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SINGLE-PHASE LINE START PERMANENT MAGNET SYNCHRONOUS MOTOR WITH SKEWED STATOR*

MACIEJ GWOŹDZIEWICZ, JAN ZAWILAK

Wrocław University of Science and Technology,
Wybrzeże Stanisława Wyspiańskiego 27, 50-370 Wrocław, Poland,
e-mail: maciej.gwozdziewicz@pwr.edu.pl, jan.zawilak@pwr.edu.pl

Abstract: The article deals with single-phase line start permanent magnet synchronous motor with skewed stator. Constructions of two physical motor models are presented. Results of the motors running properties are analysed.

Keywords: *single-phase motor, permanent magnet, skew, vibration*

1. INTRODUCTION

Single-phase induction motors almost always have skewed rotors. It is a simple and effective solution in limitation of the motor vibration, noise and torque pulsation. In the case of line start permanent magnet synchronous motors skewed rotor is extremely difficult to manufacture due to interior permanent magnets. Skewed stator is less complicated in comparison with skewed rotor [3], [4], [7], [8].

During many tests of single-phase line start permanent magnet synchronous motor physical models The authors noticed that vibration is one of the main drawbacks of these motors [1], [2]. It prompted them to construct and build a single-phase line start permanent magnet motor with skewed stator.

2. MOTOR CONSTRUCTION

Two dimensional field-circuit models of the single-phase line start permanent magnet synchronous motor were applied in Maxwell software. The models are based on the mass production single-phase induction motor Seh 80-2B type: rated power P_n = 1.1 kW, rated voltage U_n = 230 V, rated frequency f_n = 50 Hz, number of pole

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pairs *2p* = 2. Neodymium magnet N38SH type was chosen for the motor excitation. Magnetic sheet M400 was taken into account in both models.

Eighteen field-circuit models were built. Then number of the mesh nodes was circa 8000. All models are presented in Fig. 1. They differ by the number of rotor slots and permanent magnet shapes. The back EMF, starting and running properties were analysed. The goal of the investigation was to maximize the 1st harmonic *back EMF* value and simultaneously to minimize the *THD* coefficient of *back EMF* which is described by the equation

$$THD_{back\ EMF} = \frac{\sqrt{\Sigma_{i=2}^{40} E_i^2}}{E_1}. \tag{1}$$

Simulation time was equal to 21 ms. Calculation took about 5 minutes using a 4-core i7 processor type computer.

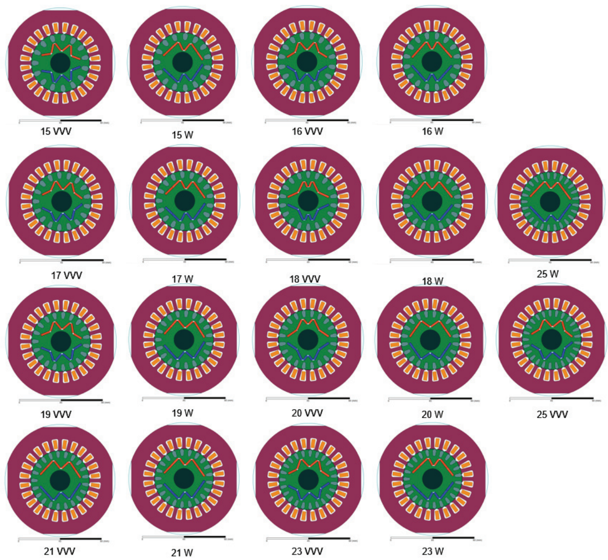


Fig. 1. Field parts of the field-circuit single-phase line start permanent magnet synchronous motor models

Results of the investigation are shown in Fig. 2. Rotor construction has strong influence especially on the *back EMF THD* coefficient.

Except electromagnetic investigation mechanical investigation was also performed. Motor rotor sheet was applied in Ansys software. Mechanical stress was investigated for speed 20% higher than rated motor speed and load torque 20 times greater than rated motor torque. Results are presented in Fig. 3. Mechanical stress is almost two times lower than rotor sheet yield strength, which is sufficient safe limit.

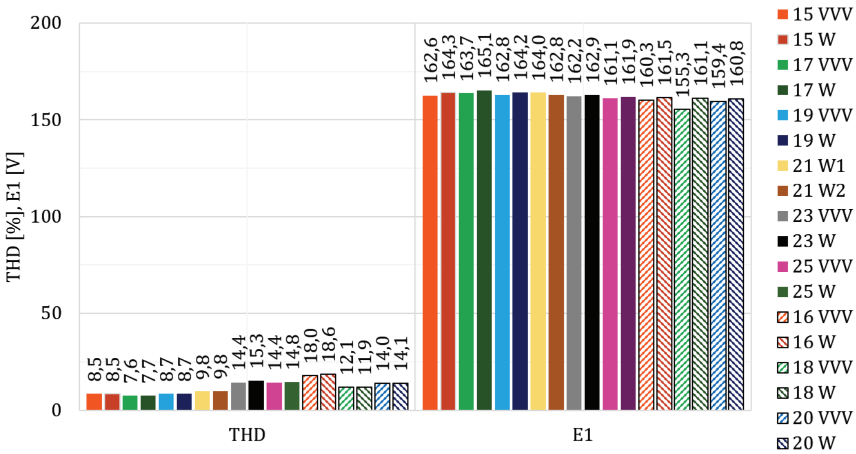


Fig. 2. Field parts of the field-circuit single-phase line start permanent magnet synchronous motor models

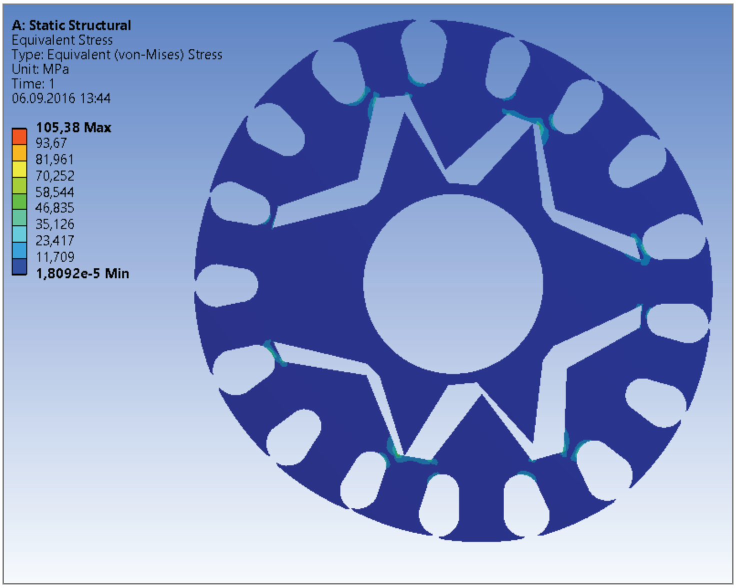
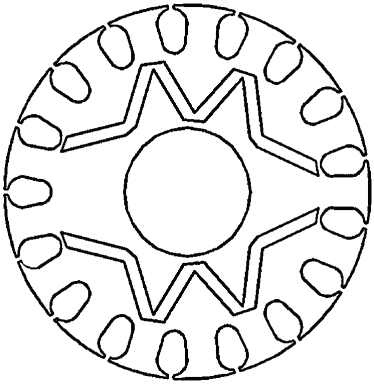


Fig. 3. Mechanical analyses of rotor sheet under stress: $n_{rotor} = 1.2n_n$, $T_{load} = 20\ T_n$

The model 17VVV (17 rotor slots, VVV permanent magnets shape) was chosen to build a physical motor model due to the best performance. Physical models of the motor are shown in Fig. 4 and Fig. 5. Two stators were built (skewed with one slot pitch skew and unskewed). One rotor was built with interior permanent magnets. The rotor cage was die casted from aluminium.



a) b)

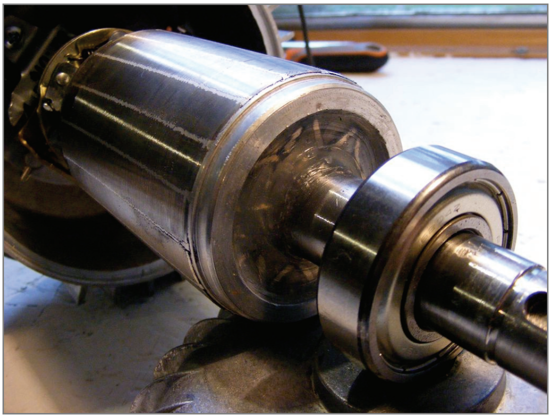


Fig. 4. Rotor with interior permanent magnets and aluminium die-cast cage:
(a) rotor sheet cross section, (b) rotor before assembly into stator

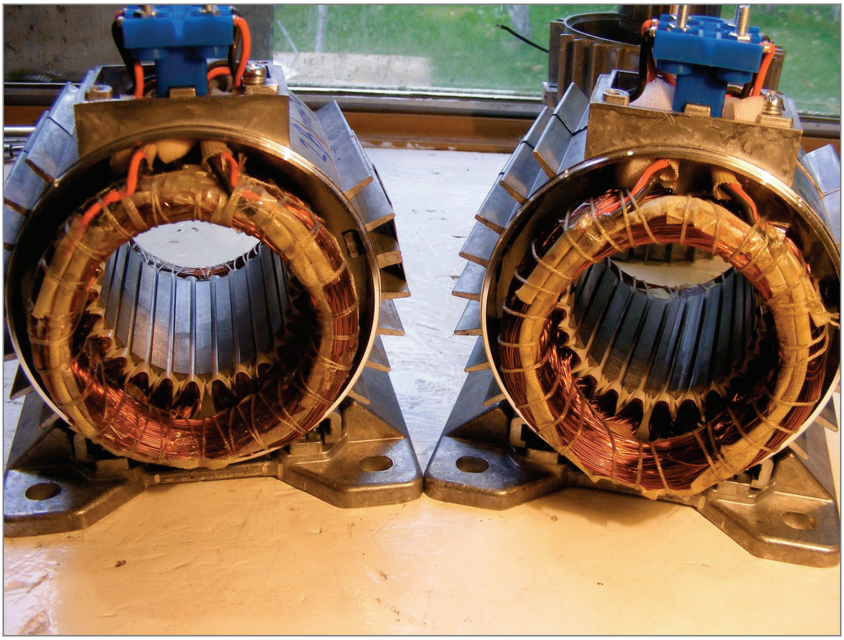


Fig. 5. Stators of the built motors: unskewed (left) and skewed (right)

The main and auxiliary phases of the stator winding are the same. Due to this solution the motor speed direction can be changed easily. Electrical scheme of this solution is presented in Fig. 6. The running capacitor capacitance C_{run} = 25 μF was estimated to obtain the maximum motor efficiency for its rated load.

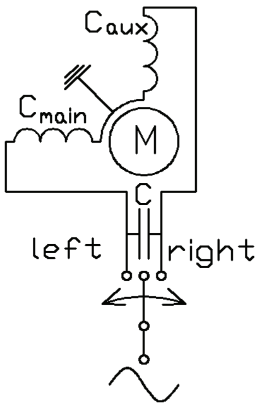


Fig. 6. Electrical scheme of the two-directional single-phase AC motor

3. COMPARISON OF MOTORS WITH SKEWED AND UNSKEWED STATORS

Running properties of both motors were investigated. The efficiency of the motor with unskewed stator is a little bit higher in comparison with efficiency of the motor with skewed stator (Fig. 7). This is caused by a little bit higher *back EMF* of the motor with unskewed stator (Fig. 8). Currents for rated load are almost the same for both motors (Fig. 9). Torque vibration is significantly lower in the case of the motor with skewed stator (Fig. 10). Due to that the motor with the skewed stator has much lower vibration (Table 1) and fulfils the norm specifications [5]. The vibration was analysed by the SVANTEK 954 (Fig. 11) vibration level meter [6] on the motor enclosure during motor idle-running.

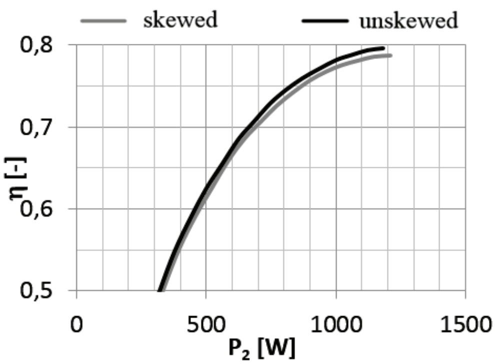


Fig. 7. Efficiency curves for the skewed and unskewed motor stator

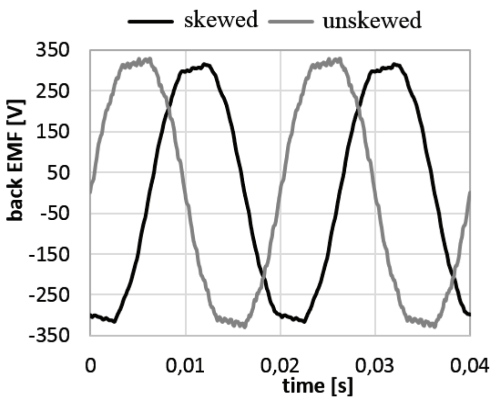


Fig. 8. *Back EMFs* in time domain for the skewed and unskewed motor stator (idle running)

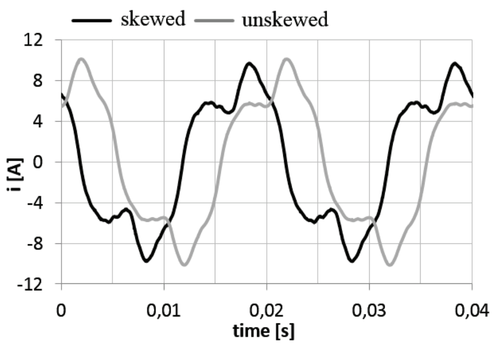


Fig. 9. Currents in time domain for the skewed and unskewed motor stator (rated load)

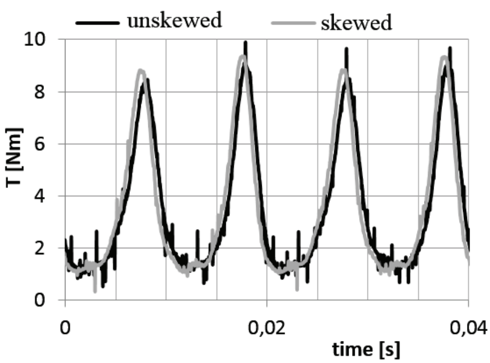


Fig. 10. Torques in time domain for the skewed and unskewed motor stator (rated load)

Fig. 11. Svantek 954 vibration level meter

Tab. 1. Results of the motor vibrations on the motor enclosure

Stator	RMS vibration speed ν [mm/s]					ν_{avg} [mm/s]
skewed	3.02	2.40	3.00	4.03	3.05	3.10
unskewed	4.03	3.80	3.63	4.32	4.03	3.96

4. CONCLUSIONS

Application of skewed stator in single-phase line start permanent magnet synchronous motor causes:

- a little bit lower back EMF,
- a little bit lower efficiency,
- less torque ripple,
- less motor vibration.

Skewed stator is a good alternative for skewed rotor in single-phase line start permanent magnet synchronous motors because it causes the same effect and is less complicated. This solution is quite difficult during manufacturing process but in comparison with skewed rotor significantly easier.

ACKNOWLEDGEMENTS

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REFERENCES

[1] BARAŃSKI M., JAREK T., *Analysis of PMSM vibrations based on back-EMF measurements*, International Conference on Electrical Machines (ICEM), 2014, 1492–1495.
[2] HYEON-JAE S., JANG-YOUNG C., HYUNG-IL P., SEOK-MYEONG J., *Vibration Analysis and Measurements Through Prediction of Electromagnetic Vibration Sources of Permanent Magnet Synchronous Motor Based on Analytical Magnetic Field Calculations*, IEEE Transactions on Magnetics, 2012, 48, 11, 4216–4219.
[3] ISLAM R., HUSAIN I., FARDOUN A., MCLAUGHLIN K., *Permanent Magnet Synchronous Motor Magnet Designs with Skewing for Torque Ripple and Cogging Torque Reduction*, Industry Applications Conference, 2007. 42nd IAS Annual Meeting. Conference Record of the 2007 IEEE, 1552–1559.
[4] MŁOT A., ŁUKANISZYN M., KORKOSZ M., *Cogging torque ripple reduction in brushless dc motor based on the stator skew*, Zeszyty Problemowe – Maszyny Elektryczne, 2010, 88, 41–45.
[5] *Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts* – Part 1, PN-ISO 10816-1:1998.
[6] www.svantek.com
[7] WANG A., LI H., LU W., ZHAO H., *Influence of skewed and segmented magnet rotor on IPM machine performance and ripple torque for electric traction*, IEEE International Electric Machines and Drives Conference, IEMDC 09, 2009.
[8] WEI X., XIE H., LIU Y., FENG Y., ZHANG Y., YANG X., YANG K., *Research of Asymmetrical Bidirectional Magnet Skewing Technique in Modular Multi-Stage Axial Flux Permanent Magnet Synchronous Motor*, IEEE Transactions on Magnetics, 2015, 51, 3.