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# A Method of Reducing Cogging Torque by Using Magnet Shifting Angle in Permanent Magnet Motor

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**Abstract**: Cogging torque is unwanted element in the PMM. It can cause many problems such as noise, vibration and speed ripple. In this study, the permanent magnet angle shifting method has been chosen to reduce cogging torque for permanent magnet motor by using JMAG software. PM angle shifting method is a method where PM is move apart from each other according to the accurate angle. Three design of PM was investigated in this research to determine the reduction of cogging torque value in the PMM. In conclusions, cogging torque of PMM is reduced by 29.4% compared to the previous PMM without angle shifting method.

**Keywords**: Cogging Torque, Angle Shifting Method, Permanent Magnet Motor

## 1. Introduction

In automotive industry, the production of hybrid-electric car is widespread to generate energy efficiently according to [1]. Most of them are using permanent magnet motor (PMM) to generate the engine. However, the uses of permanent magnet motor will contribute few problems and one of them is cogging torque. Cogging torque is the interaction between permanent magnet and slot armature lamination [2]. When the rotor teeth and stator teeth face each other, reluctant of magnetic path is minimum. So, rotor remain fixed and that is called cogging torque. permanent magnet motor will produce vibration and noise if cogging torque exist.

Few methods have been studied to reduce the cogging torque in permanent magnet motor such as teeth width design, teeth pairing design, teeth notching design, interpole design, magnet arc design, magnet edge shaping, magnetization status design, Permanent Magnet (PM) pole pairing, PM shifting, interior PM design, skewing and asymmetric motors [3].

In this study, PM shifting method is to analyse the reduction of cogging torque on PMM. This method is applied by shift the angle of PM from its original PM angle. The maximum reduction of cogging torque also depends on the number of pole pairs, the number of slot and the greatest common divisor between them [4].

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## 2. Materials and Methods

The 6-slots 4-poles permanent magnet motor structure is completed by using 2D-Finite Element Analysis (FEA) approach. JMAG is simulation software purposely for electromechanical design striving to be user-friendly while providing versatility to offer support from conceptual design to comprehensive analysis [5].

### 2.1 Materials

Figure 1 shows detail of parameters of PMM. In creating the design, the rotor needs to be design in JMAG Geometry Editor accurately to avoid air gap and overlap between it and permanent magnet. The radius of inner and outer rotor are in the Table 1 at angle 45°. The stator construction starts at 0° precisely at y=0 and x=45. The material of the rotor and stator steel used in this study is 35H210. The permanent magnet material used is Neomax-35AH. Besides, the condition setting for rotor and permanent magnet is set to motion rotation and the type of torque is nodal force. FEM coil is used for armature coil condition setting.

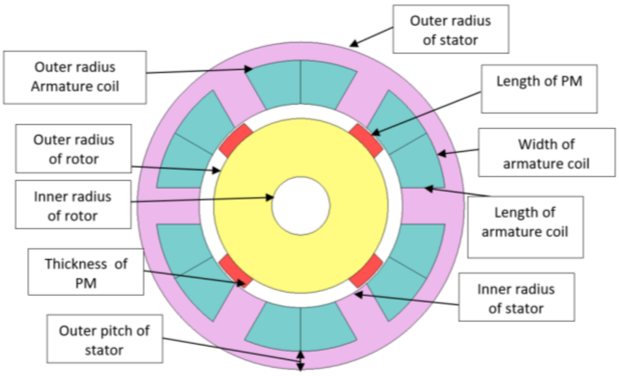


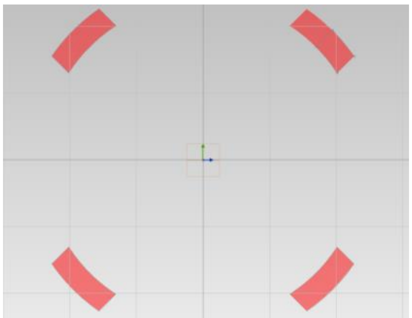

**Figure 1: Detail of parameters of PMM**

**Table 1: Permanent magnet motor specification**

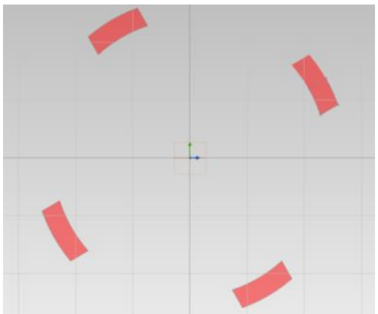
| Parameters | Size | Unit |
|---|---|---|
| Stator slot/teeth number | 6 | |
| Stator inner radius | 28 | mm |
| Stator outer radius | 45 | mm |
| Stator outer pitch | 5 | mm |
| Armature coil length | 12 | mm |
| Armature coil width | 20 | mm |
| Rotor outer radius | 24 | mm |
| Rotor inner radius | 8 | mm |
| PM thickness | 3.5 | mm |
| PM length | 10 | mm |
| Number of pole | 4 | |
| Shaft | 8 | mm |
| Stack length | 25 | mm |
| Air gap | 0.5 | mm |
| No. of turns | 10 | |
| Speed | 1200 | rpm |
| Frequency | 10 | Hz |

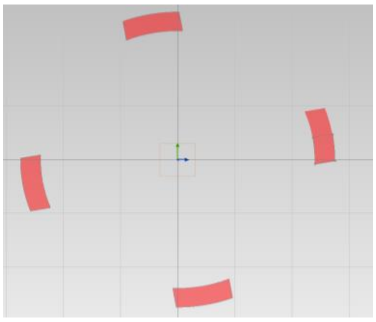
### 2.2 Methods

This study is focus on how the cogging torque can be reduce by shift the permanent magnet. The permanent magnet is shifted by move a few angles from original permanent magnet. In this study use angle 45° as the original angle of permanent magnet, then shifted to angle 30° and 10° to optimize the torque by reducing cogging torque. Then, the permanent magnet angle is shifted about 15° and 35° from original angle. The configuration of permanent magnet for original and with using permanent magnet angle shifting method as in the Figure 2.



a)





b) c)

**Figure 2: Permanent magnet configuration. a) Original angle of PM.**

**b) PM angle shifting to 30 ° a) PM angle shifting to 10 °**

## 3. Results and Discussion

The results and discussion section presents data and analysis of the study. Basically, this section is to discuss the cogging torque reduction analysis between original and shifted angle permanent magnet.

### 3.1 Cogging Torque Reduction

Cogging torque cannot be completely eliminate but it can be reduced by few methods. High cogging torque in a motor lead the motor to be vibrate, has noise and affect the self-start ability. Two angles of permanent magnet have been introduced in this study. Original angle for permanent magnet is at 45°, first shifted angle is at 30° and second shifted angle is at 10° of the rotor. All material, condition and parameter of the motor are same for all three designs but only the angle of permanent magnet is change. Figure 3 is the comparison of cogging torque occur in the original angle and shifting angle method during the armature current density is 0Arms/$mm^2$. Maximum cogging torque for original angle is 0.4316Nm but by using permanent magnet shifting angle the cogging torque is reduced to 0.305Nm.

Table 2 is a data that has been interpreted before and after the reduction of cogging torque. Original angle of cogging torque value achieve maximum value is 0.432Nm. After coming out with new design of permanent magnet which shifted the angle to 30°, the cogging torque is decrease from before. The cogging torque reduction for angle 30° is about 27.3% from original angle. Then, to make the motor more efficient, the permanent magnet come out with another new design where place the PM at angle 10°. The result from new design quite impressive because the cogging torque reduce until 29.4%. So, from the research can be said that the cogging torque reduction increase due to the distance from original to new design is increase.

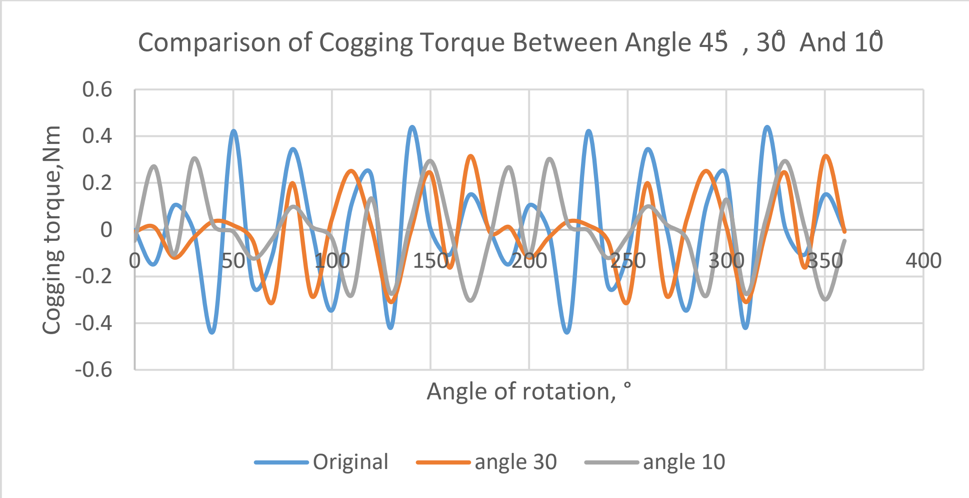



**Figure 3: Comparison of cogging torque between original angle and shifted angle in the motor**

**Table 2: The information of cogging torque reduction for both 30 ° and 10 ° design of permanent magnet.**

| | Permanent Magnet Shifted Angle | |
|---|---|---|
| | 30° | 10° |
| Maximum Cogging Torque Original Angle (Nm) | 0.432 | 0.432 |
| Maximum Cogging Torque (Nm) | 0.314 | 0.305 |
| Cogging Torque reduction (%) | 27.3 | 29.4 |

### 3.2 Armature Current Density and Torque Performance

This test is affecting the torque performance in the PMM. To observe the torque performance, research for torque with armature current density was carried out. The research consists of all three design of permanent magnet motor. The load used can be determine by (1) where $IA_{rms}$ , $J_A$ , $\alpha_A$ , $\delta_A$ , and $N_A$ is the input current, armature current density, filling factor, slot area and number of turns respectively. From the graph pattern, the graph is increasing linearly.

$$IA_{rms} = \frac{J_A \ \alpha_A \ \delta_A}{N_A} \qquad \textit{Eq. 1}$$

The average of torque versus armature current density is as illustrate in the Figure 4. The graph is containing the average of torque performance when armature current density is applied from 5Arms/$mm^2$, 10Arms/$mm^2$, 15Arms/$mm^2$, 20Arms/$mm^2$, 25Arms/$mm^2$ until 30Arms/$mm^2$. The average of torque for all design is increase when the armature current density increase.

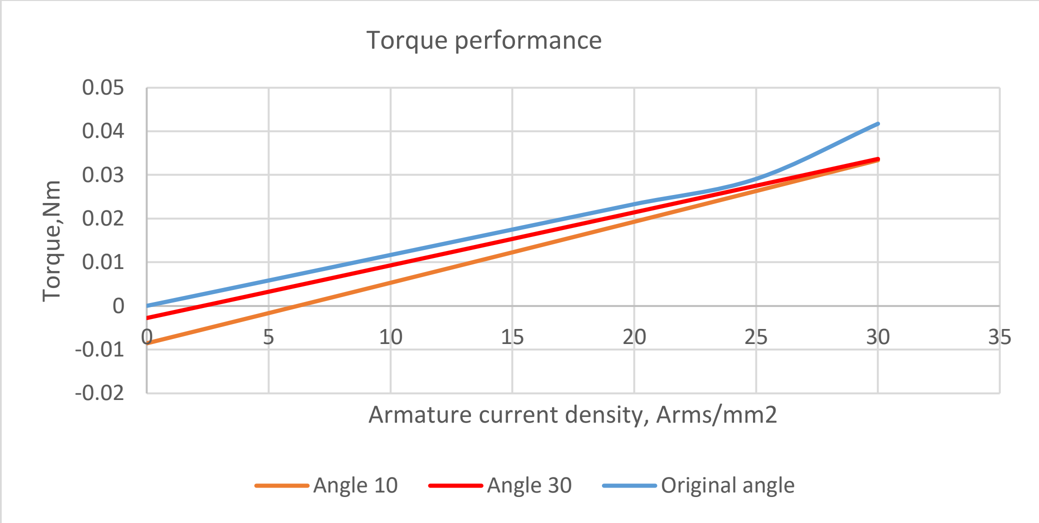



**Figure 4: Comparison between armature current density and average of torque at difference angle of permanent magnet**

## 4. Conclusion

PMMs have cogging torque which its quantity is depends on the structure of the motor. The surface mounted PMM was proposed in this study to evaluate the reduction of cogging torque. The PM shifting angle method is an effective way to reduce the cogging torque in PMM. Cogging torque occurs when the armature current density is 0Arms/$mm^2$. Besides that, the reduction of cogging torque happens for a few reasons. First, when magnetic flux linkage increases, the flux between rotor and stator decreases, which leads to cogging torque decreasing too. Second, the more the angle is shifted from the original angle, the less the cogging torque in a motor becomes. This project also investigated the performance of torque when loads are applied.

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