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A comparison of magneto-mechanical time dependencies of a brushlees motor with permanent magnet excitation in BLDC and PMSM modes

***Abstract**. In the paper the magneto-mechanical dependencies of an electric motor with permanent magnets in its rotor and three-phase stator winding are presented as dependencies of total magnetic coupling between electric circuits of stator and electromagnetic moment on currents in these circuits and on the angle of rotor rotation. The calculations were carried out for motors PMSg132 S4 BLDC and PMSg132 S4 PMSM. The results are presented in the form of charts.*

***Streszczenie.** W artykule przedstawiono charakterystyki magneto-mechaniczne silnika elektrycznego z magnesami trwałymi na wirniku i z trójfazowym uzwojeniem stojana, jako zależności całkowitych sprzężeń magnetycznych obwodów elektrycznych stojana i momentu elektromagnetycznego, od prądów w tych obwodach i od kąta obrotu wirnika. Obliczenia wykonano dla silników PMSg132 S4 BLDC i PMSg132 S4 PMSM. Wyniki przedstawiono w formie graficznej. (**Porównanie magneto-mechanicznych zależności czasowych bezszczotkowego silnika z magnesem trwałym w trybach pracy BLDC i PMSM**)*

Keywords: a brushless motor with permanent magnet excitation with trapeze control, permanent magnet synchronous motor PMSM.
Słowa kluczowe: silnik bezszczotkowy z magnesami trwałymi o sterowaniu trapezoidalnym, silniki synchroniczne z magnesami trwałymi PMSM.

Introduction

The subject of the analysis are contactless electric motors with permanent magnets in their rotors and with multi-phase stator winding, which differ in the design of excitation winding and the method of its supply. These machines are referred to as PMSM (Permanent Magnet Synchronous Motors) and BLDCM (ang. Brush-Less Direct Current Motors), according to international terminology.

PMSMs are designed to work at sine supply from a voltage or current source, whose frequencies and initial phases depend on the rotor rotation angle. Such method of supply is referred to as continuous supply.

BLDCMs are machines, whose phases are supplied from a DC source in impulse-driven way , according to the rotor position. The shape of phase current in such a machien resembles a trapeze. Such method of supply is referred to as discrete supply.

Different supply methods for PMSMs and BLDCMs as well as fundamentally different application requirements results in their different designs, in particular in the setup of active parts of the rotor.

Table 1. Nominal data concerning the motors under research

Type of the motor	IPMSg 132 S4 PMSM	PMSg132 S4 BLDC
Power	4 kW	4 kW
Nominal voltage	3x400 V	3x400 V
Nominal current	7,5 A	11,5 A
Nominal velocity	1500 rotations per minute	1500 rotations per minute
Nominal moment	25,5 Nm	25,5 Nm

Computer-aided simulations of motor operation have been carried out for two types of motors: IPMSg132 S4 PMSM and PMSg132 S4 BLDC produced by BOBRME "Komel".
Table 1 includes nominal data concering the motors under research.
The winding schemes for the stators of the examined machines do not differ much. A single-layer concentric winding with the following parameters has been prepared:
Number of phases $m = 3$;
Scheme of phase connection — Y;
Number of teeth $Z_1 = 36$;
Number of inductor poles $2p = 4$;
Partial pitch $y = 7, 9, 11$;
Number of slots per pole and phase $q = \frac{Z_1}{2pm} = \frac{36}{4 \cdot 3} = 3$.

The stator cross-section for both machines is the same. The dimensions of stator plates are given in Figure. 1.

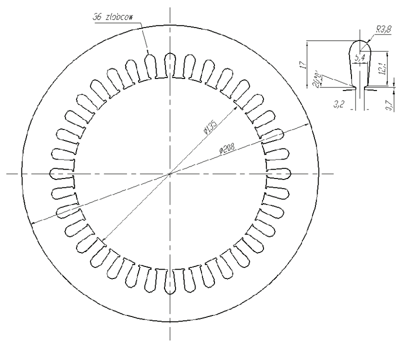


Fig.1. The dimensions of stator plate

A comparison of main dimensions and design parameters of the active parts of both machines is given in Table 2.

Table 2. A comparison of main dimensions and design parameters of the active parts of both machines being analyzed

Motor type	IPMSg 132 S4 PMSM	PMSg132 S4 BLDC
The diameter of stator boring	135 mm	135 mm
The outer rotor diameter	133,5 mm	131 mm
Active core length	100 mm	100 mm
Working air gap length	0,75 mm	2 mm
Bias of stator slots	Not present	Per unit tooth pitch

Magneto-mechanical time dependencies of the PMSM machine

Magneto-mechanical time dependencies as the dependencies of magnetic couplings of circuits and electromagnetic moments on the rotor rotation angle, for idle run state and for the constant stator current flow $i_1 = 10A,\ i_2 = i_3 = 0$, are depicted in Figure 4. The values, which correspond to the state $i_1 = 10A,\ i_2 = i_3 = 0$ are marked with the subscript "i" $\psi_{1i}[\gamma], \psi_{2i}[\gamma], \psi_{3i}[\gamma], M_i[\gamma]$.

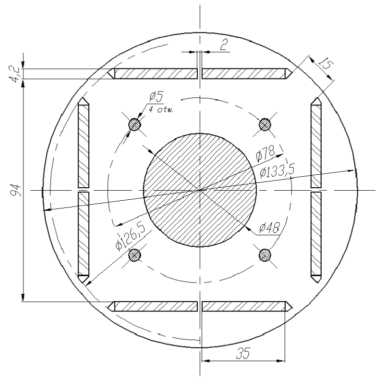


Fig.2. Dimensions of the rotor cross-section in the IPMSg 132 S4 PMSM machine

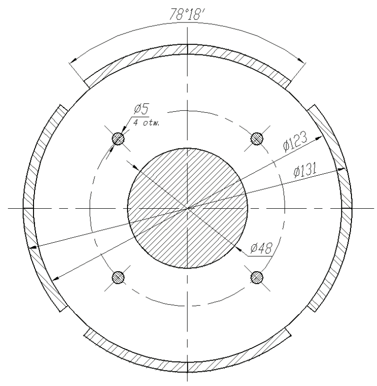
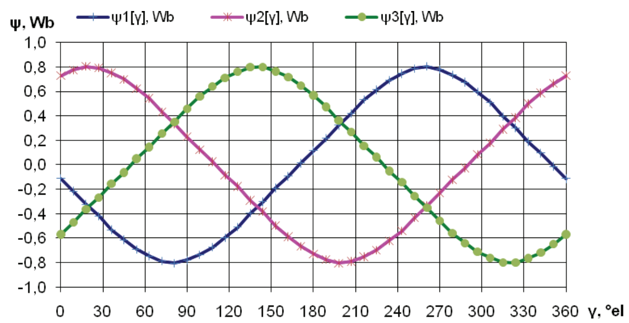


Fig. 3. Dimensions of the rotor cross-section in the PMSg132 S4 BLDC machine

In the simulations the step of angle change γ = 9°el has been assumed. After initial calculations it has turned out that this value is too small to reflect correctly the changes of the so-called reactive moment of the machine. Therefore, another calculation of magneto-mechanical time dependencies has been carried out with the step 1,3°el. in the range of angles 60 ÷112°el. The results are depicted in Fig. 4 b and c and marked as $M_p[\gamma]$.

According to the winding scheme the magnetic axes of phase L1 are skewed with respect to the axis of Cartesian coordinate system at angles 40° and 130° geom., under the condition, that the slot №1 would have the angular position 95°. If the longitudinal magnetic axis of any of rotor poles is parallel to the magnetic axes of L1 phase, then the modulus of magnetic coupling will reach the maximum value. After recalculation into electric degrees, for 2p = 4, these locations are equal to 80° i 260°E. Right at these positions in Figure 4 the magnetic coupling Ψ_1 reaches maximum values.

a)



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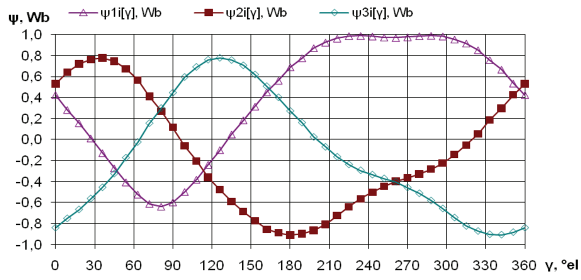

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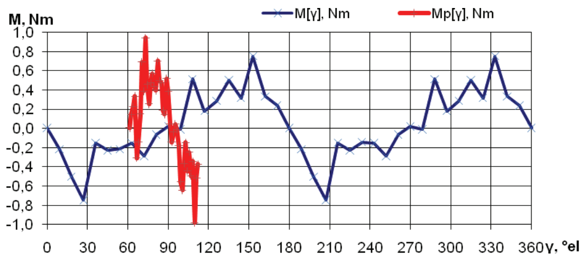

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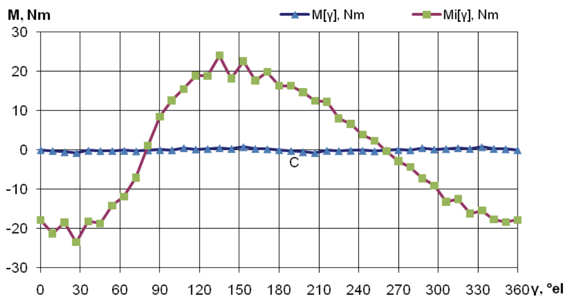

Fig. 4. Dependencies of magnetic couplings ψ_1, ψ_2, ψ_3 and electromagnetic moment M on rotor rotation angle γ, for idle run and for stator currents $i_1 = 10A,\ i_2 = i_3 = 0$

As it can be concluded from the Figure, the magnetic coupling ψ_1 of the circuit with the 10 A current, has a constant component due to this current. In other phases a significant phase offset appears. Comparing the increases of magnetic coupling under load with the coupling under idle run it can be noticed, that the positive increase is smaller than the negative one, due to magnetic saturation.

Magneto-mechanical time dependencies of the BLDC machine

Magneto-mechanical time dependencies of this machine as dependencies of magnetic couplings between circuits and electromagnetic moments on rotor rotation angle for idle run state state and for the state of constant stator currents i_1 = 15 A, $i_2 = i_3$ = 0, are depicted in Figure 5. The values, which correspond to the case $i_1 = 15A,\ i_2 = i_3 = 0$ are marked with subscript "i" $\psi_{1i}[\gamma], \psi_{2i}[\gamma], \psi_{3i}[\gamma], M_i[\gamma]$.

Similarly like in the previous case the step of angle change γ (9°el.) has turned out to be small enough to reflect correctly the changes of reactive moment of the motor. The recalculation of dependencies with the step 1,3°el. in the range of angles 60 ÷112°el. is depicted in Figure 5. b and c and marked as $M_p[\gamma]$.

The qualitative analysis of the obtained dependencies is almost the same as the one given in the former paragraph, due to the similarity of the machines. The cores of their stators are completely the same with respect to theis magnetic properties, however the data concerning windings are different.

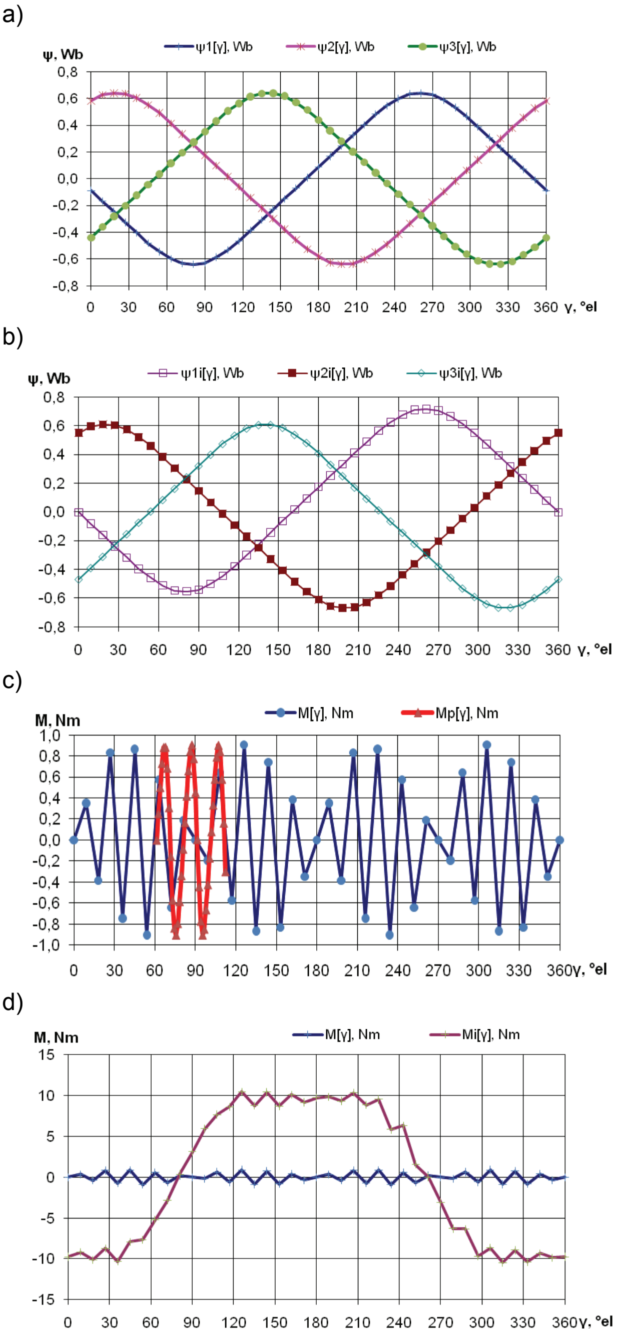

Fig. 5. Dependencies of magnetic couplings ψ_1, ψ_2, ψ_3 and electromagnetic moment M on rotor rotation angle γ, for idle run and for stator currents $i_1 = 15A,\ i_2 = i_3 = 0$

Conclusions

The machine IPMSg 132 S4 BLDC, due to a smaller number of coils in a phase (w_f=108) has a smaller phase magnetic coupling and inductance than the machine IPMSg 132 S4 PMSM. Accordingly, its electro-motoric force is smaller, thus at the same voltage supply and load the rotational speed in the motor mode shall be smaller for any control method. On the other hand, its air gap is almost three times larger $\delta = 2\,\mathrm{mm}$. It causes the minimization of demagnetizing effect (reaction) of and results in a more stable motor work under transient load conditions.

It is also interesting to compare the shapes of electro-motoric forces of both machines. The shape of electro-motoric force in a PMSM motor resembles sine wave, due to the special design of the rotor, in which the field from permanent magnets is partially screened by the ferromagnetic core of the rotor. In this case the distribution of radial component of magnetic induction vector in the air gap is close to a harmonic one, however it possesses a significant tooth order harmonic.

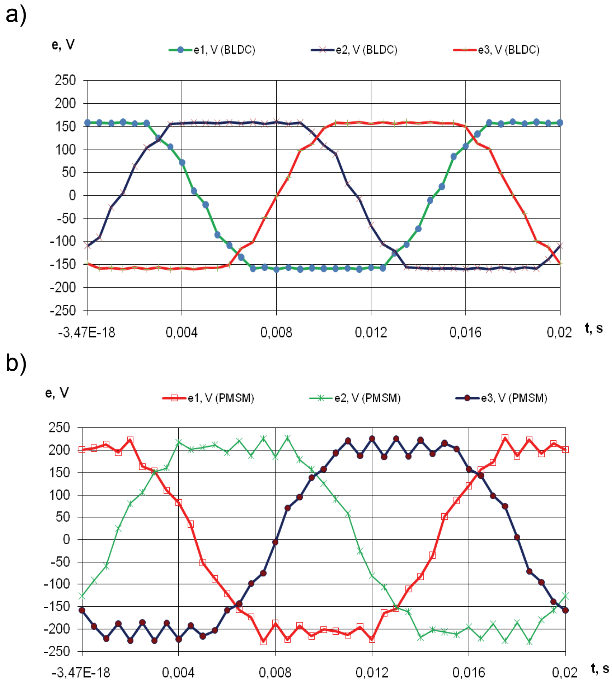

Fig. 6. Time dependencies of phase electromotoric forces e_1, e_2, e_3 under conditions of idle run and rotor rotation equal to 1500 rpm for machines PMSg132 S4 BLDC (a) and IPMSg 132 S4 PMSM (b)

A BLDC motor exhibits a trapeze-like shape of electromotoric force, which is well suited to a control discrete method, ie. such shape of electromotoric force allows us to diminish the pulsations of electromagnetic moment in the permanent magnet machine.

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