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Magneto-Mechanical Free Shape Optimization of Synchronous Reluctance Machines

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Abstract. The digest presents a free-shape optimization method which simultaneously takes into account magnetic and mechanical targets in a finite element context. It is suitable to optimize devices such as synchronous reluctance machines. The process is presented and illustrated on the optimization of a concrete synchronous reluctance machine.

Keywords: Free shape optimization, multiphysical optimization, sensitivity analysis, synchronous reluctance machines, virtual work method.

INTRODUCTION

Free shape optimization (FSO) is a numerical optimization technique with many advantages. It aims at improving the shape of a machine by considering the mesh nodes of its design boundaries as optimization variables [1]. Thus, there are far more degrees of freedom than with a more traditional parametric optimization approach. This can be applied to improve magnetic performances such as the torque, torque ripple or iron losses of synchronous reluctance machines (SynRM). However, such methods usually do not take into account the mechanical performances of the machine during the optimization [1,2]. Therefore, the resulting rotor shape can lack of mechanical strength and not be interesting in real applications. This digest proposes a FSO method to simultaneously take into account magnetic and mechanical targets in the optimization. The method is illustrated on the optimization of the rotor of a SynRM.

FINITE ELEMENT ANALYSIS

The SynRM is studied under 2D magnetostatic conditions. The main target for the optimization is the torque of the machine. N angular position of the rotor are considered to describe the complete rotation. A nonlinear magnetic material is used for ferromagnetic parts of the machine which must be taken into account in the solving process. To improve current results obtained using the magnetic FSO, the mechanical analysis of the rotor must be carried out and the mechanical objectives and constraints accounted for in the optimization process. At high speed, the predominant mechanical load is the centrifugal force. A linear elastic finite element analysis under centrifugal load at constant rotation speed is considered. The nodes of the rotor attached to the shaft are considered fixed (Dirichlet boundary condition). From this analysis, a classical Von Mises stress criterion $\sigma_{VM} \leq \sigma_{MAX}$ is computed to check whether or not the rotor can bear the centrifugal load.

OPTIMIZATION METHOD

A gradient-based iterative optimization process is used. This algorithm requires the sensitivity analysis of the optimization objectives and constraints at each iteration in order to provide a descent direction for the optimization variables. As mentioned in introduction, FSO uses mesh nodes of the boundaries of the initial design as optimization variables. At each iteration, the magnetic finite element analysis is performed along with the torque computation and sensitivity analysis using the virtual work method presented in [1]. Then, the mechanical analysis of the rotor is performed on the exact same mesh as for the magnetic analysis. This allows to compute the stress value and sensitivity based on the work in [3] on the same nodes for both analysis. This sensitivity analysis is used to update the optimization nodes.

Then, the process iterates starting from the updated mesh. To ensure mesh stability, the whole domain is remeshed every three optimization iterations. The implementation is done using Altair Flux™ and Altair Optistruct™ softwares. The method will be fully detailed in the full paper.

APPLICATION

The iterative optimization process is used on the SynRM presented in Fig.1a with $N = 40$ positions. A constant rotation speed of 6000 rpm is considered for the input centrifugal load. The mesh nodes of internal lines of the rotor are considered for the optimization. Two optimization runs are considered. In the first one, the goal is to maximize the average torque with a constraint on the volume of the rotor which must decrease by 20% compared to the initial design. In the second one, the same problem is considered but with a Von Mises stress constraint $\sigma_{VM} \leq 85\% \times \sigma_{MAX}$ where $\sigma_{MAX} = 335$ MPa is the maximal admissible stress for the rotor material. Both runs took 48 iterations and about 80 minutes of computations. In Figures 1b, 1c and Table 1, the magnetic and mechanical performances for all designs are presented. Both optimization results have improved magnetic performances. However, the pure magnetic optimization (Fig.1b) has thin bridges which cannot handle the centrifugal load. The stress is higher than the admissible value σ_{MAX} and the design is not interesting for a real application. On the other hands, the magneto-mechanical optimization (Fig.1c) has thicker bridges where the centrifugal load is high and respects the Von Mises criterion. Thus, a usable design is found thanks to the use of the mechanical constraint in the optimization process.

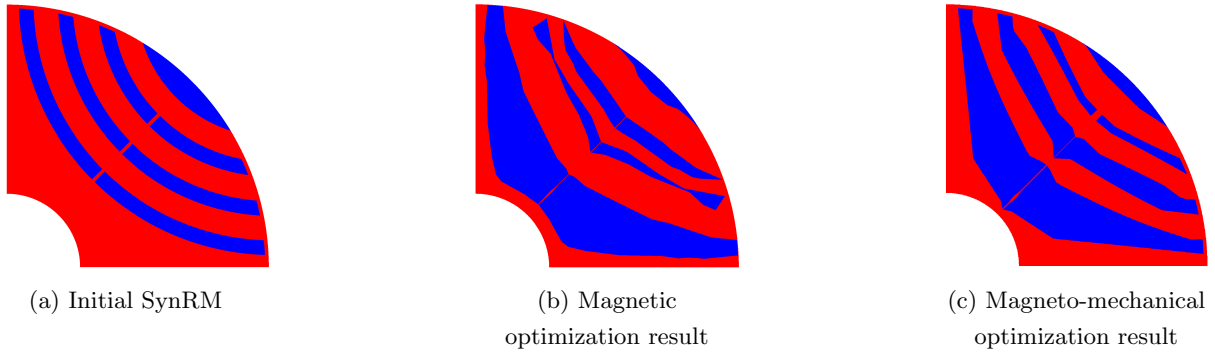


Figure 1: Views of the rotor for the three configurations

Table 1: Overview of magnetic and mechanical performances for all cases.

Run	T_{avg} (N.m)	Relative rotor mass (%)	σ_{VM} (MPa)	σ_{VM}/σ_{MAX} (%)
Initial Design	9.7	100	234	70
1	11.51(+18%)	80	757	226
2	9.91(+2%)	80	284	85

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