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Spectral analysis of phase currents of LSPMSM at asymmetric voltage supply

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Abstract

This paper presents a spectral analysis of the stator currents at power supply asymmetry of the line start synchronous motor with permanent magnets. The study was conducted for various levels of asymmetry of motor voltage and different values of load. The tested motor was developed in the Department of Mechatronics and Electrical Machines at Poznan University of Technology. The construction of the stator is based on the mass-produced four-pole, three-phase induction motor type Sg100L-4B. The examined motor has rotor with u-shaped permanent magnets. In order to control the level of asymmetry of the motor voltage supply, the system was supplied from three auto-transformers. The voltage in one phase varied in the range from -10% to +10% of rated value. To adjust the value of the load motor was connected with the eddy current brake.

Keywords: Power supply asymmetry, synchronous motor, permanent magnets.

Spektralna analiza prądów stojana silnika LSPMSM przy niesymetrycznym zasilaniu

Streszczenie

W artykule przedstawiona została analiza spektralna prądów stojana przy niesymetrii zasilania silnika synchronicznego z magnesami trwałymi o rozruchu bezpośrednim. Badania przeprowadzono dla różnego stopnia niesymetrii napięcia zasilającego silnik oraz różnych wartości obciążenia silnika. Badany silnik został opracowany w Zakładzie Mechatroniki i Maszyn Elektrycznych Politechniki Poznańskiej. Konstrukcję stojana oparto na bazie seryjnie produkowanego czterobiegunowego, trójfazowego silnika indukcyjnego typu Sg100L-4B. Rozpatrywany silniki ma w wirniku klatkę rozruchową oraz magnesy trwałe rozmieszczone w formie litery „U". W celu regulacji stopnia niesymetrii układ silnik zasilany był z trzech autotransformatorów. Napięcie w jednej z faz zmieniano w granicach od -10% do +10% wartości znamionowej. Aby regulować wartość obciążenia silnik sprzężono z hamulcem wiroprądowym. Do rejestracji i archiwizacji danych zastosowano system komputerowy z kartą pomiarową National Instruments NI PCI-6123 oraz oprogramowaniem LabVIEW.

Słowa kluczowe: niesymetria zasilania, silnik synchroniczny, magnesy trwałe.

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1. Introduction

The increase in cost of electricity leads to the search for technical solutions that ensure, inter alia, the highest energy conversion efficiency. This applies, in particular, to electromechanical transducers, including magnetoelectric synchronous motors adapted for direct starting. Machines of this type are called Line Start Permanent Magnet Synchronous Motors (LSPMSM) and have become very popular in recent years [1, 2]. The main advantages of such motors are greater efficiency and power factor in compare to conventional squirrel cage induction motors. This is why they are becoming more and more popular in the drive systems designed for continuous operation.

In exploitation of motors, particular attention is paid recently to the problem of voltage supply symmetry and the load symmetrization of power lines. The Polish standard PN-EN 50160 is intended to determine the quality of power supply, and thus to establish in detail all the parameters of voltage and power levels disorders [6]. In addition, research is conducted on the impact of machines production technology on the electromagnetic emission [8].

The simulation studies to determine the field distribution use increasingly the finite element analysis (FEA) [4]. Using FEA a motor model taking into account the asymmetry in the structure of the machine for example in the stator winding can be built [5]. However, in [7] the deformation of stator three-phase squirrel cage induction motor, caused by the asymmetry of the supply voltage is analysed.

This paper presents the results of measuring the impact of voltage asymmetry on currents in the stator winding of LSPMSM in the steady state for chosen load values.

2. Tested motor and measuring system

The object of the study, an LSPMSM motor, was developed in the Department of Mechatronics and Electrical Machines at Poznan University of Technology.

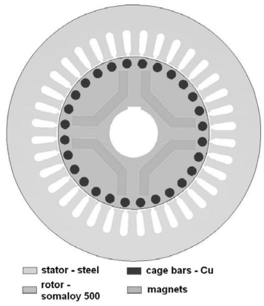

Fig. 1. Structure of the motor with cage and magnets distributed in the shape of the letter "U"
Rys. 1. Struktura silnika z klatką rozruchową oraz magnesami rozłożonymi w kształcie litery „U"

The construction of the stator is based on a mass-produced four-pole, three-phase induction motor of type Sg100L-4B. The considered motor has a rotor with u-shaped permanent magnets [3]. The structure of the motor is shown in Figure 1. In order to control the level of asymmetry, the motor was powered by three auto-transformers, Figure 2. For recording and archiving measurements a computer data acquisition system was built. The system used a measurement card National Instruments NI PCI-6123 and the LabVIEW software.

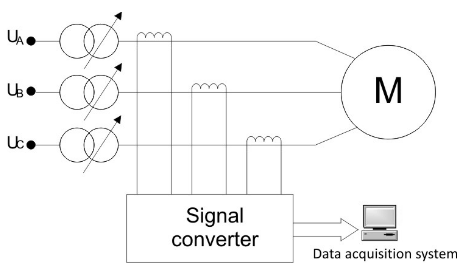

Fig. 2. Diagram of the power supply and measurement system
Rys. 2. Schemat układu zasilania i systemu pomiarowego

3. Selected results of measurements

This paper presents the waveforms of the phase currents of the stator winding and their spectral analysis. The study was carried out to test various degrees of asymmetry of motor supply voltage. The voltage in one phase varied in the range from -10% to +10% of the nominal value. To adjust the value of the load, the motor was coupled to the eddy current brake. The value of the load was changed in the range of 0Nm to 20 Nm (rated load).

In the first stage of the study waveforms of currents were measured and the frequency spectrums were calculated at the symmetrical voltage supply for load values of 0Nm, 10Nm and 20Nm. The results of measurements and calculations are shown in Figures 3, 4 and 5.

In the second stage of the study there was introduced the asymmetry of the mains voltage in phase B. The voltage changes were as follows: ΔU_B = -5% and ΔU_B = +2.5%. The measurement results were supplemented with the waveforms for symmetrical voltage supply, i.e. Δ U_B = 0%. The presented results of spectral analysis were limited to the scope of the current module 0-0.3 A to emphasize the higher harmonics.

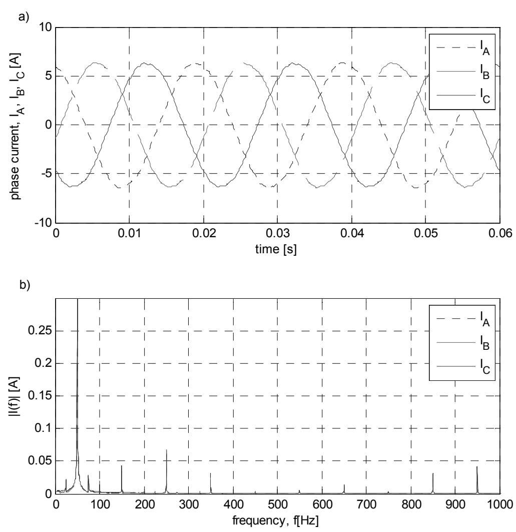

Fig. 3. Stator currents I_A, I_B, I_C for T=0Nm and symmetrical supply: a) waveforms, b) spectral analysis
Rys. 3. Prądy stojana I_A, I_B, I_C dla T=0Nm i zasilania symetrycznego: a) przebiegi czasowe, b) analiza spektralna

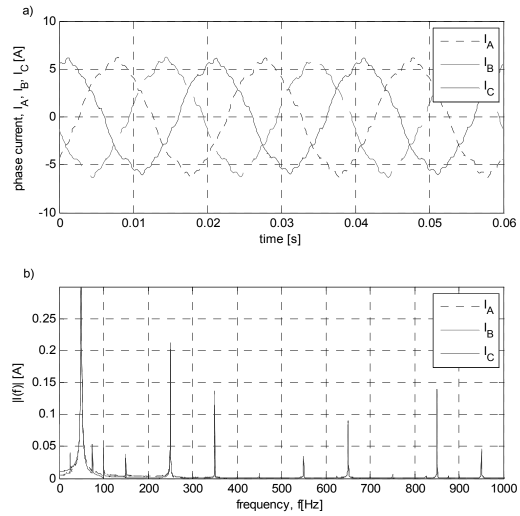

Fig. 4. Stator currents I_A, I_B, I_C for T=10Nm and symmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)
Rys. 4. Prądy stojana I_A, I_B, I_C dla T=10Nm i zasilania symetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

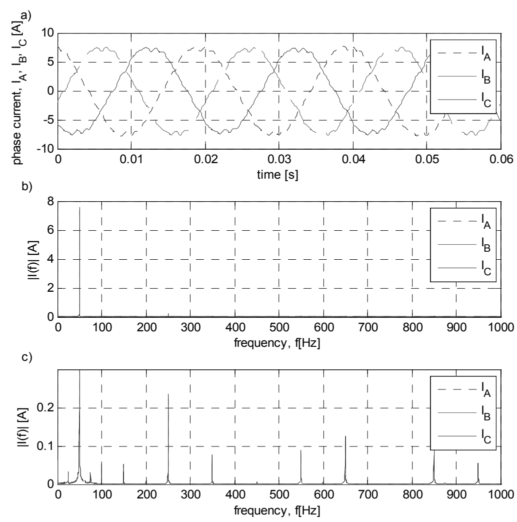

Fig. 5. Stator currents I_A, I_B, I_C for T=20Nm and symmetrical supply: a) waveforms, b) spectral analysis, c) spectral analysis limited to the current module 0-0.3 A
Rys. 5. Prądy stojana I_A, I_B, I_C dla T=20Nm i zasilania symetrycznego: a) przebiegi czasowe, b) analiza spektralna, c) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

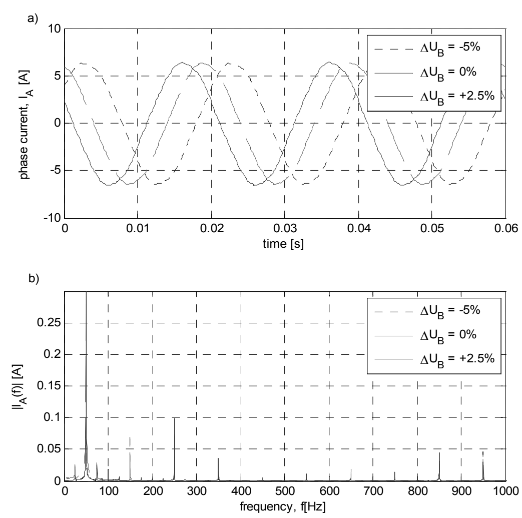

Fig. 6. Stator current I_A, for T=0 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)
Rys. 6. Prąd stojana I_A dla T=0Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

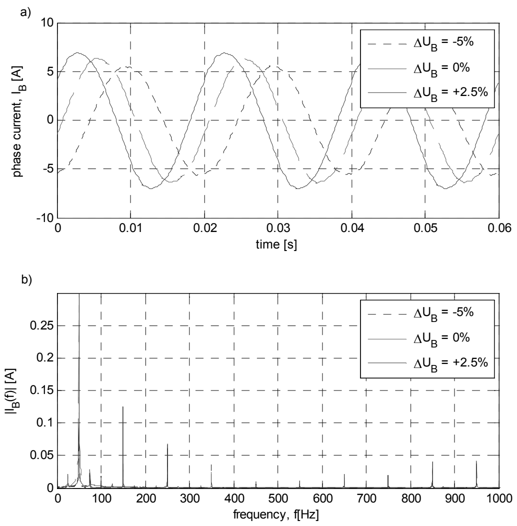

Fig. 7. Stator current I_B, for T=0 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)

Rys. 7. Prąd stojana I_B dla T=0Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

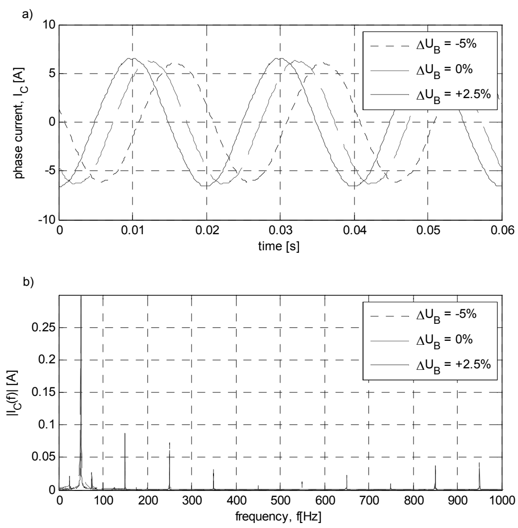

Fig. 8. Stator current I_C, for T=0 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)

Rys. 8. Prąd stojana I_C dla T=0Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

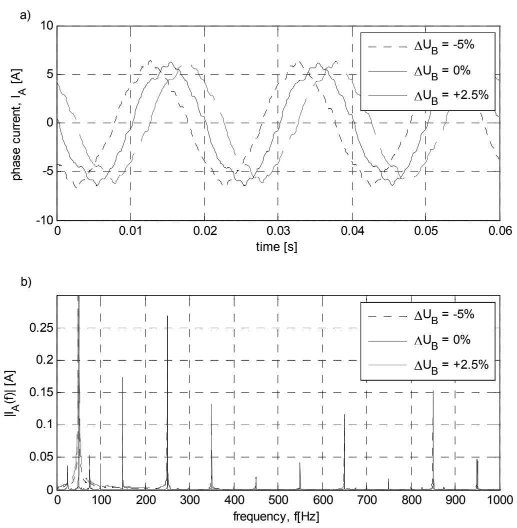

Fig. 9. Stator current I_A, for T=10 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)

Rys. 9. Prąd stojana I_A dla T=10Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

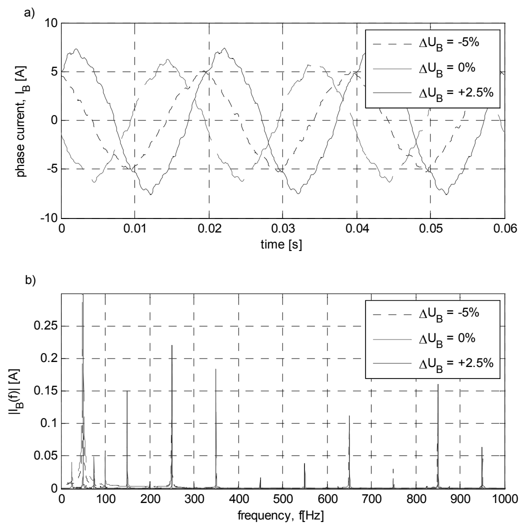

Fig. 10. Stator current I_B, for T=10 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)

Rys. 10. Prąd stojana I_B dla T=10Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

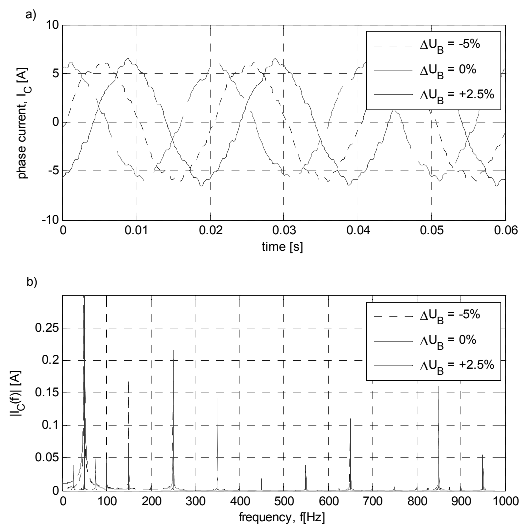

Fig. 11. Stator current I_C, for T=10 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)

Rys. 11. Prąd stojana I_C dla T=10Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

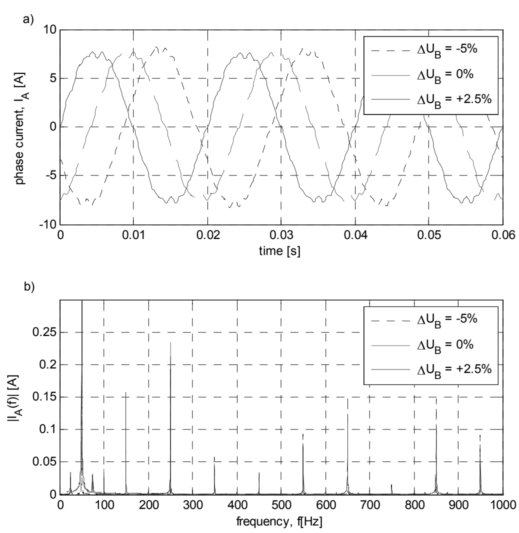

Fig. 12. Stator current I_A, for T=20 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)

Rys. 12. Prąd stojana I_A dla T=20Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

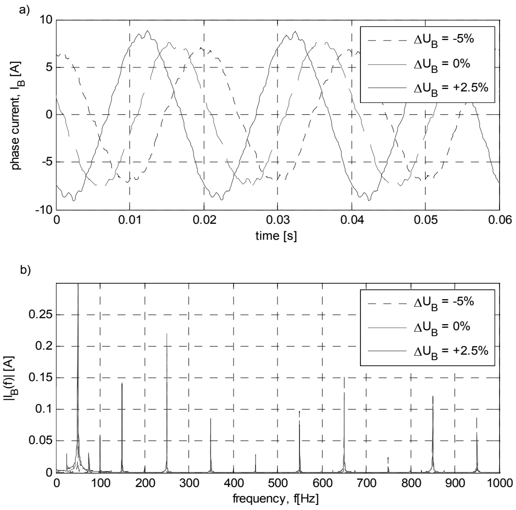

Fig. 13. Stator current I_B, for T=20 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)

Rys. 13. Prąd stojana I_B dla T=20Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

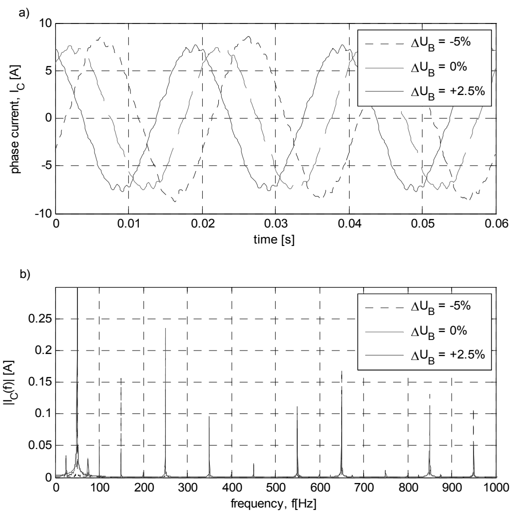

Fig. 14. Stator current I_C, for T=20 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A)

Rys. 14. Prąd stojana I_C dla T=20Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona dla zakresu modułu prądu 0-0.3 A

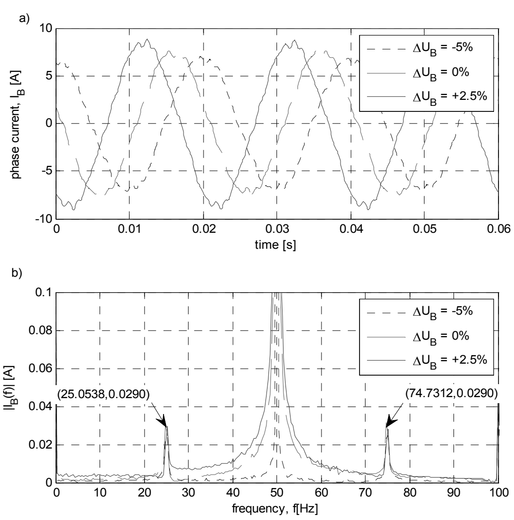

Fig. 15. Stator current I_C, for T=20 Nm and unsymmetrical supply: a) waveforms, b) spectral analysis (limited current module 0-0.3 A and frequency 0-100 Hz)

Rys. 15. Prąd stojana I_C dla T=20Nm i zasilania niesymetrycznego: a) przebiegi czasowe, b) analiza spektralna ograniczona f=(0-100) Hz oraz zakresu modułu prądu 0-0.3 A

Figures 6, 7 and 8 show the results of measurement currents I_A, I_B and I_C for unloaded motor, i.e. T = 0Nm, respectively. The measurement results for T = 10 Nm load are presented in Figures 9, 10 and 11. For the rated load (T = 20 Nm) the measurements are shown in Figures 12, 13 and 14. In addition, Figure 15 depicts the waveform of the current I_B and its spectral range was limited to the range 0-100 Hz and the current module to 0-0.3 A (rated load T = 20 Nm).

4. Summary

This paper presents the results of measurements of the phase currents of the line start permanent magnet synchronous motor. A new type of a machine rotor developed in the Department of Mechatronics and Electrical Engineering at Poznan University of Technology was investigated.

Spectral analysis of the currents with different levels of voltage asymmetry and different values of motor load is presented. In the current spectra the higher odd harmonics can be observed.

The studies show that the asymmetry increases the values of higher harmonic, particularly the 5-th and 17- th, amplitudes (see Figures 10 and 11) . This increase can be observed practically only in the current of phase B.

A radial force acting on the stator of an electric machine can be described by the empirical formula [9]:

$$p_r = \frac{1}{36q^2}\left(\frac{I_1^2}{I_0}\right)^2 B_\delta^2 k_{ns}^2$$

where: p_r – radial force per unit of the machine outside surface area, q – number of slots per pole and phase, I_1 and I_0 - stator current in under load and no-load operation, respectively, B_δ – flux density in the air gap, k_{ns} – saturation (correction) factor.

This means that the asymmetric supply under load will increase the noise level of the housing in the frequency bands of 500 Hz and around 1800 Hz. The last band practically coincides with the range of maximum sensitivity of the human ear. Even small changes in the amplitude of the sound of the band produce a distinct change in the noise perception.

5. References

[1] Popescu M., Miller, T.J.E., McGilp, M.I., Strappazzon, G., Trivillin, N.: Line start PM motor: single phase starting performance analysis, IEEE Trans., 39, n.4, pp. 1021-1030, 2013.

[2] Jędryczka C., Nowak M., Radziuk K., Stachowiak D.: Hybrid magnets in line start synchronous motors, Przegląd Elektrotechniczny R. 89 No. 9/2013, pp. 44-47, 2013.

[3] Barański M., Szeląg W., Jędryczka C., Mikołajewicz J., Łukaszewicz P.: Analysis and tests of line start permanent magnet synchronous motor with u-shaped magnets rotor, Przegląd Elektrotechniczny R. 89, No. 2b/2013, pp. 107-111, 2013.

[4] Demenko A., Nowak L., Pietrowski W.: Calculation of magnetization characteristic of a squirrel cage machine using egde element method, COMPEL, Vol. 23 No.4, pp. 1110-1118, 2004.

[5] Pietrowski W.: 3D analysis of influence of stator winding asymmetry on axial flux, COMPEL, Vol. 32 No.4, pp. 1278-1286, 2013.

[6] PN-EN 50160:2008: Parametry napięcia zasilającego w publicznych sieciach rozdzielczych.

[7] Idziak P., Rawicki St.: Analysis of stator deformations of a three-phase squirrel-cage induction motor, Przegląd Elektrotechniczny R. 86, No. 4, pp. 184-187, 2010.

[8] Idziak P.: Technologie „zero emisji" w konstrukcji silników elektrycznych, rozdz. 12 w monografii Technologie „zero emisji", praca zbiorowa, red. naukowy Jabłoński J., Wydawnictwo Politechniki Poznańskiej, s. 331-368, 2011.

[9] Kwaśnicki, S.: Hałas magnetyczny silników indukcyjnych trójfazowych klatkowych, BOBREME Komel, Katowice, 1998.

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