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Study the Effect of Combination of Shoe Height and Slot Opening width to Reduce Cogging Torque in Permanent Magnet Generator

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Abstract. Cogging torque is one important problem in a permanent magnet generator. With a good understanding of the phenomenon, the cogging torque can be minimized by using the multi-objective technique. This paper presents a combination technique for cogging torque reduction by an appropriate small stator slot opening width, stator shoe height with fractional technique in Permanent Magnet Generator. Cogging torque waveforms, along with other relevant characteristics are investigated in this research and by analysis using the finite element method, the combination width shoe height and magnet edge slotting effect to decline the cogging torque peak value. A significant value of cogging torque, when slot opening width of 1.55 mm and shoe height of 2.3 mm, provide the peak value of cogging torque in the structure is 0.00062 N-m for positive value and about -0.00064 N-m for the negative value. It can be concluded that this type of slot opening width of 1.55 mm and shoe height of 2.3 mm is the best structure of the fractional 8 slot, because it has any significant low of cogging torque and least of unbalance magnetic pull

1. Introduction

Permanent magnet machines have been used in high-performance applications because of their high efficiency, high torque density, and power factor close to unity. However, a drawback of permanent magnet machines is the cogging torque. Cogging torque causes vibration, noise caused and electromagnetic torque ripple which seriously affects the machine performance. The main machine vibration sources are found in ball bearing roughness, cooling air turbulence, electrical commutation and iron core–magnet reluctance forces. Recently, both the electric machine designers and electrical machine manufacturers have developed a better understanding of the cogging phenomenon [1].

Since the last few years, it has been increasing the application of permanent magnet generators (PMGs) for renewable power system. In small renewable power system, the PMG is coupled directly connected to the turbines, leads no any gear box. This kind of electric machine becomes attract by electric machine users since it has some advantages, such as high efficiency, simplicity and reliability of construction. However, the problem of in PMG applications is cogging torque. The presence of CT effects to reduce the PMG performance in electric energy conversion. In low wind speed condition, the blade of wind power is hard to be rotated [1]. Cogging torque in PMSG is the reluctance torque which is affected by the interaction of force from magnet edge in rotor core and stator teeth or slot opening width. The cogging torque is one the most important issue in permanent magnet application, because effect to the PMG performance, especially in low speed condition. Based on the discussion, many cogging torque reduction techniques have been proposed and studied in worldwide. The reports also have been documented [2-7]. Until recently, the research on cogging torque might be classified as shown in Figure 1.

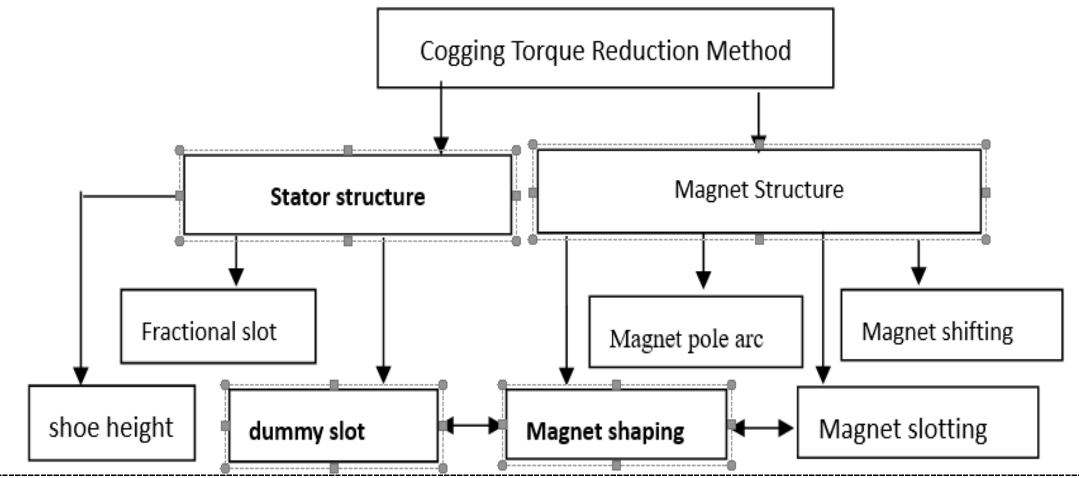

Figure 1. Cogging torque reduction technique

This paper deals with the magnetically generated in electrical machine known as cogging. This is usually large and can cause excessive machine vibrations if not properly controlled**.** Since the last few years, many varieties of techniques for minimizing cogging torque of permanent magnet machine have been reported and proposed [2-8]. In this research, a-8 pole/18 slot (fractional slot) combine with small of stator slot opening and high of stator shoe height for reduction of the peak cogging torque in PMSG is presented.

2. Motivation of the Research

Generally, the electric machine customers require production of a favourable ripple-free torque, good cogging torque waveforms are necessary. However, at the design stage and before the machine prototype is made, it is often difficult to construct any PMSG structure that produces satisfactory cogging torque shape. Moreover, no specific criteria are found to determine the magnet rotor shapes for such cogging torque waveforms. Hence, in this research, a fractional technique with certain of stator slot opening width and stator shoe height for the permanent magnet synchronous generator design is applied to reduce the cogging torque.

In this paper, a proposed permanent magnet synchronous generator (PMSG) design is studied to demonstrate the developed technique to minimize the cogging torque in PMSGs. The magnet rotor used to observe the cogging torque reduction is kept in natural, means that the magnetization is radial and there is no any specific structure in the magnet surface like slotting in the magnet edge, bread loaf or other structure as shown in Fig. 1**.** In this research, we focus only to find a feasible stator slot opening width and height of shoe in a fractional (8 pole/18 slot) of PMSG to reduce cogging torque and to minimize of unbalance magnetic pull (UMP) effect. The cogging torque of this type of PMSG fractional is compared and presented.

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3. Design Development and Proposed of PMSG

In this paper, we consider with the inset magnet rotor type. The initial design is 8 pole / 18 slot of PMSG. The geometry model of shoe height and slot opening width of the PMSG is presented in Figure 1. The result of simulation of magnetix flux distribution illustrated in Figure 2.

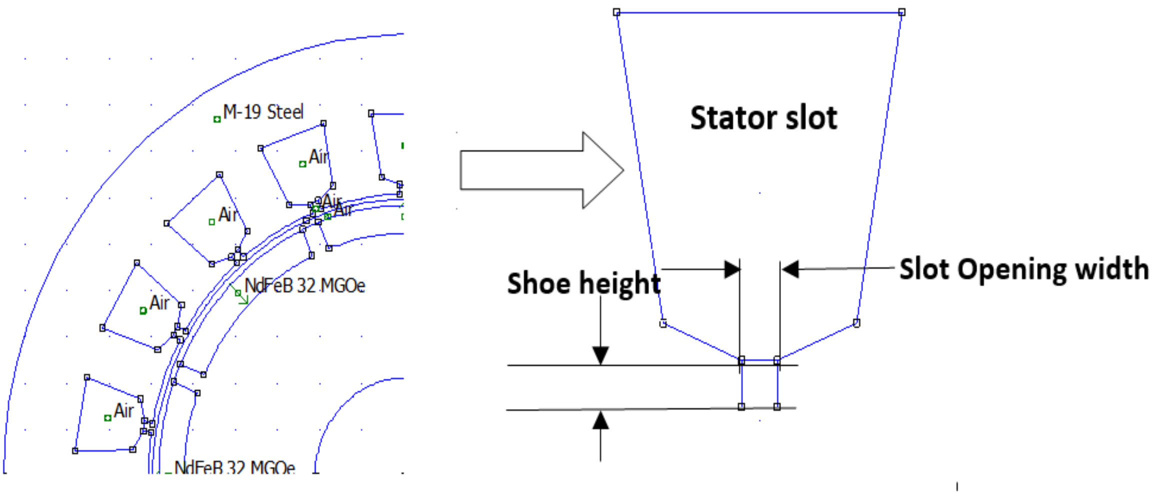

Figure 2. Model of PMSG studied a fractional slot of 8 slot /18 PMSG

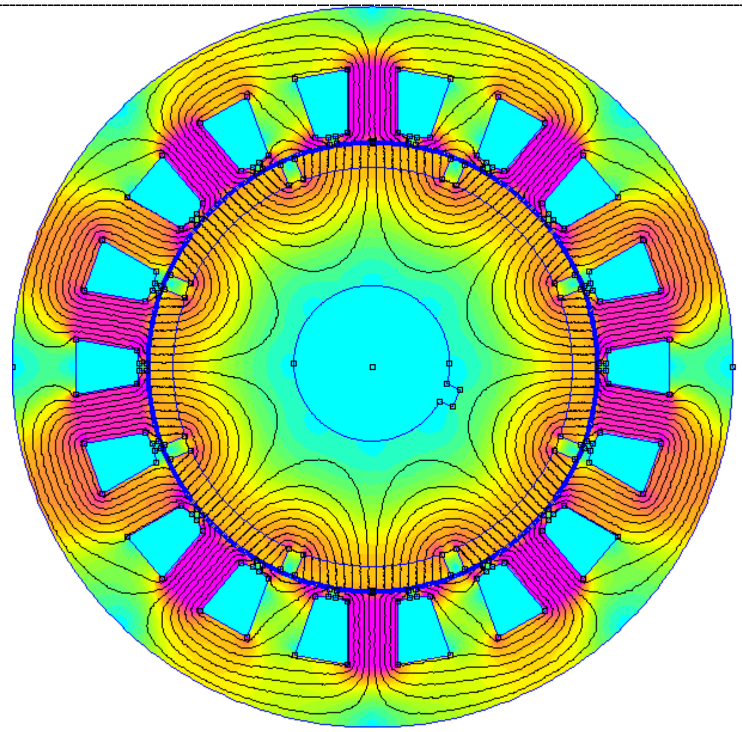

Figure 3. Magnetic Flux Distribution of Model of PMSG studied a fractional slot of 8 slot /18 PMSG

From the Figure.1, the different slot opening and stator shoe height values are applied to a fractional slot of 8 poles/18 slots of PMSG. In this paper, three steps of slot opening width of 1.60 mm (the largest), 1.55 mm and 1.50 mm (the smallest)). For stator shoe, authors investigated six steps of shoe height 2.3

mm (highest), 2.2 mm, 2.1 mm, 2.0 mm 1.9 mm, 1.80 (shortest). The values of slot opening width and shoe height combination are presented in Table 1. The effects of shoe height and slot opening width changing are calculated and simulated using finite element.

Table 1. Combination of SOW and SH in PMSG

Parameters	SOW (16.0 mm)	SOW (15.5 mm)	SOW (15.0 mm)
SH-1 (2.3mm)	2.3	2.3	2.3
SH-2(2.2 mm)	2.2	2.2	2.2
SH-3(2.1 mm)	2.1	2.1	2.1
SH-4(2.0 mm)	2.0	2.0	2.0
SH-5(1.9 mm)	1.9	1.9	1.9
SH-6(1.8 mm)	1.8	1.8	1.8

4. Fractional Techniques in PMSG

In electrical machine design, one of the important issues is cogging torque. Cogging torque can cause noise and vibration. In wind power system, if the cogging torque is too high the blade is not easy to spin, except the blade is forced by strong wind. Considering this fact, in this research we proposed based on the fractional machine with smaller stator slot opening (SOW) width and higher of shoe height (SH) is presented. However, even though fractional slot structure can reduce cogging torque, but some of structures in general create any unbalanced magnetic pull (UPM).

In this paper, we observe some structures of slots opening width and some values of shoe height of a fractional PMSG to find a suitable structure in order to reduce cogging torque and to minimize the effect of unbalanced magnetic pull. One can observe that by using a smaller of opening width and higher shoe can reducing the cogging torque. However, this method can be done so, because the slot opening width (SOW) may be not be constructed smaller than 1.50 mm, unless the winding is going to be difficult to install in the stator slot with conventional way. In the other hand, if the shoe height (SH) is very high, the cross-section area of stator slot will become smaller, means that the number of conductors can occupy the stator slot becomes limited. That is why, the value of SOW and SH is limited. By Using the Combination Fractional Slot Opening Wide and Shoe Height provide the decreasing of CT [9-12].

5. Cogging Torque Waveform and Simulation FEMM Result

In this paper, the 2D FEM (FEMM 4.2) was employed for cogging torque simulation of the PMSG. Graphical presentation and visualization of the FEMM results show the cogging torque of the PMSG. The cogging torque is generated by the tendency of the rotor magnets to align with the stator at positions where the reluctance of the magnetic circuit is minimized. In this study, the cogging torque of the PMSG is solved in the FEMM post processor. For PMSG of a-8 poles / 18 slots, the dependence of the cogging torque on the rotor position are presented in Fig. 4, 5 and 6 respectively

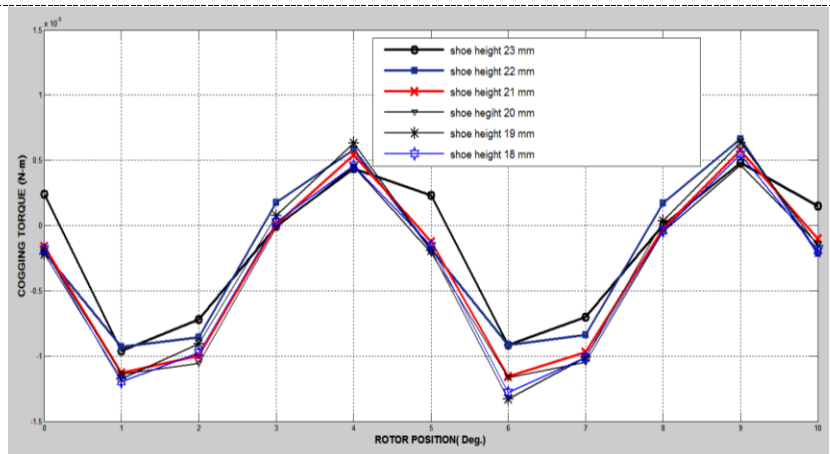

Figure 4. Comparison of Cogging torque of the PMSGs structure (slot opening width of 16.0 mm)

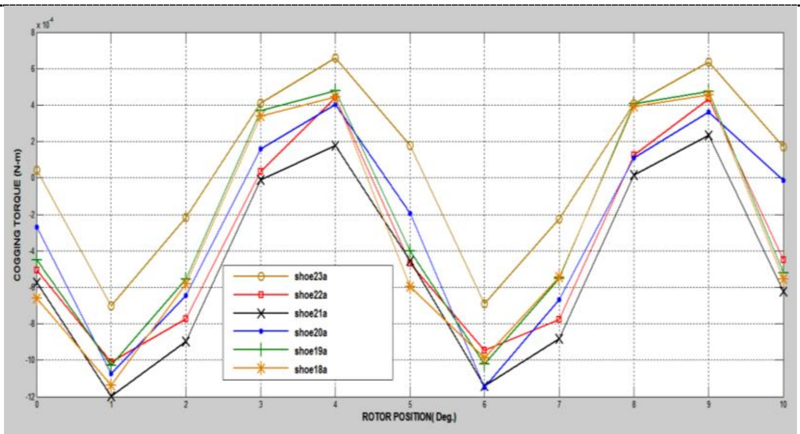

Figure 5. Comparison of Cogging torque of the PMSGs structure (slot opening width of 15.5 mm)

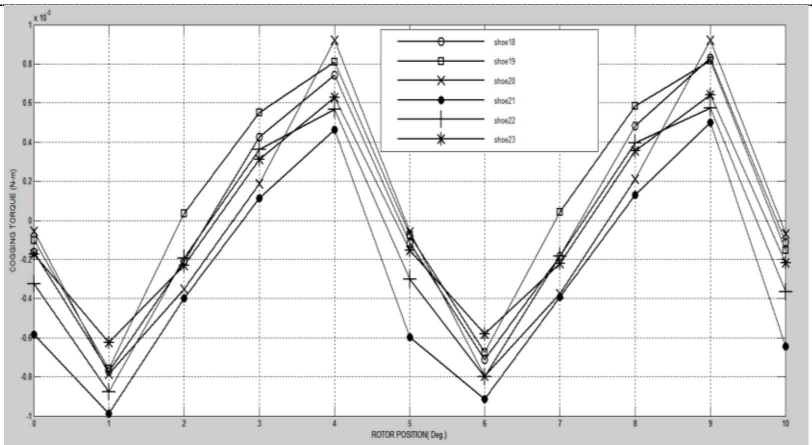

Figure 6. Comparison of Cogging torque of the PMSGs structure (slot opening width of 15.0 mm)

6. Results and Discussion

The simulation results [9], provide that the slotting design in the magnet edge can effectively reduce the cogging torque of the inset permanent magnet synchronous machine. The peak value of the cogging torque was obtained as much as 92.20% compared with the experimental model.

From the brief analysis of the Fig.3, 4 and 5 a substantial improvement of the peak cogging torque in fractional system combined with smaller slot opening width and higher of stator shoe in the PMSG is evident. For fractional machine (8 pole/18 slot) the cogging torque can be reduced by using any higher stator shoe with smaller slot opening width. However, the wave of cogging torques for all design are unbalance, it means that peak of negative and positive of the cogging torque are different value, except for PMSG structure with slot opening width of 1.55 mm and shoe height of 2.3 mm. From Fig.5 can be seen that cogging torque wave for the PMSG which has 1.55 mm of slot opening width and 2.3 mm of shoe height start from zero or close to zero.

The peak of cogging torque both positive and negative is also almost the same for every cycle. This refers to the effect of unbalance magnetic pull is least. Other advantages of the machine structure are the fact that by using slot opening width of 1.55 mm is still available and easy to install conductor in the slot compared with the slot opening width of 1.50 mm. In practical, slot opening width is limited to 1.50 mm, unless the conductor is difficult to install in the stator slot. From the series (12 models) of PMSG structures are investigated, the PMSG structure with slot opening width of 1.55 mm and shoe height of 2.3 mm it is can be accepted as the best structure.

7. Conclusion

The simulation of fractional structure of 8 pole/18 slot has been presented in this paper. It shows that by using factional structure of PMSG can reduce the cogging torque effectively. However, most of the PMSG structure simulated in this research show that their peak of both negative and positive values of the cogging torque are different. These refer to the effect the static unbalance magnetic pull (UMP). In the simulation result (as shown in Fig.3), the peak value of cogging torque in the structure is 0.00062 N-m for positive value and about -0.00064 N-m for the negative value. And other most important is that structure is not deteriorated with core saturation, the fact that is very important for the smooth of voltage waveform of the generator. It can be concluded that this typical of slot opening width of 1.55 mm and shoe height of 2.3 mm is the best structure of the fractional 8 slot /18 poles of PMSGs, because it has any significant low of cogging torque and least of unbalance magnetic pull affect.

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