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Cogging Torque Reduction of IPMSM by Adjusting the Stator Opening Width

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Abstract: A model of a 48S-8P IPMSM Nissan LEAF motor was constructed for this study, and the performance was examined using JMAG software. The JMAG Geometry Editor will be used to sketch the models, which will then be imported into the JMAG Designer, where the simulation will be run by inserting the appropriate parameters such as materials, conditions, circuit, meshing, and properties. The study was successfully simulated, and the results were obtained. The three-flux linkage results between the identical profile and theoretical data were compared to evaluate the proposed design. The flux profile for the three-phase armature coils was sinusoidal, demonstrating the motor's operating principle, according to the proposed design's simulation. To ensure the proposed motor structure's performance, a no-load test was conducted. The proposed motor has a higher back electromotive force as well as cogging torque. As a result, adjusting the width of the opening stator slot in the proposed design has the potential to improve performance. The new enhanced design, as can be observed, offers superior torque performance and efficiency to the developed motor. In terms of performance, the proposed motor has met its goal.

Keywords: Interior PMSM, Cogging Torque, Opening Stator Slot

1. Introduction

Permanent Magnet Synchronous Motor (PMSM) is one of the types of AC synchronous motor with a sinusoidal back EMF waveform that uses permanent magnets placed in the steel rotor to provide a stable magnetic field. PMSM combines a brushless DC motor and an induction motor. Its permanent magnet rotor and stator windings are identical to those of a brushless DC motor [1]. An induction motor uses windings to create a sinusoidal flux density in the machine's air gap, and the stator structure of PMSM is identical to that of an induction motor. The power density, when compared with an induction motor, is higher with similar ratings since there is no stator power allocated to magnetic field creation.

PMSM can be classed into two types based on how the magnets are mounted to the rotor: surface PMSM (SPMSM), which mounts all the magnet parts on the surface, and interior PMSM (IPMSM), which places the magnets inside the rotor [2]. Because of its advantages, such as high torque and high

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power to current ratio, high efficiency, low noise, and structural durability, IPMSM is frequently applied in high-performance applications. IPMSM is also used in electric cars, including the Nissan LEAF, Toyota Prius-III, and BMW i3. In addition, IPMSM offers a variety of rotor topologies, including inset, spoke, single-barrier, multiple-barrier, and axially laminated.

One of IPMSM's primary problems is the torque ripple that is built into their structure. This torque ripple can cause mechanical vibration, acoustic noise, and drive system difficulties. Cogging torque is one of the main causes of torque ripple [3]. This cogging torque can be defined as the torque produced by magnetic forces that act circumferentially between the embedded permanent magnet of the rotor and the slotted iron structure of the stator [4]. As a result, IPMSM produces cogging torque, therefore it is required to reduce the cogging torque. Although there are a variety of methods for reducing cogging torque, this project proposes the method of adjusting the width of the opening stator slot to reduce cogging torque. This project also focuses on sketching the 48S-8P IPMSM Nissan LEAF motor as the proposed motor design. The analysis is carried out using JMAG software as a finite element solver. Figure 1 shows the different rotor types in IPMSM

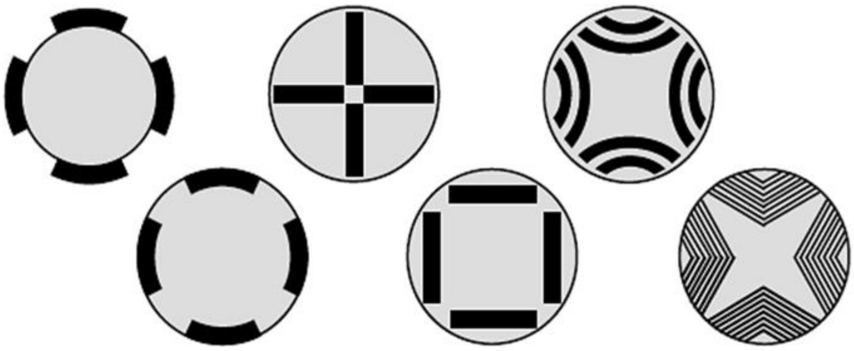


Figure 1: Different rotor types in IPMSM

2. Materials and Methods

Using the Finite Element Method in JMAG software, the 48S-8P IPMSM Nissan LEAF motor design is completed. For reference to the motor’s structure, refer to Figure 2. The main features of JMAG-Designer are the process of geometry sketching, model setup, such as the material used, condition setting, circuit, study magnetic, run analysis, mesh, and plot the graph of result. JMAG Designer and JMAG Geometry Editor are used to design specific machine parts and analyze electrochemical design performance. This software program is a complete electromechanical tool with great simulation and evaluation capabilities. This software program's high quality allows it to extract data such as complex geometry, various material properties, and the heat structure at the heart of electromagnetic fields. Moreover, this software program is user-friendly and flexible, allowing users to go from conceptual design to complete analysis. The proposed 48S-8P IPMSM Nissan LEAF motor is designed based on the specifications specified in Table 1.

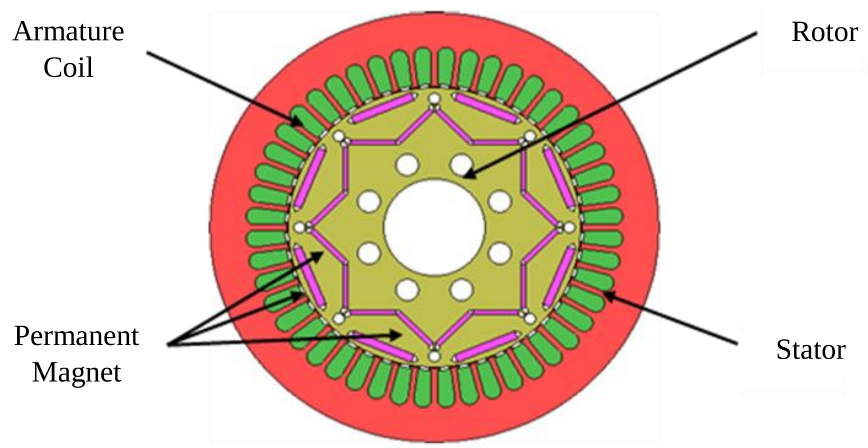


Figure 2: Proposed design of 48S-8P IPMSM Nissan LEAF motor

Table 1: Main dimensions/parameters of 48S-8P IPMSM Nissan LEAF motor

Dimensions/Parameters	Value
No. of turns per coil	28
Speed (r/min)	2500
Number of slots	48
The outer diameter of the rotor (mm)	130
The inner diameter of the rotor (mm)	45
Active axial length (mm)	151
The outer diameter of the stator (mm)	200
The inner diameter of the stator (mm)	131
Number of poles	8

2.1 Materials and Conditions

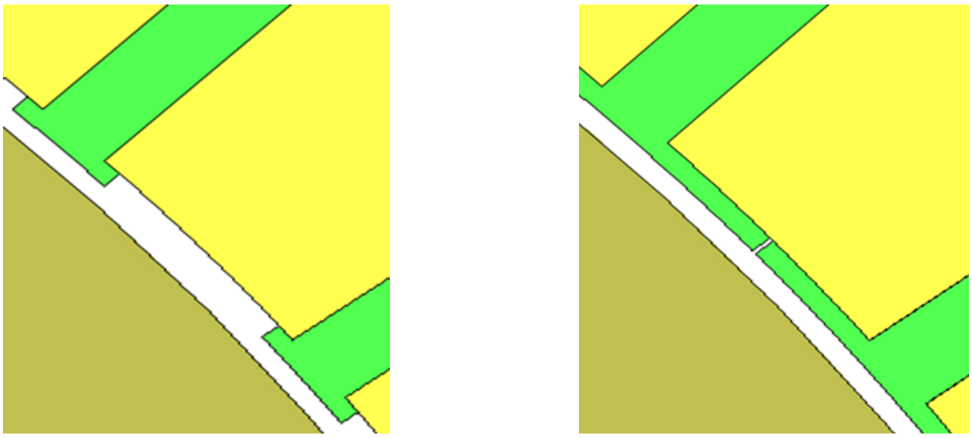
Table 2 shows the parameter of materials and conditions of the motor parts. No load and load tests performance analysis uses the same materials and conditions.

Table 2: Materials and conditions setting in 48S-8P IPMSM Nissan LEAF motor design

Parts	Materials	Condition
Rotor	Nippon Steel 35H210	Motion: Rotation
		Torque: Nodal Force
Stator	Nippon Steel 35H210	-
Armature Coil	Conductor Copper	FEM Coil
Permanent Magnet	Neomax-35AH (Irreversible)	Motion: Rotation
	(Radial Anisotropic Pattern)	Torque: Nodal Force

2.2 Methods

This study is focused on how the cogging torque can be reduced by applying the method of adjusting the width of the opening stator slot. As the slot opening width increase, the cogging torque increases initially, then drops, causing waveform distortion [4]. Applying a slotless core or decreasing the slot opening are two direct techniques for reducing cogging torque. The permeance in the air gap fluctuates due to the presence of the slot and teeth in the stator core, resulting in cogging torque. As a result, the smaller the slot opening width, the lower the cogging torque. In general, the slot opening width of the improved design is excellent at 0.3 mm, with a 64% of reduction as referred to in Figure 3 (a) and Figure 3 (b).



(a) **(b)**

Figure 3: Applying the method of adjusting the width of the opening stator slot (a) Initial design (b) Improved design

3. Results and Discussion

The 48S-8P IPMSM Nissan LEAF motor design was examined using a 2-dimensional finite element method, and the outcomes of both the initial and improved topologies are covered in this section.

3.1 Cogging Torque

The characteristics of cogging torque phenomena, which were connected to improper vibration and noise, decreased performance, poor position control, and running discomfort, was what led to torque pulsation. The peak-to-peak torque of a decent electric motor should not be more than 10% of the average torque [5]. The whole one electric cycle of produced torque was tested under these conditions, as shown in Figure 4. The Nissan LEAF 48S-8P IPMSM motor generated four cogging torque cycles, with the number of cycles varying depending on the type of motor, and slot and pole numbers. According to the observations in Figure 4, the improved design's peak-to-peak cogging torque is 40.175 Nm, lower than the original design's 166.804 Nm.

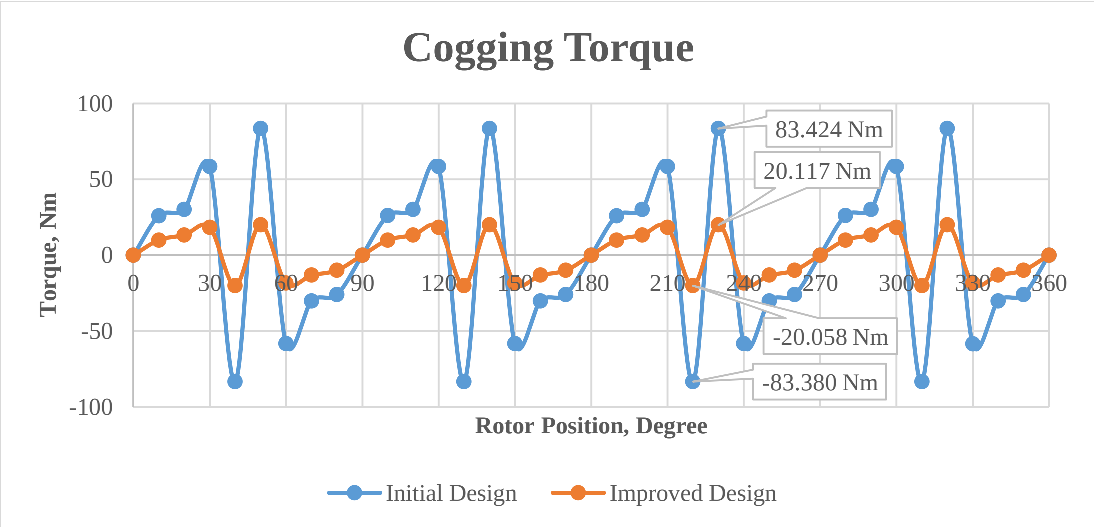


Figure 4: Comparison of cogging torque graph for 48S-8P IPMSM Nissan LEAF motor

3.2 Torque at Various Armature Coil Current Density, Ja

The torque versus Ja analysis was performed to determine the graph, whether is increasing or decreasing. Without using a particular number of degrees, the maximum average torque value from Ja 5 to Ja 30 was applied. According to the observations in Figure 5, the improved design's output torque is 43.137 Nm, higher than the original design's 37.499 Nm, as shown in Figure 5.

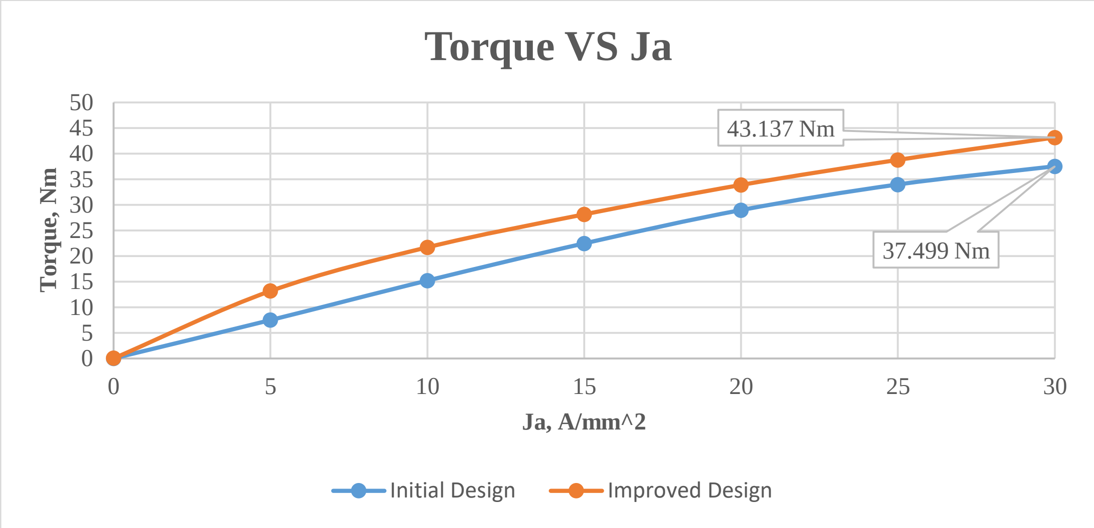
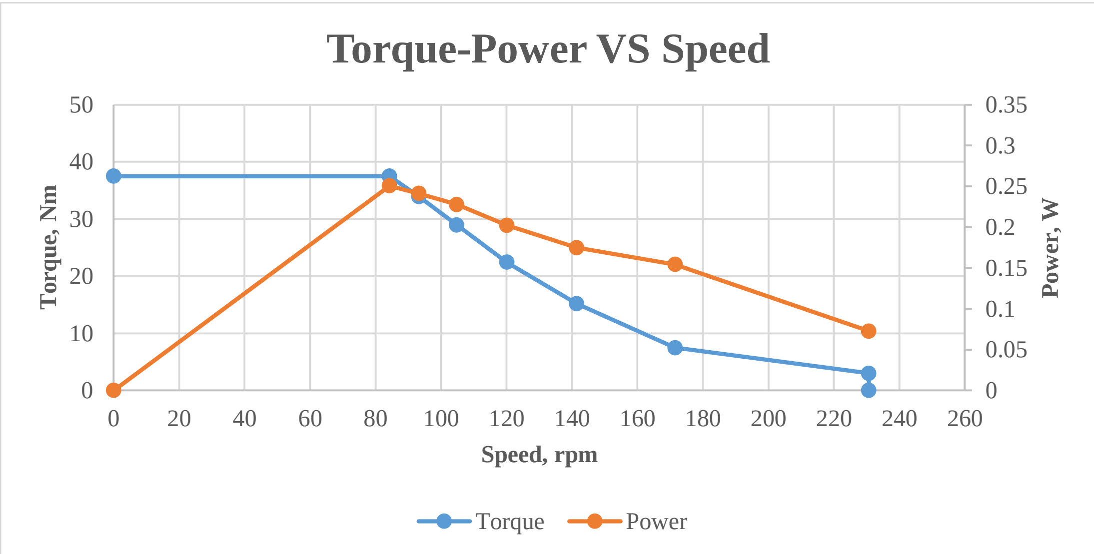


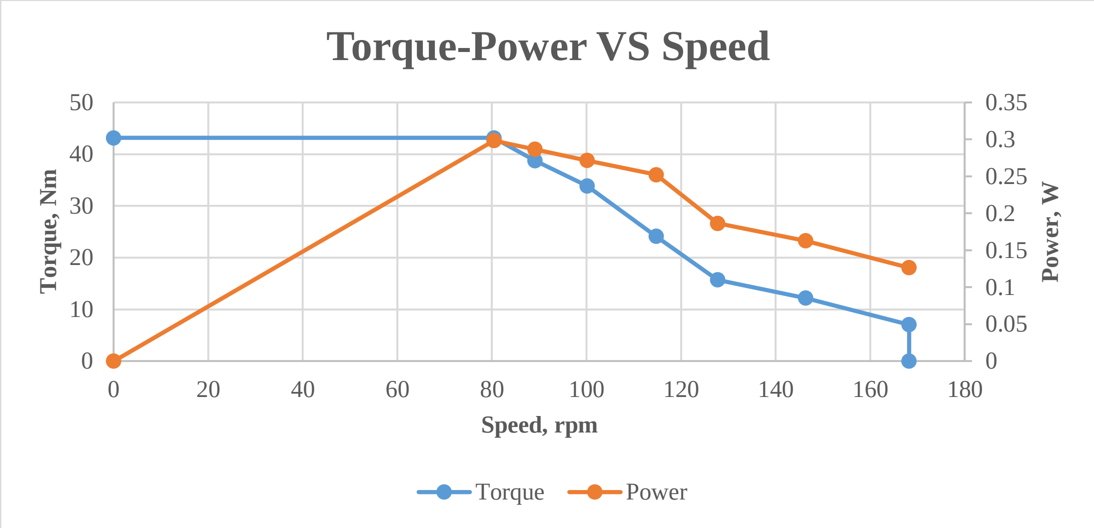
Figure 5: Comparison of torque versus Ja graph for 48S-8P IPMSM Nissan LEAF motor

3.3 Torque and Power versus Speed

A torque and power analysis were performed to identify the maximum values for torque, power, and speed. The output power may be determined by varying the torque and speed parameters in the earlier simulation after all the necessary data has been gathered and evaluated. For both the initial and improved designs of the motor, the result of torque and power vs speed was achieved, as shown in Figure 6 (a) and Figure 6 (b). The highest output power produced by both designs is 0.2508 W and 0.2984 W, respectively. Compared to the initial design, the improved version has the highest maximum output power. Meanwhile, the graph reveals that the initial design has the maximum speed condition, which is 230.65 rpm compared to the initial design, which is 168.22 rpm. In the final analysis, the maximum output torque produced for both designs is 37.499 Nm and 43.137 Nm, respectively, with the improved design having the highest value compared to the initial design.



(a)



(b)

Figure 6: Torque and power versus speed graph for 48S-8P IPMSM Nissan LEAF motor (a) Initial design (b) Improved design

4. Conclusion

In this study, the 48S-8P IPMSM Nissan LEAF motor model has been constructed to analyze the performances using JMAG software. The three-flux linkage results between the identical profile and theoretical data were compared to evaluate the proposed design. The proposed design's simulation revealed that the flux profile for the three-phase armature coils was sinusoidal, proving the motor's operating principle. A no-load test was performed to confirm the proposed motor structure's performance. The proposed motor construction features a higher back electromotive force and cogging torque. The proposed design's cogging torque has been examined when the armature coil's current density is zero. The proposed design has high cogging torque at 83.424 Nm. As a result, the proposed design will affect the motor’s output torque performance. Therefore, the new improved design was created to produce a superior motor design in terms of performance, especially the cogging torque. Adjusting the width of the opening stator slot was applied to reduce the cogging torque. As a result, the motor's cogging torque has reduced from 83.424 Nm to 20.117 Nm. In conclusion, this study has successfully achieved its main objective of reducing the cogging torque. However, there are a few ideas for motor development that can be implemented in the future, such as:

1. Modify the rotor size or shape of the motor to minimize the cogging torque and enhance the torque density.
2. Optimize the motor using the Local Optimize Method (LOM) to get a better motor performance in terms of torque density and efficiency.
3. Change the conventional motor design to double stators so that the motor can be controlled separately to increase the motor torque density. Since it has double stators, the motor has high starting torque with low cogging torque.

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