

Optimization of IPM motor using Advanced Iron Laminations for High-Speed Electric Vehicle Applications

Vasileios I. Vlachou¹, Theoklitos S. Karakatsanis², and Antonios G. Kladas¹, *Senior Member, IEEE*

¹School of Electrical and Computer Engineering, National Technical University of Athens, 9, Iroon Polytechniou street, 15780 Athens, Greece, vasilvlachou@mail.ntua.gr, kladasel@central.ntua.gr

²Department of Production and Management Engineering, Democritus University of Thrace, 12, Vasilisis Sofias street, 67100 Xanthi, Greece, thkarak@pme.duth.gr

Permanent magnet synchronous motors (PMSMs) have attracted increased research interest recently within electrification initiative, as they meet the challenges of high-speed operation in electric vehicle applications. The paper proposes an optimization procedure for interior permanent magnet (IPM) motor with the magnets arranged in V-type configuration in the rotor implementing advanced iron laminations; the methodology is based on genetic algorithms (GAs) in conjunction with finite element analysis (FEA) enabling to meet the desired performance while minimizing the involved losses. The proposed method has been applied in a 50 kW motor example and the simulated results have been validated by measurements in a prototype.

Index Terms—Finite element analysis, electric vehicles, permanent magnet motors, genetic algorithm.

I. INTRODUCTION

NOW-A-DAYS the high-speed permanent magnet synchronous motors (PMSMs) constitute a dominant technology in electrification applications, as they exhibit high efficiency and power density. Numerous different PMSM topologies have been proposed, involving variations in the design of winding structure, the configuration of rotor core as well as the arrangement of permanent magnets (PMs) [1].

The surface-mounted PMSMs constitute a favored configuration in electromobility applications due to their advantages in terms of construction and low losses [2]. Many research efforts have been devoted to optimize PMSMs in terms of improved performance and reliability by using algorithms involving genetic algorithms [3]. Their use is particularly important to improve power density and reduce vibrations by adopting procedures of multi-objective optimization targeting rotor design parameters presenting low harmonic content [4] as well as reduced core loss factors [5]. The simulation of key operational characteristics of the machine is usually carried out by developing Finite Element Analysis (FEA). The excessive computational cost of solving multi-objective problems involving large numbers of optimization variables requires introduction of appropriate reduction strategies (such as Kriging models) with separate optimization of significant PMSM design parameters [6].

In the frame of this last mentioned research direction, a methodology has been developed to investigate the impact of introducing an advanced iron lamination material in stator core construction, in order to reduce the core losses and improve the overall machine efficiency. Thus, the electro-magnetic analysis of a PMSM was investigated by means of 2D and 3D FEA, enabling detailed exploitation of the magnets placed at V-type configuration and the windings behavior at the end zone parts. The optimization methodology incorporates a preliminary sensitivity analysis of machine parameters by identifying areas of linear or no-linear correlation, selection of an appropriate genetic algorithm and the optimum design machine is tested

under various operating conditions. Measurements on a prototype motor validated the proposed method accuracy.

II. METHODOLOGY AND RESULTS

The considered motor has a nominal output power of 50 kW at 1500 rpm involving 8 poles/48 slots and PMs of neodymium-iron-boron with 1.23 T remanent flux density. The initial design stage is based on standard formulae and the main geometrical parameters derived are reported in table I.

The proposed design optimization methodology is described in the flowchart shown in Fig. 1. It consists of several steps of comparative investigation of particle swarm optimization (PSO)

TABLE I
MOTOR GEOMETRIC PARAMETERS AT INITIAL AND OPTIMIZED STAGE

Parameter	Initial (mm)	Optimized (mm)
Active length/Mean airgap diameter	200/215.57	
Stator inner/outer diameter	269.2/161.9	265/159
Rotor inner/outer diameter	160.4/110.6	158/108
Stator slot opening/base/top width	2.1/3.1/5.6	2.5/3.5/6
Stator slot opening/tip/body height	1.3/0.1/29.7	1.5/1.2/30.5
Tooth width	4.9	5.2
Air-gap length	1.5	1.2
Magnet thickness	6.5	6.8

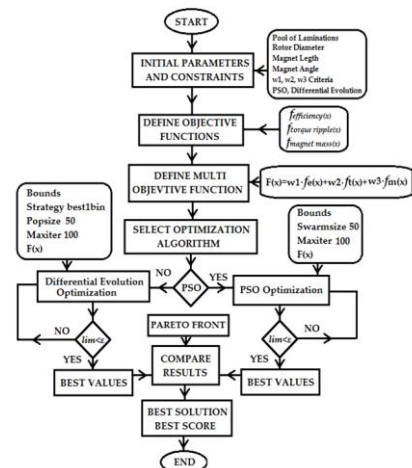


Fig. 1. Flowchart of the methodology introduced in the PMSM optimization.

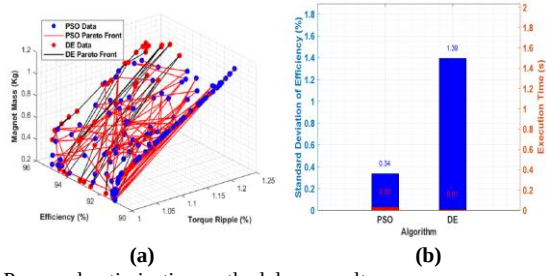


Fig. 2. Proposed optimization methodology results.
(a) Scatter plot of final Pareto front in the objective space.
(b) Comparative study best solutions algorithms.

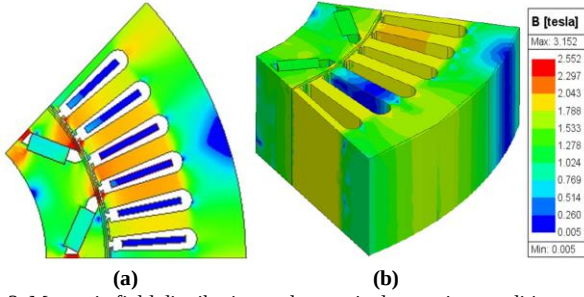


Fig. 3. Magnetic field distribution under nominal operating conditions.
(a) 2-D FEA, (b) 3-D FEA.

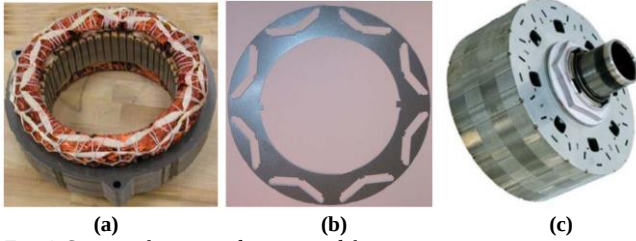


Fig. 4. Stator and rotor configuration of the motor prototype,
(a) Stator part, (b) Rotor iron lamination, (c) Rotor part.

combined with differential evolution (DE) algorithms by exploiting key geometric characteristics of the machine. The obtained optimized motor main geometrical parameters are equally given in table I. The optimization objective function is determined based on Pareto front as shown in Fig. 2a while the performance of each algorithm is shown in Fig. 2b.

Figure 3 shows one pole part of the optimized motor geometry with the respective 2D and 3D flux density distributions under nominal operating conditions. These results demonstrate the symmetric magnetic field distribution with a maximum flux density of 3.1 T with a flux concentration in the rotor part above the magnets while in the other parts there is a small leakage and no pronounced saturation.

The constructed prototype motor stator part, rotor lamination and rotor part are shown in Figs 4a, 4b and 4c, respectively. The relative magnetic permeability and the properties of the material were evaluated through measurements using an Epstein frame. Fig. 5 compares the plot of electromotive force (EMF) computed by FEA and the respective graph measured experimentally. The results of the present study show similar magnetic and efficiency responses to the IPMSM case considered in [7]. In Fig. 6a are compared the simulated and measured output torque values for a wide range of applied currents under different operating loads. The almost linear torque variation proportional to the current observed in this figure indicates that no strong saturation occurs in the stator.

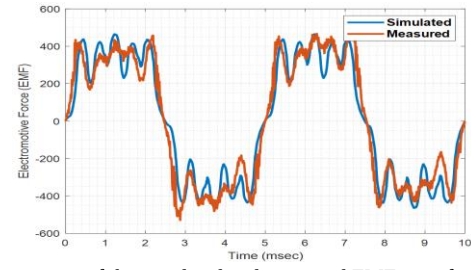


Fig. 5. Comparison of the simulated and measured EMF waveforms.

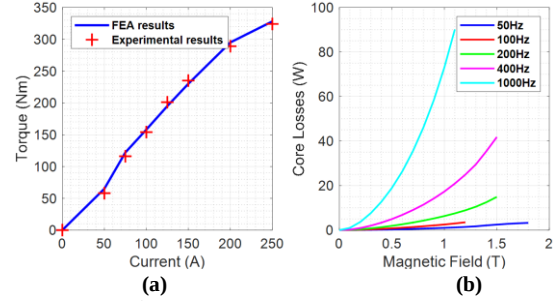


Fig. 6. Comparison of simulated and measured motor characteristics.
(a) Output torque with the applied phase current.
(b) Core losses as a function of magnetic field density.

The computed core losses depend on the operating frequencies and magnetic field density as shown in Fig. 6b. The good agreement observed between simulated and measured results illustrates the proposed method validity and applicability in this class of problems.

III. CONCLUSION

An efficient PMSM optimization methodology has been introduced based on investigation of PSO and DE algorithms involving reduced computational cost while achieving satisfactory performance levels. The PSO illustrated greater stability according to standard deviation and exploration of optimal solutions in space. The proposed method has been applied in a V-type IPM configuration and the optimized design results have been validated by measurements in a prototype.

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