PRZEGLĄD ELEKTROTECHNICZNY

Ukazuje się od 1919 roku 6'17

Organ Stowarzyszenia Elektryków Polskich • Wydawnictwo SIGMA-NOT Sp. z o.o.

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doi:10.15199/48.2017.06.01

Limitation of torque ripple in medium power line start permanent magnet synchronous motor

***Abstract**. The paper deals with two solutions of limitations of torque ripple in medium power low-voltage 4-pole line start permanent magnet synchronous motor. Influence of the rotor slots number and various rotor top slots openings on the motor torque ripple was investigated. Double cage permanent magnet synchronous motor is presented.*

***Streszczenie.** Artykuł przedstawia dwa rozwiązania ograniczenia pulsacji momentu w czterobiegunowym silniku synchronicznym z magnesami trwałymi o rozruchu bezpośrednim. Zbadano wpływ liczby żłobków wirnika oraz szerokości otwarcia górnych żłobkach wirnika na pulsację momentu. Przedstawiono konstrukcję dwuklatkowego silnika synchronicznego z magnesami trwałymi.*
*(**Ograniczenie pulsacji momentu w silniku synchronicznym z magnesami trwałymi o rozruchu bezpośrednim średniej mocy**)*

Keywords: synchronous motor, permanent magnet, torque ripple, vibration
Słowa kluczowe: silnik synchroniczny, magnesy trwałe, pulsacje momentu, drgania

Introduction

Line start permanent magnet synchronous motors, hereinafter LSPMSM, have many advantages such as high efficiency, high power factor, relatively simply construction. However, they have one significant drawback: torque ripple during motor starting due to permanent magnet. Torque ripple and motor vibration are the same problems both for permanent magnet synchronous motors and induction motors. The simplest solution to reduce torque ripple in electric motors is skew application [1, 3, 4]. In induction motors skewed rotors are used. In case of surface-mounted permanent magnet synchronous motors step-skewed rotors are applied. In case of inner-mounted permanent magnet synchronous motors skewed rotors are more difficult to obtain in comparison with skewed stators. Skew application in line start permanent magnet synchronous motors is not desired due to inner-mounted permanent magnets. In LSPMSM torque ripple limitation can be obtained primarily by the proper selection of the rotor slot number but there are also other solutions to obtain torque ripple reduction.

Four-pole 160 kW permanent magnet synchronous motor

In Ansys Maxwell software circuit-field model of 4-pole 160 kW line start permanent magnet synchronous motor was built. Rated voltage U_n=400 V, rated efficiency η_n=97,4% and power factor=1,00 (theoretical values for the motor with Qr=46 slots). Maximum torque ratio T_{max}/T_n=1,7. Rotor sheets are made from M400 steel. The rotor has two cages: top cage is made from bronze, bottom cage is made from copper. Rotor rings are made from copper. Permanent magnets N38SH type were used for the motor excitation. Cross-section of the motor is show in Fig. 1. Motor running properties are presented in Table 1 and starting properties in Table 2. Motor rotor construction is shown in Fig. 2 and rotor assembly drawing in Fig. 3.

During construction of the motor model mechanical stresses in the rotor sheets under load was investigated in Ansys software. Results for the speed n=1,2 n_n and T_{load}=10 T_n are presented in Fig. 4. The problem is connected with the distance between rotor cage bars slots and permanent magnets slots. This distance should be low to limit leakage magnetic flux from permanent magnets and simultaneously should be high to limit mechanical stresses due to centrifugal forces and electromagnetic torque. Maximum mechanical stress was assumed below 120 MPa what is about two times lower than sheet yield strength what is enough safe limit.

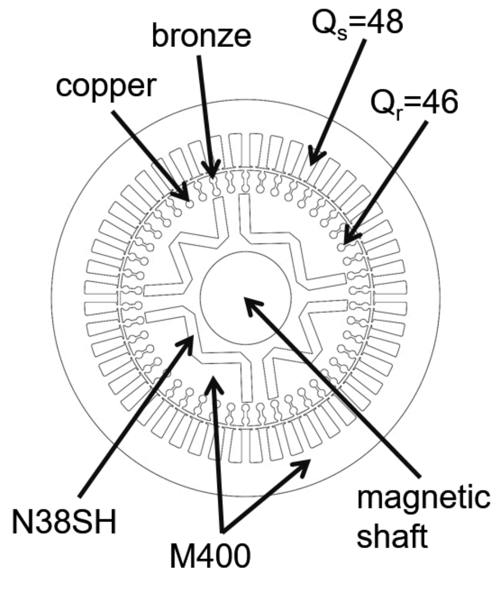


Fig.1. Cross-section of 4-pole 160 kW LSPMSM with 46 rotor slots

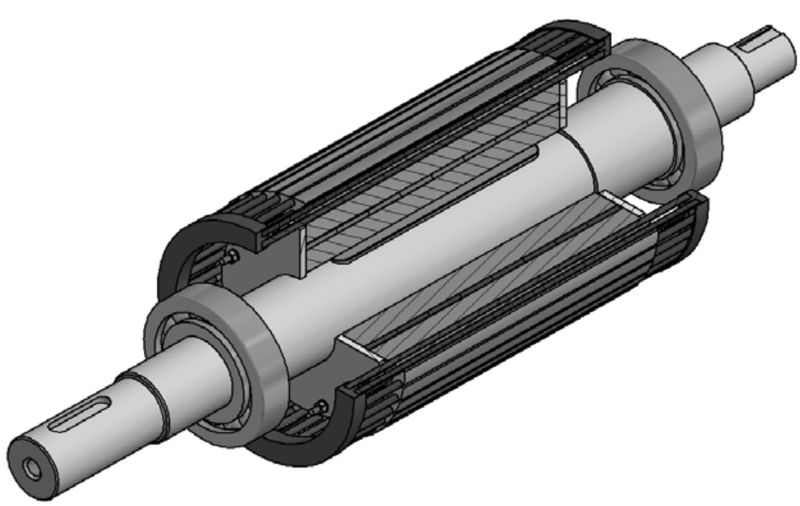


Fig.2. Motor rotor construction

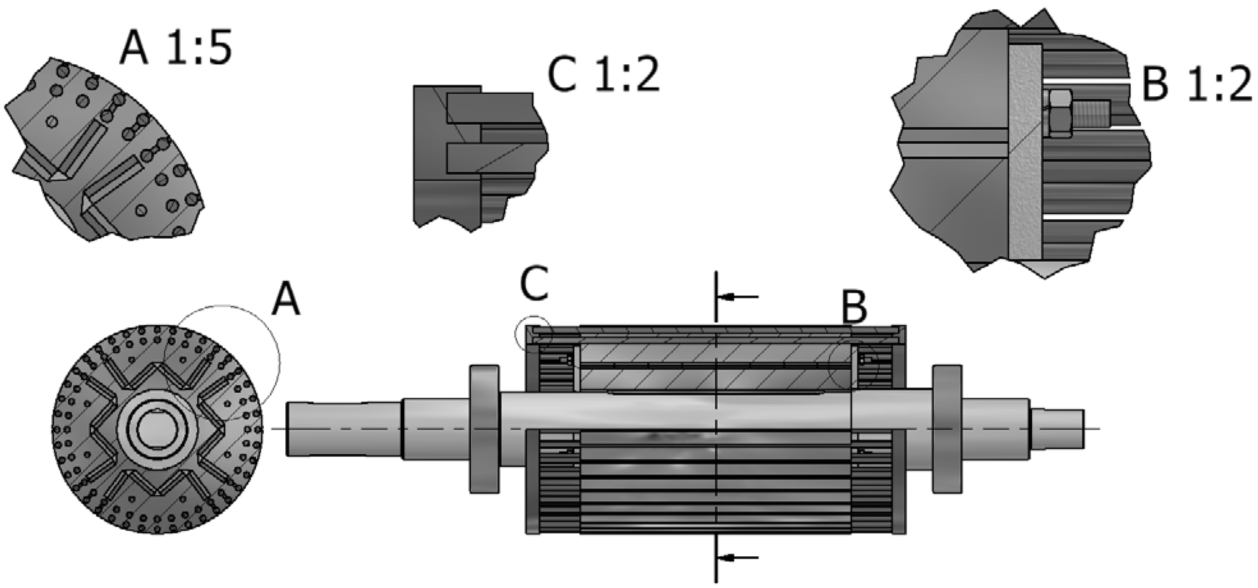


Fig.3. Motor rotor assembly drawing

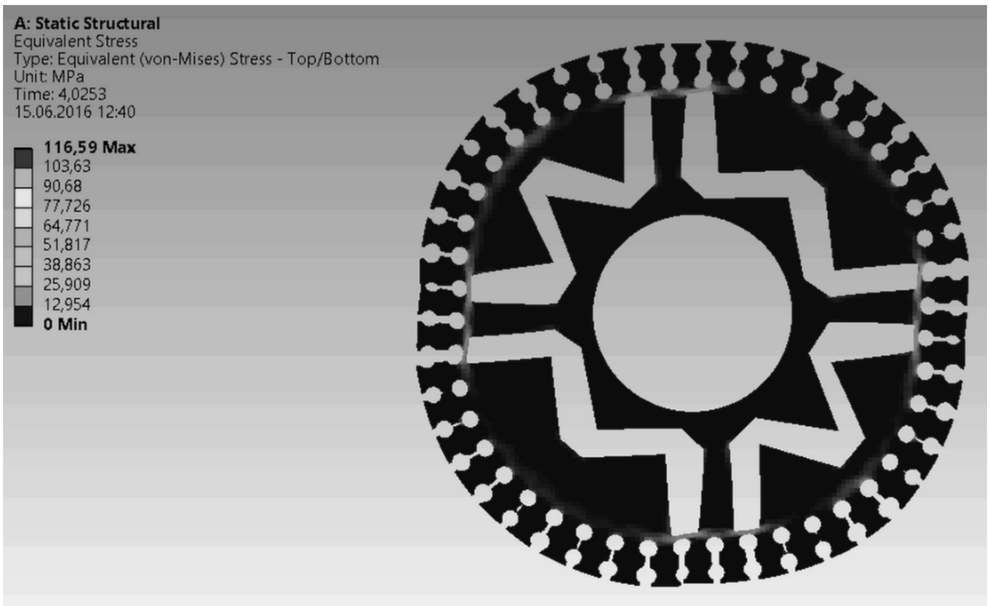


Fig.4. Mechanical stresses in the rotor sheet for n=1,2 n_n and T_{load}=10 T_n

Table 1. Motor running properties

p_{load}	*efficiency*	*power factor*
--	%	--
0,50	96,8	1,00
0,75	97,3	1,00
1,00	97,4	1,00

Table 2. Motor starting properties for bronze B8 type

starting torque [p.u.]	1,9
starting current [p.u.]	6,6
pull-in torque [p.u.]	1,8

Four-pole 160 kW permanent magnet synchronous motor

Influence of the rotor slot number on the *back EMF*, torque ripple and cogging torque was investigated. The rotor slot numbers from 32 – 46 were taken into account (Fig. 1 and Fig. 5). Torque ripple factor T_{pkavg} was calculated according to formula

$$T_{pkavg} = \frac{T_{\max} - T_{\min}}{\frac{1}{time_{period}} \int_0^{time_{period}} T(t)dt} \cdot 100\% \qquad (1)$$

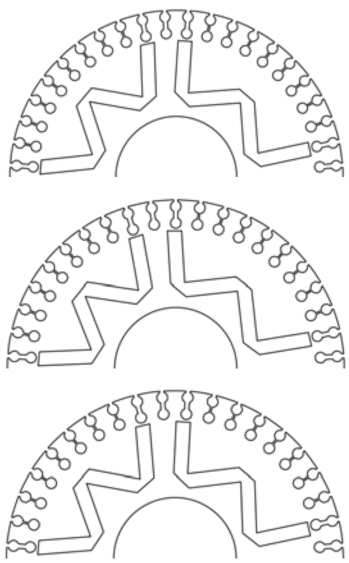
Torque ripple factor T_{pkavg} is a ratio of peak-to-peak to average value of the motor torque.

Cogging torque was calculated as a ratio of maximum of the torque absolute value over rated torque value according to equation

$$T_{cogging} = \max|T| / T_n \cdot 100\% \qquad (2)$$

Results of the investigation are presented in Fig. 6. The results shows that the *back EMF THD* influences on the torque ripple and cogging torque. Good solution is to select the LSPMSM rotor slot number which is divisible by the pole pair number and simultaneously is not divisible by the pole number. Moreover, the LSPMSM rotor slot number should be greater than 0.8 of the stator slot number.

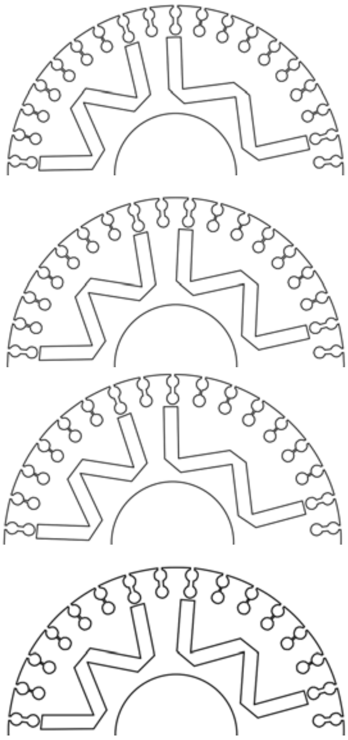
The magnetic pull forces of the motors were not calculated due to symmetry of the motor rotors.



a)

b)

c)



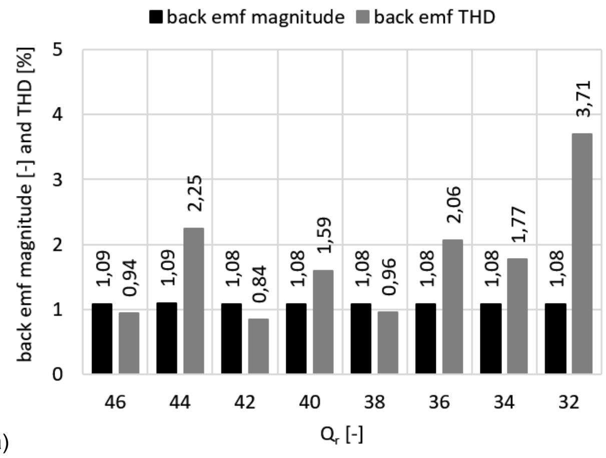
d)

e)

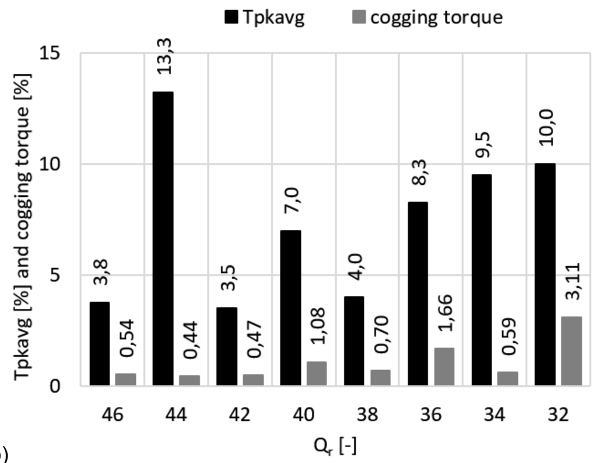
f)

g)

Fig.5. Four-pole 160 kW LSPMSM rotors with:
a) 44, b) 42, c) 40, d) 38, e) 36, f) 34, g) 32 slots



a)



b)

Fig.6. Influence of the rotor slots number on:
a) *back emf* magnitude and *back emf THD*,
b) torque peak-to-peak to average ratio T_{pkavg} and cogging torque

Influence of the rotor slot openings width on torque ripple

There is another solution to limit the torque ripple in LSPMSM [2, 5]. This solution is shown in Fig. 7. Rotor slots openings width are not the same for the all slots. Slots openings between magnetic poles are wider due to limitation the leakage magnetic flux from permanent magnets. Obtained results are presented in Fig. 8. For all load power factors the best solution in torque ripple limitation is rotor slots openings width *rtBs0*=3 mm. It is 75% of the rotor slots openings width between magnetic poles.

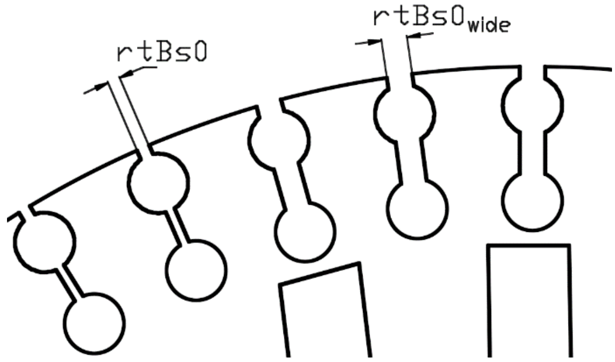


Fig.7. Top rotor slots openings with various width

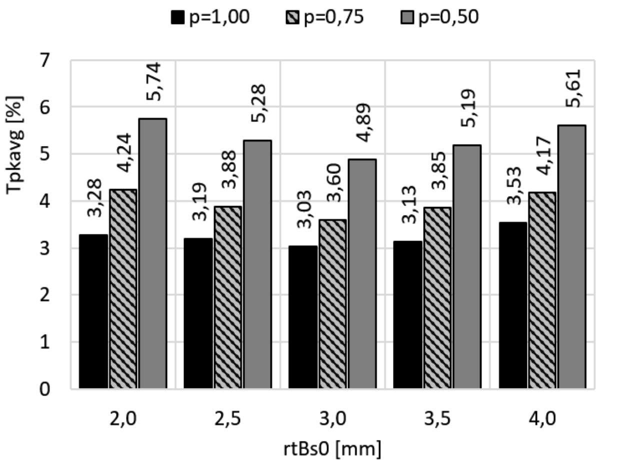


Fig.8. Influence of the rotor slots openings width *rtBs0* on the torque peak-to-peak to average ratio T_{pkavg} for various load power factor $p=T_{load}/T_n$=1,00; 0,75; 0,50

Conclusions

Torque ripple and cogging torque in line start permanent magnet synchronous motors can be limited by the proper selection of the rotor slot number and various rotor slots openings width. The rotor slot number should be divisible by the pole pair number *p* and simultaneously not divisible by the pole number *2p*. Rotor slots opening width between magnetic poles should be greater about 33% in comparison with the rest rotor slots opening width.

Calculations have been carried out using resources provided by Wroclaw Centre for Networking and Supercomputing (http://wcss.pl), grant No. 400.

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REFERENCES

[1] Młot A., Łukaniszyn M., Korkosz M., Cogging torque ripple reduction in brushless dc motor based on the stator skew, *Zeszyty Problemowe – Maszyny Elektryczne* nr 88/2010.

[2] Cvetkovski G., Petkovska L., Lefley P., Topological modifications in function of cogging torque reduction of permanent magnet synchronous motor", *Przegląd Elektrotechniczny* 12/2014.

[3] Wang L., Bao X., Di Ch., Li J., Effects of Novel Skewed Rotor in Squirrel-Cage Induction Motor on Electromagnetic Force, *IEEE Transactions on magnetics*, vol. 51, no. 11, November 2015.

[4] Bianchi N., Bolognani S., Design Techniques for Reducing the Cogging Torque in Surface-Mounted PM Motors", *IEEE Transactions on industry applications*, vol. 38, no. 5, september/october 2002.

[5] Goryca Z., Pakosz A., Experimental determination of impact on the value of open slot in cogging torque in selected permanent magnets machine", *Zeszyty Problemowe – Maszyny Elektryczne* nr 4/2014.