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A New Design of Double Stator Permanent Magnet Flux Switching Machine Employing H-Configuration Modular Rotor Using Finite Element Analysis

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Abstract: Permanent Magnet Flux Switching Machine (PMFSM) are widely used in medium to high scale industries of electrical vehicles. Due of the PMFSM flux's current focus on the utilizable stator, PMFSM has gained a lot of interest in motor design for the armature windings and permanent magnet excitation source and the salient rotor pole which is simple yet robust. However, a double stator of Alternate Circumferential Radial Flux (AlCiRaF) with a salient rotor of PMFSM has passed down the flux cancellation, high winding losses and high iron losses which can decrease the motor's efficiency and torque. Therefore, to overcome these weaknesses and disadvantages, in this study, a double stator PMFSM by employing H-configuration modular rotor was designed to improve the results of torque and efficiency of the motor. This newly designed motor is suitable to be used domestically for electric vehicles. The primary goals of this project are to develop and design for upgrading the torque density and the motor efficiency to be used in an electric vehicle that has a good system and flexible use in industries where the motor design developed can reduce the losses of the motor. In this project, the design of the double stator of PMFSM with modular rotor used JMAG Designer 16.0 is used as the main software to design this project from design to simulation step to observe the motor. The result shows this double stator of PMFSM with a modular rotor have high torque and efficiency compared to the design of double stator AlCiRaf of PMFSM with a salient rotor.

Keywords: PMFSM, Torque, Modular Rotor

1. Introduction

In 1955, Rauch and Johnson has introduced a single-phase PMFSM while in 1997, E.Hoang et al. built a three-phase system [1]-[2]. Electric motors are the most important element of the motor drive system. The demand for applications for high torque motors and high efficiency may be seen in electric

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motors as a result of rapid technology and innovation in electrical motors [3]-[4]. Due to the overwhelming advantages and more configurations that have been introduced by previous researchers, the rising research and design of permanent magnet flux switching machines (PMFSM) have shown to be attractive.

Consequently, many studies have been conducted to produce an electric motor with a robust rotor, high torque, high power, lightweight, and high efficiency [5]-[7]. However, with consistent PM flux operating as the only excitation flux source, it endures a demagnetization effect, flux leakage to the shaft, inability to produce torque for heavy-duty applications, and difficult PM flux regulation. There are various disadvantages of alternate circumferential and radial (AlCiRaF) PMFSM that lower the torque and efficiency of the motor, such as flux cancellation. Recently, PM with alternative circumferential and radial directions as illustrated in Figure 1 has been developed [8].

To resolve the issue, optimization of a double stator with H-configuration modular rotor permanent magnet PMFSM with unique features of non-overlap winding, low copper losses, high efficiency and a smaller number of permanent magnets (PM) has been proposed in this paper. This project purpose is to optimize a double stator PMFSM by employing H-configuration modular rotor to identify the motor performance. Figure 1: Conventional design of DS-PMFSM.

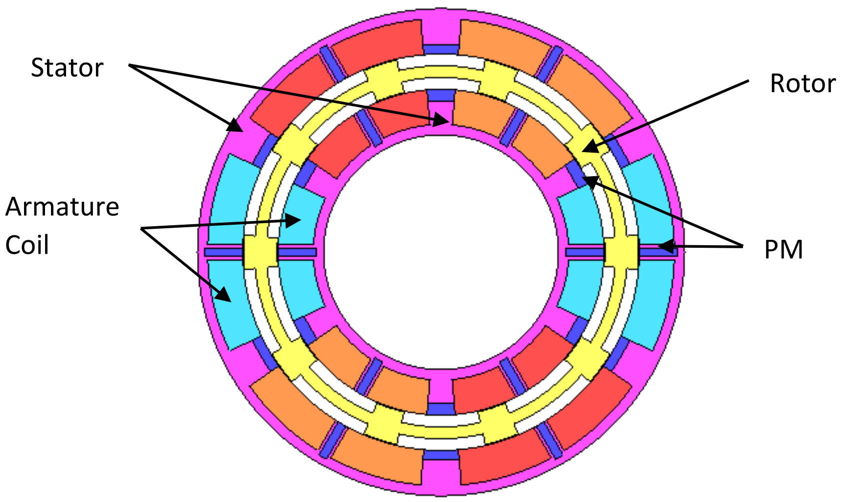

Figure 1: Conventional design of DS-PMFSM

2. Materials and Methods

Additionally, the methodology of this study will be carried out in order to complete and optimize the data collection and analysis process by employing JMAG-Designer version 16.0 software in a more systematic and organized way. JMAG software is divided into two parts for instance, JMAG Designer and JMAG Geometry Editor which is used to design individual parts of the machine and analyse the electrochemical design performance. Moreover, this software is user-friendly and can require flexibility to support users from analytical design to overall comprehensive analysis.

2.1 Materials and conditions

The materials and setup procedures for the rotor, stator, armature coil, and permanent magnet are shown in Table 1. Moreover, the rotation of the rotor part is set to rotate at a durable revolution speed of 1500 r/min. Additionally, the rotational axis acquires the exact identical application of the torque nodal force. This is because to define and estimate the torque operating value on magnetic materials.

Table 1: List of specific materials and conditions

Parts	Materials	Condition
Rotor	Nippon Steel 35H210	Motion: rotation
		Torque: nodal force
Stator	Nippon Steel 35H210	-
Armature Coil	Conductor Copper	FEM Coil
Permanent Magnet	Neomax35AH (irreversible)	Motion: rotation
	(Alternate Radial and Circumferential Anisotropic Pattern)	Torque: nodal force

2.2 Methods

The proposed design of the Double Stator H-configuration Modular Rotor PMFSM has been conducted separately in two phases which are JMAG Designer and JMAG Geometry Editor. Each part of the motor is initially designed in the geometry editor while JMAG-Designer is used to develop and set the material and condition for the motor in order to analyze and simulate the motor. The workflow of the design is shown in Figure 2.

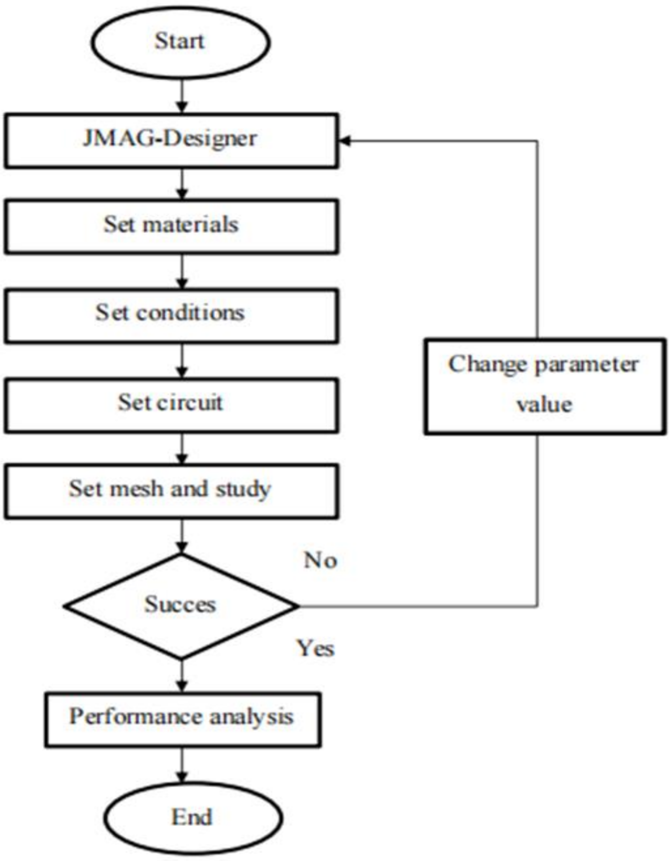

Figure 2: JMAG-Designer workflow

2.3 Design topologies and specifications

The design of the DS H-Configuration modular rotor PMFSM is based on the conventional double stator design PMFSM. Thus, the specification and design of the rotor and stator is derived from the DS-PMFSM design. Table 2 shows the specification of the designed motor.

Table 2: Specification of designed motor

Description	Value
Inner diameter of inner stator, mm	30.0
Outer diameter of inner stator, mm	45.5
Inner diameter of outer stator, mm	131.25
Outer diameter of outer stator, mm	154.5
Stator tooth width, mm	6.0
Motor stack length, mm	70.0
Inner diameter of rotor, mm	45.8
Outer diameter of rotor, mm	130.8
Rotor tooth width, mm	21.4
PM weight, kg	0.5
Air gap, mm	0.3
Rotor tooth	20
Number of turn of outer Armature coils	107
Number of turn of inner Armature coils	50

2.3.1 Mesh, magnetic and properties setting

There are a few values that need to be set up in the properties of JMAG Designer software. It is divided into two parts which are step control and model conversion. The full model conversion is where the stack length is established, while the step control component is where the end time, division, and steps are determined. The parameters for the stack length, division, end time, and steps are set at 37, 0.0028s, 36, and 70 mm, respectively. Equation (1) is used to acquire the end time, t_e of the motor.

$$t_e = \frac{1}{f_e} \tag{1}$$

where t_e stands for the end time and f_e is electrical frequency. The expression describes electrical frequency as shown Equation (2).

$$f_e = N_r f_m \tag{2}$$

where f_e is stand for the frequency of electricity. N_r is described as motor rotor pole number, while f_m is defined as the motor frequency. Meanwhile, the motor frequency, f_m can be defined by Equation (3).

$$f_m = \frac{n}{60} \tag{3}$$

In which f_m is the frequency of the motor while n is defined as motor speed.

2.3.2 Load test

The electric motor performance can be evaluated under load conditions. The load test condition can be analysed by varying the armature current density from 0 A_{rms}/mm^2 to 30 A_{rms}/mm^2. The formula that is used to determine the input current value is as shown in Equation (4). Other than that, the load condition of the motor is analysed based on the torque performance, power, speed, iron and copper losses and efficiency. Table 3 shows the value of peak armature current and RMS armature current for the inner stator.

$$I_A = \frac{\sqrt{2}\, J_A \alpha_A \delta_A}{N_A} \quad (4)$$

where

I_A = Inject current value of armature coil, A(peak)
J_A = Armature coil current density, A_{rms}/mm^2
α_A= Armature coil filling factor (set to 0.5)
δ_A= Armature coil slot area.
N_A= Number of turns.

Table 3: Inner Stator Current injection of I_{peak} and I_{RMS} to its current density, J_A

Armature current density, Ja	Ia, rms	Ia peak
5	10.7255	15.168
10	21.4510	30.3362
15	32.1764	45.5044
20	42.9019	60.6725
25	53.6274	75.8406
30	64.3529	91.0087

An analysis of torque and power vs speed was conducted in order to determine the values of maximum torque, output power, and motor speed (rpm). By using Equation (5), which is based on the torque versus speed curve, the output power of the motor can be determined and calculated.

$$P_o = \frac{2\pi N_M \tau}{60} \quad (5)$$

where

N_M = Motor speed (rpm)
τ = Torque

3. Results and Discussion

The design of Double Stator with H-configuration modular rotor PMFSM has been constructed as shown in Figure 3. This proposed designed has two stators, 24 armature coils, 12 permanent magnets and 5 rotors.

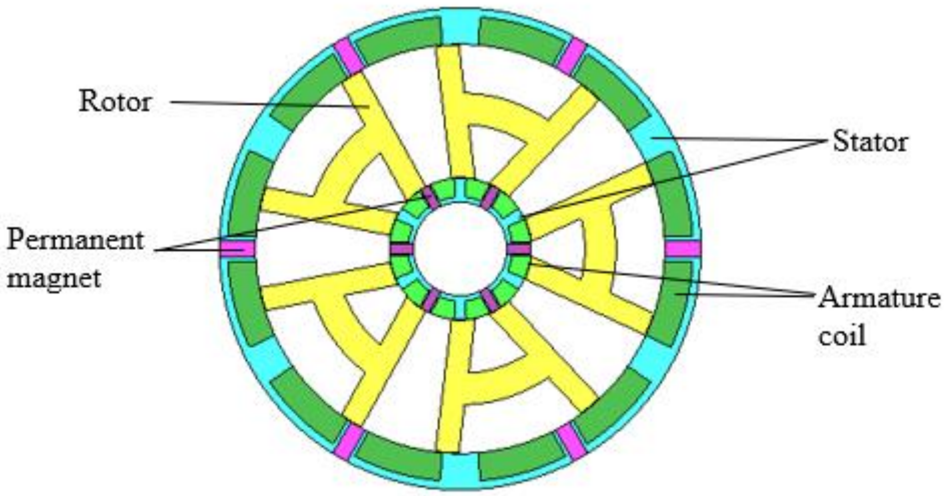

Figure 3: The design of Double Stator with H-configuration modular rotor PMFSM

3.1 Coil Test Analysis

For coil flux linkage, the connection and coil link for U, V and W coil test circuits must be in the correct connection because the circuit is slightly different from the other coil test. To ensure that the principle operation of double stator PMFSM is verifiable, U, V and W coil test is accomplished in each armature coils and the results is as shown in Figure 4.

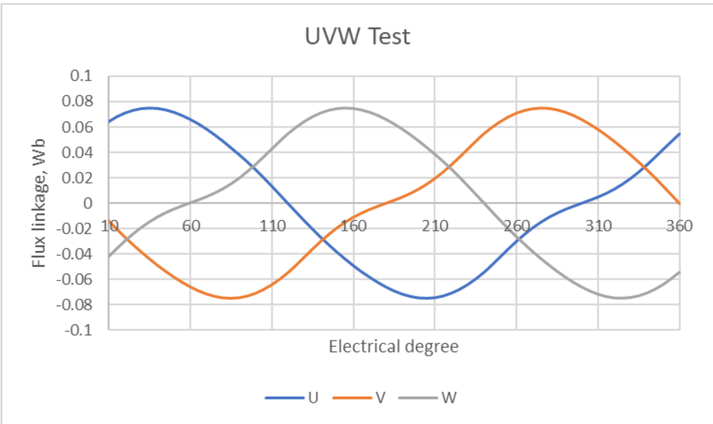

Figure 4: UVW Test

3.2 Flux Line and Flux Distribution

To complete one full flux cycle, all flux lines travels from the stator to the rotor and return. Flux-orientation observation were observed under open circuit conditions in which all machine topologies are compared at zero-degree rotor position. Figure 5(a) below shows the flux line of the motor. Next, flux distribution analysis is done to determine the flux distribution of the DS PMFSM where the colour determine the magnetic flux density as shown in Figure 5(b) Based on the observation of the flux distribution, the maximum flux density is 2.9994 Nm and the minimum value is 0.00004 Nm.

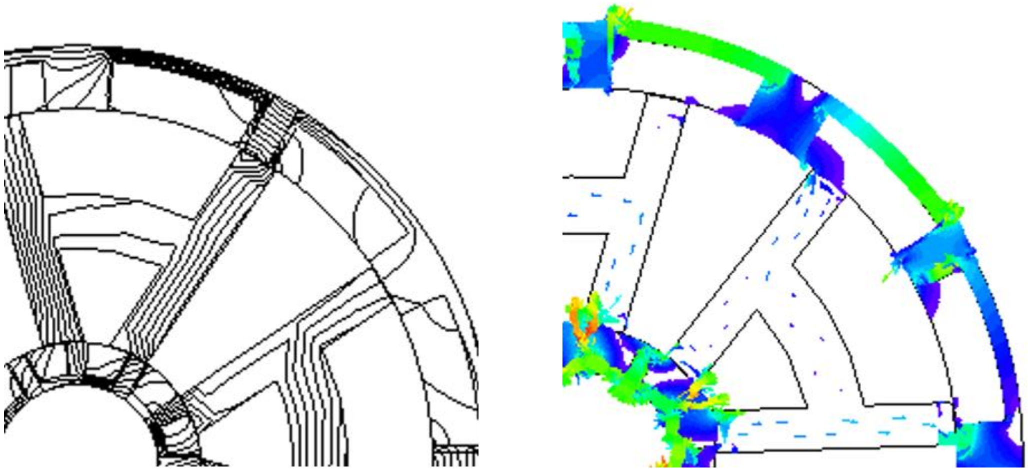

Figure 5: (a) Flux Line of the motor (b) Flux Distribution

3.3 Torque Density Analysis

Figure 6 represent the torque density graph for the proposed design of DS-PMFSM. The data shows that, DS-PMFSM has the peak to peak torque density value of 46.13 Nm. The results obtained shows that the increasing value of Ja will eventually cause the torque increased respectively.

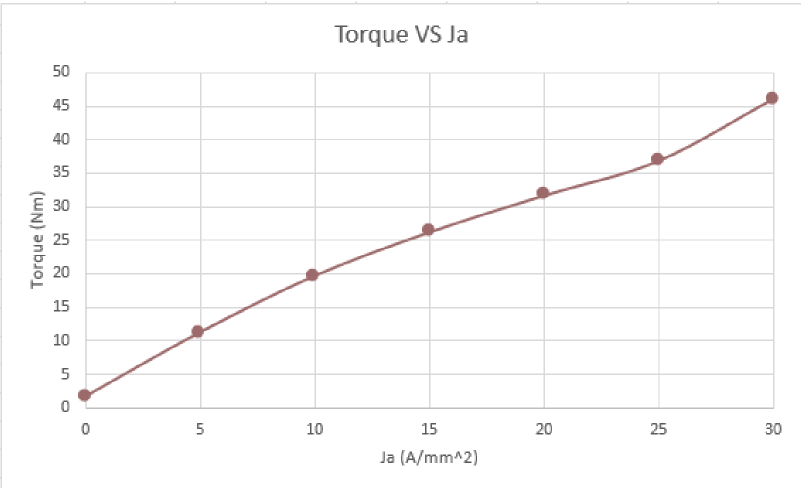

Figure 6: Torque versus current density

4. Conclusion

As a conclusion in this paper, a double stator with H-configuration modular rotor PMFSM has been designed to analyse it performances by using JMAG software. The design procedure has been discussed in detail. The design was examined under two different conditions which is no-load condition and load conditions. The observation included the analysis of magnetic flux linkages, cogging torque, induced voltage, and flux line distribution of DS-PMFSM. Next, the design was analyzed under load condition which is to determine the performance of DS-PMFSM in terms of torque performances. It was determined that the proposed designed in this paper achieved 46.13Nm.

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