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Torque Performance Analysis on Interior Permanent Magnet (IPM) Arrangement of Synchronous Motor

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Abstract

This study proposes designs of Interior Permanent Magnet Synchronous Motor (IPMSM) with different Interior Permanent Magnet (IPM) topology. The purpose of this study is to analyse and determine which IPM topology generate the highest torque. JMAG Desginer 18.1 software is used to construct a model of an 18-slots, 8-poles Permanent Magnet Synchronous Motor (PMSM) with five different variations of IPM topology. The proposed design incorporates many different IPM topologies, including U-shape, V-shape, UU-shape, VV-shape as well as UV-shape. The torque performance of the proposed design has been analysed by using software simulation. Based on the current finding, it is found that the double layer IPM arrangement produced higher torque rather than single layer IPM arrangement. Between single layer topologies, the V-shape topology was shown to have a greater amount of torque than the U-shape topology, while the VV-shape topology was found to have the highest torque of all the designs presented.

1. Introduction

Permanent magnet synchronous motors (PMSMs) are widely used in various industries, including manufacturing, industrial machines, and renewable energy. They have a high torque to volume ratio, high effectiveness, a wide range of operating speeds, and excellent controllability [1]. Interior permanent-magnet (IPM) machines have gained attention for their use in electric vehicles (EVs) for traction applications due to their high torque and power densities [1]. As new EVs become more widely used, advancements in rotor topologies for IPM machines have been made to enhance their performance. The machine that has been proposed comes with two different shapes of PMs, U-shape and V-shape, with a relatively large interval between them. This project aims to design and analyze the combination of different types of PM arrangements to improve the torque performance of the IPM machine. The aims for this project are to simulate different permanent magnet arrangements consists of single layer U-shape, single layer V-shape, double layer U-shape, double layer V-shape and combination of UV-shape topology, to evaluate the torque performance of each permanent magnet arrangements and to compare and determine which combination interior permanent magnet arrangement produced highest torque.

As well known, PMSMs are widely used in various industries, including manufacturing, industrial machines, and renewable energy [2]. They have a high torque to volume ratio, high effectiveness, a wide range of operating speeds, and excellent controllability. IPM machines have gained attention for their use in EVs for traction applications. IPM motors operate on Alternating Current (AC) and use permanent magnets integrated into the rotor. The stator configurations of IPMSM are analyzed to enhance efficiency by utilizing either distributed winding or concentrated winding. The utilization of distributed winding is prevalent in high-power applications such as electric vehicles EVs, hybrid electric vehicles (HEVs), and traction drives [3]. As new energy vehicles become more commercially used, more intricate rotor topologies have been introduced to enhance motor performance [4]. Thus, this project aims to design and analyses the combination of different types of permanent magnet arrangements to improve the torque performance of IPM machines

2. Literature Review

2.1 Permanent Magnet Configuration

The performance and efficiency of an EV IPM motor are significantly influenced by the configuration of its permanent magnets. There are three primary magnet configurations which are surface-mounted, inset, and buried. Surface-mounted magnets provide high density of magnetic flux but increase cogging torque and demagnetization risk [5]. Inset magnets compromise the density of magnetic flux, cogging torque, and rotor strength. Buried magnets minimize cogging torque but face flux density and temperature management issues. For optimal acceleration, high torque at low speeds is necessary. Buried magnet configurations offer the highest torque density but also pose heat issues [6]. The number of poles affects torque and speed, with larger pole numbers resulting in higher torque but lower torque. The shape and magnetization of a magnet also impact flux density and cogging torque distribution [7,8]. The orientation of magnetization can be axial or radial, affecting flux density and torque ripple.

2.2 Permanent Magnet Synchronous Motor (PMSM)

A synchronous motor operates at a consistent speed, converting electrical energy into mechanical energy. It consists of a stator and rotor, with the stator providing the armature winding and the rotator driving the field windings. Neodymium-iron-Boron magnets are used due to their cost-effectiveness and lower space requirements [9]. PMSM has a stator with three phases and a rotor with permanent magnets. A cage is installed on the rotor for direct power line start-up, but most PMSM drives are powered by inverters. The motor's characteristics depend on the type of magnets applied and their arrangement on the rotor. PMSMs are classified into Surface Permanent Magnet (SPM) and IPM.

2.3 Torque in Electric Motor

Torque is the rotational force generated by the crankshaft of a motor. The motor's work performance is directly proportional to the amount of torque it generates. Torque is a vector that acts in a certain direction, it is typically measured using quantities like Nm or pound-feet. As the torque value increases, the motor's ability to generate rotating force also increases. This is essential for applications that necessitate a significant amount of initial power. In electric motors, torque and speed are not exactly proportional. Torque may be increased by raising current or voltage, but rotational speed is frequently sacrificed in the process. On the other hand, decreasing voltage or current may increase speed but reduce torque. Fig. 1 shows the IPM torque vs speed curve.

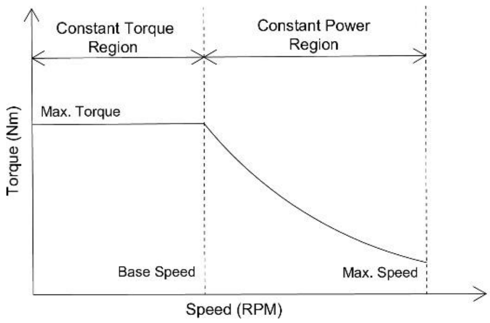

Fig. 1 *IPM Torque vs Speed curve*

3. Methodology

JMAG-Designer is a simulation software utilized for the development and design of electrical machines in this project. The software is used to construct a model of 18-slot, 8-pole PMSM with five different variations of IPM topology. The Geometry Editor tool was used to create the IPM topology for the U-shape, V-shape, UU-shape, VV-shape, and UV-shape.

3.1 Parameters and Materials

Table 1 shows the parameters used for this project with 18 slots and 8 poles of IPMSM designs. The materials used for motor designs shown in Table 2.

Table 1 *Parameters of 18 slots-8poles IPMSM design*

Parameters	Value
Outer stator diameter (mm)	264
Inner stator diameter (mm)	161.7
Permanent magnet weight (kg)	3.312
Number of poles	8
Number of stator slots	18
Airgap length (mm)	0.53
Outer rotor diameter (mm)	161.17
Number of phases	3
Remanence of PM (T)	1.2
Magnet density (kg/m^3)	7500
Stack length (mm)	150
Number of turns of armature coil	297
Motor speed (rpm)	1200

Table 2 *Motor materials and conditions*

Part	Material	Condition
Rotor	Nippon Steel 35H210	Motion: Rotation Torque: Nodal Force
Stator	Nippon Steel 35H210	-
Armature coil	Conductor copper	FEM Coil
Permanent magnet	NdFeB_Br=1.2(T)	Motion: Rotation Torque: Nodal Force

3.2 System Flowchart

Fig. 2 illustrates the flowchart of torque performance analysis of IPMSM. The process is divided into two phase which are design phase using Geometry Editor and simulation phase for No Load Test Analysis and Load Test Analysis using JMAG Designer.

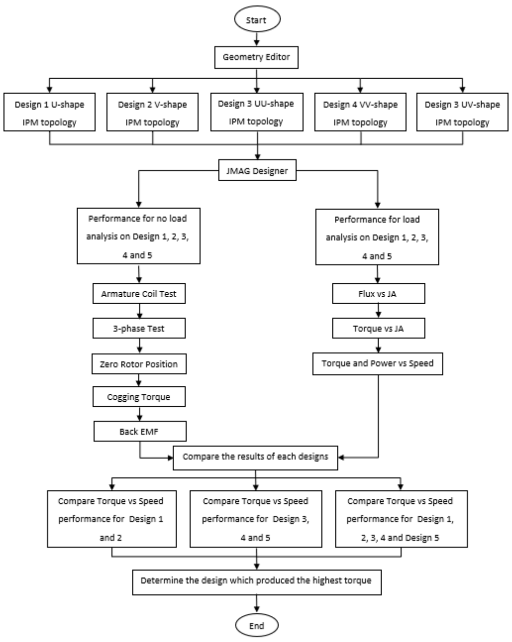

Fig. 2 *Flowchart of torque performance analysis of IPMSM*

4. Result and Discussion

Fig. 3 illustrates the design configuration of IPM topology with 18 slot and 8 poles of IPMSM.

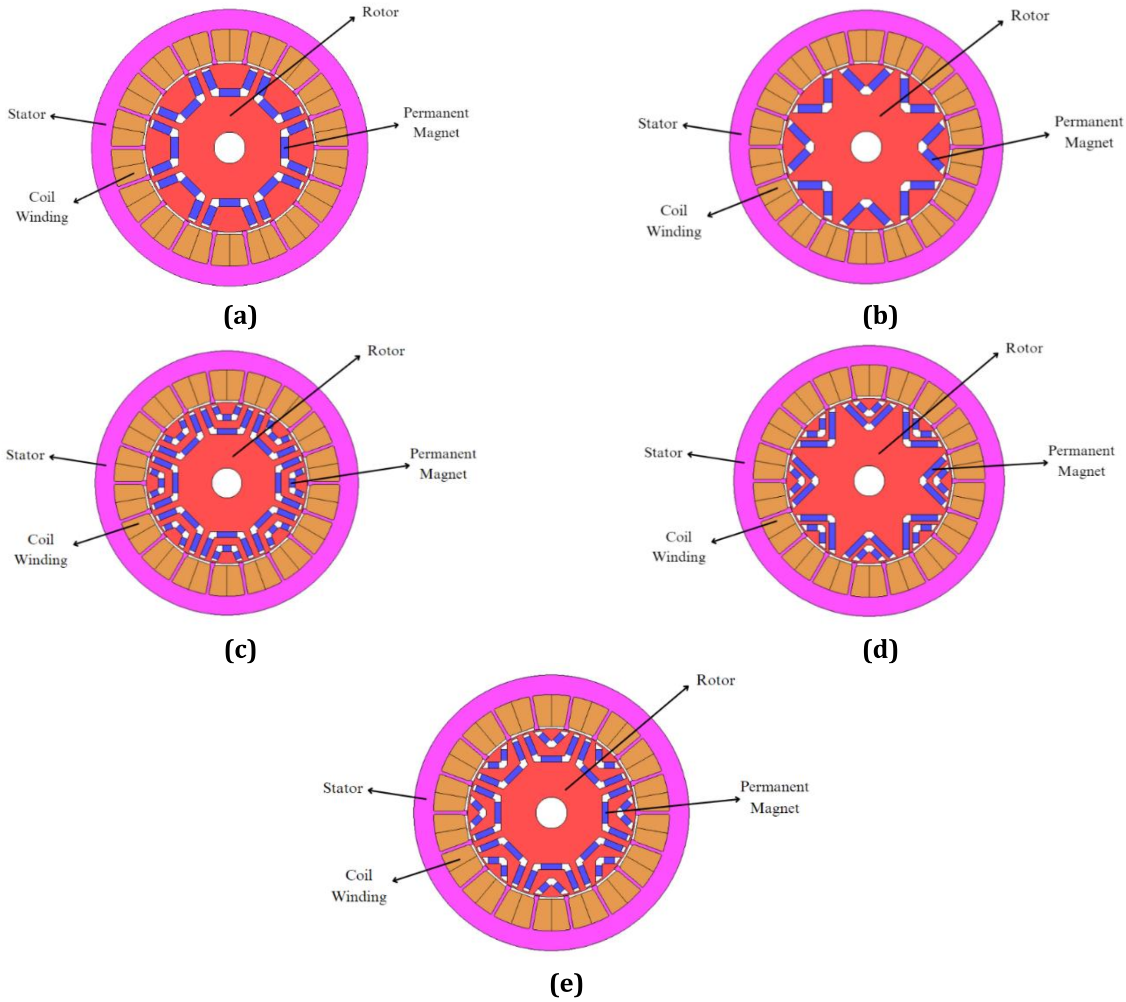

Fig. 3 *Design configuration (a) Design 1; (b) Design 2; (c) Design 3; (d) Design 4; (e) Design 5*

Fig. 3(a) shows Design 1 which represents as U-shape IPM topology. Figure 3(b) illustrates Design 2 which represents V-shape topology. It is worth mentioning that Design 1 and Design 2 are the conventional designs for the previous project. Meanwhile, Fig. 3(c), 3(d) and 3(e) illustrate Design 3 (UU-shape), Design 4 (VV-shape) and Design 5 (UV-shape) respectively.

4.1 Flux Distribution

The arrangement of magnetic field intensity within a space is referred to as flux distribution. It is an essential concept in the field of electromagnetism, particularly when it comes to electric motors. The distribution of magnetic flux within a motor has a substantial impact on its performance in terms of torque production, efficiency, noise and vibration [10]. Fig. 4 present the maximum and minimum flux distribution of all proposed designs.

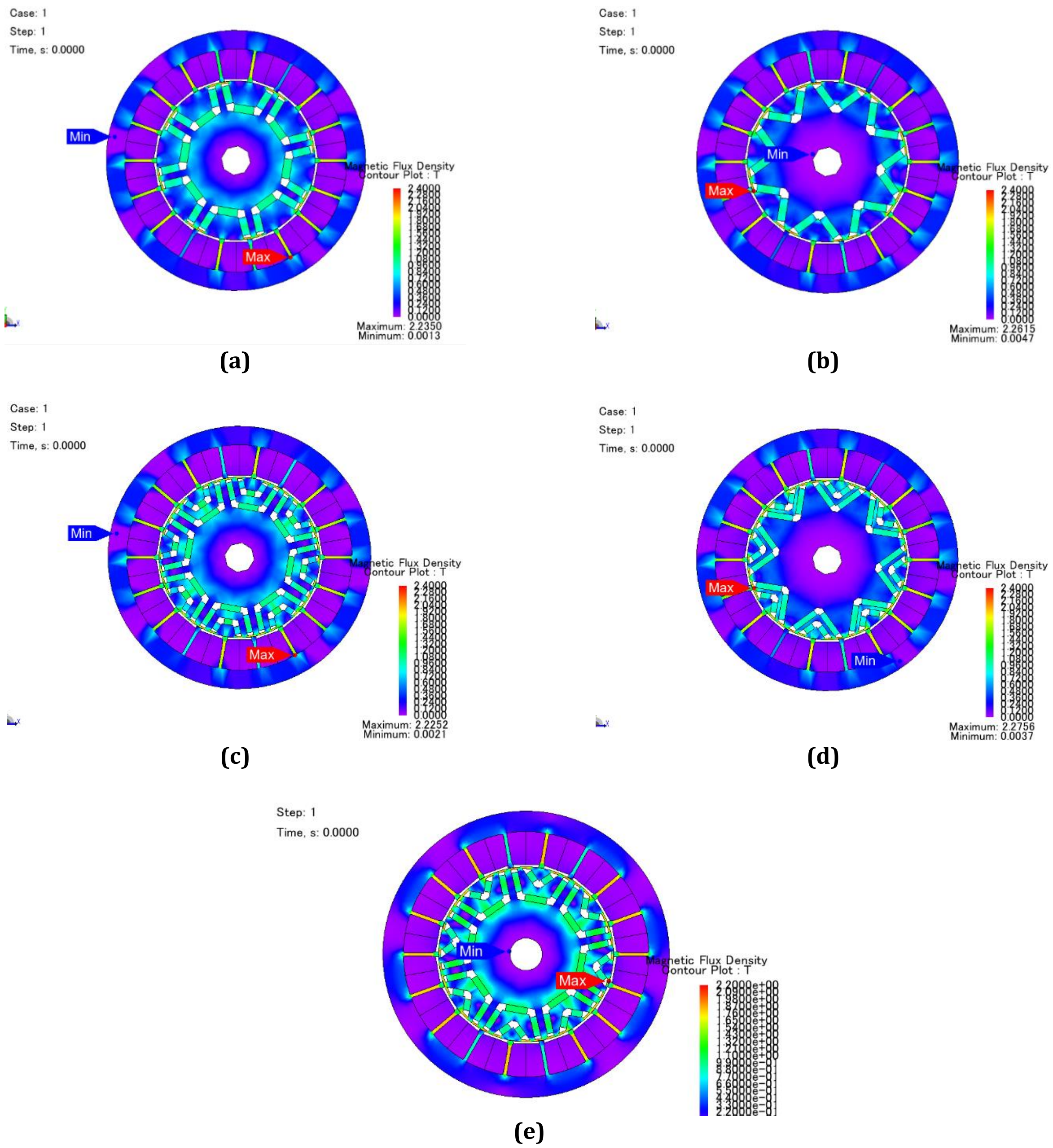

Fig. 4 *Flux distribution (a) Design 1; (b) Design 2; (c) Design 3; (d) Design 4; (e) Design 5*

4.2 Torque Performance

Fig. 5 illustrate the graph of torque vs speed for single layer IPM topology designs; Design 1 and Design 2. From the graph, V-shape IPM topology shows higher torque produced than U-shape topology. Fig. 6 present the torque performance for double layer IPM topology. Design 4, VV-shape IPM topology, lead the highest torque generated with 25.82Nm. Combination of V-shape permanent magnet topology results in better torque performance than combination of U-shape and UV-shape topology. In Fig. 7, the graph illustrates the comparison on torque performance among all proposed design. As seen in the graph, double layer of IPM topology has improved the torque performance than single layer IPM topology.

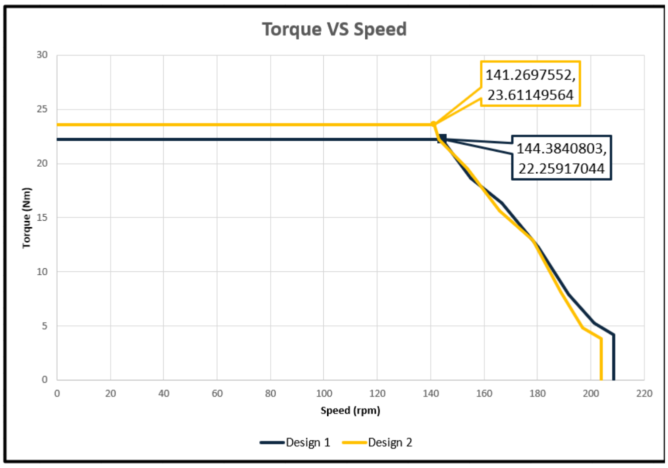

Fig. 5 *Result Torque vs Speed on Single Layer IPM Topologies*

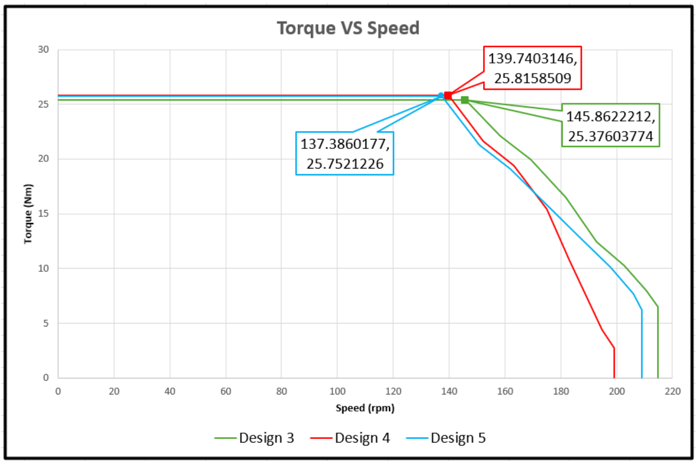

Fig. 6 *Result Torque vs Speed on Double Layer IPM Topologies*

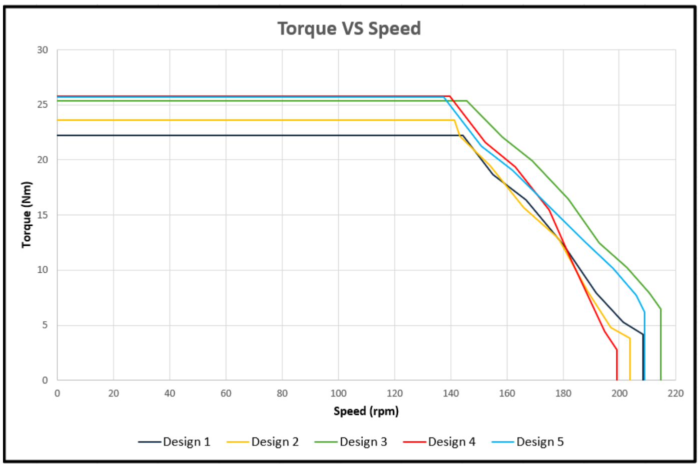

Fig. 7 *Result Torque vs Speed on all proposed IPM topologies*

4.3 Results of No-Load Test and Load Test

Table 3 shows the overall results of No-Load Test and Load Test for all proposed designs consists of Cogging Torque, Flux vs JA, Torque vs JA, Torque and Power vs Speed. As a final result, Design 4 which is VV-shape IPM topology was determined as the best design which generated the highest torque performance among all designs of U-shape, V-shape, UU-shape and UV-shape IPM topology.

Table 3 *Overall Results of No-Load Test and Load Test Analysis*

Design	Design 1 U-shape	Design 2 V-shape	Design 3 UU-shape	Design 4 VV-shape	Design 5 UV-shape
Cogging Torque (Nm)	5	13	10	13	12
Flux (Wb) at JA 30	2.77	2.78	2.70	2.79	2.87
Torque (Nm) at JA 30	20.28	22.99	21.73	24.45	20.28
Max. Power (W)	336.6	349.3	387.6	377.8	370.5
Max. Torque (Nm)	22.26	23.61	25.38	25.82	25.75

5. Conclusion

In conclusion, the designs of IPM topology that are presented in this project are U-shape, V-shape. UU-shape, VV-shape and UV-shape. Based on the evaluation of the results, it has been shown that all different designs have its own performance. Through the use of JMAG Designer, the electromagnetic performances of all designs are investigated and compared. According to the findings of the comparative test conducted without any load, the UU-shape topology has a greater back electromagnetic field (EMF) and V-shape produced the highest cogging torque. In addition to that, the results of the load test indicate that various IPM topology designs each have significant results. According to the findings, the VV-shape topology was determined as the design which generated the highest torque among the others designs. Double layer of IPM topology has better torque performance compared to single layer IPM topology. In summary, this project objectives have been achieved in term to determine the best design which have the best torque performance. However, these designs need optimization on the motor design to withstand a variety of intensive operating conditions safely.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author attests to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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