Journal of Engineering and Applied Sciences 13 (Special Issue 7): 5619-5623, 2018
ISSN: 1816-949X

Examination and Design of Low-Speed Six-Phase Fractional-Space Concentrated-Winding PM Motor Applied to Marine Propulsion

J.S. Ashwin and N. Manoharan
AMET University, Chennai, India

Abstract: The space post organize requirement state of low-speed six-stage half-symmetrical partial opening concentrated-winding PM engine connected to marine drive is investigated, all space shaft mixes connected to six-stage fragmentary space engine inside 60 spaces and 52 posts are recorded. The space post blend upgraded choice technique in view of hypothetical examination is proposed. Fundamentally, considering of expanding winding circulation variable and lessening cogging torque, a 48 openings and 44 posts six-stage partial space concentrated-winding PM engine with 20 kW evaluated power is planned. Trial comes about demonstrate that the PM engine has great exhibitions and the proposed technique connected to the plan of multi-stage partial opening concentrated-winding PM engine is doable.

Key words: Fractional-slot, concentrated-winding, marine propulsion, PM engine, evaluated power, proposed

INTRODUCTION

With the developments of AC motor control theory and power electronic technology, electric propulsion has become the trend of marine power development. The propulsion motor in the ship has high requirements such as high load, low speed, wider adjustable speed (0-300r/min), small size and especially small axial disturbance in order to adapt to the requirements of the cabin and so on.

Common low-speed motor has more poles, distance between poles is relatively small, q shouldn't be designed too big or the stator external diameter of motor will be increased and it is difficult to be manufactured. If a small integer is selected for q, the total amount of stator slots will be decreased but the tooth harmonic electrical potential order will be small and its amplitude are large, resulting in high harmonic distortion of the induced electromotive force in the windings (Reddy *et al*., 2015). But when fractional-slot winding is used, each coil of the windings in the same phase can be arranged under different poles. In this distribution as there exists space shift between teeth and slots under each antipode, resulting in the phase angles of teeth harmonic electromotive force induced by serial conductor in the same phase are different, making synthetic electromotive force weaken and sinusoidal. Because of space-shift between cogging under each pair of poles, cogging harmonic wave electromotive force inducted by serial connected conductors in windings of one phase will have phase differences, its combined electromotive force will be weakened on account of phasor composition and a better sinusoidal wave of electromotive force will be acquired. Besides by using fractional slot concentrated-winding (winding pitch equals 1), coils can be wrapped in a single stator cog directly, substantially reducing the length of winding-end extended part and shorting axial length of the motor. Moreover, it saves materials and reduces motor's thermal-loss. Therefore, fractional-slot concentrated-winding PM motor is an appropriate choice in marine electric- propulsion field. Though fractional-slot concentrated-winding has nice electromotive force waveform, harmonic wave magneto motive force produced by stator current can be very strong which may cause big torque fluctuation in motor. Multi-phase motor has apparent advantage in reducing torque fluctuation, therefore, multi-phase fractional-slot motor will definitely be widely used in the marine propulsion field.

There are many literatures which have studied on this kind of PM motor. By Patel *et al*. the influence on torque ripple and loss caused by different tooth and cog combinations and the amount of armature winding layers in fractional-slot concentrated winding PM motor was analyzed. By Klingshirn (1983) and Levi (2008) fault-tolerant operation of multi-phase motor was analyzed. Literature (Wu *et al*., 2009) air gap magnetic field effected by a 3-phase 10-poles 12-slots fractional-slot, concentrated-winding PM motor by using FEM was analyzed by Wu *et al.* (2009). An 18-slots, 14-poles fractional-slot concentrated-winding, PM motor with wide speed-adjustable range and low toque ripple was designed optimally by Dutta *et al.* (2013). Speed-adjustable control without position sensor of a 12-slots 10-poles double 3-phase fractional-slot

Corresponding Author: J.S. Ashwin, AMET University, Chennai, India

concentrated winding PM motor was analyzed by Massimo *et al.* (2012). The magneto motive force harmonic affected by multi-layer windings (>2 layers) was discussed by Thiagarajan and Manoharan (2006) Balakrishnan and Balasubramanian (2012) and Fayaz *et al.* (2014). All of the above researches have good results but the PM motor in most of the researches is low power and the research goals are economic. None of them studied the PM motor from the viewpoint of applying to shipboard with high power and low speed.

Disputed study, adapting concurrent engineering approach for design and development of a new rotary hydraulic motor for marine application (Thiagarajan and Manoharan, 2006) initializing a hydraulic motor to adapt concurrent approach of design and development of marine application. A physicochemical study of the adulteration of motor gasoline with a mixture of aliphatic and aromatic hydrocarbons (Balakrishnan and Balasubramanian, 2012) organizes a motor gasoline or a study of motor for processing aromatic hydrocarbons. Bottom hole assembly and mud motor for directional drilling discover drilling motors suffer to drill on compound structure of surface.

MATERIALS AND METHODS

Six-phase fractional-slot concentrated winding PM motor's slot-pole coordinate: Six-phase half-symmetrical winding includes two sets of star-connected three-phase winding, one lags behind the other 30°. Which can be shown as in Fig. 1, A1 phase is 30° prior to A2 phase and A2 phase is 90° prior to B1 phase and the rest can be done in the same manner. Whole-symmetrical windings mean 6 phases are distributed on phase-plane averagely, the nearest two have 60° phase angle error.

Constraint factors for concentrated winding: In part of combinations can be designed to fractional-slot concentrated-winding. Forming fractional-slot concentrated-winding needs winding pitch y = 1, demanding that two conductor's edges belonging to the same coil should have their electrical angles error as possible as 180°. Using one phase belt's electrical angle as a reference, slot distance electrical angle's supplementary angle is required of $\beta \leq 60°$. Can be derived by using this constraint.

Therefore, the mismatch condition combinations are deleted, the rest one which can constitute fractional-slot concentrated winding. In grids with fractions are selective

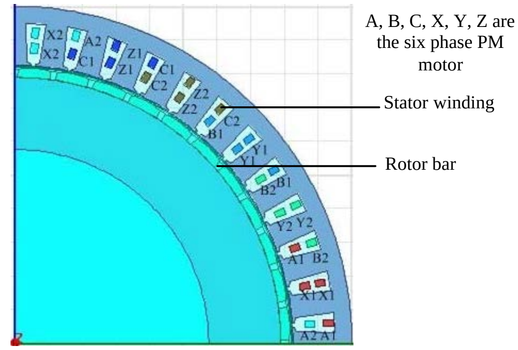

Fig. 1: Motor winding assignment

Considering that the star graph of slot electromotive force is composed of Z/t spokes and each spoke includes t vectors. To ensure that opposite odd phasors and even phasors can be paired when phase belt is divided, half of the number of spokes should be even. For example, the number of unit motor t = 2 in 24 slots 10 pole-pairs motor, the number of spoke is 12, each spoke has 2 double phasor. Among them, red (dotted line), blue (short dotted line), respectively mark slot electromotive force phasor including phase A1 and A2. Among odd number phasors, number 19, 7, 1, 13 (odd) phasor distributed on two spokes of opposite directions. Among even number phasors, number 14, 2, 8, 20 (even) phasor distributed on neighboring spokes. Let's discuss the condition that dividing the number of spokes by two equals an odd number.

Winding-distribution coefficient: The coefficient is defined as a proportion of each same-phase coil's EMF phasor summation and numerical summation. Therefore, different slot-pole coordination's distribution coefficient can be confirmed by star graph of slot EMF as follows.

The stator uses half-block slot, double-layer winding, magnetic steel N35UH. Both stator and rotor use silicon steel 50 DW 310-Z. Use Ansoft Software to build model for PM motor, motor winding assignment is shown in Fig. 1.

Air gap flux under no load is shown in Fig. 2. Flux harmonic distribution under no load is shown in Fig. 3. As is shown in Fig. 4 and 5, fundamental (22th) has the biggest flux amplitude, about 0.9362 T, three times (66th) harmonic follows, about 0.1 T.

Back electromotive force with its fundamental under No load is shown in Fig. 4, back electromotive harmonic distribution is shown in Fig. 5. Fundamental phase voltage peak value is about 311 V, three times harmonic voltage is about 30 V.

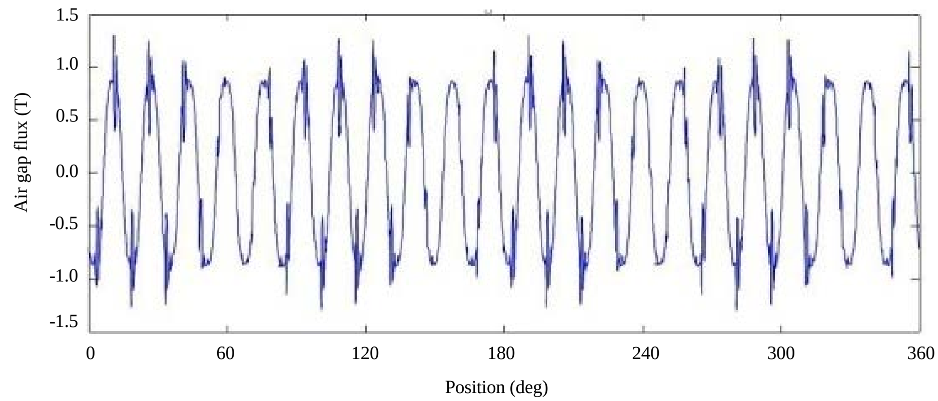

Fig. 2: Air gap flux distribution under no load

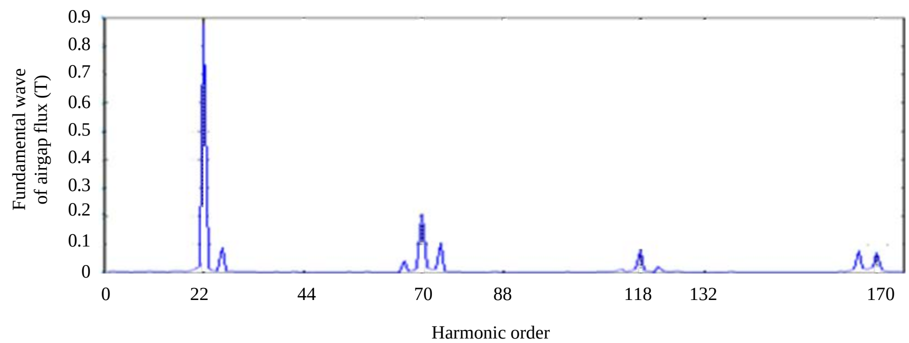

Fig. 3: Flux harmonic distribution under no load

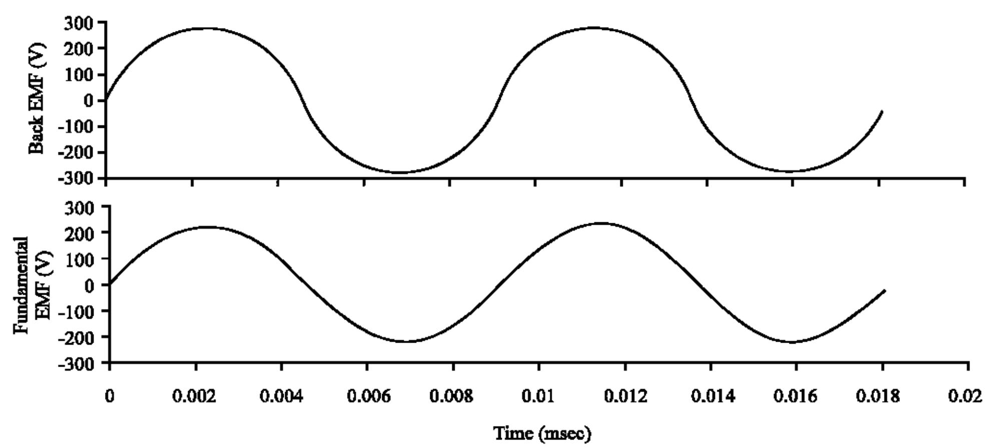

Fig. 4: Back electromotive force with its fundamental

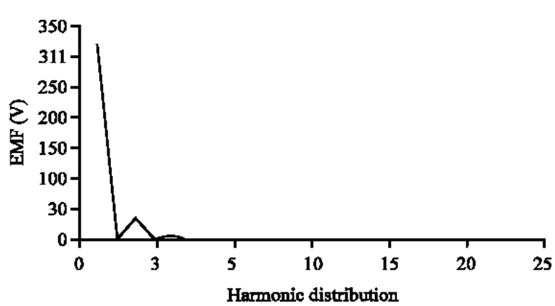

Fig. 5: Harmonic distribution of back electromotive force

combinations, the rest blank grids can't constitute fractional-slot concentrated winding but they can still form 6-phase fractional-slot winding.

According to magnetic calculations, the prototype of the PM motor is built. In order to reduce the eddy influence on magnetic steel, 5 pieces of magnetic steel are set on rotor's axial direction. Each steel has 10 parts on axial. On the circle, there are 5 pieces of steel which means 50 small steel stick together.

Fig. 6: Experimental system

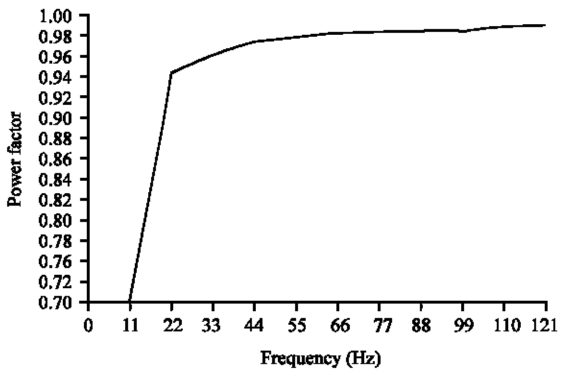

Fig. 7: The curve of power factor varies with frequency under loaded

RESULTS AND DISCUSSION

The motor's power is supplied by 6-phase inverters, the load is a 6-phase PM motor. The experimental system has shown Fig. 6. When the back electromotive force is tested, the motor works as a generator dragged by the load motor and the back electromotive waveform of different rotor speeds is acquired. According to the charts, calculated results and real-test results are close and the error is smaller than 2% which satisfies the needs of engineering.

The motor research as an electromotor to drag loaded motor during the loaded experiments and the loaded motor is directly connected to resistance. While the resistance value can satisfy the rated rotate speed of 300 r/min (110 Hz), the motor has full-load output power (20 kW).

The power coefficient transformation condition according to the change of rotate speed (frequency) of the motor is in whole speed-adjustment range. It can be known that when motor's frequency is above 22 Hz (60 r/min), the power coefficient can be higher than 0.94. Figure 7 shows the curve of power factor varies with frequency under load.

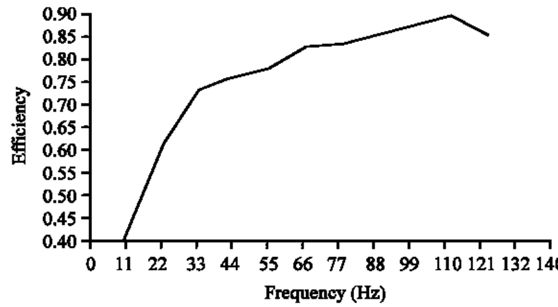

Fig. 8: The curve of efficiency varied with frequency changed under loaded

It can be seen that as frequency increases, the motor's efficiency increases and the efficiency value reaches the peak 90% when rotor speed arrives at the rated value. Figure 8 shows the curve of efficiency varied with frequency changed under load.

CONCLUSION

This study analyzed 6-phase fractional-slot concentrated-winding PM motor slot-pole coordinate constraint factors and optimized method. A 20 kW 48-slot 44-pole 6-phase fractional-slot concentrated-winding PM motor is designed and from experimental results some conclusions can be obtained as follows. Fractional-slot, fractional-slot concentrated-winding and half-symmetrical fractional-slot 6-phase PM motor constraint factors are analyzed, 6-phase fractional-slot PM motor slot-pole combinations are different constraint factors. Slot-pole combinations which can make motor have good performances should have the following characteristics.

REFERENCES

Balakrishnan, J. and V. Balasubramanian, 2012. A physicochemical study of the adulteration of motor gasoline with a mixture of aliphatic and aromatic hydrocarbons. Petroleum Sci. Technol., 30: 237-246.

Dutta, R., L. Chong and M.F. Rahman, 2013. Design and experimental verification of an 18-slot-14-pole fractional-slot concentrated winding interior permanent magnet machine. IEEE. Trans. Energy Convers., 28: 181-190.

Fayaz, B.A., A. Sunny and N. Nazeel, 2014. Bottom hole assembly and mud motor for directional drilling. Biosci. Biotechnol. Res. Asia, 11: 201-206.

Klingshirn, E.A., 1983. High phase order induction motors-part I-description and theoretical considerations. IEEE. Trans. Power Apparatus Syst., 102: 47-53.

Levi, E., 2008. Multiphase electric machines for variable-speed applications. IEEE Trans. Ind. Electr., 55: 1893-1909.

Massimo, B., F. Adriano and B. Nicola, 2012. Sensorless rotor position detection capability of a dual three-phase fractional-slot IPM machine. IEEE. Tran. Ind. Appl., 48: 2068-2078.

Reddy, P.B., A.M. El-Refaie and K.K. Huh, 2015. Effect of number of layers on performance of fractional-slot concentrated-windings interior permanent magnet machines. IEEE. Trans. Power Electron., 30: 2205-2218.

Thiagarajan, D.I. and N. Manoharan, 2006. Adapting concurrent engineering approach for design and development of a new rotary hydraulic motor for marine application. ARPN. J. Eng. Appl. Sci., 10: 5564-5568.

Wu, L.J., Z.Q. Zhu, J.T. Chen, Z.P. Xia and G.W. Jewell, 2009. Optimal split ratio in fractional-slot interior permanent magnet machines with non-overlapping windings. Proceedings of the IEEE International Conference on Electric Machines and Drives IEMDC'09, May 3-6, 2009, IEEE, Miami, Florida, USA., ISBN:978-1-4244-4251-5, pp: 1721-1728.