s saliency, the rotor’s basic optimal shape does not change; the flux barriers shape are adjusted function of the stresses applied, particularly at speeds over 20 rpm and the press-fitting effect on the stator. Detailed equations on the magneto-static model coupling and BESO TO will be given in the extended paper.

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