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GA Optimization for Regression Modeling of Electromagnetic Performances Predicted by a Subdomain Model for SMPMSM in an Electric Vehicle †

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Abstract: This paper investigates a nonlinear modeling optimization of 12s/8p surface-mounted permanent magnet synchronous machines (SMPMSM) with a radial magnetization pattern. The modeling is based on subdomain model (SDM) computation, where the analytical models are developed to predict the electromagnetic (EM) performances, such as, average EM torque and EM torque ripple in PM machines. A genetic algorithm is applied to the proposed model in order to search for the optimal solutions. The objective function of the optimizations is obtaining a higher average EM torque and achieving the minimum EM torque ripple. The data, *viz*, and the average EM torque and its ripples predicted by SDM are employed in regression analysis in order to find the model of best fit. After that, the most suitable fit of the computing equation is selected. The preliminary and optimal designs of 12s/8p PM motors are also compared in terms of parameters and motor performance. As a result, the regression model and GA framework has reduced the use of magnet materials and the EM torque ripple of the SMPMSM, making it ideal for use in an electric car. Lastly, the proposed model can determine the appropriate configuration design parameters for SMPMSM in order to achieve the best motor performance.

Keywords: regression model; genetic algorithm; subdomain model; surface-mounted; permanent magnet synchronous machine; electric vehicle; EM performance

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1. Introduction

In recent years, electric vehicles (EVs) have been acknowledged as the alternatives to fuel vehicles [1]. In comparison to other electric motors, PMSM is frequently employed in the field of EVs due to its high power density [2]. However, having a higher electromagnetic (EM) torque ripple influences the PM motor performances, which leads to greater vibrations and noise [3]. Electromagnetic performances are becoming more crucial in the design of PM machines in order to increase the dependability and operational resilience of EVs.

The structural parameters of PM machines have a significant influence on electromagnetic motor performance, such as average electromagnetic torque and torque ripple. Therefore, a design optimization method is proposed to optimize the motor performance in order to obtain the suitable design parameters. Generally, numerical methods such as the finite element (FE) technique are commonly used to evaluate the performances of PM machines [4]; however, this method requires excessive computation time. Due to the rapid and high predicted accuracy of machine geometry, a subdomain model (SDM) is used [5–8].

The SD model, on the other hand, lacks the capability of addressing multiple objectives in SMPMSM optimization, where a trial-and-error process is used to discover a solution that meets the trade-offs of design optimization. Then, the genetic algorithm with a regression model is applied to solve the optimization problem. Therefore, the main contribution of this paper is to design the optimum setting framework in a manner with stochastic optimization algorithms, in order to evaluate the optimum electromagnetic performances that can provide the optimal solutions.

The organization of this paper is as follows. The framework of the regression method in SMPMSM is presented in Section 2. Section 3 describes the result and analysis of the computing framework for the initial and optimal design solutions. Concluding remarks are presented in Section 4.

2. The Framework of the Regression Method in SMPMSM

The proposed investigation is to calculate the finest performance of a 12s/8p SMPMSM., i.e., the average electromagnetic torque (T_{em_avg}) and ripple of the torque as a percentage ($\%T_{em}$) by varying the winding of slot-opening (b_{oa}) from 5.5° to 30° mech. and changing the permanent magnet pole-span ratio (α_p) from 120° to 180° elects. The parameters of the PM motor are as follows: thickness of stator yoke, W_{sy} = 6 mm; the tooth body width, W_{tb} = 7.5 mm; radius of slot-opening, R_t = 30.5 mm; number turns per coil, $Ntpc$ = 413 turns; and the number of stator slots and pole pairs are 12 and 8, respectively.

The data for magnet pole-span, slot-opening angle, EM torque ripple, and the average EM torque are collected by using the SDM. Then, the regression method is applied, where the data collected are used to fit the polynomial functions. Multiple fits of polynomial functions are fitted, and the goodness-of-fit statistics are collected. Then, the most suitable fits of the computing equations for T_{em_avg} and $\%T_{em}$ are

$$\%T_{em} = \begin{array}{l} 1.58e^4 - 425.6x + 152.1y + 4.29x^2 - 4.464xy + 8.325y^2 - 0.00193x^3 + 0.0354x^2y - 0.0655xy^2 - 0.01669y^3 \\ +3.212e^{-5}x^4 - 8.048e^{-5}x^3y + 7.134e^{-5}x^2y^2 + 0.000858xy^3 + 0.0010y^4 \end{array} \quad (1)$$

$$T_{em\_avg} = \begin{array}{l} 3.771 - 0.0542x - 0.1525y + 0.000651x^2 + 0.0050xy - 0.0045y^2 - 1.764e^{-6}x^3 - 3.835e^{-5}x^2y - 3.546e^{-5}xy^2 \\ +0.000224y^3 - 2.634e^{-10}x^4 - 8.616e^{-8}x^3y + 1.172e^{-7}x^2y^2 + 1.451e^{-7}xy^3 - 4.133e^{-6}y^4 \end{array} \quad (2)$$

where x and y are the α_p and the b_{oa} of PM motors, respectively. Finally, the optimum fit is selected, where the fit is used in the GA computation framework to search for optimum designs.

3. Result and Analysis

Figure 1a,b shows the 3D plot for the polynomial function of computing equations fit by the curve-fitting tool in MATLAB, with the variables of α_p and b_{oa} for predicting the motor performances. The fitness value of the computational framework throughout generations must be discovered in order to identify the best configuration of the PM motor, as shown in Figure 2. Figure 2 reveals that the minimum point of fitness value is located at the 2nd generation, beginning to become saturated at the 25th generation. Next, Figure 3 shows a comparison of the EM torques produced by the preliminary and optimum designs for 12s/8p PM motors by using the computing framework, where a comparison between the preliminary and the optimum designs is tabulated in Table 1.

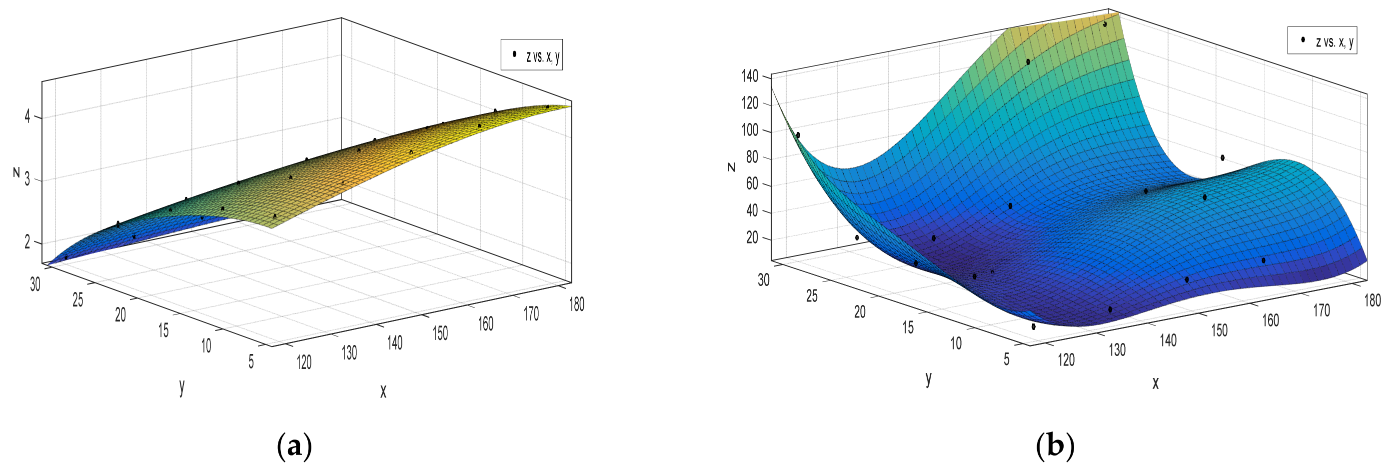

Figure 1. 3D plot for the polynomial function of computing equations fit by the curve-fitting tool in MATLAB, with the variables of α_p and b_{oa} for predicting the motor performances. (**a**) The average EM torque. (**b**) The EM torque ripple.

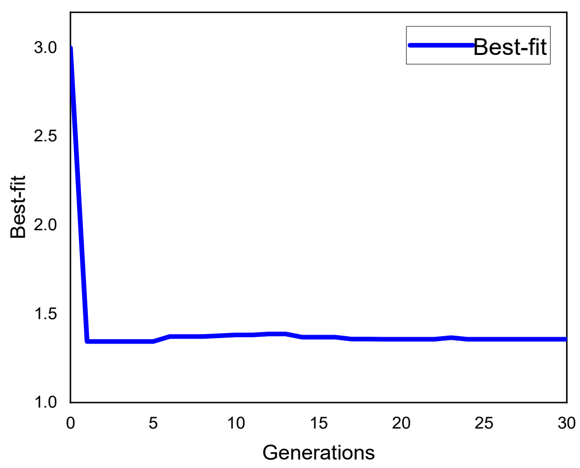

Figure 2. The computing framework's fitness value throughout generations.

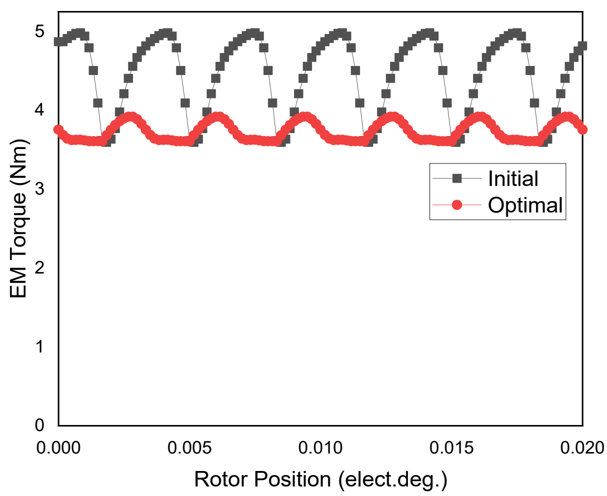

Figure 3. Preliminary and optimal PM motor designs compared in terms of electromagnetic torque under on-load conditions.

Table 1. The comparison of EM torque between the preliminary and the optimum designs.

Design	Preliminary Design	Optimal Design	Improvement (%)
Generations	-	2	-
Best-fit	-	1.3438	-
α_p (elec. deg.)	180	127.31	−29.27
b_{oa} (mech. deg.)	5.50	8.01	-
Average EM Torque (Nm)	4.46	3.73	−16.37
EM Torque Ripple (%)	31.17	8.40	−73.05

The optimum magnet pole-span for 12s/8p of the PM motor is 127.31° elect., while the optimum slot-opening angle is 8.01° mech. As for evaluating the motor performances, the average EM torque is 3.74 Nm and the EM torque ripple is 8.40% after being optimized with the computing framework.

Table 1 displays a comparison of the produced EM torques between the preliminary and optimum designs. As shown in Table 1, the average EM torque for the best design is lower than that of the preliminary design, with a decrease of roughly 16.34%. Meanwhile, the optimum design for EM torque ripple is reduced to 73.05% from the preliminary design, where the reduction is achieved as displayed in Table 1.

Based on Figure 3, a reduction in amplitude between the preliminary and optimum designs is also achieved, where the ripples are repeated every 60° elect. The optimum design PM motor has lower electromagnetic torque compared to the preliminary design, which leads to less noise and motor vibrations. As a result, the framework of optimum design solutions using a regression method is capable of reducing vibration and noise in the design of SMPMSM, allowing reliability and smoothness in motor operations.

4. Conclusions

Finally, in electric vehicle applications, the best design configuration for 12s/8p of SMPMSM with an RM pattern has been used. The optimization was carried out utilizing a computer framework and a regression approach, resulting in decreased T_{em_avg} and $\%T_{em}$ values. The regression model was applied on EM torque ripple and the average EM torque to generate the equations, which estimate the parameters of the process with reasonable accuracy and give insight into the process of minimization. The optimum setting of PM motors in RM by using the computing framework across the generations has been presented. As a consequence, the framework of an optimum design solution utilizing a regression approach is capable of decreasing the use of magnet materials and EM torque ripple while preserving the average EM torque in the design of SMPMSM.

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References

1. Hong, G.; Wei, T.; Ding, X. Multi-Objective Optimal Design of Permanent Magnet Synchronous Motor for High Efficiency and High Dynamic Performance. *IEEE Access* **2018**, *6*, 23568–23581. [CrossRef]
2. Wang, S.; Li, H. Reduction of Electromagnetic Vibration and Noise in Permanent Magnet Motor for EVs by Optimizing Design of Rotor Based on GPR-PSO Model. *J. Electr. Eng. Technol.* **2020**, *15*, 1231–1243. [CrossRef]
3. Zuo, S.; Lin, F.; Wu, X. Noise Analysis, Calculation, and Reduction of External Rotor Permanent-Magnet Synchronous Motor. *IEEE Trans. Ind. Electron.* **2015**, *62*, 6204–6212. [CrossRef]
4. Wang, D.; Wang, X.; Qiao, D.; Pei, Y.; Jung, S.Y. Reducing cogging torque in surface-mounted permanent-magnet motors by nonuniformly distributed teeth method. *IEEE Trans. Magn.* **2011**, *47*, 2231–2239. [CrossRef]
5. Tiang, T.L.; Ishak, D.; Lim, C.P.; Kamarol, M. A Novel Analytical Method Using Virtual PM Blocks to Optimize Magnet Segmentations in Surface-Mounted PM Synchronous Machines. In Proceedings of the 2015 18th International Conference on Electrical Machines and Systems (ICEMS), Pattaya, Thailand, 25–28 October 2015; pp. 4–9.
6. Liu, Z.J.; Li, J.T. Analytical solution of air-gap field in permanent-magnet motors taking into account the effect of pole transition over slots. *IEEE Trans. Magn.* **2007**, *43*, 3872–3883. [CrossRef]

7. Lubin, T.; Mezani, S.; Rezzoug, A. Two-dimensional analytical calculation of magnetic field and electromagnetic torque for surface-inset permanent-magnet motors. *IEEE Trans. Magn.* **2012**, *48*, 2080–2091. [CrossRef]
8. Tiang, T.L.; Ishak, D.; Lim, C.P.; Jamil, M.K.M. A comprehensive analytical subdomain model and its field solutions for surface-mounted permanent magnet machines. *IEEE Trans. Magn.* **2015**, *51*, 1–14. [CrossRef]