Characteristic analysis for Concentrated Multiple-layer Winding Machine with Optimum Turn ratio

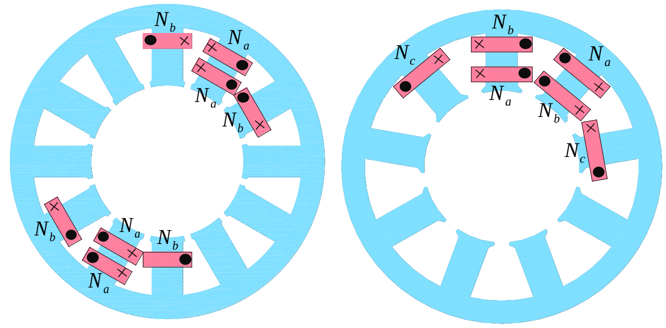
Hae-joong Kim, Do-Jin Kim, Jung-Pyo Hong
[1]Department of Automotive Engineering, Hanyang University 222 Wangsimni-ro, Seoul 133-791, Korea
hongjp@hanyang.ac.kr

***Abstract*—The aim of this paper is to analysis the characteristic of the three phase concentrated multiple layer (4-layer) winding motor with optimum turn ratio which reduces the amplitude of the sub-space harmonics of the MMF. The low order sub-harmonics of the MMF caused by the armature reaction affect the performance degradation of the motor such as eddy current loss in the permanent magnet and a vibration problem. In order to reduce the sub-space harmonics amplitude of the MMF, the optimum turn ratio in the four layer winding should be determined. By calculation of the winding factor, the optimum turn ratio can be found. The sub-space harmonics of the MMF are reduced or eliminated by decision of the turn ratio in four layers. The models with different turn ratio are analyzed based on a comparison of the deformation of the stator and eddy current loss at permanent magnet. Two examples of three phase concentrated windings are presented and analyzed as primitive windings, 9slots/8poles and 10slots/12poles.**

***Index Terms*—AC motors, eddy current, vibration, harmonic analysis, stators.**

I. Introduction

The alternative of fractional slot winding is being considered in such application due to the simplicity of the winding manufacturing and reducing the amount of copper by less the end winding length [1], [2]. Usually a winding is arranged so as to realize the maximum winding factor for the main harmonic. Typically single layer and double layer windings, i.e. with one or two layers, are considered in the literature. Even though the various solutions exhibit a similar winding factor for the main harmonic, they exhibit different characteristics since their magneto-motive force (MMF) harmonic content is different. As a result, their performance is also different. In order to reduce the amplitude of the MMF harmonics, it is possible to increase the number of layers and, to determine the turn ratio in the winding [3]-[7]. The aim of this paper is to analysis the characteristic of the three phase concentrated multiple layer (4-layer) winding motor with optimum turn ratio which reduces the amplitude of the sub-space harmonics of the MMF. The low order sub-harmonics of the MMF, which is caused by the armature reaction affects the performance degradation of the motor such as the eddy current loss in the permanent magnet and the vibration problem [2]. In order to reduce the sub-space harmonics amplitude of the MMF, the optimum turn ratio in the four layer winding should be determined. From calculation of the winding factor, the optimum turn ratio can be found. The sub-space harmonics of the MMF are reduced or eliminated by the decision of the turn ratio in four layers. The models with different turn ratio are analyzed based on a comparison of the deformation of the stator and eddy current loss at permanent magnet.



(a) 12 slot 10 pole (b) 9 slot 8 pole

Fig. 1. The 4-layer winding motors

II. Layout of The Multi-Layer Windings

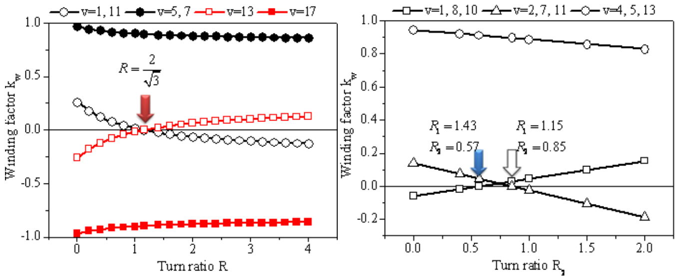
In Fig. 1 the winding diagram for the 4-layer winding the configuration is presented. In Fig. 1-(a), the coil N_a and N_b from the top part of the group wound around the teeth have the turn ratio $R=N_b/N_a$. If the coils N_a wound around the top part of the tooth have N_a turns, the N_b wound around the bottom part of the tooth will have $R\cdot N_a$ turns. The winding factor with the turn ratio between the number of turns of the N_a coil and the N_b coils results from Fig. 2 where the optimum turn ratio is presented for the space harmonic of the 12 slot 10pole 4-layer winding. The electric angles between the two adjacent spokes are 30^o. From the star of the coils, it follows that the winding factor k_w of the three-phase 12 slots 10 pole 4-layer winding machine equals the product of a distribution factor k_d times a pitch factor k_p.

$$k_w = \frac{1+R\cos(\pi-\nu\beta)}{1+R}\sin\left(\frac{\nu\beta}{2}\right) \quad (1)$$

The ratio S/t for the 9 slot 8 pole is an odd number. The number of spokes in the positive sectors differs by 1 with respect to the spokes number in the negative sector. The shift angle is equal to half the angle between the two spokes [3], [8], [9]. The coil N_a, N_b and N_c from the top part of the group wound around the teeth has the turn ratio $R_1=N_b/N_a$, $R_2=N_c/N_a$. The electric angles between the two adjacent spokes are 40^o. From the star of the coils, the winding factor k_w of three-phase 9 slots 8pole 4-layer winding machine is

$$k_w = \frac{(1+R_1)\cos\left\{\frac{1}{2}(\pi-\nu\beta)\right\}+R_2\cos\left\{\frac{3}{2}(\pi-\nu\beta)\right\}}{1+R_1+R_2}\sin\left(\frac{\nu\beta}{2}\right) \quad (2)$$

In Fig. 2, the winding factor according to the results of adjusting the turn ratio for the 12 slot 10 pole and 9 slot 8 pole



(a) 12 slot 10 pole (b) 9 slot 8 pole

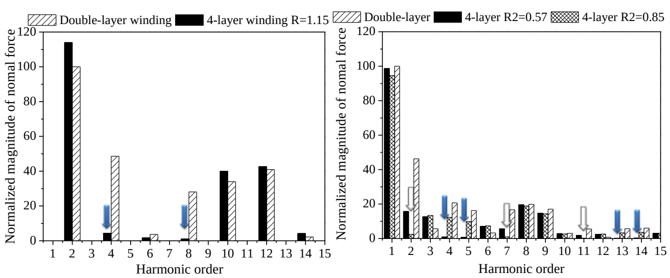
Fig. 2. The winding factor of 4-layer winding

4-layer winding is presented. One can see that there is a turn ratio point for canceling the winding factor of the space harmonic.

III. Characteristic Analysis

The reduction of the sub-harmonic of the magnetomotive force down to zero can be achieved by adjusting the turn ratio for the 4-layer winding.

A harmonic analysis of the radial the force was achieved to look for main frequency that influences the noise and vibration. In fig. 3, one can be seen that by introducing the turn ratio of the 4-layer winding, the harmonics for the normal force are reduced for 12 slot 10 pole, 9 slot 8 pole combinations.



(a) 12 slot 10 pole (b) 9 slot 8 pole

Fig. 3. The normal force spectrum

The high conductivity of permanent magnet materials leads to significant eddy current losses and this may cause the thermal demagnetization of magnets. In the full paper, using 3D FE methods the eddy current losses for the double layer winding, the 12 slots 10 pole, 9 slots 8 pole 4-layer winding will be investigated. During the determination of the PM eddy current losses, the considered PM machine will be investigated for the under load condition. The eddy current losses due to stator MMF harmonics (armature reaction field) are reduced significantly with the Optimum Turn ratio winding.

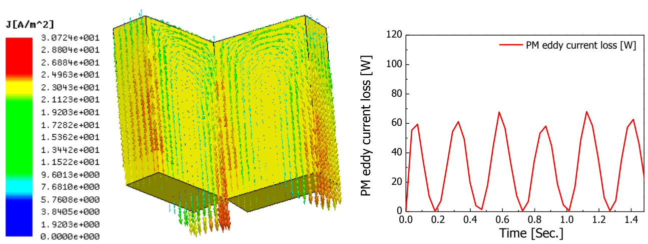


Fig. 4. The eddy current loss analysis at the PM

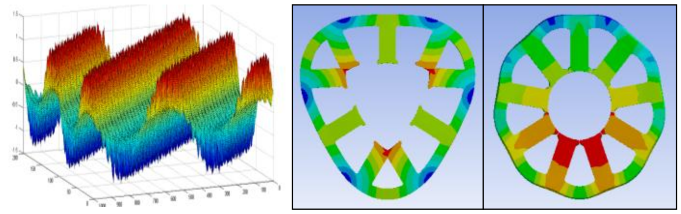


Fig. 5. The deformation analysis of the stator

Additionally, the vibration generated from the deformation of stator will be analyzed with considering local force harmonic component according to turn ratio in four layers. The effectiveness of each turn ratios on vibration reduction is concluded.

IV. Conclusion

The fractional tooth concentrated windings have sub-space harmonics in the MMF of armature reaction because of very low value of the number of slots/pole/phase. In the paper turn ratios are presented to reduce or even to cancel some of the space harmonics of the armature reaction based on decreasing the winding factors. The eddy current losses due to stator MMF harmonics (armature reaction field) are reduced significantly with the Optimum Turn ratio winding. The effectiveness of each turn ratios on vibration reduction is concluded. In the full paper, three types of concentrated windings will be analyzed as 10slots/12poles 4-layer winding, 9slots/8poles 4-layer winding.

References

[1] M. V. Cistelecan, F. J. T. E. Ferreira, and M. Popescu, “Three phase tooth-concentrated multiple-layer fractional windings with low space harmonic content,” in 2010 IEEE Energy Conversion Congress and Exposition (ECCE), 2010, pp. 1399 –1405.

[2] F. Magnussen and C. Sadarangani, “Winging factors and joule losses of permanent magnet machines with concentrated windings,” in proc. *IEEE IEMDC*, Madison, WI, Jun. 2003, pp. 333-339.

[3] Luigi Alberti, Bicola Bianchi, “Theory and Design of Fractional-Slot Multilayer Windings” in *2011 IEEE Energy Conversion Congress and Exposition (ECCE)*, 2011, pp. 3112 –3119.

[4] N. Bianchi, S. Bolognani, M. D. Pre, and G. Grezzani, “Design considerations for fractional-slot winding configurations of synchronous machines,” *IEEE transactions on industry applications*, vol. 42, pp. 997–1006, Jul. 2006.

[5] J. Pyrhonen, T. Jokinen, and V. Hrabovcova, “*Design of Rotating Electrical Machines*,” Chichester, United Kingdom: John Wiley & Sons Ltd, 2008.

[6] P. Salminen, M. Niemela, and J. Pyrhonen, “Performance analysis of fractional slot wound PM-motors for low speed applications,” *Proc. IEEE Industry Applications Society Conf.*, vol. 2, pp. 1032-1037, 2005.

[7] Jérome Cros, Philippe Viarouge, “Synthesis of High Performance PM Motors With Concentrated Windings”, *IEEE Transactions on Energy Conversion*, Vol. 17, No. 2, p.p. 248-253, June 2002.

[8] Rahman, MF, Dutta, RD & Chong, GL, 2007, “Application of concentrated windings in interior permanent magnet machine,” in *Australasian Universities Power Engineering Conference (AUPEC 2007)*, presented at Australasian Universities Power Engineering Conference (AUPEC 2007), Perth, WA, 9 - 12 December 2007.

[9] N. Bianchi, M. Dai Pr´e, L. Alberti, and E. Fornasiero, “Theory and Design of Fractional-Slot PM Machines,” Sponsored by the *IEEEIAS Electrical Machines Commitee, Ed. Padova: CLEUP* (ISBN 978-88-6129-122-5), 2007.