Multi-objective optimization of an induction machine using design of experiments

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***Abstract*— The evaluation of the electromagnetic, structural and acoustic behavior of an induction machine is computationaly expensive. Optimization algorithms are therefore not applicable. This papers demonstrates that the methodology of design of experiments (Taguchi method) has been successfully applied for the multi-objective optimization of such multiphysics devices. A significant improvement of the machine performances can be achieved with this approach after only a few evaluations of the coupled FE model.**

I. Introduction

Design optimization of electrical machines is a challenging process as contradictory objectives must be conjugated in the final design. Optimization algorithms, such as genetic algorithms, evolution strategies or simulated annealing has been widely used [1]. The required computational effort is very high and therefore, they are only appliable if the model evaluation is computationally inexpensive.

An alternative approach is the use of design of experiments. First, the performance response and the parameters, i.e. factors, which have an effect on it, are identified. Then, the values (levels) of this factors are decided. A factorial experiment, i.e. all possible combinations of levels across all factors are simulated, is then planned with an experiment matrix with orthogonal columns. The performance responses of the experiments, i.e. simulations, are used to calculate the main effects and the interactions of the factors and to suggest an improvement in the design using statistical analysis of mean and variance. This method has been already used to optimize the electromagnetic behavior of electrical machines [2]. In this paper, not only the electromagnetic behavior but also the structural and acoustic behavior of an induction machine are optimized with this approach. The objectives of the optimization are the reduction of the torque ripple (ΔM) and the minimization of the logarithmic sum of the body sound index for all frequencies (L) under the constraint of delivery of the rated torque (M). ΔM and M are evaluated by a 2D electromagnetic simulation. The magnetic forces are extracted from it and given as excitation to a 2D structural simulation to evaluate L. After some initial investigations the factors chosen for the optimization are the air gap length (A), the depth of the mounting notches of the outer contour of the stator (D) and the position of this mounting notches (P).

TABLE I
Simulation and result matrix

Experiment	G	A	D	M(Nm)	ΔM (Nm)	L(dB)
1	-	-	-	4.74	13.08	61.72
2	-	-	+	4.74	13.08	61.72
3	-	+	-	4.25	20.00	61.84
4	-	+	+	4.15	21.93	61.32
5	0	-	-	4.48	12.50	57.25
6	0	-	+	4.48	12.50	57.25
7	0	+	-	4.05	17.27	57.70
8	0	+	+	3.94	19.73	57.42
9	+	-	-	4.22	11.08	53.64
10	+	-	+	4.22	11.08	53.64
11	+	+	-	3.86	14.70	54.47
12	+	+	+	3.75	17.88	54.36

II. Simulations and Results

Three levels {0.2(-), 0.25(0) and 0.3(+) mm} have been chosen for the factor A because some initial explorations have shown a non-linearity of the response with this factor. On the other hand, only two levels are taken for D {0(-) and 3.5(+) mm} and P {mounting notch over a tooth (-) and over a slot (+)}. Therefore, a full factorial analysis of the problem implies 12 experiments. Table I shows the simulation matrix and the three performance responses. Actually, only 10 simulations are necessary because experiments 1 and 2, and 9 and 10 are equivalent, due to the strong interaction between depth and position of the mounting notches. The analysis of the simulation results allows to propose an improved design, which delivers the same rated torque as the original machine but with 36% less torque ripple and 7.6% less L (logarithmic sum of the body sound index for all frequencies).

III. Conclusions

This paper shows the validity of the design-of-experiment approach for the multi-objective optimization of an induction machine. More detailed results and analysis will be presented in the full paper.

References

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