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Influence of pole number on the characteristics of permanent magnet synchronous motor (PMSM)

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ABSTRACT

This paper present the influence of pole number on the characteristics of permanent magnet synchronous motor (PMSM). This study is devoted to construct three different motors with varying pole numbers and investigating its effect on the characteristics of permanent magnet synchronous motor (PMSM). It is a study on an influence of pole numbers on electromagnetic and thermal characteristics of the PMSMs all while maintaining the same motor dimensions, parameters and slot number. The study is conducted to analyse the best slot-pole combination for a given dimension to determine if pole numbers have a role in the motor performance. The analysis for these permanent magnet motors is done via finite element analysis (FEA) in which JMAG Designer software is used. The software is used to analyse the motor performance in terms of cogging torque, speed, power, iron loss, copper loss as well as the efficiency of the motor itself. All three motors were simulated in no load and load condition.

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1. INTRODUCTION

Studies Studies on electric vehicles are actively pursued as an environment friendly technology as it is becoming important as the possibilities to improve fuel efficiency is higher using regenerated kinetic energy; mainly utilizing electric motors. Electric machines are devices that are used in conversion of electromechanical energy and conversion of electrical energy to mechanical energy by electrical motors can be divided into two; direct current (DC) motor and alternating current (AC) motor [1].

Often used in electric vehicles are the permanent magnet motors as these motors are highly efficient because secondary copper loss does not occur as current induced magnetic field is unnecessary [2-3]. Besides, it has an advantage of making the motor smaller by being able to raise the magnetic flux density [4]. As per basic requirements, electric vehicle drive system requires high efficiency, high torque density as well as constant power at high speed and permanent magnet motor will be suitable in experimenting for these characteristics.

Permanent magnet synchronous motors and synchronous motors basically works the same way and have similar performance characteristics. A standard synchronous motor without field winding and slip rings can be exactly alike in configuration to that of a permanent magnet synchronous motor. Magnetic pole number and line frequency determines the speed of the synchronous motor [5].

When compared to induction motors as in Figure 1, it is also similar but the only difference is that in PMSM, the permanent magnet generates the rotor magnetic field. Substantial air gap magnetic flux produced by the usage of permanent magnet allows the designing of highly efficient permanent magnet motors.

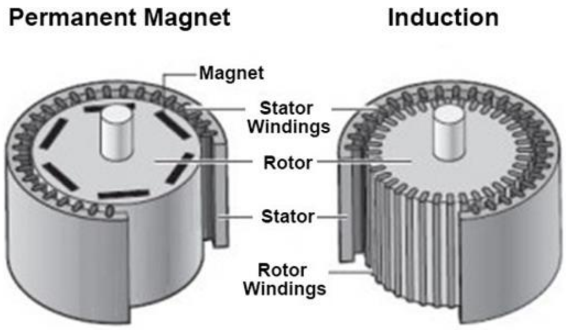


Figure 1. Comparison of permanent magnet motor and induction motor

From Figure 2, we can see the cross section of a basic permanent magnet synchronous motor. It generally has a stationary element also known as stator, an electromagnet, which makes up the outer part of the motor. Soft steel strips make the stator laminations windings in axial air gap machines. Those laminations have teeth slots for the armature windings and its thickness is affected by the cost and armature source voltage frequency. The magnetic path is completed by the yoke of the motor.

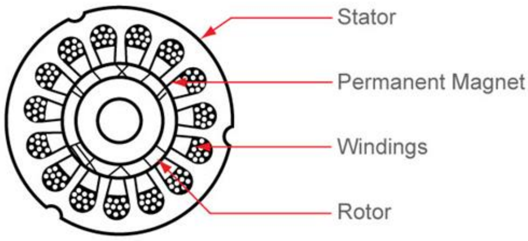


Figure 2. Cross section of simple PMSM

2. DESIGN RESTRICTIONS AND SPECIFICATIONS

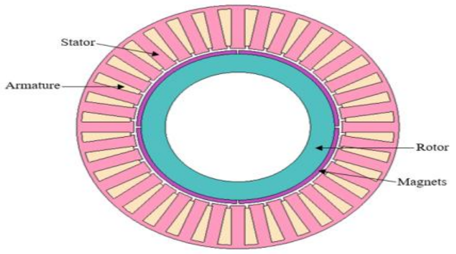
The relationships between parameters of the motor design are used to study the pole number effect on electromagnetic characteristic of the permanent magnet synchronous motors. These motors have their designs modified to have their electromagnetic characteristics tested at 1500 rpm with the design constraints as in Table 1.

Table 1. Design parameters of proposed PMSMs

Items	Dimensions
Rated speed [rpm]	1500
Stator diameter [mm]	260
Rotor diameter [mm]	156
Number of slots	36
Number of poles	4,6,12
Slot opening [mm]	2.532
Core back width [mm]	3.9
Tooth width [mm]	11
Tooth tang depth [mm]	3
Gap between magnet [mm]	1.692
Number of turns of armature coil	15

The three-phase PMSM motors that were designed are 36S-4P, 36S-6P and the 36S-12P respectively. They have the same stator pole number with the stated dimension specifications while number of pole is varied from one and the other. The cross-sections of the motors are shown in Figure 3.

JMAG Designer version 14 was used to carry out this study. Data analysis in the form of 2D-FEA are the results obtained in this study.



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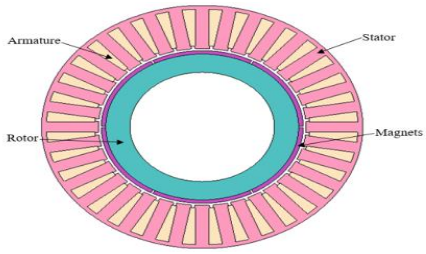

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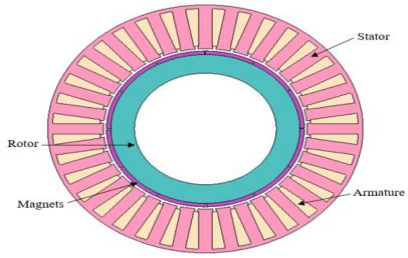

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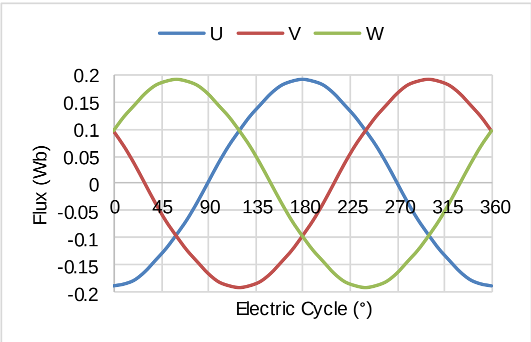
Figure 3. Finished design of PMSM motors (a) 36S-4P (b) 36S-6P (c) 36S-12P

3. PERFORMANCE OF 36S-4P, 36S-6P and 36S-12P PMSMs

3.1. Armature Coil Operating Principle Analysis

The operating principle and arrangement of armature coils are verified through the coil test conducted at no load condition. The aim of this test is to validate the operating principle of the designed PMSMs by setting the position of the armature coils. Accordingly, the tests are conducted separately for each coil thus defining the armature coil phases into its conventional three phase system; U, V and W. Figure 4 illustrates the 3-phase flux linkage achievement with separate phase of 120° apart.



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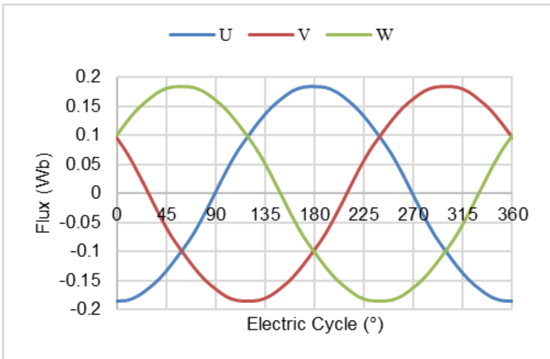

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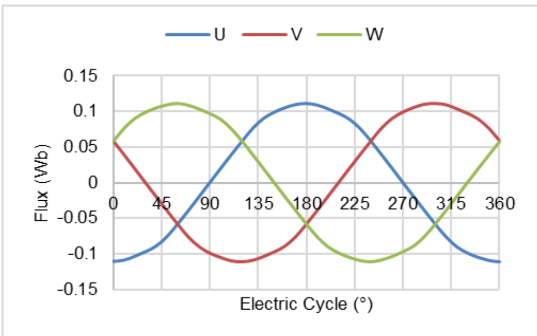

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Figure 4. Graph of Flux linkage (a) 36S-4P PMSM (b) 36S-6P PMSM (c) 36S-12P PMSM

3.2. Back -Emf

Figure 5 shows the back-emf graph the 36S-4P PMSM, 36S-6P PMSM and the 36S-12P PMSM configuration when the motors rotate at a speed of 1500 rev/min. The 36S-4P conventional PMSM is observed to have an amplitude of 204.11 V while the proposed 36S-6P PMSM has a peak value of 313.53 V whose waveform is characterized by degraded harmonics. Meanwhile, the 36S-12P PMSM achieved back-emf value of 400.36 V with a better sinusoidal waveform.

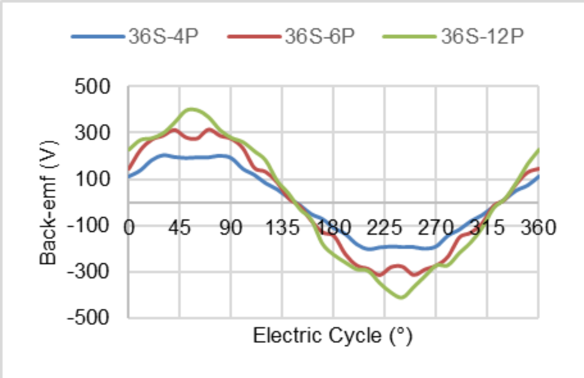


Figure 5. Comparation of back EMF for all three motors

3.3. Torque versus Armature Current J_A

The torque against armature current density of the motors is conducted by injecting the current varied from J_A 5 A/mm^2 to J_A 30 A/mm^2 into the FEM coil in order to analyse the pattern of torque behaviour. Simulated results of the 36S- 4P, 36S-6P and 36S-12P PMSMs are shown in Figure 6. From the graph, it can be observed that the torque gradually increases as higher value of current is injected. The highest torque is obtained with the maximum armature current density of 30A /mm^2. The torque values for the 36S-4P, 36S-6P and 36S-12P motors are recorded as 112.6 Nm, 187 Nm and 205.4 Nm respectively. It is obvious that the 36S-12P motor has the highest output torque followed by the 36S-6P and lastly 36S-4P PMSM.

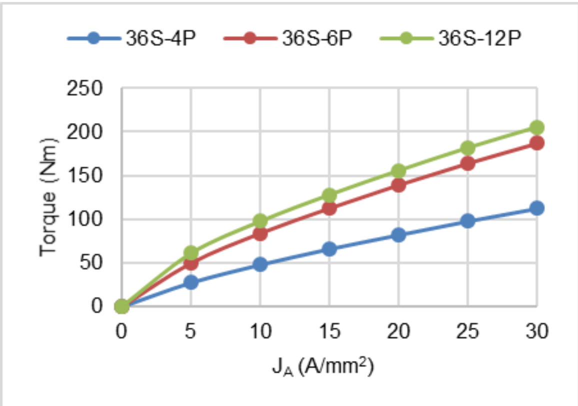


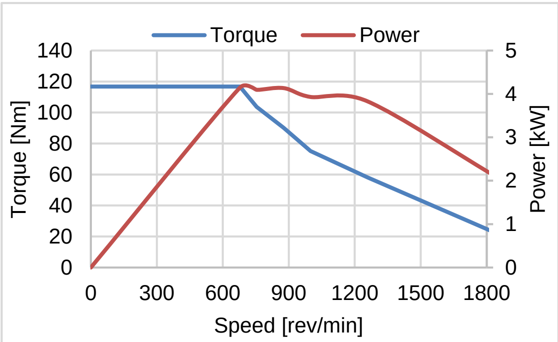
Figure 6. Torque vs various J_A for different number of poles

3.4. Torque and Power versus Speed

The torque and power versus speed characteristics of the designed motors are shown in Figures 7. In each plot, the blue curve represents torque versus speed while the orange line represents the power versus speed curve. Figure 7(a) shows that at base speed of 678 rpm, the highest torque of the 36S-4P PMSM is 116.8 Nm at which the power output is 4.15kW. At the maximum speed of 1800 rpm, there is a decline in the output power up to 45%, where the value is 2.3kW.

As in Figure 7(b), the 36S-6P PMSM reached a maximum torque of 189.26 Nm at the base speed of 768 rpm and begins to decrease when operated beyond the base speed region due to high iron loss. Furthermore, the power accomplished is 7.6 kW before decreasing to 2.9kW which is about 62%, upon reaching a maximum speed of 1800 rpm.

However, the 36S-12P motor as in Figure 7(c), achieved the highest output torque when compared with all three designs. The torque value is 209.5 Nm at a base speed of 960rpm is achieved. The output power peaked at 10.52kW and as the speed reached its maximum at 1800 rpm, the power gradually reduces about 12.55% to 9.2kW.



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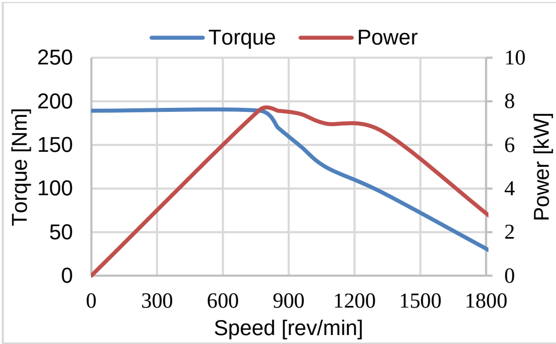

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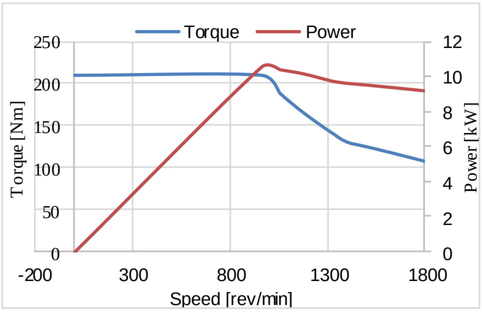

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Figure 7. Torque and power vs speed graph for (a) 36S-4P PMSM (b) 36S-6P PMSM (c) 36S-12P PMSM

4. CONCLUSION

Effects of pole number on the electromagnetic characteristics has been evaluated and analyzed. The selected pole number combination that is analyzed are 36S-4P, 36S-6P and 36S-12P PMSMs. The operating principles of all three designs with varying pole number was observed and validated through successful development of design and coil test analysis as well as its performance tested through no load and load analysis. It is evident that the pole number plays a role in determining the efficiency and smoothness of a motor.

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