Analysis of Two-phase Permanent Magnet Synchronous Machines Used for Hybrid Vehicles

Tsvetomir Stoyanov
General Electrical Engineering
Technical University of Sofia
Sofia, Bulgaria
cmetodiev@tu-sofia.bg

Radoslav Spasov
Electrical Machines
Technical University of Sofia
Sofia, Bulgaria
rls@tu-sofia.bg

***Abstract*— This paper present the results from a study of two-phase V-shaped permanent magnet synchronous machines, used in hybrid cars. The analysis based on the main harmonic of the magnetic flux density in the air gap and emf. Also has been made a comparison between this machine and synchronous machines with three-phase winding (both machines have the same geometry), used Clarke transformation. The comparison of the electromagnetic torque produced by both machines is presented. The analysis is performed by finite element magnetic field modeling and program modules for of magnetic flux density and emf.**

***Keywords—permanent magnet synchronous machine, finite element method, Clarke transformation, electromagnetic torque** (key words)*

I. Introduction

The synchronous machines with V-shaped permanent magnets in the rotor (SMPM) are very often used as a traction motors in hybrid vehicles. The reasons for this are the following: high reluctance torque, wide speed range, high power density and high efficiency [2, 5]. One of the ways to achieve these features is through the optimization of the stator winding. There is a huge variety of windings uses in SMPM, They are two, three, five, twelve-phase. [1, 6]. The variety of SMPM research methods is also immense. One of them is by finite element magnetic field modeling used in analyzing electrical machines [3,4]. The aim of this paper is through modeling of the magnetic field of the synchronous machines with V-shaped permanent magnets in the rotor and determine the main harmonic of the magnetic flux density in the air gap and emf. Clarke transformation is used to be make a comparison between this machine and synchronous machines with three-phase winding.

II. Machine configuration

The geometry of the analyzed machine is presented in Table 1.

TABLE I. DATA ABOUT THE MACHINE

Number of phases	-	3	2
Number of slots per pole and phase	-	q = 2	q = 3
Air gap	mm	0,7	0,7
Rotor stack length	mm	90	90
Stator inner diameter	mm	184,2	184,2
Stator outer diameter	mm	242	242
Number of stator slots	-	60	60
Angle between two slots in electrical degrees	deg	30	30
Width of slots	mm	5,8	5,8
Height of slots	mm	18,1	18,1
Outer rotor diameter	mm	182,8	182,8

Cross-section of the three-phase machine is shown in Fig.1. Cross-section of the two-phase machine is shown in Fig.2.

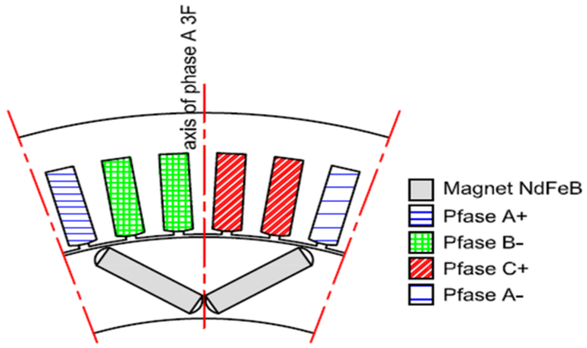

Fig. 1. Cross-section of the three-phase machine

On the figure are presented depicted the axis of the phase.

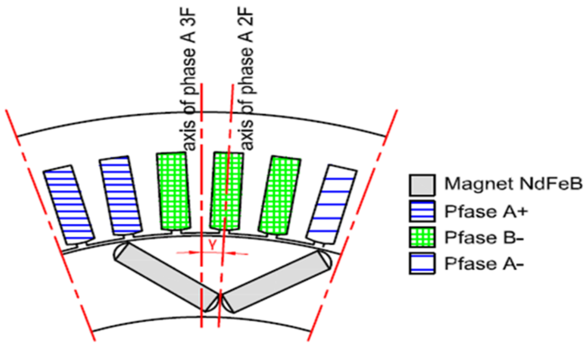

Fig. 2. Cross-section of the two-phase machine

The machine have three-phase or two-phase stator winding. The angle between the axis of the two types of stator winding is Y. Transformation from coordinate system “abc” to coordinate system “αβ” by Clarke transformation is presented on Fig. 3.

The transformation is presented by formula [1] to

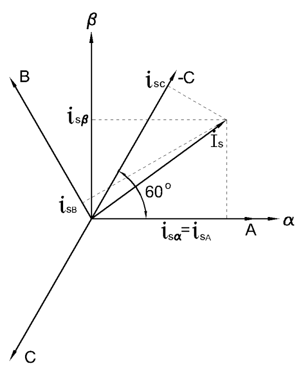

Fig. 3. Clarke transformation

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formula [5].

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \mathrm{X} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} \tag{1}$$

$$i_\alpha = \frac{2}{3}\left(i_A - \frac{1}{2} i_B - \frac{1}{2} i_C \right) \tag{2}$$

$$i_\beta = \frac{2}{3}\left(\frac{\sqrt{3}}{2} i_B - \frac{\sqrt{3}}{2} i_C \right) \tag{3}$$

$$i_\alpha = i_A \tag{4}$$

$$i_\beta = \frac{1}{\sqrt{3}}\left(i_B - i_C \right) \tag{5}$$

$$i_A + i_B + i_c = 0 \tag{6}$$

Where i_A, i_B, i_C are stator currents in coordinate system “abc” and i_α i_β in coordinate system “αβ”. The stator wending is shown in Fig.4.

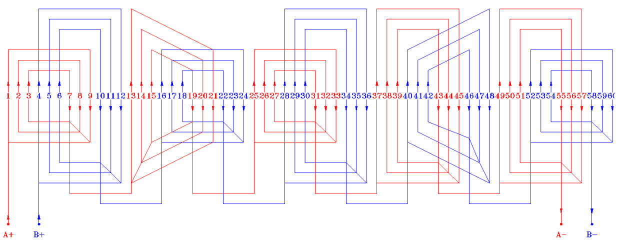

Fig. 4. Stator wending

III. ANALYSIS

The two type of the stators’s windings are analyzed with stator current is equivalent to the current densities in the stator is equals to 20 [A/mm^2]. The analysis carried out starts at the time instant when the instantaneous value of the current densities in phase A equals its maximum value. The instantaneous values of the currents densities in phase B and C are equal to half the maximum value and are negative (about three-phase stator winding). When the stator winding is two- phase the start point in time is the moment when the current density in phase A has a maximum value and the current density phase B is zero. The flux density and the phase electromotive force is calculated forty times. The time interval be-tween each calculation is set to interval of t = 0.0005 s that represents one turn of the machines rotor. The rotor spins clockwise with an angle of 1.8 degree (geo-metrical) that can be represented by 0.0005 seconds in the time line for each calculation. Distribution factor (k_{d3F} =0.96) of the stator three- phase winding is beiger then distribution factor (k_{d2F} =0.91) of the two- phase stator winding. The flux line path of the electromagnetic field (above- two- phase stator winding , down- three-phase stator winding) is shown on Fig.5. Fig.6. shows the electromotive force as time function. The main harmonic of the magnetic flux density at different moment of time is presented on Fig.7. Fig.8. shows the relationships between the flux linkages and time. Fig.9. presents the changes of the flux linkages at different stator’s slots. The main harmonic of the electromotive force, electromagnetic torque and the total harmonic distortion (THD) are presented in Table 2. Electromotive force for the second to twentieth harmonic are presented on Fig.10. Fig.11. shows the electromagnetic torque as time function.

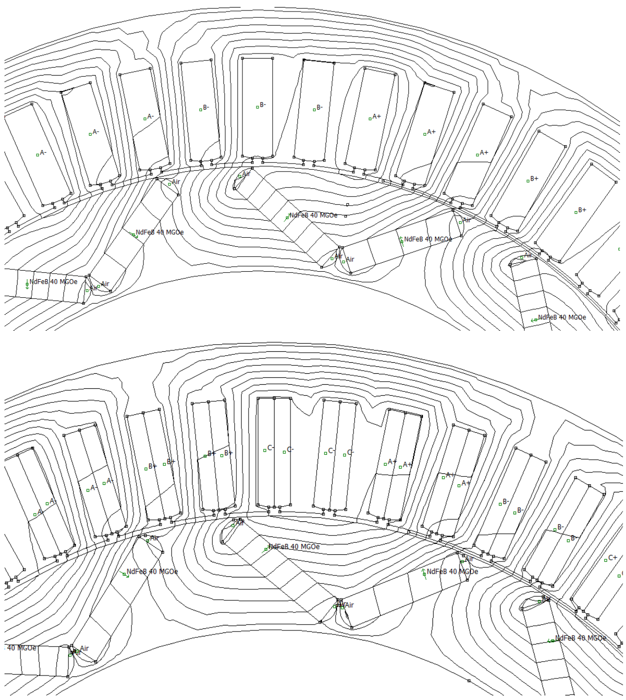
Fig. 5. Flux line path of the electromagnetic field

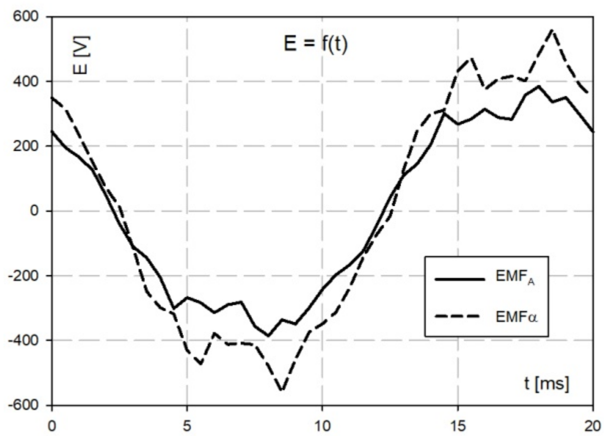

Fig. 6. Electromotive force

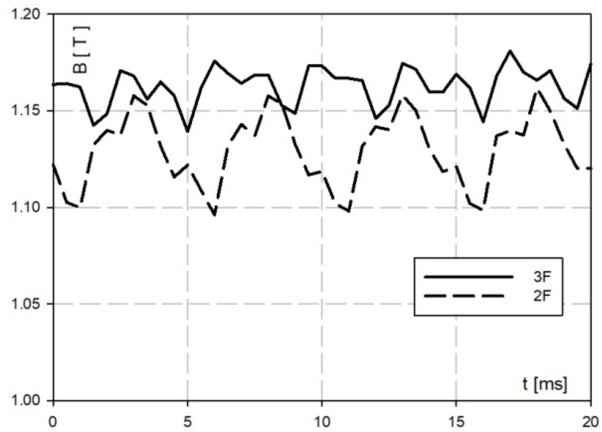

Fig. 7. Main harmonic of the magnetic flux density

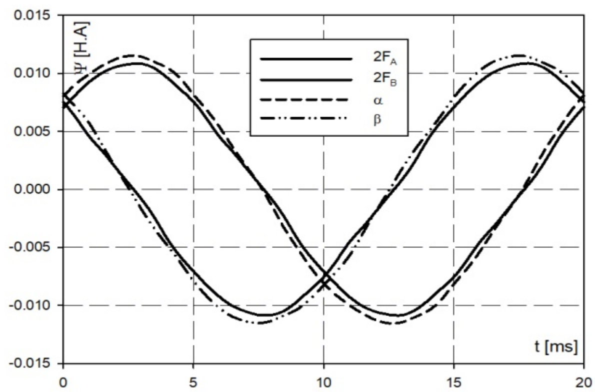

Fig. 8. Flux linkages

The main harmonic of the electromotive force, electromagnetic torque and the total harmonic distortion (THD) are presented in Table 2.

TABLE II. DATA ABOUT THE MACHINE ELECTROMAGNETIC TORQUE AND THE TOTAL HARMONIC DISTORTION (THD)

	EA [V]	THD [%]	M [N.m]
2F	339,8	13,93	429,2
3F	361,5	12,23	458,9

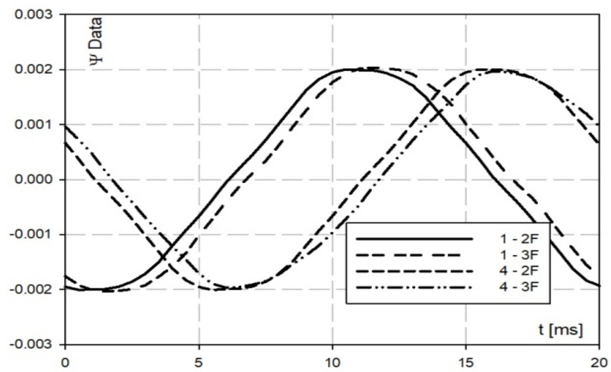

Fig. 9. Changes of the flux linkages at slot №1 and №4

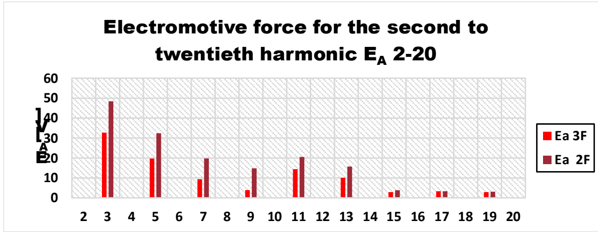

Fig. 10. Electromotive force for the second to twentieth harmonic

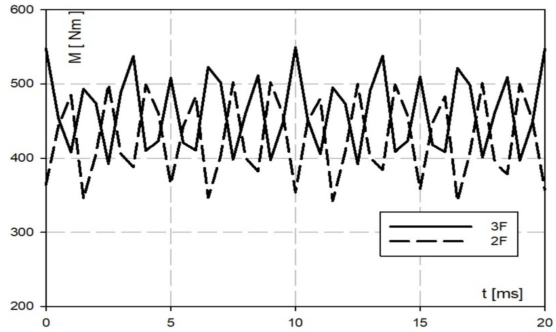

Fig. 11. Electromagnetic torque

IV. Conclusion

The different amplitude of the flux linkages across the two-phase and the three-phase winding is due to the lower coefficient of distribution of the two-phase winding. The displacement of the flux linkages over time is due to angle γ.

The amplitude of the main harmonic of the emf , electromagnetic torque at the three-phase winding is higher and the percentage of THD is lower.

Using a two-phase stator winding of the traction motor in hybrid vehicles is not recommended for the above reasons, although it would require simpler inverter control and reduce the number of power switches.

References

[1] Aslan, B. , J.Korecki, T. Vigier, E. Semail, Influence of rotor structure and number of phases on torque and flux weakening characteristics of V-shape In-terior PM electrical machine, https://hal.archives-ouvertes.fr/hal-00784749/document, 2011.

[2] Hahlbeck, S. , D. Gerling, Design considerations for rotors with embedded V-Shape permanent magnets, Proceedings of the 2008 International conference on electrical machines, 2008, pp. 2024-2028, ISSN 978-1-4244-1735-3.

[3] Rizov, P., Study of the influence of the form of the rotor pole on the some of the parameters of synchronous machine with permanent magnets, Proceedings of Technical university of Sofia 2011, Volume 67, Issue 1, pp. 261-270, ISSN 1311-0829.

[4] Stoev, B., G. Todorov, P. Rizov, G. Pagiatakis, L. Dritsas, Finite element analysis of rotating electrical machines, An educational approach IEEE Global Engineering Education Conference, EDUCON, pp. 262-269.

[5] Tariq, A. , C. Baron, E. Strangas, Iron and magnet losses and torque calcula-tion of interior permanent magnet synchronous machines using magnetic equivalent circuit, IEEE transactions on magnetics, vol. 46, no. 12, december 2010.

[6] Toader, F. , H. Petru, M. Claudia, B. Agoston, Multiphysics modeling of an permanent magnet synchronous machine, scohost.com/eds/pdfviewer/ pdfviewer?sid=f4977efe-88da-4f97-ade7-9dc2252cec19%40sessionmgr104&vid= 0&hid=117, 2012.