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COMPARISON OF CONCENTRATED AND DISTRIBUTED WINDING IN TERM OF THE MAGNETIC FIELDS

BY

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Abstract. This paper describes the advantages and disadvantages of concentrated winding compared to classical distributed winding. Using the Finite Element Method (FEM) we shows and describe the magnetic fields of concentrated winding – permanent magnet synchronous motor (CW–PMSM) and distributed winding – permanent magnet synchronous motor (DW–PMSM), in no-load condition, in loaded condition and in the condition of armature reaction.

Key words: concentrated windings; distributed windings; finite element method; permanent magnet synchronous motor.

1. Introduction

Permanent magnet synchronous motors (PMSM) have broad field of application *e.g.* in electric and hybrid vehicles, computer technology, small household appliances, aeronautical equipment, healthcare equipment etc. They can also be found in battery powered tools and other special equipment such as rotary uninterruptible power supply units.

In conventional “inrunner” configuration of the PMSM, the permanent magnets are part of the rotor, while stator windings surround the rotor. An

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external rotor "outrunner" configuration is possible with stator windings forming the centre, while the permanent magnets surround the stator attached to overhanging rotor.

Stator of the PMSM consists either of concentrated windings (CW–PMSM) or distributed windings (DW–PMSM). The concentrated windings configuration of PMSM is currently becoming more popular than a distributed windings configuration due to its good and cheap manufacturability, higher power density and lower losses (Sekerák *et al.*, 2012; Abolhassani, 2005; Cros *et al.*, 2002; Lee *et al.*, 2008). The losses in PMSM with concentrated and distributed windings are referred in papers elaborated by Jussila *et al.*, 2006; Klug *et al.*, 2008; Zhang *et al.*, 2012; Yamazaki *et al.*, 2009 and Wang *et al.*, 2006.

2. The Magnetic Fields of Investigated Motors

Important tool for optimization of electric machines performance is modelling of the magnetic fields. Several computer software packages for magnetic fields simulation such as ANSYS, FLEX r FEMM are available nowadays. These programs offer satisfactory results which may be preferably used for further performance optimization. Nevertheless designer´s good knowledge of theory of electrical machines is still needed.

In our further work we have utilized the Finite Element Method Magnetics (FEMM) software suite to solve distribution of static and low frequency magnetic fields in CW–PMSM and DW–PMSM. Software is used to solve problems in two-dimensions (2-D) and axial symmetrical environment.

Investigated CW-PMSM has twelve stator tooths on which twelve coils of concentrated windings are placed. Eight surface mount ferrite permanent magnets are placed on the rotor (Fig. 1). The investigated DW–PMSM has the twenty four stator slots with distributed winding and eight surface mount ferrite permanent magnets are placed on the rotor (Fig. 2).

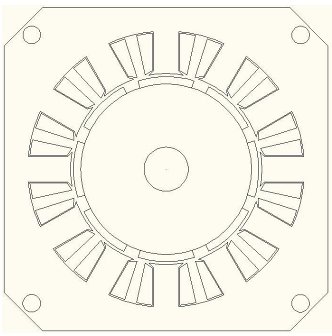

Fig. 1 – 2-D diagram of CW–PMSM.

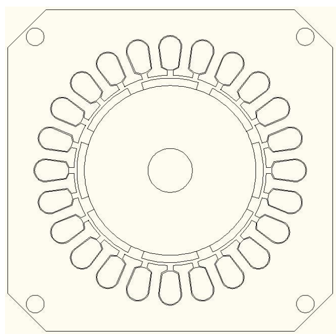

Fig. 2 – 2-D diagram of DW–PMSM.

Rated parameters of investigated CW–PMSM and DW–PMSM, which were the basis for solving the magnetic fields, are given in Table 1.

Table 1
Nominal Parameters of CW–PMSM and DW–PMSM.

SBMPM			SMPM		
Parameter	Value	Unit	Parameter	Value	Unit
Nominal power, P_n	550	W	Nominal power, P_n	500	W
Number of phases, m	3	–	Number of phases, m	3	–
Number of poles, $2p$	8	–	Number of poles, $2p$	8	–
Number of tooths per pole and phase, q_t	0.5	–	Number of slots per pole and phase, q_s	1	–
Total number of stator tooths, N_t	12	–	Total number of stator slots, Q_s	24	–
Rated speed, n_n	16,700	rpm	Rated speed, n_n	5,000	rpm
Nominal moment, M_n	0.3	Nm	Nominal moment, M_n	0.2	Nm
Nominal phase current, I_f	2.5	A	Nominal phase current, I_f	2.5	A
Permanent magnet remanence (ferrite), B_r	0.34	T	Permanent magnet remanence (ferrite), B_r	0.34	T
Permanent magnet coercitive force (ferrite), H_c	270,000	A/m	Permanent magnet coercitive force (ferrite), H_c	270,000	A/m
Nominal efficiency Ω_N	0.8	–	Nominal efficiency, Ω_N	0.8	–
Rated power factor $\cos\varphi_n$	0.8	–	Rated power factor $\cos\varphi_n$	0.8	–

2.1. No-load Condition

After creating 2-D diagrams and inputting materials parameters, „Solver" subroutine was launched, solving Maxwell´s eqs. in order to obtain values of the magnetic fields. After that 2-D diagram of CW–PMSM and DW–PMSM are divided into many triangles – meshes. Subroutine „Solver" makes calculations using FEM. Finally, the subroutine „Postprocessor" displays the results of magnetic flux density as a map.

No-load condition in the software FEMM is characterized by zero current, I_0, in stator windings. Cooper windings of the stator are than replaced by air. Surface mount ferrites permanent magnets on the rotor are oriented in an angle of 90°. Resulting magnetic fields for this case are shown on Figs. 3 and 4. Normal component of magnetic flux density in air gap for this case is shown on Figs. 5 and 6.

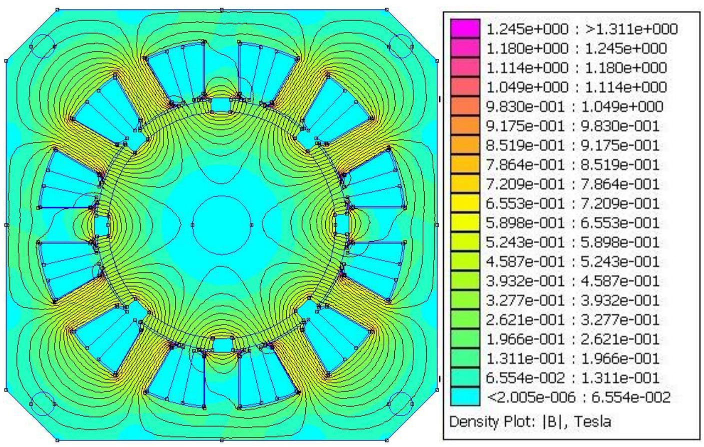

Fig. 3 – The magnetic field map of CW–PMSM in no-load condition.

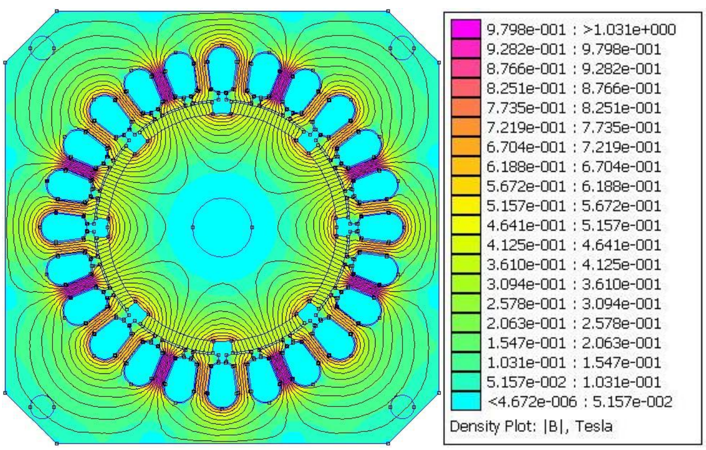

Fig. 4 – The magnetic field map of DW–PMSM in no-load condition.

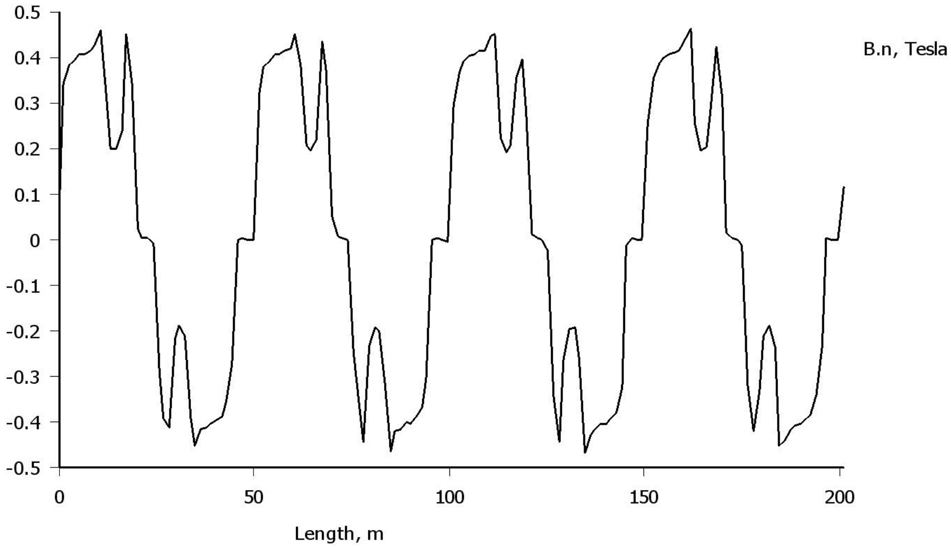

Fig. 5 – Normal component of magnetic flux density of CW–PMSM with no-load.

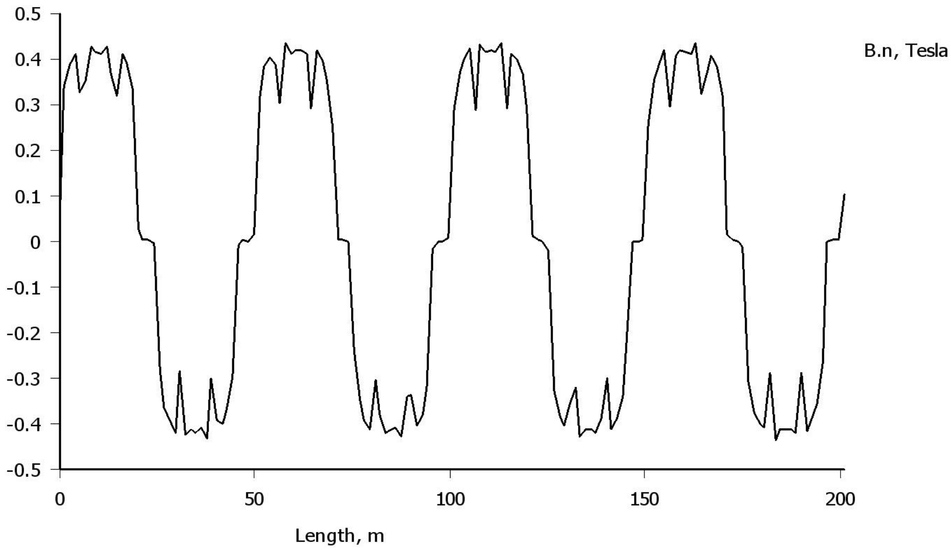

Fig. 6 – The normal component of magnetic flux density of DW–PMSM with no-load.

2.2. Loaded Condition

The investigated CW–PMSM and DW–PMSM have their stator windings connected into wye (star connection). This means that only two phases windings will be powered at the time. Therefore we set in FEMM environment: four coils of stator windings to be loaded with positive nominal phase current ($I_f = I_n$), further four coils of stator windings to be loaded with negative nominal phase current ($I_f = I_n$) and four remaining coils to have no load on them (I_f = 0 A). Surface mount ferrites permanent magnets on the rotor are oriented at an angle of 90°. The magnetic field maps and the normal component of magnetic flux density in air gag charts for CW–PMSM and DW–PMSM in loaded condition are shown on Figs. 7,…,10.

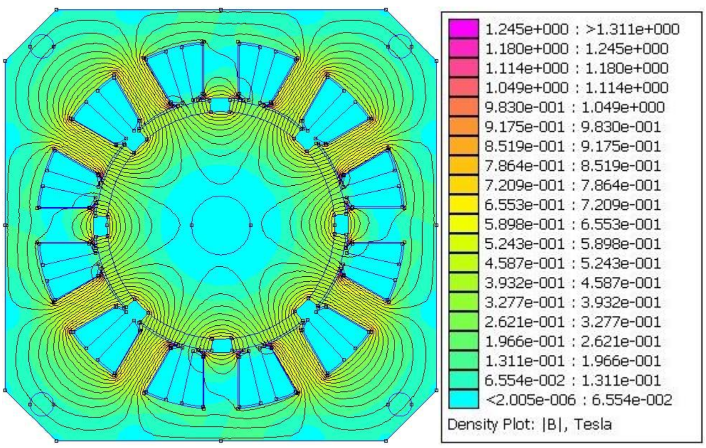

Fig. 7 – The magnetic field map of CW–PMSM in loaded condition.

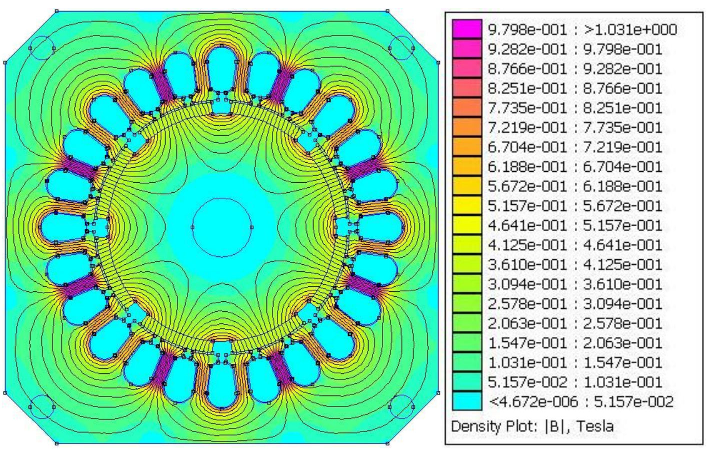

Fig. 8 – The magnetic field map of DW–PMSM in loaded condition.

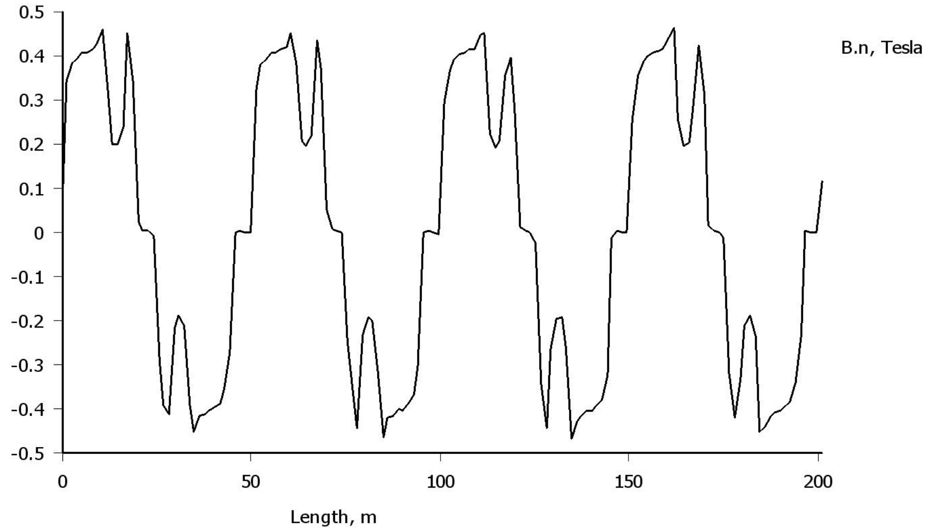

Fig. 9 – The normal component of magnetic flux density of loaded CW–PMSM.

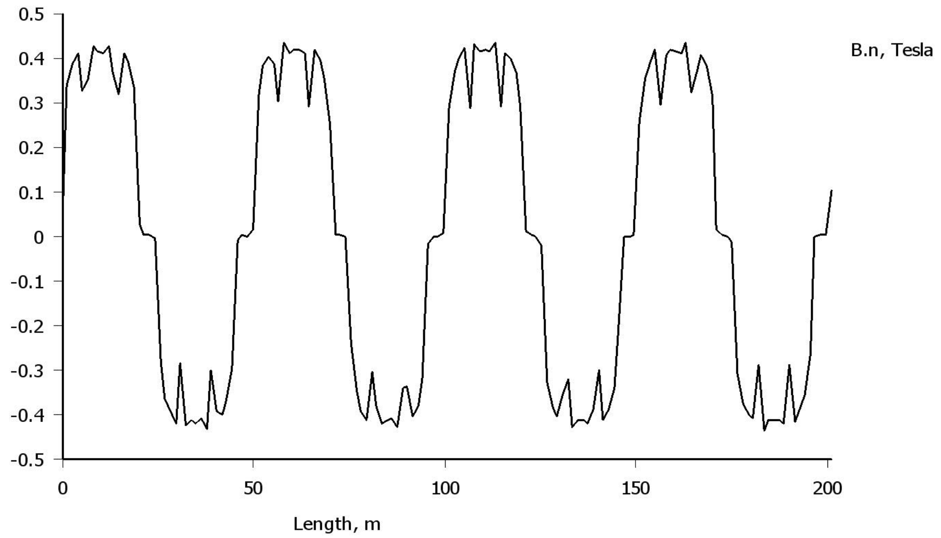

Fig. 10 – The normal component of magnetic flux density of loaded DW–PMSM.

2.3. Condition of Armature Reaction

The only difference of the condition of armature reaction in comparison to loaded condition is that the permanent magnets are replaced by air. The magnetic field map for CW–PMSM and DW–PMSM in the condition of armature reaction is shown on Figs. 11 and 12. The normal component of magnetic flux density in air gap is shown on Figs. 13 and 14.

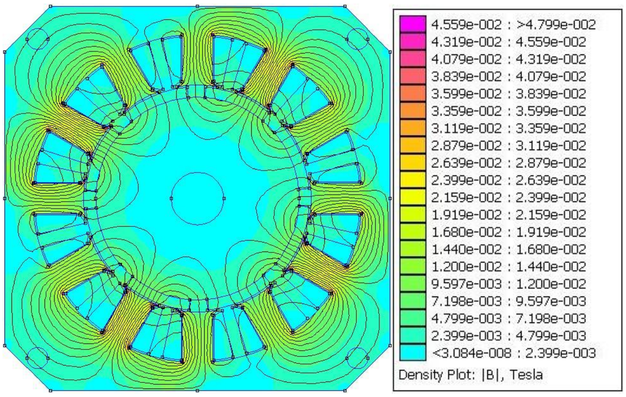

Fig. 11 – The magnetic field map of CW-PMSM in the armature reaction condition.

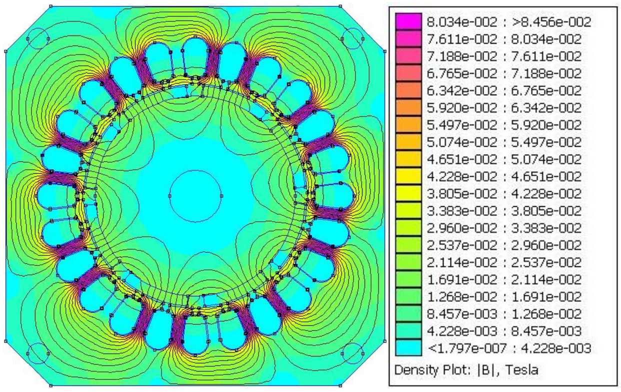

Fig. 12 – The magnetic field map of DW-PMSM in the armature reaction condition.

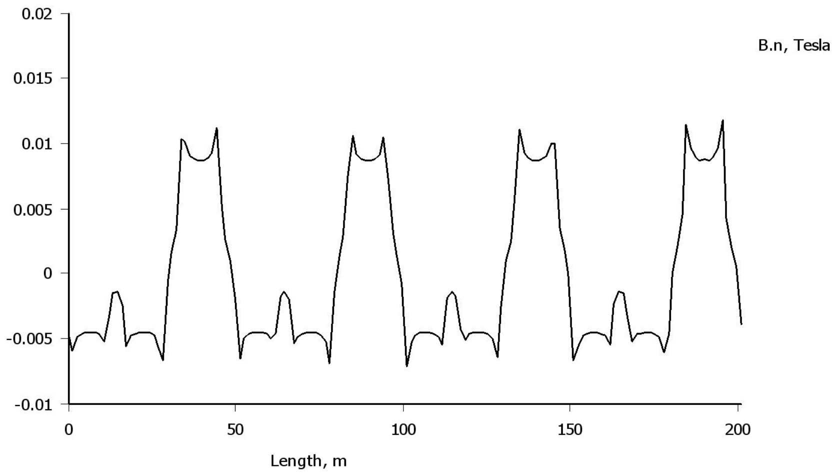

Fig. 13 – The normal component of magnetic flux density of CW–PMSM in the armature reaction condition.

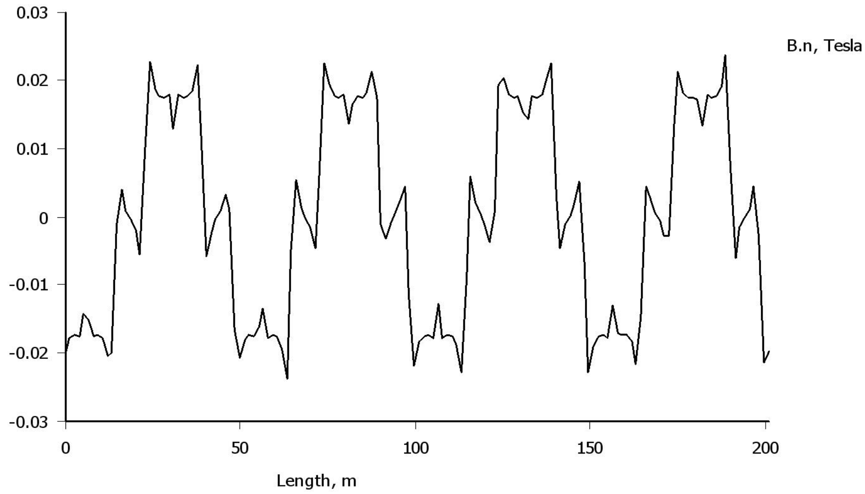

Fig. 14 – The normal component of magnetic flux density of DW–PMSM in the armature reaction condition.

3. The Joule Losses

The aim of the electromagnetic analysis in loaded condition is also to determine the Joule losses, P_J , [W] in concentrated and distributed windings. Values of Joule losses we calculated from magnetic fields maps by analytical integration over each surface element of the winding coil using FEM. Summation of the results for all defined elements in the corresponding area are the Joule losses for particular coil of winding. The final results of electromagnetic analysis in loaded condition for an nominal phase currents in range of I_f = (0.5…5) A, are given in Table 2.

Table 2
The Joule Losses of CW–PMSM and DW–PMSM.

SBMPM		SMPM	
I_f, [A]	P_J, [W]	I_f, [A]	P_J, [W]
0.5	0.326	0.5	0.421
1	1.306	1	1.685
1.5	2.938	1.5	3.792
2	5.241	2	6.764
2.5	7.691	2.5	9.925
3	11.781	3	15.203
3.5	16.061	3.5	20.726
4	20.967	4	27.058
4.5	26.527	4.5	34.232
5	32.783	5	42.306

Comparing the losses of distributed and concentrated windings on Fig. 15 reveals that losses of concentrated windings are smaller than losses in distributed windings. Table 2 shows that losses in distributed winding are significantly larger than in concentrated counterparts.

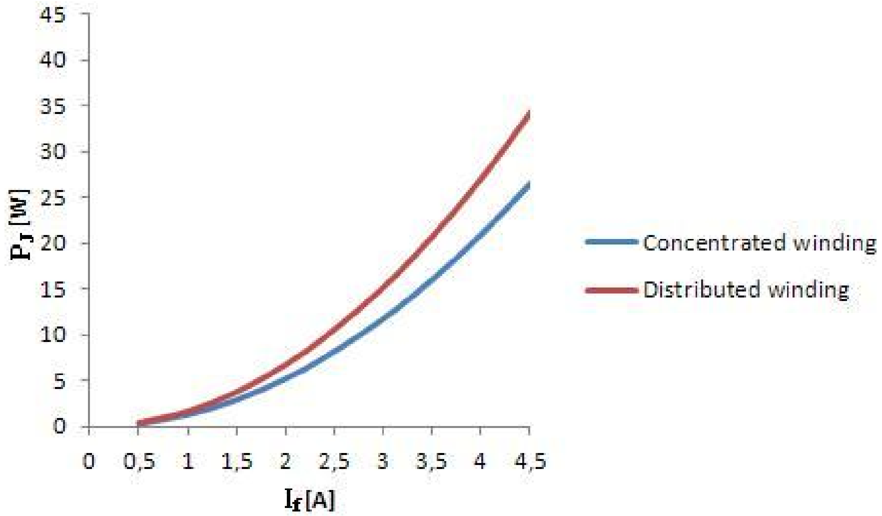

Fig. 15 – Joule losses of concentrated and distributed windings.

4. Conclusions

This paper deals with magnetic fields in concentrated and distributed windings of PMSM. Magnetic field maps of flux density and the distribution of normal component of magnetic flux density for individual conditions are presented.

Comparing these maps and charts for different states we can see that both concentrated and distributed windings will create the air gap magnetic fields different from ideal sin wave shape. Deviated (non-harmonic) normal component of magnetic flux density will result in presence of higher harmonics in current supplying the coils. Also the non-harmonic magnetic fields in the air gap generate vibration and noise of the machine. This is a significant problem in household appliances. Therefore, manufacturers of these appliances with PMSM have also to eliminate the presence of higher harmonics in these motors, for example using filtering.

Considering results from power losses calculation it is obvious that PMSM with concentrated windings are more efficient due to lower Joule losses.

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COMPARAȚIE ÎNTRE CÂMPURILE MAGNETICE CREATE DE ÎNFĂŞURĂRILE CONCENTRATE ŞI CELE DISTRIBUITE

(Rezumat)

Se descriu avantajele şi dezavantajele înfăşurărilor concentrate comparate cu cele distribuite considerate a fi clasice. Folosind metoda elementului finit se arată şi se descrie câmpul magnetic al înfăşurării concentrate – motor sincron cu magneți permanenți (CW–PMSM) şi al înfăşurării distribuite – motor sincron cu magneți permanenți (DW–PMSM) în funcționarea şa gol, funcționarea în sarcină şi cu reacția indusului.