Multidisciplinary Robust Optimization Design of Electrical Drive System with PM Transverse Flux Machine and BLDC Control Scheme

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Abstract — From our former study, permanent magnet (PM) transverse flux machine (TFM) with soft magnetic composite (SMC) core is a very promising motor. To provide more practical application for this machine, we present multidisciplinary robust optimization design (MROD) method to deal with an electrical drive system with this motor and brushless DC (BLDC) control scheme in this work. Firstly, new system modelling and decomposition method based on system sensitivity analysis and design of experiments are constructed to efficiently organize the information exchanges between different disciplines. Secondly, an efficient system level robust optimization framework is presented, namely dual levels integrated method. Thirdly, sequential optimization method is proposed to solve the disciplinary problems. Finally, the gained robust solution is compared with that from traditional deterministic optimization method.

I. Introduction

An electrical drive system is mainly composed of two parts, motor part and drive device part. Design such an drive system includes the performance analysis of several disciplines, such as electromagnetics, materials, mechanics and thermotics. Therefore, optimization design of such a system is a multidisciplinary problem [1], [2]. Generally, the total benefit after multidisciplinary design for an electrical drive system can be expressed as

$$\Delta_{\text{Design}} = \left| \sum_i \Delta_{\text{Discipline } i} \right| + \Delta_{\text{MOD}}, \quad (1)$$

where the first term in the right side represents the sum benefit of optimizing all sub-disciplines, and the second term is the benefit derived from the multidisciplinary coupling interaction. It is clear that we must also investigate the interaction between different disciplines so as to gain the optimal system benefit.

There are very few discussions about this system design problem. In traditional method, motor part and drive device part are always optimized separately. Actually, in practical application, the most popular way is that the researcher firstly optimizes the motor model, and then selects a drive control device. No one would know if we have acquired the optimal system performance. Recently, our group has introduced multilevel genetic algorithm to deal with such problems and have achieved some valuable results [3], [4]. Compared with the traditional genetic algorithm, multilevel genetic algorithm has a module-based architecture with each module corresponding to a discipline which makes it possible to handle the relationship between disciplines in multilevel problems. And the number of populations in each level can be adjusted to achieve satisfactory optimums.

However, the solution derived from the algorithm optimization is an optimal value only on the conception of deterministic optimization. Is the solution robust? We still do not know. But in the engineering application, it is known that the robust design is more important than the deterministic optimization and reliability design. Therefore, we need new methods that can cover this consideration.

II. The Electrical Drive System

This system includes a PM TFM and a BLDC control device. Fig. 1 illustrates the magnetically relevant parts of the TFM with SMC stator core [5], [6]. SMC is a very promising material which has many unique advantages for the motor design, such as 3-D magnetic isotropy, low eddy current loss and low cost manufacturing.

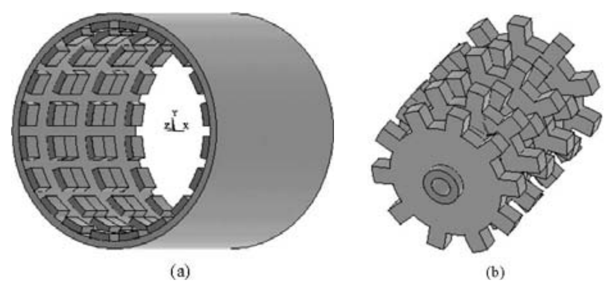

Fig. 1. Magnetically relevant parts of SMC TFM, (a) rotor and (b) stator

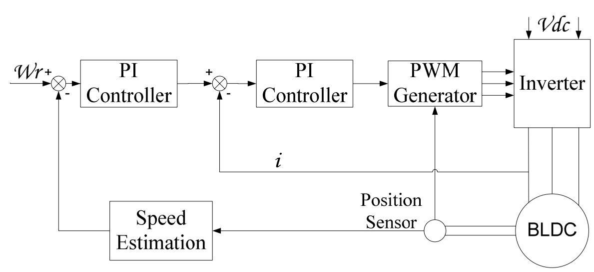

Fig. 2. BLDC control scheme for the SMC TFM

The motor was designed to operate with a BLDC control scheme, delivering a power of 640 W at 1800 rev/min. Fig. 2 is the BLDC control scheme for the this system. The objective of this electrical drive system is to minimize the motor cost which mainly depends on the cost of PM and copper winding as SMC is very cheap. Furthermore, three constraints are needed to be considered. One is the motor efficiency (η); the second is the fill factor of the winding (*sf*) and the last is the current density (in A/mm^2) of the cooper wire (J). They are defined as follows.

$$\begin{aligned} \min: \quad & y = \text{Cost(PM)+Cost(Cu)} \\ \text{s.t.} \quad & \begin{cases} g_1 = 0.795 - \eta \le 0 \\ g_2 = sf - 0.8 \le 0 \\ g_3 = J - 6 \le 0 \end{cases} \\ & \text{and } \mathbf{x}_l \le \text{x} \le \mathbf{x}_u \end{aligned} \quad (2)$$

where $\mathbf{x}_l, \mathbf{x}_u$ are the lower boundary and upper boundary of design parameters. For the robust optimization formula, the objective and constraints are

$$\begin{aligned} \min: \quad & z = F(\mu_y(\mathbf{x}),\ \sigma_y(\mathbf{x})) \\ \text{s.t.} \quad & \begin{cases} g_i(\mu_y(\mathbf{x}),\ \sigma_y(\mathbf{x})) \le 0 \\ \mathbf{x}_l + n\sigma_{\mathbf{x}} \le \mu_{\mathbf{x}} \le x_u + n\sigma_{\mathbf{x}} \end{cases} \end{aligned} \quad (3)$$

III. System Level Optimization Method

Fig. 3 is the system level optimization flowchart of the studied electrical drive system after the system sensitivity analysis process.

Fig.4 is the flowchart of MROD. In the flowchart, there are two subsystems, cost and performance analysis. Cost can be optimized with the structure parameters of PM and winding; while performance analysis includes the three constraints. There are three optimization processes in the DROM. First is the subsystem optimization, form this process, we can gain the structure parameters and performance parameters. Second is the algorithm optimization for the obtained parameters. Third is the robust design of the total system.

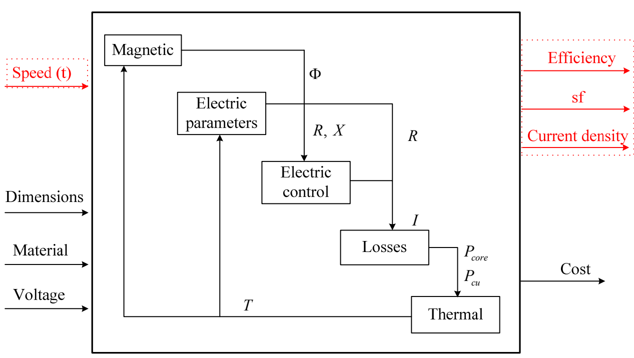

Fig. 3. Flowchart of the studied electrical drive system

IV. Discussions and Results

In this preliminary work, we only select six motor parameters for the MROD. Two are the dimensions of PM, circumferential angle and axial width; two for SMC tooth, circumferential length and axial width; two for winding, number of turns and the diameter of cooper wire. Other dimensions and parameters of TFM can be found in [6]. With the proposed method, we can get the optimal solution: PM dimensions are of 11.2º and 8.6mm, winding number of turns is 130 and wire diameter is 1.18mm, SMC tooth dimensions are 8.8mm and 8.5mm. The cost is RMB 99, which is slightly smaller than the direct optimization method (RMB 106). Most importantly, the robustness levels of the solution by the proposed method are all bigger than 3σ, which are obviously better than the direct optimization method, in which the smallest level is 0.5σ.

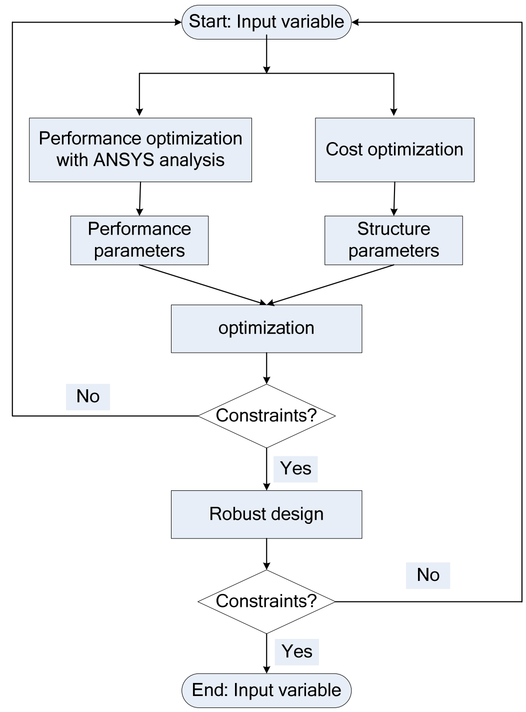

Fig. 4. Flowchart of the MROD

In the full paper, we will give a detailed discussion about the system optimization performance about the motor and control system. We believe that the proposed method has great application potential for the early stages of industrial design, which will greatly reduce design cycles and save resources. Most importantly, new method will benefit the development of new products and remarkably improve their qualities and reliabilities.

V. References

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