Finite Element Computation of Magnetic Vibration Sources in 100kW Two Fractional-Slot Interior Permanent Magnet Machines for Ship

Sun-Kwon Lee[1], Gyu-Hong Kang[1], *Senior Member IEEE* and Jin Hur[2], *Senior Member IEEE*
[1]Korea Marine Equipment Research Institute, SongJeong-Dong, GangSeo-Gu, Busan, 1631-10, Korea
[2]Dept. of Electrical Engineering, University of Ulsan, 102. Street Dae-hak, Nam-gu, Ulsan 680-749, Korea
sunkwonlee@komeri.re.kr

Abstract — Magnetic forces are different according to pole and slot combination in the interior permanent magnet machine (IPM). Those have influence not only on the torque aspect, but also on the acoustic noise and vibration and result in shorten bearing life. In this paper, the magnetic vibration sources of 100kW two fractional-slot IPM machines for ship are analyzed. The vibration is very important for ship application due to strict regulations such as electro-magnetic comparability (EMC). The two fractional slot models have 8 pole-12 slot and 10 pole-12 slot respectively, and the other structural conditions are the same. The magnetic forces are calculated according to rotor position, current phase angle, and load by FEA. The results will be validated by experiments in extended paper.

I. Introduction

In comparison to surface-mounted PM (SPM) motors, IPM motors are a more attractive option for various applications because of their high torque density, wide speed range, excellent efficiency, and robustness [1].

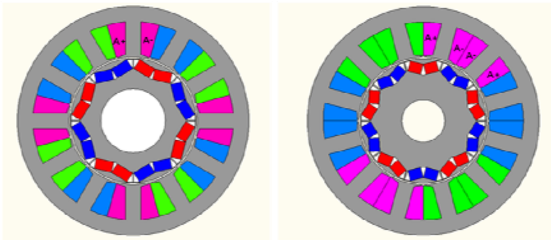
The electromagnetic performance of PM machines which have a fractional number of slots per pole and concentrated winding have shorter end windings and overall length, high efficiency, and high torque and power density while the small number of slots/pole is a distinct manufacturing advantage. Furthermore, the cogging torque can be extremely low, without the use of design features such as a skew [2], [3]. So the fractional slot PM machines are chosen to achieve high efficiency and low vibration which affects to get certification of strict regulations such as EMC for ship application.

Several researches [2], [3], [5] deal many kinds of pole slot combinations, but their scopes are limited to small sized SPM machines. The study [4] shows the vibration source reduction method by modifying the core structure such as slot open.

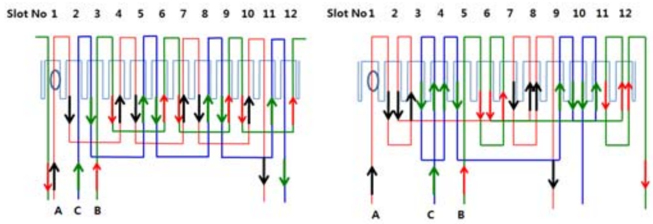
In this paper, the comparison study of magnetic induced vibration source of large IPM machines (rated output power is 100kW at 2000rpm) which have 8 pole-12 slot and 10 pole-12 slot is performed by 2D FEA. The main purpose of this study is to reduce the vibration source. The induced vibration sources are presented such as cogging torque, torque ripple, and radial force distribution including harmonic components. The back EMF constants of comparative models and stator core structure are equal to compare correctly.

II. Analysis models

Fig.1 shows the cross section of the analysis models to comparison study. Fig.2 presents the winding patterns of different fractional pole-slot combination when the stator slot number is 12. TABLE I shows the detail specifications of analysis models. The usage of PM of 10-pole machine is low compare to 8-pole machine to obtain same back EMF level.



(a) 8 Pole-12 Slot *(b) 10 Pole-12 Slot*
Fig. 1. Cross section of comparative models



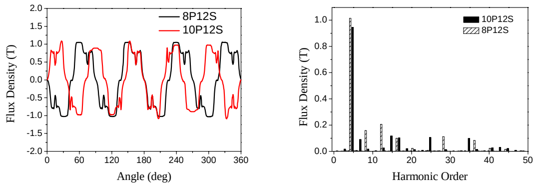
(a) 8 Pole-12 Slot *(b) 10 Pole-12 Slot*
Fig. 2. Winding layouts

TABLE I
Specifications

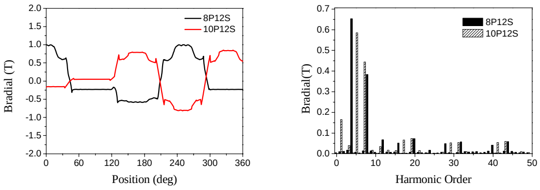
Items	8 Pole-12 Slot	10 Pole-12 Slot
Stator OD(mm)	324	324
Stack Length(mm)	270	270
PM thickness(mm)	15	15
PM Width(mm)	25.1	18.7
PM Area(mm^2)	6,024	5,610

III. Analysis Results

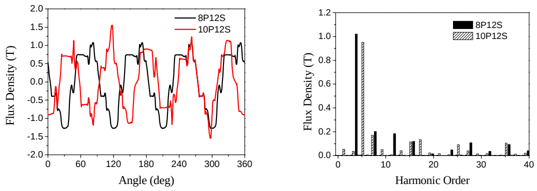
Fig.3 shows the air-gap flux density distribution and their harmonic components according to excitations such as no load, armature reaction, and full load (150A). The 10 pole-12 slot machine has asymmetrical flux density distribution. The regional high flux density at load makes the saturation at stator pole shoe, so the average torque of 10 poles machine at overload (over 350A) is decreased. Due to the pole and slot pitch combination, the cogging torque of 10 pole-12 slot model is lower than 8 pole-12 slot model's. Fig. 4 shows cogging torque and torque ripple comparison between two models. The torque fluctuation of 10 pole-12slot machine is significantly low in comparison with 8 pole-12slot machine. Fig. 5 present the radial force applied to 1 tooth according to rotor position and current phase angle. The radial force component on the contour in air-gap near stator tooth was integrated. The 10 pole-12slot machine has less radial force level than 8 pole-12slot machine. Because the 8th and 10th components of that force can induce the large vibration and noise at specific condition such as resonance, that should be reduced. The radial force distribution in air-gap at specific rotating angle is illustrated in the fig. 6. The 8 pole-12 slot machine has 4-directional force while the 10 pole-12 slot machine has 2-directional force as you can see the flux line in fig. 7.



(a) No load condition

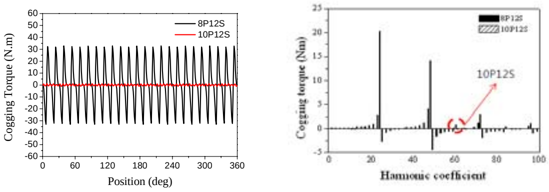


(b) Armature reaction (150A)

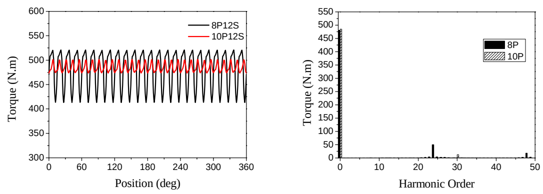


(c) Full load condition (150A)

Fig. 3. Magnetic flux density

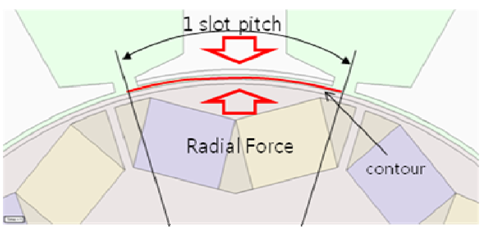


(a) Cogging torque

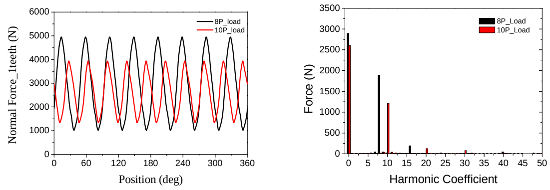


(b) Instantaneous torque

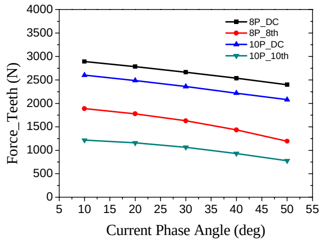
Fig. 4. Torque Comparison



(a) 1 tooth integration contour



(b) Radial force at 1 tooth



(c) Radial force according to current phase angle

Fig. 5. Radial Force at 1 tooth

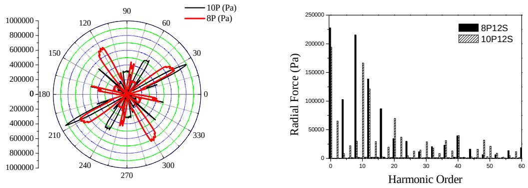


Fig. 6. Radial Force distribution

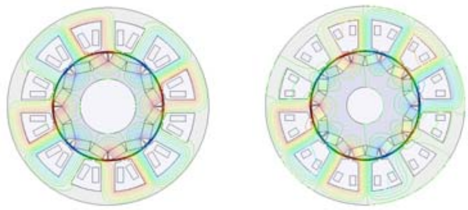

(a) 8 Pole-12 Slot *(b) 10 Pole-12 Slot*

Fig. 7. Flux line at full load

IV. ACKNOWLEDGEMENTS

This work is supported by the DongNam Leading Industry Office, Korea, (No. D21410913)

V. REFERENCES

[1] T.J.E Miller, Design of Brushless Permanent Magnet Motor, Clarendo press, Oxford, 1994

[2] Z.Q. Zhu, Dahaman Ishak, David Howe, and Jintao Chen, "Unbalanced Magnetic Forces in Permanent-Magnet Brushless Machines With Diametrically Asymmetric Phase Windings," *IEEE Trans. On Industry Applications*, vol. 43, no. 6, pp. 1544-1553, 2007.

[3] Z.Q. Zhu, Z.P. Xia, L.J. Wu, and Geraint W. Jewell, "Analytical Modeling and Finite-Element Computation of Radial Vibration Force in Fractional-Slot Permanent-Magnet Brushless Machines," *IEEE Trans. On Industry Applications*, vol. 46, no. 5, pp. 1908-1918, 2010.

[4] Taeyong Yoon, "Magnetically Induced Vibration in a Permanent – Magnet Brushless DC Motor with Symmetric Pole-Slot Configuration," *IEEE Trans. On Magnetics*, vol. 41, no. 6, pp. 2173-2179, 2005.

[5] David G. Dorrell, Mircea Popsescu, and Dan M. Ionel, "Unbalanced Magnetic Pull Due to Asymmetry and Low-Level Static Rotor Eccentricity in Fractional-Slot Brushless Permanent-Magnet Motors With Surface-Magnet and Consequent-Pole Rotors, IEEE Trans. On Magnetics, vol 46, no. 7, pp.2675-2685, 2010.