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Study the Effect of Dummy Slot in Stator and Rotor on the Cogging Torque Reduction in Permanent Magnet Machine

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Abstract. In this study, the effect of dummy slot in stator core and magnet in rotor core greatly affects the value of the cogging torque reduction in permanent magnet machine. The structure of permanent magnet machine was analysed employed finite element based on the finite element method magnetic (2D). In this study, 4 type of permanent magnet machine structure has been analysed. Permanent magnet machine structure in rotor have 4 type design magnet, permanent magnet machine with initial structure magnet, bread loaf, magnet edge slotting, and magnet edge slotting-magnet slot of surface. The cogging torque reduction of the proposed permanent magnet machine were computed and compared with the initial structure. Using the finite element, authors have computed and found that the cogging torque reduction of type 3 and type 1. The cogging torque of proposed permanent magnet machine could be reduced to 97.17% by employing the dummy slot in stator core.

1. Introduction
In renewable energy systems, the permanent magnet generators have been applied widely. The reason is that this kind of machines has some advantages over the other electric machine type. However, the most drawback of the permanent magnet generator is the cogging torque. The presence of cogging torque effect to reduce the permanent magnet generator and makes some undesirable performance such as noise, vibration and may be more. Based on the discussion, in this paper authors have offered a kind of cogging torque reduction technique. The effectiveness of the proposed technique was validated using finite element method magnetics. A novelty of this research is the fact that cogging torque can be reduced effectively as much as 93.19% compared with the initial structure. While if the structure was compared with the bread loaf structure, the cogging torque reduction is 97.17 %.

In this paper, the influence of combination of the fractional number of slot per pole of 24 slot / 14 pole has been studied. The Construction of Stator and Rotor in Permanent Magnet Machines are shown in Figure 1 [1-2]. For the purpose of study, shape of slot has been simplified. The structure of the machine was analysed employed finite element based on the FEMM.

The purpose of this study is to come up with and analysed the effect of incorporating the magnetic shaping method with dummy slot to reduce the cogging torque. For the cogging torque prediction, we adopt the finite element method magnetic (2D) as a tool [1].

In the study, the Maxwell Stress Tensor Method for the calculation of the cogging torque has been used. In the simulation, one must rotate the rotor of Permanent Magnet Machine by small steps and at each position has to be calculated the change of cogging torque in air gap in machine. The cogging torque that has been developed in the machine can be written as the partial change in cogging torque with respect to the virtual displacement of the rotor. The cogging torque in permanent magnet machine can be computed using the following equation [2-3] :

$$T_c = \frac{L_{st}}{\mu_0}\int_0^{2\pi} r^2.B_n.B_t.d_\theta \tag{1}$$

where, Tc = Cogging Torque, Lst = Stack Length of the Machine, r = Radius where the cogging torque is measured, B_n = Normal Flux Density, B_t = Tangential Flux Density, dθ = Rotor Displacement
From the equation (1), the most effecting on the cogging torque in permanent magnet machine are Normal Flux Density and Tangential Flux Density.

2. Permanent Magnet Machine Structure

In Figure 1 represents the permanent magnet machine structures studied in this paper. Analyse 4 types of permanent magnet machine. Permanent magnet machine with dummy slot and without dummy slot in stator. Permanent magnet machine with initial structure magnet, bread loaf, magnet edge slotting, and magnet edge slotting-magnet slot of surface in rotor.

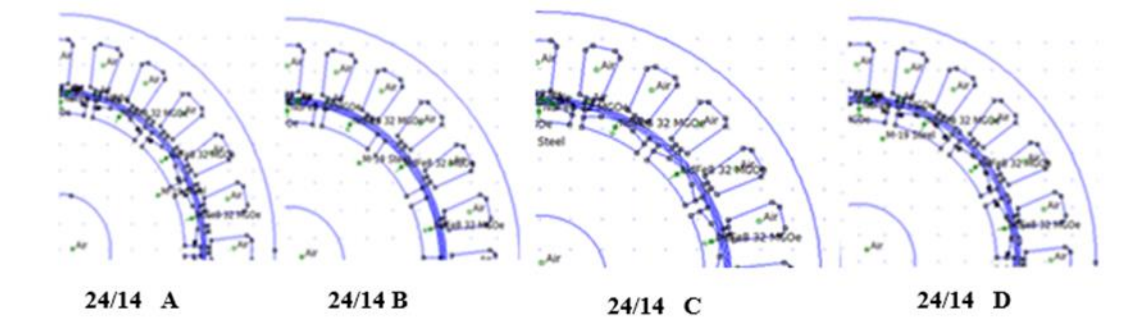

Figure 1. Construction Stator and Rotor in Permanent Magnet Machine.

Based on figure 1. This paper studied 4 types permanent magnet machine structure. This permanent magnet machine has 4 types of permanent magnet in rotor dan 2 type of dummy slot in stator. In the following of this paper, authors have summarized the specification of the 4 types of the permanent magnet machine.

2.1.Type 1

In this type, refers to the permanent magnet structure of 24 slot/14 pole A. As can be observed in the Figure 2, the permanent magnet machine with dummy slot in stator and magnet edge slotting in rotor.

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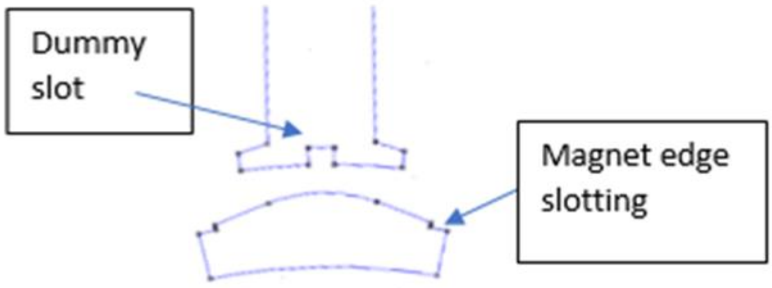


Figure 2. Permanent Magnet Structure 24/14 A

2.2.Type 2

As can be seen in Figure 3, the structure of the permanent magnet machine refers to original permanent magnet structure (24/14 B). In this type, the structure has no slotting both of stator and in rotor core.

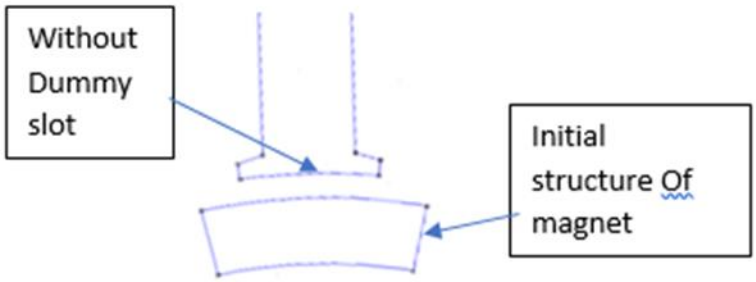


Figure 3. Original Permanent Magnet Structure 24/14 B

2.3.Type 3

For the type 3, is the permanent magnet structure of 24/14 C. In this type of machine, without dummy slot in stator and bread loaf of magnet in rotor core.

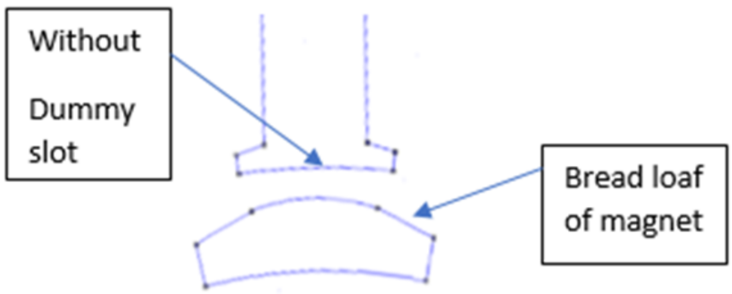


Figure 4. Permanent Magnet Structure (bread loaf) 24/14 C

2.4.Type 4

Type 4 is permanent magnet structure 24pole/14slot D. Permanent magnet machine with dummy slot in stator and used slotted in magnet surface – magnet edge slotting in rotor.

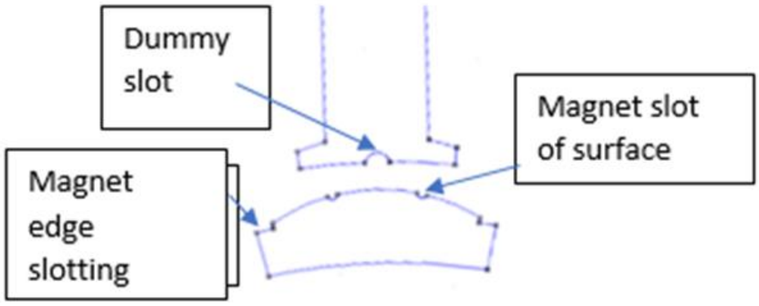


Figure 5. Permanent Magnet Structure 24/14 D

3. Normal flux density and tangential flux density

The slotting in stator and magnet rotor core of the machine effects to the normal and tangential flux density. The normal and tangential flux density are two of important parameters which give the most contribution in the cogging torque value. In the following, authors present the normal and tangential flux density of 4 types of permanent magnet machine and depicted in Table 1.

Table 1. Bn and Bt

	2414 A (Tesla)	2414 B (Tesla)	2414 C (Tesla)	2414 D (Tesla)
Bn	0.8	0.8	0.9	0.9
Bt	0.15	0.21	0.19	0.16

In Table 1 represents the value of normal flux density (B_n) and tangential flux density (B_t) flowing in Stator and Rotor core of the permanent magnet machine form 4 types permanent magnet machine structure.

The profile of normal flux density and tangential flux density can be observed in Figure 6 and Figure 7, respectively. The profile of both normal flux density and tangential flux density was analysed using finite element based on FEMM. Figure 6 is normal flux density (B_n), the dot (black color) is representation FEMM computation, while the line (red color) refers to the analytic of type 1 (24/14 A). It can be seen that wave from is sine. It can be concluded that the normal flux density is not destroyed by the changing of the machine structure, thus, this can be accepted. In Figure 7, we can see the value of tangential flux density (Bt) gained by analytic and finite element computation of 24slot/14pole A (type 1) permanent magnet machine. The peak of tangential flux density tends to be reduced effect of the dummy slot in stator core and edge slotting in magnet of the machine. The reduction of peak tangential flux density has a contribution to decline the tangential force in air gap. In addition, with the lower peak of tangential flux density, the cogging torque of the machine was expected to be reduced significantly.

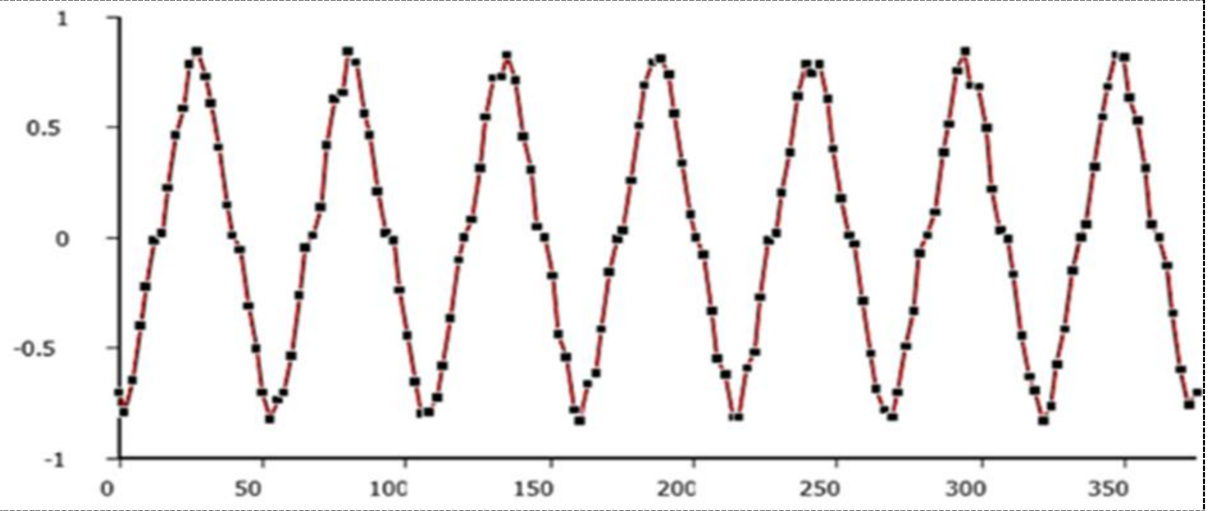


Figure 6. Normal Flux density (Bn) of the propose structure of 24slot /14pole A

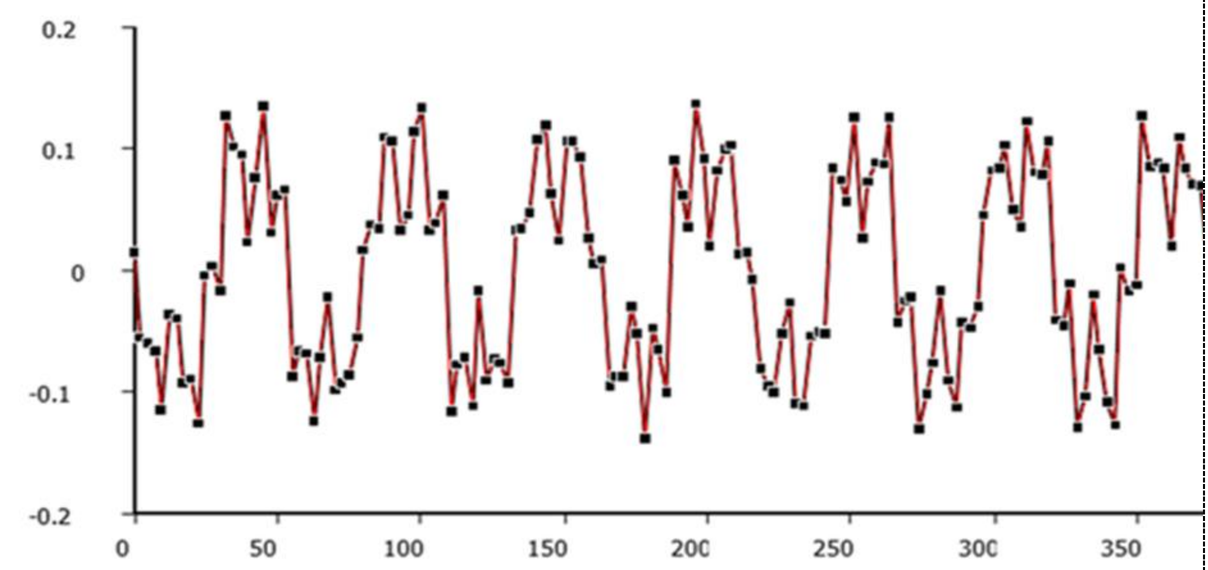
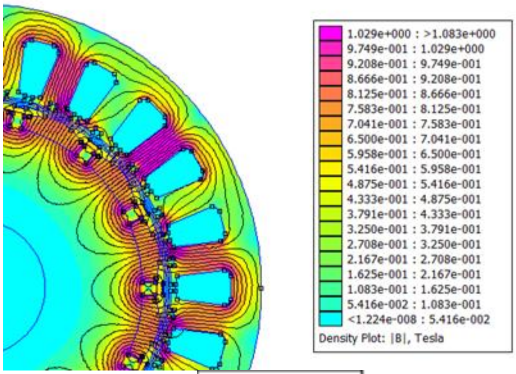


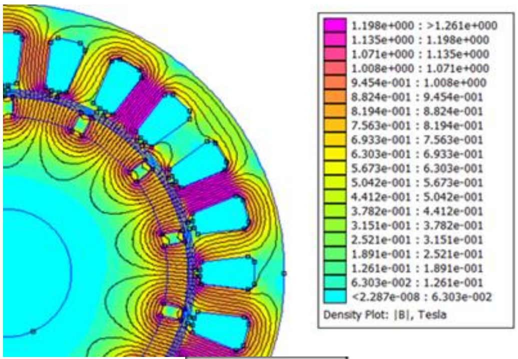
Figure 7. tangential flux density (B_t) of the propose structure of 24slot /14pole A

4. Magnetic flux distribution

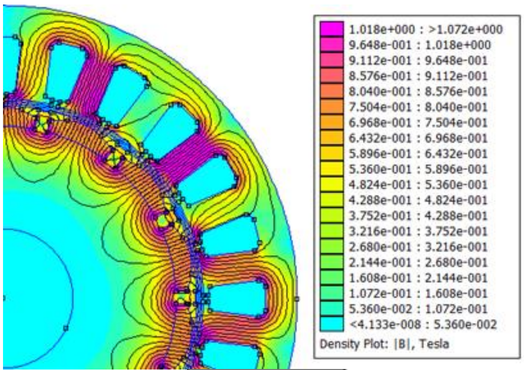
The magnetic flux distribution of the permanent magnet machines studied was presented in this paper. One can observed that the effect of slotting in rotor and stator effect to magnetic flux distribution and magnetic flux density in the machine core. For example, the magnetic flux density in 24/14 A, the flux density in core is 1.029 Tesla, while the structure of 24/14 B, the flux density in core is 1.198 Tesla. The structure of 24/14 C, the flux density in the core of the machine is 1.018 Tesla, while the structure of 24/14 D, the flux density in core is 1.069 Tesla. The lowest flux density is 24/14 C structure. In general, the value of flux density in core of machine structure represent the losses in the machine core. In other word, the higher the flux density in the core, the higher the losses in the core. However, for material M-19, the flux density can be allowed.



24/14 A



24/14 B



24/14 C

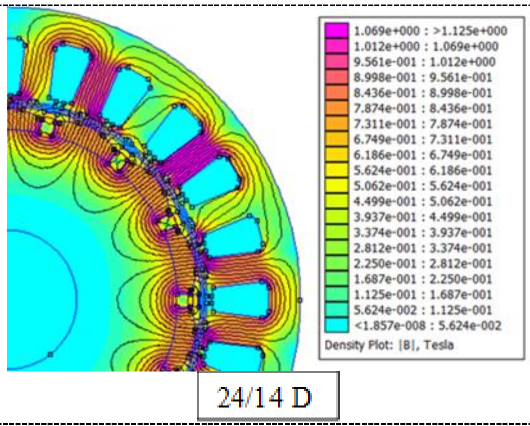


Figure 8. Magnetic flux distribution

5. The cogging torque simulation

In this simulation, the LUA 4.0 scrip has been used to perform the permanent magnet machine analysis [1]. The advantage of using LUA is the fact that simulation process can be done parallel. It save the time of computation of the simulation. The illustration of cogging torque reduction of the propose structure of 24 slot / 14 pole from 4 type of machine structure was given and compared. The peak of cogging torque of 24/14 C (type 3) has been found as much as 0.0008954 N.m and the peak of cogging torque of 24/14 A (type 1) is 0.0000253 N.m. In this study, authors have found that cogging torque reduction technique proposed can be reduced effectively as much as 97.17%. The peak of cogging torque of 24/14 B (type 2) is 0.0003716 N.m, while the peak of cogging torque of 24/14 A (type 1) is 0.0000253 N.m. Another comparison has done in this study. It was found the cogging torque of type 1 can be reduced effectively as much as 93.19% compared with the initial structure (24/14 B) type 2 .

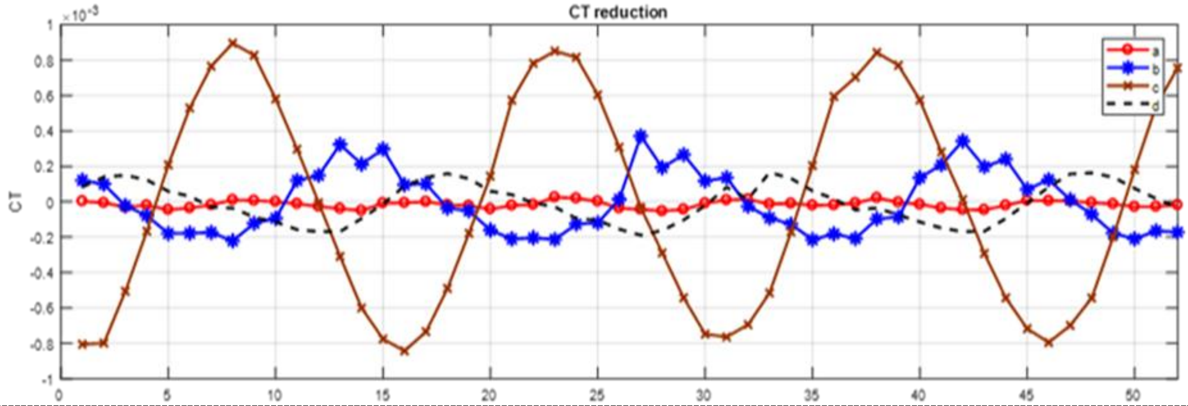


Figure 9. Cogging Torque of the propose structure of 24slot /14pole

6. Conclusion

In this study, the effect of combining of dummy slot in both of stator and rotor on cogging torque reduction in permanent magnet machines have been presented and compared. The greatest cogging torque reduction among the permanent magnet machine studied was the type 1 as much as 97.17 % compared with type 3. When compared with type 2 to type 1, the cogging torque reduction about 93.19 %. It can be concluded that the permanent magnet machine type 1 offers permission to be the best cogging torque reduction among them.

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