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Research Article

Examination of Cogging Torque for Surface Mounted PMSM with Outer Rotor

Mümtaz Mutluer[1*]

[1*] Necmettin Erbakan University, Faculty of Engineering, Departmant of Elecelectrical & Electronics Engineering, Konya, Turkey, (ORCID: 0000-0002-6781-8937), mmutluer@erbakan.edu.tr

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Abstract

One of the most important structural problems for permanent magnet synchronous motors is the cogging torque. One of the most effective ways to reduce the cogging torque is that magnets or slots are skewed. However, this will negatively affect the motor cost and production time. On the other hand, the cogging torque depends on the change in the reluctance of the motor in the air gap during operation. Therefore, the most important design approach to reduce the cogging torque is to examine the parameters that affect the air gap reluctance. In this study, the change of air gap reluctance of surface mounted permanent magnet synchronous motor with outer rotor during operation is investigated. For this purpose, the five most important parameters affecting the air gap reluctance change are selected. In this way, the best motor model with low cogging torque is tried to be obtained.

Keywords: Air-gap reluctance, Cogging torque, Outer rotor, Permanent magnet synchronous motor

Dış Rotorlu Yüzeye Monte PMSM için Vuruntu Momentinin İncelenmesi

Öz

Sabit mıknatıslı senkron motorlar için en önemli yapısal sorunlardan biri vuruntu momentidir. Vuruntu momentini azaltmanın en etkili yollarından biri, mıknatısların veya olukların kaykılı olmasıdır. Ancak bu işlem, motor maliyetini ve üretim süresini olumsuz etkileyecektir. Öte yandan, vuruntu momenti, çalışma sırasında motorun hava boşluğundaki relüktans değişimine bağlıdır. Bu nedenle vuruntu momentini azaltmak için en önemli tasarım yaklaşımı, hava boşluğu relüktansını etkileyen parametreleri incelemektir. Bu çalışmada, dış rotorlu yüzeye monte sabit mıknatıslı senkron motorun hava boşluğu relüktansının çalışma sırasında değişimi incelenmiştir. Bu amaçla, hava boşluğu relüktans değişimini etkileyen en önemli beş parametre seçilmiştir. Bu sayede düşük vuruntu momentane sahip en iyi motor modeli elde edilmeye çalışılmıştır.

Anahtar Kelimeler: Hava boşluğu relüktansı, Vuruntu momenti, Dış rotor, Kalıcı mıknatıslı senkron motor

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[*] Corresponding Author: mmutluer@erbakan.edu.tr

1. Introduction

Permanent magnet synchronous motors (PMSM) are preferred in many industrial applications for reasons such as providing high torque at low speeds, high power density and high efficiency [Mutluer et al, 2020]. Contrary to the works in which gear system is used, the fact that it offers gearless operation makes PMSM more preferred. Especially in elevator systems, the use of surface mounted PMSM with inner at low speeds is quite popular [Yetiş et al, 2018; Tükenmez Ergene et al, 2018]. In high-speed electrical vehicles, the use of surface mounted PMSM with outer rotor as hub-motor is also suitable for the ease of use of permanent magnets and to obtain high magnetic power density.

Permanent magnet synchronous motors are very superior and bring some difficulties in design and drive systems. The most important challenge encountered in design is cogging torque. Cogging torque is a structural problem and is related to air gap reluctance [Hanselman, 2006]. It can be minimized in effective solutions such as skew in design [Guemes et al, 2008]. However, it is possible to produce solutions based on parameters besides the solutions that are difficult in terms of time and cost.

One of the ways to reduce cogging torque is to choose the appropriate slot/pole combination before starting design. It should be noted that fractional slot PMSMs have lower cogging torque than integral slot PMSMs. Also, the larger the lowest common multiple of the number of slots and the number of poles, the lower the cogging torque will be. This is because the cogging torque created by magnets is added to each other in integral slot PMSMs, while in fractional slot PMSMs they can be opposite to each other. These opposing forces significantly reduce the net cogging torque at the highest the least common multiple between the number of slots and the number of poles [Hanselman, 2006]. However, low cogging torque does not always guarantee low torque vibration [Meier, 2008].

One of the most important methods of cogging torque reduction is to optimize the parameters that will affect the air gap reluctance change [Herlina, 2017]. Generally, these parameters are magnet sizes and stator slot wedge sizes. By optimizing these parameters, a motor model that will minimize the cogging torque can be obtained. Sempere et al. analyzed the cogging torque for radial and parallel magnetized dc and ac motors. First, the analytical model was developed and then the results were confirmed by finite element analysis. In the cogging torque analysis, only the effects of changing the magnet shape were investigated [Sempere et al, 2017]. Saxena and Fernandes tried to reduce the cogging torque, which is the most important factor in reducing the noise of fan motors. In order to achieve this, they tried to find a solution by magnet skew by single step and by changing the stator tooth shape [Saxena and Fernandes, 2015].

In this study, five parameters selected such as stator slot opening, slot opening height, magnet thickness, magnet offset and magnet embrace and then cogging torque of the motor are investigated. First of all, finite element analysis of the initial motor is made with the basic sizes of these parameters. Then, cogging torque change is observed with the change of selected parameters. According to the results, a motor model with a very small cogging torque value is obtained.

2. Analysis of the PMSM

Surface mounted permanent magnet synchronous motors have two structures: inner rotor and outer rotor. Due to the increase in the diameter of the magnet in the outer rotor structure, the power density in the same volume is high. As the rotor is outside and the magnets are adhered to the inner surface of the rotor, the magnets are protected against centrifugal force, so that the permanent magnets are not thrown from the rotor surface. In this type of motors, the magnet flux is radial. Distributed or concentrated winding is used according to the slot/pole combination of the motor. In this study, the cogging torque of a PMSM suitable for high powers has been investigated. The two-dimensional representation of the PMSM is given in Figure 1.

In this study, cogging torque analysis of a 50kW surface mounted PMSM with outer rotor is performed. The motor has forty-eight slots and eight poles. The number of slots per phase per pole is two, and a double layer distributed winding is used. NdFe30 is used as a permanent magnet. Stator and rotor steel is M19-26G. The outer diameter of the motor is 270mm, the shaft diameter is 110mm and the stack length is 86mm.

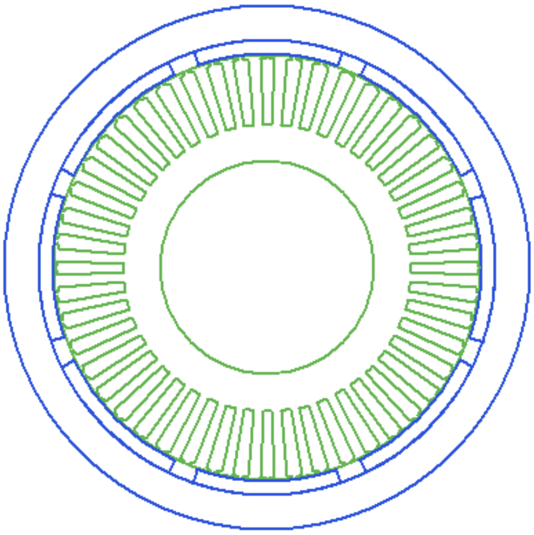

Figure 1. 2D view of the surface mounted PMSM with outer rotor

3. Application of the TLVCM Analysis

3.1. Results

Cogging torque is the holding torque in the air gap of the PMSM expressed by equation 1 [Hanselman, 2006]. In this study, five parameters that affect cogging torque such as stator slot opening, slot opening height, magnet thickness, magnet offset, magnet embrace are selected. Three of these parameters are permanent magnet parameters, the other two are stator parameters. Since surface mounted permanent magnet synchronous motors are non-salient, the effect of stator tooth parameters is especially important. In addition, the magnitude of the magnetic flux in the air gap and its interaction with the stator teeth are also important. Therefore, these parameters affect the change of air gap reluctance during operation. Thus, the variation of air gap reluctance affects the cogging torque magnitude. In the first stage of the study, according to the basic magnitudes of these five parameters are given in Table 1 the cogging torque value of the motor is calculated. The cogging torque of the first motor is obtained as 1.83Nm and its graph is given in Figure 2. The speed of the motor here is 3600rpm, so the ratio of cogging torque to rated torque is about 1.4%.

$$T_{cog} = -\frac{1}{2}\phi^2\frac{d\Re}{d\theta} \qquad (1)$$

where ϕ is the magnet flux of the air gap and $\Re$ is the magnetic reluctance of the air gap.

Table 1. Five geometric parameters of the PMSM

Structure Parameter	Value
Stator slot opening (mm)	1.93
Slot opening height (mm)	1
Magnet thickness (mm)	7.5
Magnet offset (mm)	0
Magnet embrace	0.85

In the second stage of the study, these parameters are changed between starting and ending values are shown in Table 2. The cogging torque values of the PMSM is calculated for each parameter. According to these values, the lowest cogging torque value is obtained as 2.95E-7Nm. Stator slot opening 0.5mm, slot opening height 0.5mm, magnet thickness 5mm, magnet offset 0mm, magnet embrace 0.5 were obtained for this cogging torque value. The graphs of cogging torque are drawn in Figure 2.

The geometries of the air gap of the PMSM obtained using five parameters are given in Figure 3. According to these figures, the geometry of the air gap to minimize the reluctance of the air gap for the minimum cogging torque is obtained. In this way, the impact of the cogging torque during operation is minimized. However, a more useful model can be obtained by including different objectives in the problem and rearranging the parameter boundaries. This study also proposes that a smaller value for cogging torque can be obtained by adjusting the geometric parameters in design optimization applications. Moreover, a linear relationship can be established between geometric parameters and cogging torque. In other words, simple equations can be obtained for some outputs that are difficult to obtain due to the nonlinear nature of the motor. With the mathematical equation obtained in this way, it is possible to perform more precise optimization operations in future studies.

Table 2. Variables and Values

Structure Parameter	Values
Stator slot opening (mm)	0.5-1.0-1.5-2.0-2.5
Slot opening height (mm)	0.5-1.0-1.5-2.0-2.5
Magnet thickness (mm)	5-6-7-8-9-10
Magnet offset (mm)	0-0.5-1.0-1.5-2.0
Magnet embrace	0.5-0.7-0.9

In a study on axial flux PMSM, the design of the motor was made with the ANSYS Maxwell program, variable ranges were assigned to the design parameters selected for this and the obtained performance values were examined. After obtaining all the results, the artificial neural network model was established and trained based on these data, and ultimately the optimal design parameters were determined and these results were compared. In other words, using the ANSYS Maxwell program, a database of the motor was created with different design parameters and these data were used for artificial neural network training and testing. In this way, the torque of the motor was tried to be improved [Talay and Erkan, 2019]. The method applied here is a preliminary study to create a model for further studies by converting the cogging torque of a radial flux surface mounted PMSM into a simple equation based on the design parameters.

4. Conclusions and Recommendations

One of the biggest structural problems of permanent magnet synchronous motors is cogging torque. Although some techniques such as skew are used to solve this problem, there are some difficulties in terms of cost and time. In this study, some geometric parameters are optimized to minimize the cogging torque. In this way, the air gap reluctance change during motor operation is minimized. While the initial cogging torque was 1.83Nm, this value decreased to 2.95E-7Nm by optimizing the design parameters. By optimizing the geometric parameters, cogging torque is virtually eliminated. As a result of this study, it is also revealed that a linear relationship between cogging torque and design parameters could become possible.

5. Acknowledge

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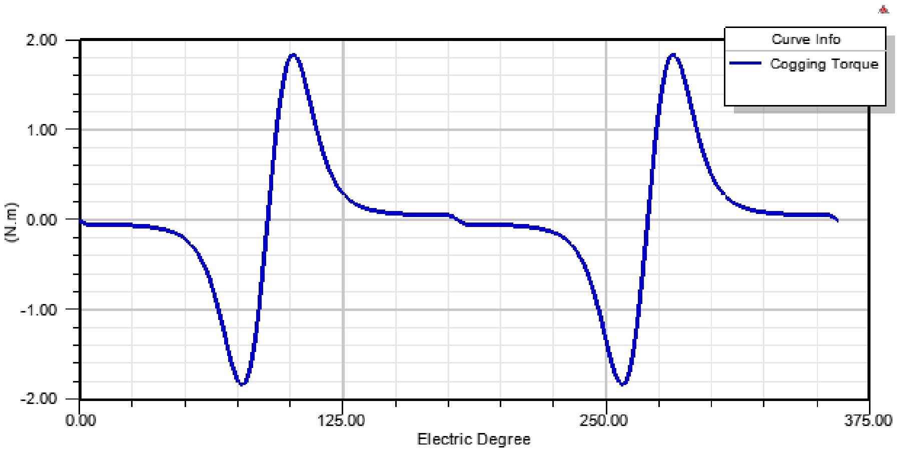
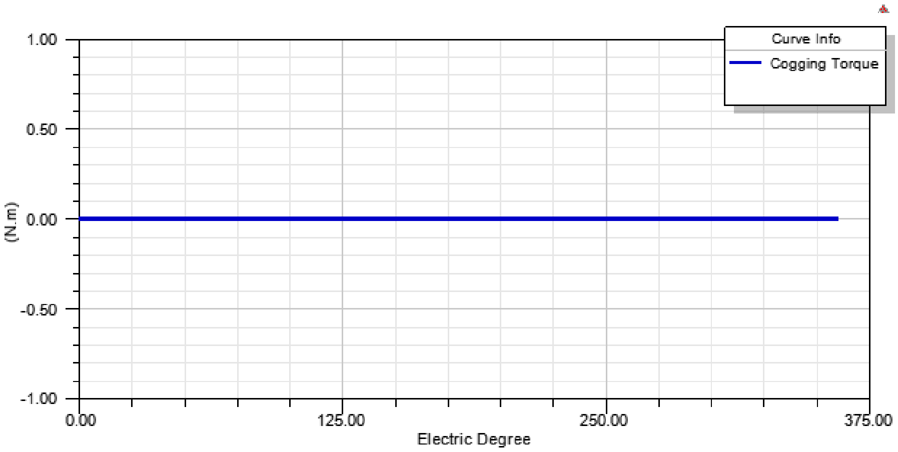
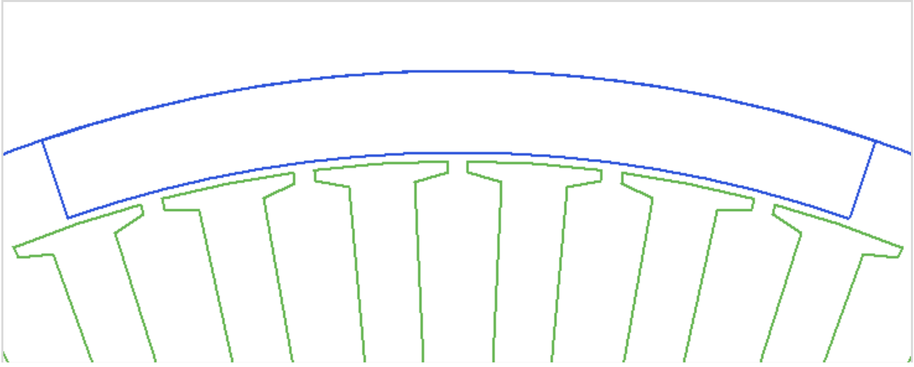


a) First model

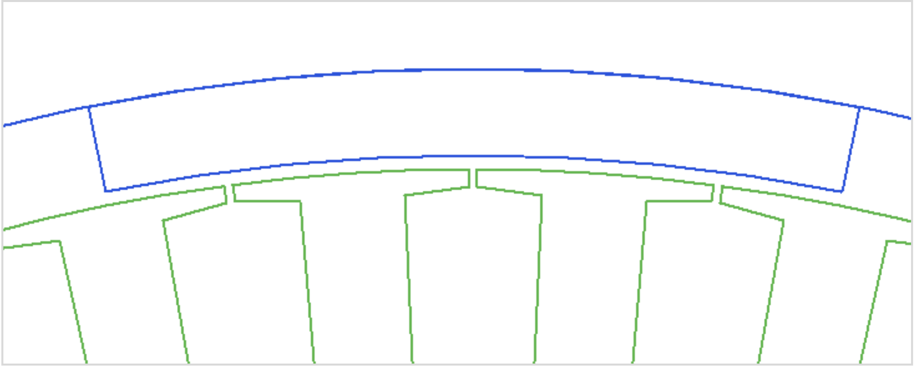


b) Optimized model

Figure 2. Cogging torque graphics of the PMSM



a) First model



b) Optimized model

Figure 3. 2D view of air gap geometry of PMSM

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