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AIR GAP ANALYSIS OF A NOVEL DUAL ROTOR HYBRID EXCITATION FLUX SWITCHING MACHINE (DR-HEFSM)

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ABSTRACT
Air gap in one of the factor need to consider before designing a machine. It plays a major part in the machine operation and greatly affects the motor performances. As a result different air gap for designing Dual Rotor Hybrid Excitation Machine (DRHEFSM) are being investigated. 0.4mm air gap has been chosen because of the influence of the existing Hybrid Excitation Flux Switching Machine (HEFSM) that used total 0.8mm air gap and successful in performing the machine operating principle. Furthermore, the machine also successfully obtaining good result in motor torque and speed. Total 0.8mm air gap are being used for the new design, 0.4mm for the outer rotor air gap and 0.4mm for the inner rotor air gap. Besides that, 0.3mm and 0.5mm air gap are being investigated in order to analyse the optimum air gap for the design machine. Flux characteristic, cogging torque and back-emf of each air gap design are the parameter that being analyse and compared in determining the best air gap design. As conclusion, the 0.4mm air gap successfully follow the operating phase of three-phase machine, obtaining lowest cogging torque and own small harmonic back-emf.

Key words: Dual Rotor・Air Gap・HEFSM・

INTRODUCTION

Hybrid Excitation Flux Switching Machine (HEFSM) (Sulaiman et al. 2011) has been proved to perform admirably compared to Interior Permanent Magnet Synchronous Motors (IPMSM), Permanent Magnet Flux Switching Machine (PMFSM) and Field Excitation Flux Switching Machine (FEFSM). Initially, HEFSM are created by referring the parameter build of IPMSM, where the machine has been used widely in Hybrid Electric Vehicle (HEV) nowadays. The motor are created in order to solve problem encountered by IPMSM such as complicated cooling system and long coil armature end. Not to mention, the advantage possess by HEFSM such as simple cooling system mainly because all of its active parts located on the stator and controllable flux.

Dual Rotor Hybrid Excitation Flux Switching Machine (DRHEFSM) consist of two rotor, inner and outer rotor which its purpose to fully utilise the flux produced by both Permanent Magnet (PM) and Field Excitation Coil (FEC). Additionally, the motor is expected to perform much better than existing HEFSM mainly because of dual rotor structure it posses compared to structure retain by existing HEFSM. Furthermore, high reliability, wide speed range and constant power exhibit by Dual Rotor Switch Reluctance Machine (DRSRM) (Yang et al. 2010) should be inherit by DRHEFSM. What's more, because of compact winding distribution by dual rotor, the motor efficiency is significantly increased (Baun & Krotsch 2013). Magnetic path also become shorter because of dual rotor in effect, results less iron less.

Air gap is one of the importance aspects when designing new motor. The design air gap can influence the flux produced by the motor. Different air gap design are need to analyse before proceed to main test such as load test. Besides, it need to analyse the design air gap in order to obtain suitable air gap length for the propose motor. Wrong choice of air gap length can lead the design to fail in follow the desired working principle, three phase operating principle. As reported in (Xiaoyuan et al. 2008), the bigger the air gap, the greater the reluctance and impossible to do a very small air gap design. No load current also will increase if the air gap bigger meanwhile when the air gap smaller, the electrical loss and noise were increased. In addition, with increasing the air gap length, the flux density become smaller (Zhao & Yani 2005). Furthermore, with appropriate increase of air gap, it can reduce the harmonics amplitudes (Wang et al. 2011).

This paper presents an analysis for the design motor 6-Slot 7-Pole DRHEFSM in different air gap length. The flux produced by the different air gap design are analysed and compared to each other in order to obtain the most suitable air gap length for the design motor.

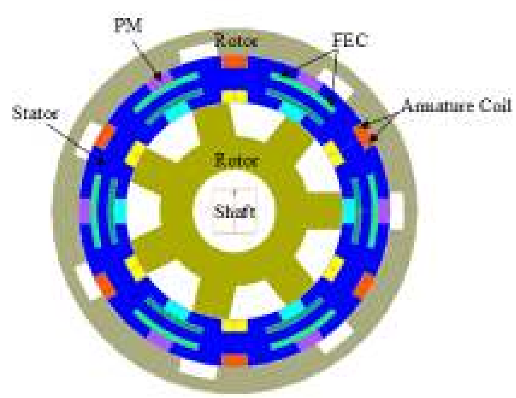

Figure 1: DRHEFSM

AIR GAP ANALYSIS

The air gap design for the motor structure

The design motors possess single stator and two rotor structures as shown in Figure 1. Generally, all the design follow the parameter as in listed Table I while the changing parameter for designing different air gap are listed in Table II. Figure 2, 3 and 4 illustrate the cross section view of the motor design with different air gap.

The material for stator and rotor are silicon steel (35AH210) while the material for shaft is steel. The Permanent Magnet (PM) use is Neomax 35AH as in IPMSM. Other than that, the Armature Coil and FEC used copper as its winding material.

Table 1

Parameter	Detail	Value
	PM volume(kg)	1.0
D1	Outer Rotor radius (mm)	132
D2	Outer Rotor pole height (mm)	9
D3	Outer Rotor pole width (mm)	13.384
D4	Inner Rotor radius (mm)	78
D5	Inner Rotor pole height (mm)	24.52
D6	Inner Rotor pole width (mm)	13.384
D7	Stator Radius (mm)	112.4
D8	PM width (mm)	4.35
D9	PM height (mm)	18.124
D10	FEC width (mm)	4.35
D11	FEC height (mm)	23.873
D12	Armature coil width (mm)	18.124
D13	Armature coil height (mm)	23.6

Table 2

Parameter	Air Gap (mm)		
	0.3	0.4	0.5
Outer Rotor Inner Radius	112.7	112.8	112.9
Outer Stator Radius	112.4	112.4	112.4
Inner Stator Radius	78.4	78.4	78.4
Inner Rotor Outer Radius	78.1	78	77..9

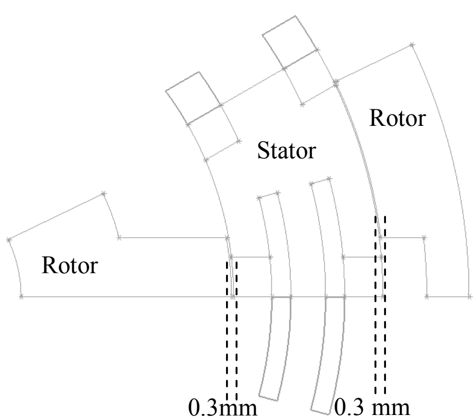

Figure 2: Motor design structure with 0.3mm air gap

Armature coil observation

Armature coil observation is the test conducted independently for each armature coil in order to confirm how the machine operates plus each armature coil phase position are set. The system will be fed with DC FE coil current and the flux linkages of each armatures coil will be observed. The flux linkage of each coils are compared and classified the armature coil phases according to conventional three phase system. Figure 5, Figure 6 and Figure 7 illustrate the FEC and Armature Coil arrangement while Figure 8 illustrates the flux linkage by three different air gaps.

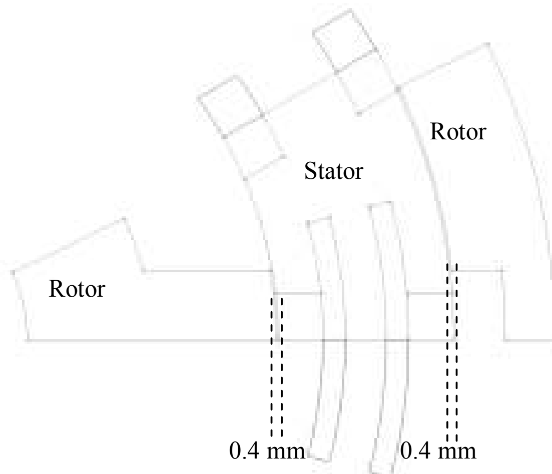

Figure 3: Motor design structure with 0.4mm air gap

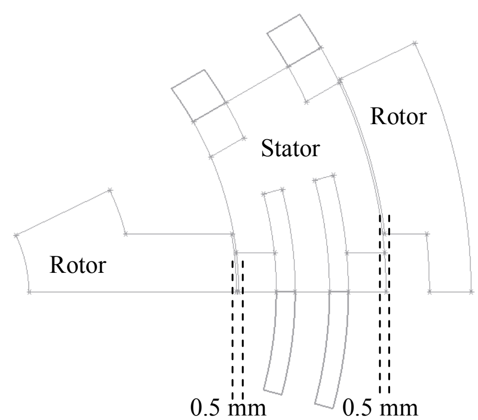

Figure 4: Motor design structure with 0.5mm air gap

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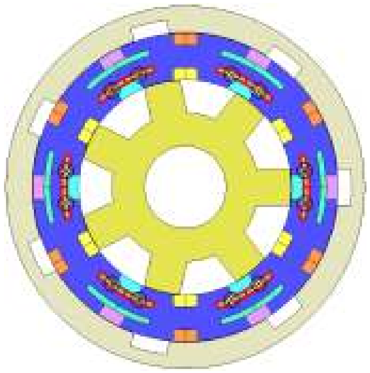

Figure 5: Inner FEC windings

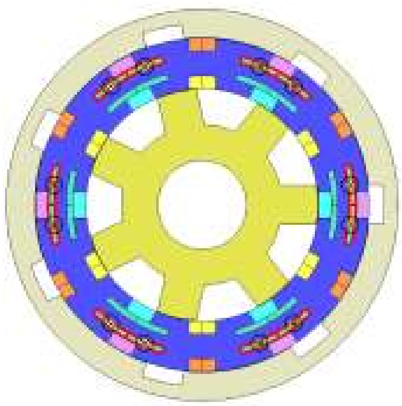

Figure 6: Outer FEC windings

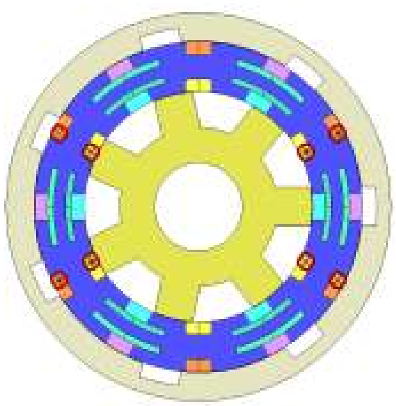

Figure 7: Armature coil windings

It is clear that both 0.3 mm and 0.4 mm air gap has successfully achieved the fundamental three phase machine operating principle while the 0.5 mm air gap failed to achieve it.

Cogging Torque

The cogging torque for different air gap of the proposed model are depict in Figure 9, Figure 10 and Figure 11. The 0.5mm air gap model achieved highest peak to peak cogging torque value, 20.6Nm for outer rotor and 9.4Nm for inner rotor while the 0.4mm air gap model achieved lowest peak to peak cogging torque value, 0.4Nm for outer rotor and 0.62Nm for inner rotor. This proved the 0.4mm air gap design is the most suitable design for the further analysis because higher cogging torque value will only lead to higher jerkiness thus model with lower cogging torque should be choose.

Harmonic Back-Emf

Figure 12, Figure 13 and Figure 14 illustrates the harmonic for back-emf of 0.3mm, 0.4 mm and 0.5mm air gap design meanwhile Figure 15 portrays the harmonic for back-emf of all air gap design at open circuit condition from FEC with speed of 1200 rpm. The harmonic produce by 0.3mm design has the highest amplitude, 29.4V when compare to the 0.4mm and 0.5mm air gap design which only produce 7V and 6.4V. Event though the back-emf produce by 0.3mm air gap design is high still the generated back-emf are considered small and acceptable.

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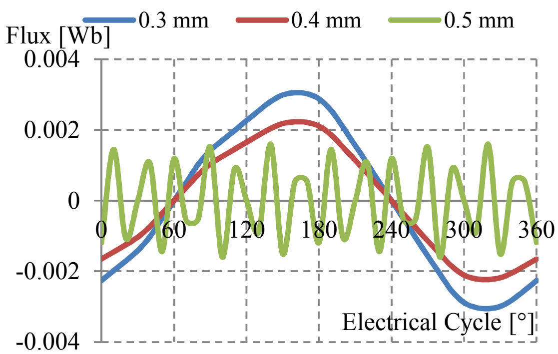

Figure 8: Flux linkage of three different air gap

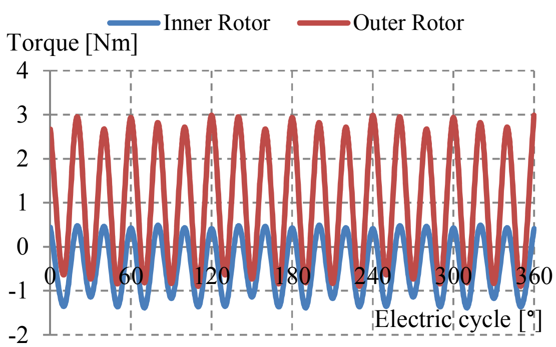

Figure 9: Cogging torque for 0.3mm air gap

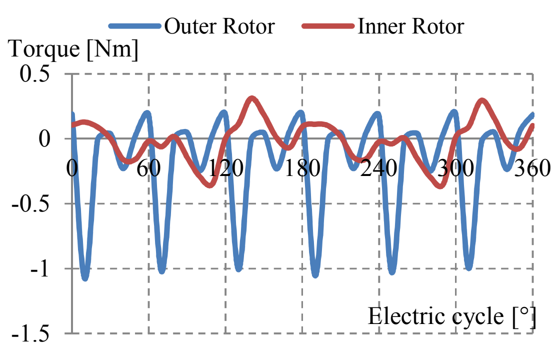

Figure 10: Cogging torque for 0.4mm air gap

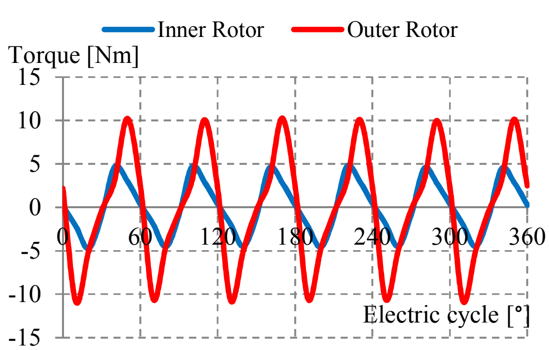

Figure 11: Cogging torque for 0.5mm air gap

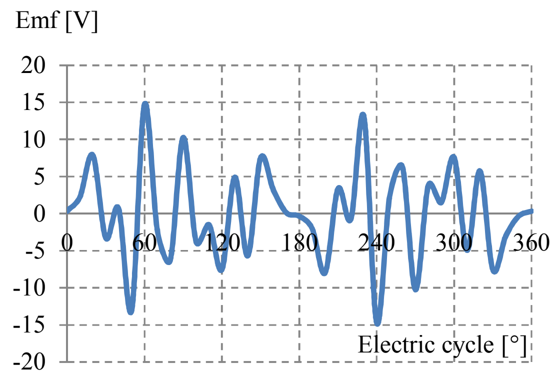

Figure 12: 0.3mm air gap harmonic back-emf

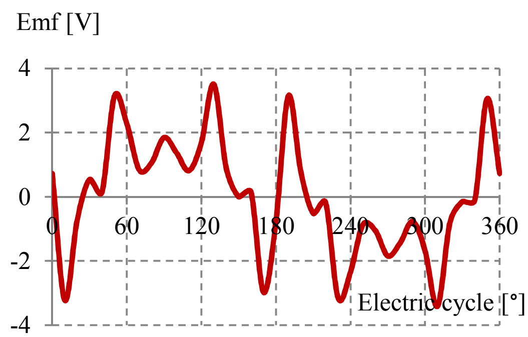

Figure 13: 0.4mm air gap harmonic back-emf

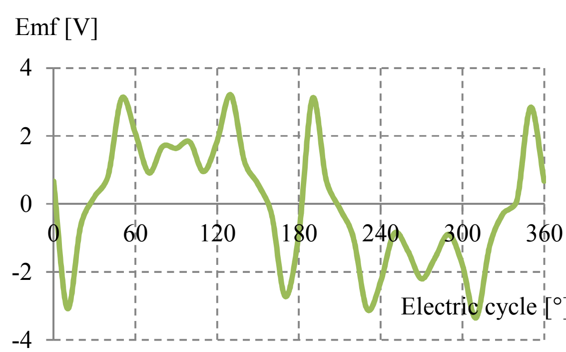

Figure 14:0.5mm air gap harmonic back-emf

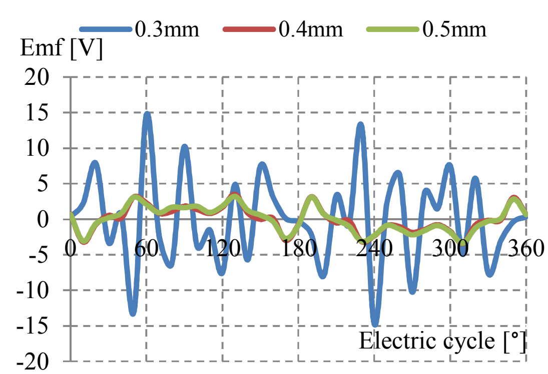

Figure 15: Harmonic for back-emf of all design

CONCLUSION

In this study, DRHEFSM with different air gap design has been presented. 0.3mm, 0.4mm and 0.5mm air gap parameter and structure has been clearly shown. The armature observation has been stated and operating principle of 0.3mm and 0.4mm air gap design has been proved while 0.5mm air gap design failed to work in desired operating principle. Other analysis such as cogging torque and back-emf has been presented, thus 0.4mm air gap design has been prove to be best design compared to 0.3mm air gap design for newly design DRHEFSM.

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