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# Efficient Design Using Successive Analytical Subproblems Method: Application to Axial Magnetic Couplings

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**Abstract**—The authors propose a simple but efficient method for design problems. Instead of using directly a heavy numerical code in an optimization process, we successively define some approximated subproblems thanks to an appropriate analytical model. These subproblems can then be solved exactly by a deterministic global optimization solver and the procedure is updated until the approximation matches a 3D FEM computation. The method is applied to an axial magnetic coupling, and preliminary results show the effectiveness of this approach.

**Index Terms**—Design, Axial magnetic coupling, Global optimization, Successive analytical subproblems.

## I. INTRODUCTION

It is usual to see design problems as optimization ones, generally defined as MINLP (mixed integer non-linear programs) [1]. However some criteria or constraints are often defined thanks to a numerical model and the resulting problems become hard to solve. The authors present in this paper a simple but efficient technique to solve this kind of design problems when an analytical approximation exists.

## II. AXIAL MAGNETIC COUPLINGS

A basic structure of axial magnetic coupling is considered as shown in Fig.1.(a). In [2], the authors develop, test and use a complete analytical explicit model of such a structure. So it is possible to compute the electromagnetic torque very quickly. If this model is compared to experimental values, it appears that it gives the right tendencies but overestimates significantly interesting quantities such as the torque as it appears on Fig.1.(b). A 3D FEM model is much closer to the measurements. This model is based on a scalar potential formulation solved using a general commercial finite element solver (FlexPDE), and encapsulated in a dedicated black-box.

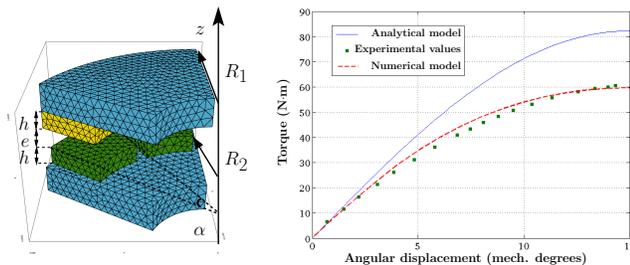


Fig. 1. (a): Geometry of the studied structure (only 2 poles); and (b): Models vs. Experimental Values Comparison

## III. SUCCESSIVE ANALYTICAL SUBPROBLEMS METHOD

The idea is to use both advantages of the two modeling tools: swiftness of the analytical and accuracy of the numerical

one. A corrected analytical model is defined by multiplying the initial model by a corrective factor  $\beta_k$ . The associated optimization ( $S_k$ ) is solved using a global deterministic optimization code (IBBA) [1]. A comparison with 3D FEM for the found minimum is performed, the corrective factor is updated and the procedure iterated until the difference between the two models is less than a fixed tolerance  $\varepsilon_{tol}$ .

In order to show the interest of the developed technique, a small numerical example is performed. The considered problem deals with the minimization of the volume of the magnets ( $V_m$ ) with a maximum torque ( $\Gamma$ ) greater than 100 N·m. It has 5 variables (with 1 integer: the pole pair number) and 2 additional geometric constraints. The overall procedure corresponding to SAS is given by Algorithm 1.

### Algorithm 1 SAS: Successive Analytical Subproblems

$\varepsilon = \infty; \beta_1 = 1; k = 0$

**while** ( $\varepsilon > \varepsilon_{tol}$ ) **do**

$k = k + 1$

Solve **exactly**: ( $S_k$ )  $\left\{ \begin{array}{l} \min_{\mathbf{x}} V_m(\mathbf{x}) \\ \text{s.t. } \beta_k \cdot \Gamma_{ana}(\mathbf{x}) \geq \Gamma_{fixed} \\ g_i(\mathbf{x}) \leq 0, \quad i \in \llbracket 1, n_g \rrbracket \end{array} \right.$

$\tilde{\mathbf{x}}_k = \text{argmin}(S_k); \quad \Gamma_{num} = \Gamma_{3D}(\tilde{\mathbf{x}}_k)$

$\beta_{k+1} = \frac{\Gamma_{num}}{\Gamma_{ana}(\tilde{\mathbf{x}}_k)}; \quad \varepsilon = \frac{|\beta_{k+1} \cdot \Gamma_{ana}(\tilde{\mathbf{x}}_k) - \Gamma_{num}|}{\Gamma_{num}}$

**end while**

$\tilde{\mathbf{x}} = \tilde{\mathbf{x}}_k \quad \{Found\ solution\}$

The proposed method is compared with a classical genetic algorithm (GA) provided by the MATLAB *Global Optimization Toolbox* with 20 individuals evolving during 30 generations. Results are given in Table I which clearly show the efficiency of the proposed methodology.

TABLE I  
PRELIMINARY RESULTS : SAS VS. GA (min  $V_m$ ,  $\Gamma_{fixed} = 100$  N·m).

	SAS	GA*
$V_m$ (cm <sup>3</sup> )	<b>44.76</b>	<b>58.89</b>
$\Gamma_{3D}$ (N·m)	100.11	100.04
n° of 3D FEM Comput.	3	623
CPU Time	< 3 min	212 min

\* best run over 10

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