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RANGES OPTIMIZATION OF ELECTRICAL MACHINE USING COMPONENT SHARING

B. SESANGA *, F. WURTZ* and A. FOGGIA*

*Grenoble Electrical Engineering Laboratory (G2Elab) ENSE[3] (Grenoble INP-UJF, CNRS UMR 5529) BP 46 – 38402 Saint Martin d'Hères Grenoble Cedex, France, E-mail: Bill.sesanga@g2elab.grenoble-inp.fr

Abstract. In this paper is about the machine ranges optimization (from a few kW to more than 300 kW, and for speeds ranges between 750 rpm to more than 5500 rpm). The industrial approach that consists in sharing components to design ranges of products was retained to lead this study. If it is true that the use of the same components for families of different products allows the manufacturers to offer a high variety of products to a low cost of industrialization and development, with this approach the best performances are obtained?. To answer this question, an analytical model (magnetic and thermal) that is coupled with an optimization tool was developed. For this, a deterministic optimization algorithm called Sequential Quadratic Programming (SQP) is used. The paper will more especially the complexity of such an optimization problem (number of inputs, outputs, constrained)

Keywords: Component sharing, Optimization ranges, Synchronous machines.

INTRODUCTION

The concept of machine ranges optimization is not very developed in the design of electromagnetic devices, especially motors. Usual studies care, more usually about only one machine for one application. However, this notion takes importance if we are placed in an industrial context of mass production **[1],[2]**. For a given diameter and a sheet metal workshop fixed by the polarity, the manufacturers propose a series of machines for applications with various speeds (750, 1500, 3000, 4500 and 5500 rpm). The optimization of the same sheet metal workshop for the various applications leads to a different optimum. Thus, if the manufacturer wants to propose a complete range of optimized machines, he will have to make so many sheet metal workshops as machines of the same diameter. Now this approach is not possible for costs reasons of industrialization and management.

MODELING

Induction calculation in the air gap is the central issue in the modeling. The waveform of this induction is obtained by solving a nonlinear implicit equation system (1). The first equation of this system is directly obtained using the Ampere's theorem. To do this, the evolution of the magneto motive force (MMF) was supposed sinusoidal. The MMF amplitude, the ampere's-turns in the back iron and the polar pieces were neglected. The second equation of the system is obtained applying the flux conservation law.

$$(1) \quad \begin{cases} H_{mg} * W_{m\_mg} + \dfrac{2 * B_g(\theta)}{\mu_0} * \left[g(\theta) + \dfrac{kt * h_{te}}{\mu_r(B_g(\theta))} \right] = Line\_Load * \dfrac{\Phi_b}{p} * \sin(\theta - \alpha) \\ \Phi_{mg}(H_{mg}) = \Phi_g(B_g(\theta)) + \Phi_f(H_{mg}) + \Phi_{f3D}(H_{mg}) \end{cases}$$

In this equation H_{mg} is the magnetic field in the magnets, W_{m_mg} is the minimal magnet width, h_{te} is the height of stator teeth, k_t is a geometric coefficient that allows computing the induction in the teeth given the air gap induction. $B_g(\theta)$ is the air gap induction, $g(\theta)$ is the corrected mechanic air gap, θ is the electrical angle that can vary along a polar piece and α is the internal angle. Φb is the bore diameter and p the pair of poles. All variables are calculated using the induction. Φmg is the flux created by two magnets common to a pole, this flux feeds at the same time the air gap flux (Φ_g), the leak flux at the hub level (Φ_f) and the three-dimensional leak flux (Φ_{f3D}) in the motor edge. The thermal model included takes into account conduction and convection phenomenon but doesn't consider radiation.

RANGE OPTIMIZATIONS

After the elaboration and validation of the analytical model, the optimization stage is aborted. The objective function is the minimization of the material costs at nominal torque without degradation of the efficiency and power factor. Nine machines of 300 mm outside diameter were selected over a range of speeds [3].

The optimization problem has 698 parameters, 397 input parameters with 225 constraints and 281 output parameters with 217 constraints: this shows the complexity of such an optimization problem what will be explained with more details in the full paper.

Table 1. Characteristics of machines

Outside diameter (mm)	300								
Speed (rpm)	750	900	1500	1800	2400	3000	3600	4500	5500
Length of machine (mm)	160	200	120	260	300	160	220	140	160
Power output (kW)	16,5	25	25	70	100	65	90	80	100
Torque (N.m)	210	265	159	371	398	207	239	170	174

This ranges optimization can be decomposed in different stages. In the first step, we determine the performances of the initial machines. In the second step, every machine is optimized independently of each others. It is in this step that the best theoretical results are obtained, but at an enormous cost of industrialization. After an analysis of the designs obtained in the second stage, we notice that some of them are very similar. For this reason, in the third step we decided to share the same components for these machines. Then it is the optimization algorithm that determines the sizes of the components to be shared. This process is continued until coming down to a new only sheet metal workshop for the whole range.

The results of these various optimizations allow determining curves of “Pareto range”, it is the analysis of these curves that allows to make strategic choices. The final sheet metal workshop brings an increase of 13.6 in the ratio torque/kg (red arrow) and a reduction of 5.3 in cost by N.m (blue arrow). The blue ellipse shows that it is really interesting to have three laminations while optimize the range of motor. Actually, when we reach from 3 to 5 steel laminations we notice that the observed values de not change a lot. On an other hand, we observe sensitive variations when we pass from 1 to 3 different laminations.

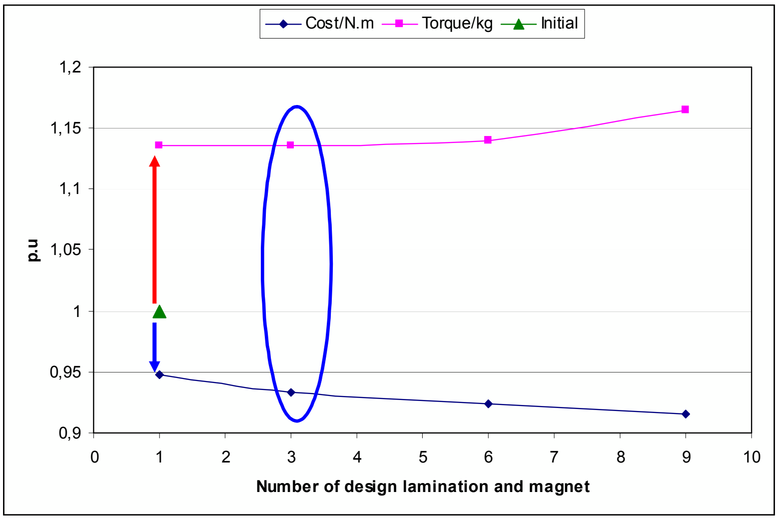

Figure 1. Pareto curves of ranges.

CONCLUSIONS

In this article the optimization problem of a wide range machines has been treated. For this, an analytical model of the machine (magnetic and thermal) was established. The sizing method using optimization of components shared between several machines (sheet steels stator and rotor magnets) showed interesting results. The number of possible designs is a function of the machine speed.

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