Study of Micro-Flux-Switching Permanent-Magnet Generator for TPMS on Smart Robots

An-Yun Yang, Cheng-Tang Pan, Shao-Yu Wang, Chun-Chieh Chang, Gu-Xuan Lin, Yu-Jen Wang
Department of Mechanical and Electromechanical Engineering, National Sun Yat-sen University,
No. 70, Lienhai Rd., Kaohsiung 80424, Taiwan
panct@mail.nsysu.edu.tw

Roger Chenglung Lee, Ting-Hung Chung
Naroller Electronics, Kaohsiung, 80424, Taiwan
335i2007@gmail.com

Abstract

Flux-Switching Permanent-Magnet Generator (FSPMG) with high flux density and high efficiency was designed due to its double salient structures. This study presents a micro FSPMG which was applied to tire pressure monitoring system (TPMS) on the smart robots. In this paper, finite element method (FEM) was utilized to simulate the magnetic properties of generator and then the flux and voltage output was obtained. The magnetic material used in this study was ferrite magnet which has the advantage of lower-cost.

Keywords: Generator, Flux-Switching, Tire pressure monitoring system, Finite element method.

1. Introduction

In automotive and aerospace fields, high efficiency machines are necessary nowadays. The axial field permanent magnet (PM) machine was concerned [1-3]. However, when the rotor temperature raise, the magnets inside the rotor on the conventional PM machine is irreversible demagnetize and mechanical damage. In 1995, the flux-switching PM (FSPM) machine was first proposed [4]. The feature of FSPM was that magnets in the stator with double salient structure were able to avoid the problem above [5]. FSPM machines are also high torque density with appropriate control [6-11]. The FSPM machines tend to investigate on FSPM motors so far, only few study mention about FSPM generator (FSPMG). In this study, finite element method (FEM) was utilized to simulate two types of FSPM generators properties and compared with the surface permanent magnet (SPM). Meanwhile, the FSPM generators apply on tire pressure monitoring system (TPMS) with stable electromotive force (EMF) was discussed.

2. Design of generator

2.1. *Steps of winding design*

There are many combinations of slot-pole ratio, feasible winding poles formula was shown in Eq. (1) and (2) [12].

$$N_s = k_1 m \tag{1}$$
$$N_r = N_s \pm k_2 \tag{2}$$

Where Ns is slots of stator, Nr is poles of rotor, m is phase number.

If the motor is multi-teeth, feasible winding poles formula was shown in Eq. (3) and (4) [13].

$$N_r = 2N_s \pm 1 \tag{3}$$
$$N_r = N_s(2n-1) \pm 1 \tag{4}$$

The FEM was used to analyze a three-phase FSPMG. The schematic of 12/10-pole FSPMG with a doubly-salient structure and 6/17-pole FSPMG with multi teeth were shown in Fig. 1.

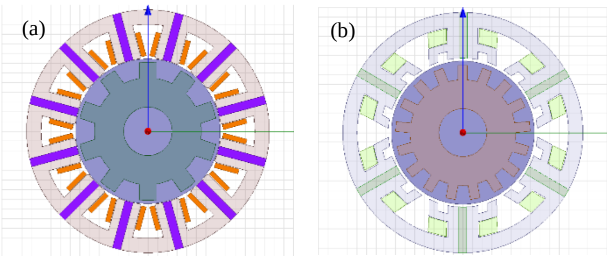


Fig. 1. (a)The structure of 12/10-pole FSPM generator (b) The structure of 6/17-pole FSPM generator

Calculation of the span in every slot , the slot of phase offset and the slot numbers of span were shown in Eq. (5), (6) and (7) [14].

$$\theta_s = \frac{N_p}{N_s} \tag{5}$$

$$K_0 = \frac{120°+q\times 360°}{\theta_s} \tag{6}$$

$$S^* = \max[fix\left(\frac{180}{\theta_s}\right), 1] \tag{7}$$

Where the θ_s and the K_0 are all integer.

2.2. *Winding Factor*

Eq. (8) was calculated the winding factor [15],

$$K_d = \frac{\sin(\frac{Qv\alpha}{2})}{Q\sin(\frac{v\alpha}{2})} \tag{8}$$

where Q is the number of EMF vectors per phase, α is the angle between two adjacent vectors, and v is the order of harmonic. Stator slots, rotor poles and the number of phases can decide winding factor.

The winding factors of the FSPM machines with different combination of stator pole and rotor pole numbers cause different results. Table 1 shows the designs specifications including traditional SPM, FSPM and multi-teeth FSPM.

Table 1. FSPM, multi-teeth FSPM and SPM specification

Type of machines	FSPM	multi-teeth FSPM	SPM
Slot-pole ratio	12/10	6/17	12/10
Stator outer radius	25mm		
Stator inner radius	15mm		
Airgap length	0.58 mm	0.13mm	0.5 mm
Turns per coil	400		
Rated speed	500rpm		
Resistance	100 ohm		
Magnet magnitude	-253000 A/m		

3. Results and Discussion

The equivalent circuit of the generator was shown in Fig. 2. The circuit was including inductance and resistance with 100 ohm. The inductance was regarded as input.

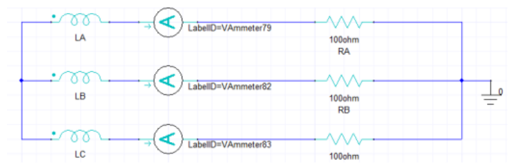


Fig. 2. The equivalent circuit

3.1. *Flux distributions in FSPM, multi-teeth FSPM and SPM*

Three generators were investigated by FEM. The flux distributions were shown in Fig. 3. From the flux distribution, the density of flux in the stator back-iron is lower than that in the stator teeth due to leakage flux.

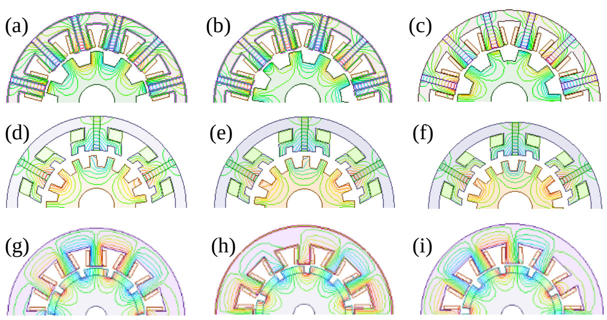
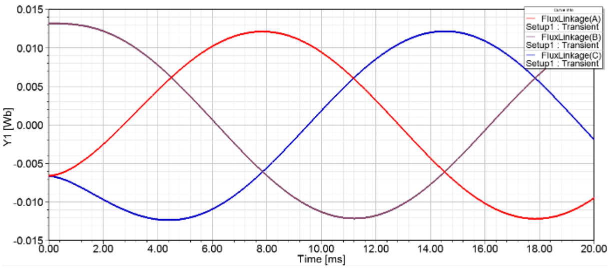


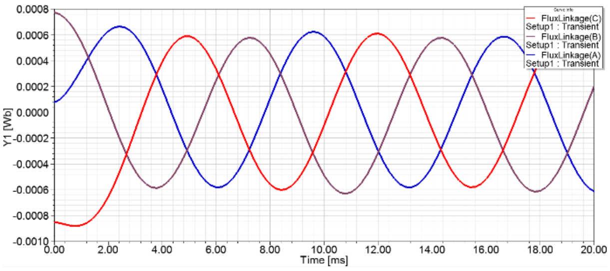
Fig. 3 (a)-(c) FSPM flux distributions from 0 s to 0.01s (d)-(f) multi-teeth FSPM flux distributions from 0s to 0.01s, (g)-(i) SPM flux distributions from 0s to 0.01s

3.2. *Flux-linkage in FSPM, multi-teeth FSPM and SPM*

Fig. 4 show that three generators flux-linkage were almost sinusoidal. The FSPM is between ±0.0121 Wb, the multi-teeth FSPM is between ±0.0006 Wb and the SPM is between ±0.0096 Wb



(a)



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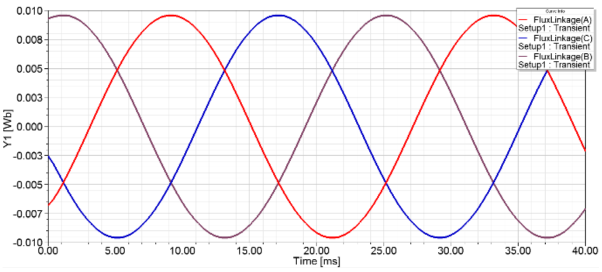
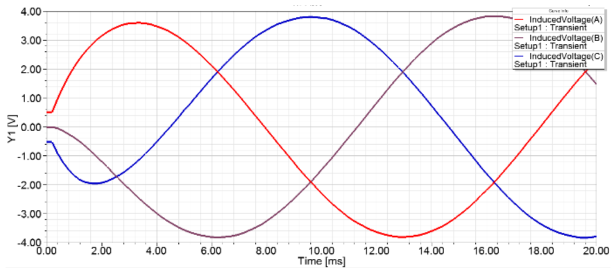


(c)

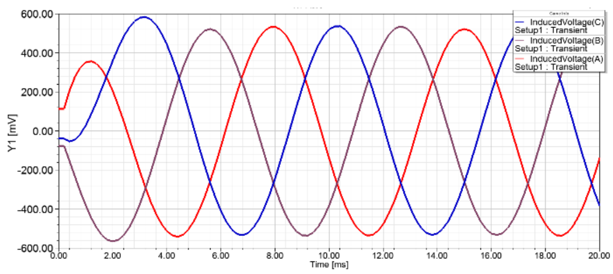
Fig. 4 The flux-linkage of (a) FSPM generator, (b) multi-teeth FSPM generator and (c) SPM generator.

3.3. *EMF in FSPM, multi-teeth FSPM and SPM*

Fig. 5 shows the EMF of three generators were almost sinusoidal. The FSPM is between ±3.6 V, the multi-teeth FSPM is between ±0.58 V and the SPM is between ±2.5 V.



(a)



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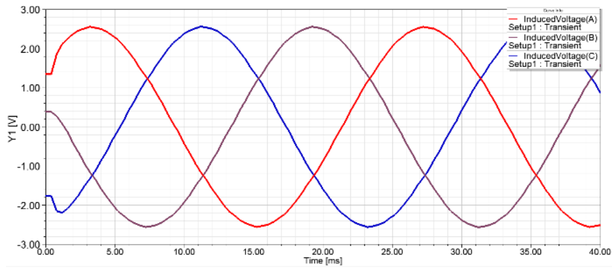
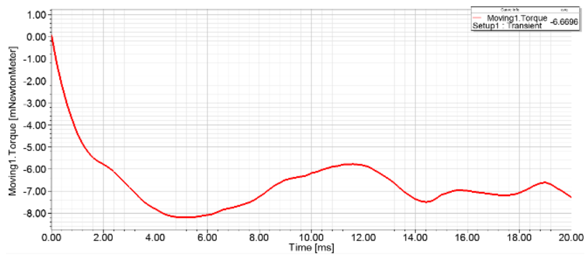


(c)

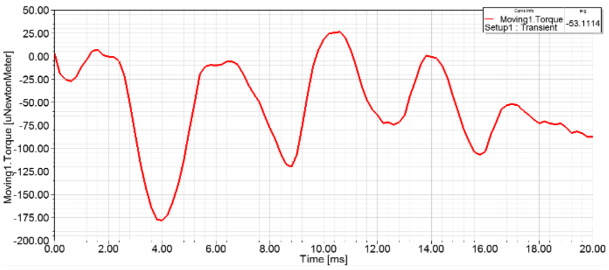
Fig. 5 The EMF of (a) FSPM generator, (b) multi-teeth FSPM generator and (c) SPM generator.

3.4. *Torque in FSPM, multi-teeth FSPM and SPM*

Fig. 6 shows the torque of three generators. After 6ms, the torque of FSPM is about -7 mN-m and the SPM is about -1.79 mN-m. The average torque multi-teeth FSPM is about -53.7 N-m.



(a)



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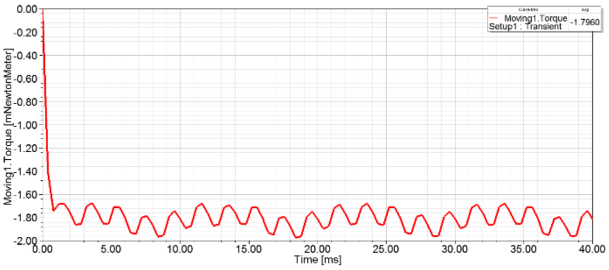

(c)

Fig. 6 The torque of (a) FSPM generator, (b) multi-teeth FSPM generator and (c) SPM generator.

4. Conclusion

A FSPM generator was proposed because of better power generation than traditional SPM. The ripple of FSPM is larger than SPM when generator, stable operation. Due to the Magnetic circuit of FSPM is complicated, it still can be improved by structure design. The power generation of FSPM is up to 3.6V. It was improved about 44% than traditional SPM. Also the frequency of EMF in FSPM is higher than SPM, it means the FSPM can save more energy than SPM in the same time. In multi-teeth FSPM, the ripple is obvious at first, but it was tended to be stable after 18 ms.

5. References

1. Y. Chen, P. Pillay, and A. Khan, “PM wind generator topologies,”IEEE Trans. Ind. Appl., vol. 41, no. 6, pp. 1619–1626, 2005.
2. A. Parviainen, J. Pyrhönen, and P. Konthanen, “Axial flux permanent magnet generator with concentrated wind power applications”, in IEEE Int. Conf. Electric Machines Drives, San Antonio, TX, USA, 2005, pp. 1187–1191.
3. S. Huang, J. Luo, F. Leonardi, and T. A. Lipo, “A comparison of power density for axial flux machines based on general purpose sizing equations,” IEEE Trans. Energy Convers., vol. 14, no. 2, pp. 185–192, 1999.
4. S. E. Rauch and L. J. Johnson, “Design principles of the flux switch alternator,” AIEE Trans., vol. 74, no. 3, pp. 1261–1268, 1955.
5. E. Hoang, A. H. Ben-Ahmed, and J. Lucidarme, “Switching flux permanent magnet polyphased synchronous machines,” in Proc. 7th Eur. Conf. Power Electron and Applicat, 1997, vol. 3, pp. 903–303.
6. E. Hoang, A. H. Ben-Ahmed, and J. Lucidarme, “Switching flux permanent magnet polyphased synchronous machines,” in Proc. 7th Eur. Conf. Power Electron. and Applicat, 1997, vol. 3, pp. 903–303
7. H. Wei, C. Ming, Z. Q. Zhu, and D. Howe, “Study on static characteristics of novel flux-switching doubly salient PM machine,” in Proc. CSEE, 2006, vol. 26, no. 13, pp. 129–134.
8. Z. Q. Zhu, Y. Pang, and D. Howe, “Analysis of electromagnetic performance of flux-switching permanent magnet machines by non-linear adaptive lumped parameter magnetic circuit model,” IEEE Trans. Magn., vol. 41, no. 11, pp. 4277–4287, 2005.
9. W. Hua, M. Cheng, and G. Zhang, “A novel hybrid excitation fluxswitching motor for hybrid vehicles,” IEEE Trans. Magn., vol. 45, no.10, pp. 4728–4731, Oct. 2009.
10. W. Hua, M. Cheng, Z. Q. Zhu, and D. Howe, “Analysis and optimization of back-EMF waveform of a flux-switching permanent magnet motor,” IEEE Trans. Energy Convers., vol. 23, no. 3, pp. 727–733, Sep. 2008.
11. J. T. Chen, Z. Q. Zhu, and D. Howe, “Stator and rotor pole combinations for multi-tooth flux-switching permanent-magnet brushless ac machines,” IEEE Trans. Magn, vol. 44, no. 12, pp. 4659–4667, Dec. 2008.
12. Z. Q. Zhu, and J. T. Chen, “Advanced flux-switching permanent magnet brushless machines,” IEEE Trans. Magn., vol. 46, no. 6, pp. 1447-1453, Jun. 2010.
13. Z. Q. Zhu, J. T. Chen, Y. Pang, D. Howe, S. Iwasaki, and R. Deodhar, “ Analysis of a novel multi-tooth flux-switching PM brushless AC machine for high torque direct-drive applications,” IEEE Trans. Magn., vol. 44, no. 11, pp. 4313-431, Nov. 2008.
14. R. L. Owen, Z. Q. Zhu, A. S. Thomas, G. W. Jewell, and D. Howe, “ Fault-tolerant flux-switching permanent magnet brushless AC machines, ” IEEE Trans. Ind. Appl., vol. 45, no. 6, pp. 1971–1981, Oct. 2009.
15. N. Bianchi, M. D. Pr´e, L. Alberti, and E. Fornasiero, Theory and Design of Fractional-Slot PM Machines. Padova, Italy: CLEUP, 2007.