Investigation of Outer Rotor Structures for Dual Mechanical Port Machine

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Abstract — Dual mechanical port (DMP) machine, an electrical continuous variable transmission, has attracted more and more attention for wind power application, hybrid electrical vehicles and so forth, in which the permanent magnet (PM) outer rotor is a key component. The surface-mounted PM outer rotor provides simple structure and easiness to optimization but require more PM materials and a glass or carbon fiber bandage to overcome the centrifugal force of magnets and the rotating torque, hence limits torque density and high speed capability. In this paper, in order to achieve robust outer rotor structure and better performances, the structures with buried PMs are analyzed and one outer rotor with one-whole buried PM structure is designed for prototype manufacture by finite element analysis (FEA).

I. INTRODUCTION

Dual mechanical port machine – a kind of continuous electrical variable transmission, is a very competitive alternative for vulnerable constant speed-ratio mechanical planetary gearbox in wind power application and hybrid electrical vehicles [1-2]. While surface-mounted double layer PM DMP machine as shown in Fig. 1 provides simple structure and easiness to optimization, a major problem in the design and manufacture is reliably holding the PMs in place at high speed and high torque applications [3-4].

This paper evaluates a kind of unique outer rotor structure of DMP machine with buried outer layer PMs and surface-mounted inner layer. This buried magnet design, which is capable of reliably holding the PMs, offers both easier and cheaper assemble when compared with the methods used in surface-mounted PM machines. Electromagnetic performances of buried structures with one-whole and multi-pieces of PMs are compared and the outer rotor with one-whole buried PM structure is analyzed for prototype manufacture by FEA.

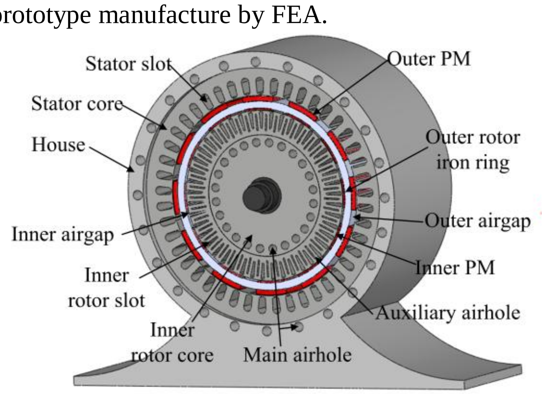

Fig. 1. Double layer PM DMP machine

II. OUTER ROTOR STRUCTURE TOPOLOGIES

The commonly used surface-mounted outer rotor structure with carbon fiber is shown in Fig. 2(a). If the PMs are buried within the rotor surface brace, no carbon or glass fiber bandage is needed, thus, reducing the total electromagnetic air-gap and the required amount of magnet material. Therefore, buried outer layer PM as one-whole piece and surface-mounted inner layer PM as shown in Fig. 2(b) is proposed in this paper.

Exact calculation of the mechanical stresses on the iron bridge and surface brace could be conducted by mechanical design and the minimum thicknesses to support the PMs as well as resist the rotating torque could be calculated. In order to attenuate the iron bridge and the surface brace which would probably influence the flux-leakage greatly, outer rotor structures which contain multi-pieces of buried outer layer PMs are presented as shown in Fig. 2(c) and Fig. 2(d), of which the iron bridge and the surface brace could be thinner. The air gap between each PM salient is retained from surface-mounted structure to probably lessen the flux-leakage in buried PM structures.

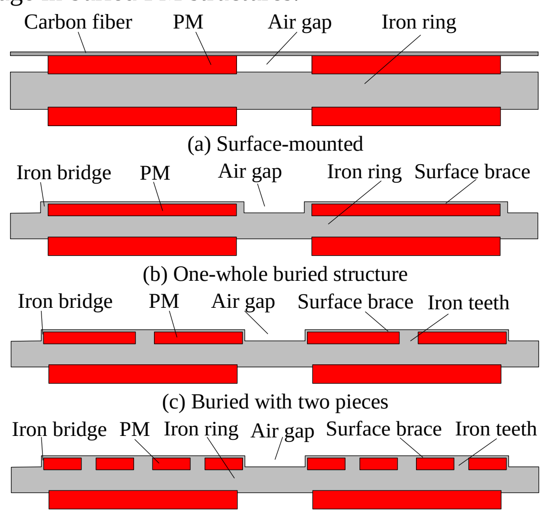

Fig. 2. Double layer PM outer rotor structures

III. FINITE ELEMENT ANALYSIS

FEA has been studied for the analysis and design of outer rotor structures, considering the flux-leakage, the saturation effect in the teeth and the eddy current effect in the core.

A. *PM Piece Number Selection*

Models of buried outer rotor structures with different number of pieces of PMs are built with the same stator and inner rotor. The influence of piece number to the flux-linkage is shown in Fig. 3, from which it can be seen that with the same capacity of PM, when the piece number increases, the flux-linkage of the stator winding drops almost 14% from one-whole piece to four-pieces structure. Even though the iron bridge and the surface brace could be thinner and the structure could be more robust when the piece number increases, the reduction of the flux-linkage makes the multi-pieces PM structures in this prototype machine design undesirable. While there is slightly difference between one-whole piece and surface-mounted structures, which is because the decreased electromagnetic air-gap is only 0.5mm in the prototype machine and it was compromised by the flux-leakage of the buried PM structure.

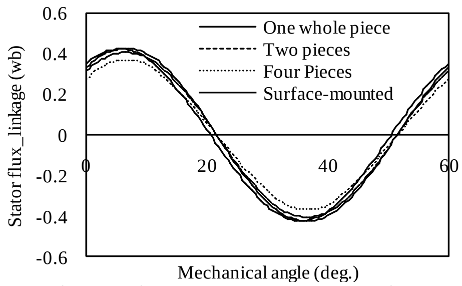

Fig. 3. Influence of PM piece number on stator flux-linkage

B. *Influence of Thicknesses on Stator Flux-linkage*

The influences of surface brace thickness and iron bridge thickness on stator flux-linkage are shown in Fig. 4 and Fig. 5. It can be seen that when the thickness of the surface brace increases from 1mm to 2mm with the constant iron bridge thickness 4.29mm, the flux-linkage drops 5%, while when the thickness of the iron bridge increases from 2.86mm to 5.72mm with 1.5mm surface brace, the flux-linkage only drops 0.8%. Even when there is no air gap between each PM salient, the flux-linkage only drops 1.3% compared with the iron bridge thickness of 2.86mm, from which it can be seen that the thickness of the surface brace influences the stator flux much greater.

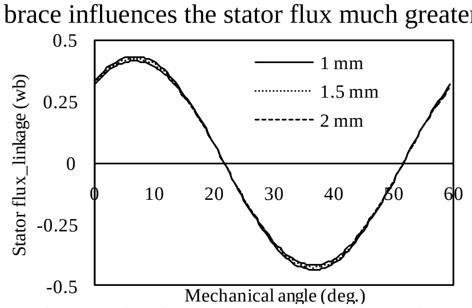

Fig. 4. Influence of surface brace thickness on stator flux-linkage

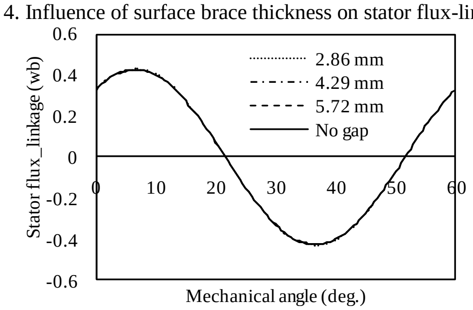

Fig. 5. Influence of iron bridge thickness on stator flux-linkage

C. *New Structure*

The fact analyzed above that the top of the magnet retaining surface brace while not the side of the magnet retaining iron bridge is the element that limits the amount of flux-leakage suggests a possible way to improve the design by removing the air gap between each PM salient and the new structure which is more simple and robust as well as easier for manufacture is shown in Fig. 6.

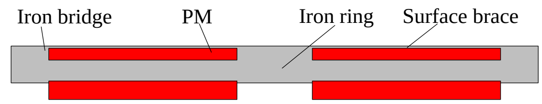

Fig. 6. New structure without gaps

D. *FEA Results*

The design of the new structure mainly focuses on the back-EMF THD as well as cogging torque minimization and the influence of buried outer layer PM pole arc coefficient on the THD is shown in Fig. 7. The cogging torque is shown in Fig. 8 which could be eliminated by slot skewing [5] and compared with surface-mounted structure, the cogging torque increases greatly because of the decreased electromagnetic air-gap.

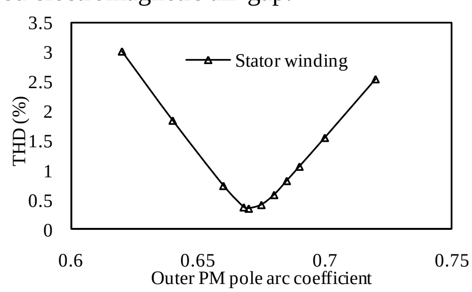

Fig. 7. THD optimization

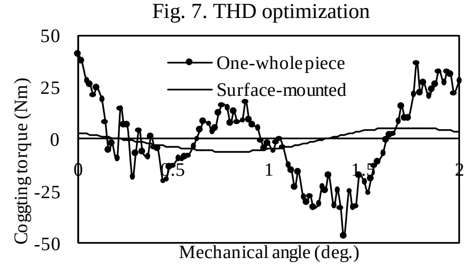

Fig. 8. Cogging torque with no skewing

IV. REFERENCES

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