1. Lina H. Hussienat[1], 2. Suad Omar Aldaikh[1], 3. Mohamed QAWAQZEH[1], 4. Oleksandr VOVK[2], 5. Serhii HALKO[2], 6. Serhii KVITKA[2], 7. Andrii SABO[2], 8. Mykola OSTROVERKHOV[3], 9. Oleksandr MIROSHNYK[4], 10. Taras SHCHUR[5], 11. Paweł KIEŁBASA[6]

Al Balqa Applied University (1), Dmytro Motornyi Tavria State Agrotechnological University (2),
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" (3), State Biotechnological University (4),
Cyclone Manufacturing Inc, Mississauga, Ontario, Canada, shchurtg@gmail.com (5),
Faculty of Production and Power Engineering, University of Agriculture in Krakow (6)
ORCID: 1. 0000-0002-8276-4906; 2. 0000-0002-0664-892X; 3. 0000-0001-7027-5577; 4. 0000-0003-0154-6972;
5. 000-0001-7991-0311; 6. 0000-0001-9234-9274; 7. 0000-0002-7948-6933; 8. 0000-0002-7322-8052; 9. 0000-0002-6144-7573;
10. 0000-0003-0205-032X, 11. 0000-0003-0249-8626

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Asynchronous motor functional state monitoring based on the relative deviations of the power losses

***Abstract**. The article proposes a method for monitoring the functional state of asynchronous motors. Relative deviations of power losses in the electric motor are used as diagnostic parameters determined under the same conditions at operating intervals. Experimental testing showed its high ability to detect faults. The advantage of this research is obtaining a diagnostic method that allows to establish not only that the asynchronous motor is faulty, but also to determine in which node the malfunction occurred.*

Streszczenie.** W artykule zaproponowano metodę monitorowania stanu funkcjonalnego silników asynchronicznych. Jako parametry diagnostyczne wyznaczane są względne odchyłki strat mocy w silniku elektrycznym w tych samych warunkach w odstępach czasowych. Testy eksperymentalne wykazały jego wysoką zdolność do wykrywania usterek. Zaletą tych badań jest uzyskanie metody diagnostycznej, która pozwala nie tylko stwierdzić, czy silnik asynchroniczny jest uszkodzony, ale także określić, w którym węźle wystąpiła awaria. (**Monitorowanie stanu funkcjonalnego silnika asynchronicznego na podstawie względnych odchyleń strat mocy)

Keywords: asynchronous motor; functional state; diagnostic parameter; power loss.
Słowa kluczowe: silnik asynchroniczny; stan funkcjonalny; parametr diagnostyczny; utrata mocy.

Introduction

The most widespread power electrical equipment used to drive various machines and mechanisms is an asynchronous motor with a short-circuited rotor. The total number of such electric motors is approximately 70% of all electric machines used in various technological processes [1, 2]. Asynchronous motors have been widely used due to their high structural reliability and relatively low manufacturing and installation costs [3-5]. However, at European enterprises, up to 4% of asynchronous motors drive work machines are rejected annually and about 8% of the cash flow of the economic sectors is spent on their restoration. In addition, there are additional costs associated with the sudden stop of technological processes [6-8]. Failures of electric motors in operating conditions occur due to the imperfection of control and protection devices or the asynchronous motor maintenance systems. Today the mentioned systems do not ensure the maintenance of the asynchronous motor structural reliability in the conditions of various operational influences (deviation and asymmetry of the supply voltage [9, 10], various overloads from working machines, vibration, humidity, aggressive environment, ambient temperature, etc.) [11-13].

Thus, the development of a method for diagnosing an asynchronous motor to provide an assessment of the functional state of both the electric motor as a whole and its individual elements as well as simplify the practical implementation of diagnostics in comparison with the existing one is an urgent task. It is necessary to develop a method of diagnosing an asynchronous motor, which allows to determine the motor damage presence and indicates its faulty unit and simplifies the practical implementation of diagnostics in comparison with the existing one and check the developed method experimentally.

1. Materials and Methods

Diagnosing an asynchronous motor consists in recording changes in its functional state during operation. At the beginning of operation, the electric motor that just arrived from the manufacturer and is installed on the working machine is considered to be in good condition (it does not have malfunctions). At this stage, no-load and short-circuit tests are carried out on it as indicated above. According to the results of these experiments the basic values of individual power losses according and total losses (summing individual losses) are determined. Also they determine the permissible relative deviation of the total losses according.

After some time of operation (it is set in each case individually depending on the conditions of operation of the electric motor), idle and short-circuit tests are again carried out as indicated above. According to the results of these experiments the current values of individual power losses according and total losses (summing individual losses) are determined [14, 15]. Then the relative values of individual losses according and total losses according are determined. The current relative deviation of total losses is compared with the permissible one [16, 17]. If it exceeds the permissible limit the electric motor must be repaired. The electric motor node in which the largest relative deviation of power losses is observed is faulty and needs to be given the most attention when troubleshooting. There can be several such nodes if several relative deviations of individual losses differ significantly from others.

2. Results

An accelerated experiment used in works [18-23] was used to test this method of diagnosis. Its essence consists in deliberately introducing certain malfunctions into the electric motor and detecting a faulty node (or faulty nodes) using a developed diagnostic method. An asynchronous motor with a short-circuited rotor with a capacity of 2.2 kW with two pairs of poles (type АИР90L4) was taken as the controlled one. It had six output clamps and was designed for a voltage of 220/380 V. This electric motor has $\delta_{\Sigma(per)}$ = 1.19. Electronic electrical measuring devices were used to measure voltage, current and active power - voltmeter, ammeter and wattmeter. A measuring bridge was used to measure the resistance of the stator winding. The electric motor was powered from the laboratory electrical network 220/380 V. Each of the experiments was carried out with five-fold repetition. In the tables with the results of the experiments, which are given below, the average values of the measured values are indicated. The following damages were introduced into the electric motor: 1) short circuit in the stator winding; 2) short circuit in the stator winding and wear of the bearing; 3) short circuit in the stator winding, wear of the bearing and breakage of the rotor rod; 4) short circuit in the stator winding, wear of the bearing, breakage of the rotor rod and violation of the inter-sheet insulation of the stator magnetic conductor.

Table 1. Baseline test results

$U_{it(1)}$, V	$I_{it(1)}$, A	$P_{it(1)}$, W	$U_{it(2)}$, V	$I_{it(2)}$, A	$P_{it(2)}$, W	$r_{1it,}$ Ohm	$U_{sc,}$ V	$I_{sc,}$ A	$P_{sc,}$ W	$r_{1sc,}$ Ohm
220	1.25	83	380	1.68	125	2.9	73	7.4	1025	3.3

Case 1 – short circuit in the stator winding. The damage was carried out by processing part of the turns of the stator winding with fire from a gas burner (Fig. 1).

Fig.1. Malfunction of the stator winding

After that, idling and short-circuit experiments were conducted, the current values of power losses in the electric motor and their relative deviations were determined. The results of the experiments are shown in Table 2.

Table 2. Results of short-circuit tests in the stator winding

$U_{it(1)}$, V	$I_{it(1)}$, A	$P_{it(1)}$, W	$U_{it(2)}$, V	$I_{it(2)}$, A	$P_{it(2)}$, W	$r_{1it,}$ Ohm	$U_{sc,}$ V	$I_{sc,}$ A	$P_{sc,}$ W	$r_{1sc,}$ Ohm
220	1.3	84	380	1.74	129	2.8	73	8.9	1258	3.1

The results of calculations of power losses relative deviations are shown in Fig. 2.

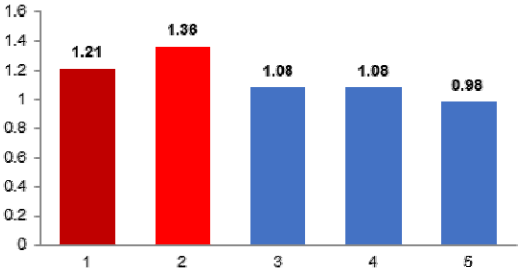

Fig.2. Relative deviations of power losses during short-circuiting in the stator winding (1 – δ_{Σ}; 2 – δ_1; 3 – δ_2; 4 – δ_3; 5 – δ_4)

From the given results (Fig. 2), it can be seen that the relative deviation of the amount of power losses exceeds the permissible value (1.21 > 1.19), therefore the electric motor is faulty and needs to be repaired. The node of the electric motor with the largest observed relative deviation of power losses (36%) is the stator winding. This is explained by the increase in current consumption due to the introduced short circuit in the stator winding. A slight increase in the relative deviation of power losses in the rotor winding (by 8%) is explained by an increase in the current strength in it due to an increase in the consumed current. An increase in the current consumption also leads to the increase in the magnetic induction in the electric motor and an increase in the relative deviation of the power losses in the magnetic circuit by 8%. The decrease in the relative deviation of mechanical losses by 2% is explained by the increase in power losses in the rotor winding leading to an increase in slippage and a decrease in the frequency of rotation of the electric motor.

The increase in the relative deviation of the power losses in the stator winding is much greater than the increase in the relative deviations of the power in the rotor winding and in the magnetic field (36% vs 8%). Therefore, it is most likely that there is a malfunction in the stator winding and there are no malfunctions in other nodes.

Case 2 – short circuit in the stator winding and bearing wear. Bearing wear was added to the short circuit in the stator winding introduced in the case 2. Bearing wear was introduced by adding sand (fraction 0.05 mm, mass 0.3 g) to one of the bearings of the electric motor (Fig. 3).

Fig.3. Bearing failure

After that, idling and short-circuit experiments were conducted, the current values of power losses in the electric motor and their relative deviations were determined. The results of the experiments are shown in Table 3.

Table 3. Results of short-circuit tests in the stator winding and bearing wear

$U_{it(1)}$, V	$I_{it(1)}$, A	$P_{it(1)}$, W	$U_{it(2)}$, V	$I_{it(2)}$, A	$P_{it(2)}$, W	$r_{1it,}$ Ohm	$U_{sc,}$ V	$I_{sc,}$ A	$P_{sc,}$ W	$r_{1sc,}$ Ohm
220	1.32	95	380	1.76	140	2.81	73	8.9	1258	3.1

The results of calculations of relative deviations of power losses are shown in Fig. 4.

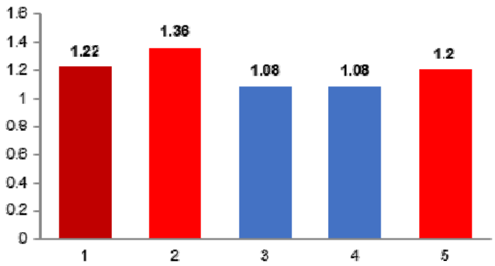

Fig.4. Relative deviations of power losses during shorting in the stator winding and bearing wear (1 – δ_{Σ}; 2 – δ_1; 3 – δ_2; 4 – δ_3; 5 – δ_4)

From the given results (Fig. 4), it can be seen that the relative deviation of the amount of power losses exceeds the permissible value (1.22 > 1.19), therefore the electric motor is faulty and needs to be repaired. The node of the electric motor in which the largest relative deviation of power losses (36%) is observed is the stator winding. This is explained by the increase in current consumption, which is due to the introduced malfunctions. The next node with an increase in the observed relative deviation of power losses (by 20%) is the bearing node. This is due to an increase in the frictional forces in the bearing with a malfunction. A slight increase in the relative deviation of the power losses in the rotor winding (by 8%) and in the magnetic field (by 8%) is explained by the same as in the case 1.

The increase in the relative deviations of the power losses in the stator winding and mechanical losses is greater than the increase in the relative deviations of the powers in the rotor winding and in the magnetic field (36% and 20% vs 8%). Therefore, it is most likely that there are malfunctions in the stator winding and the bearing unit and there are no malfunctions in the other units.

Case 3 – short circuit in the stator winding, wear of the bearing and breakage of the rotor rod. In addition to the short circuit in the stator winding and the wear of the bearing introduced in the case 2, the breakage of the rotor core was added. The break of the rotor core was introduced by making a 30 mm deep hole in two cores of the rotor winding with a drill with a diameter of 8 mm (Fig. 5).

Fig.5. Malfunction of the rotor winding

After that, idling and short-circuit experiments were conducted, the current values of power losses in the electric motor and their relative deviations were determined. The results of the experiments are shown in Table 4.

Table 4. Test results for shorting in the stator winding, bearing wear and rotor core breakage

$U_{it(1)}$, V	$I_{it(1)}$, A	$P_{it(1)}$, W	$U_{it(2)}$, V	$I_{it(2)}$, A	$P_{it(2)}$, W	r_{1it}, Ohm	U_{sc}, V	I_{sc}, A	P_{sc}, W	r_{1sc}, Ohm
220	1.33	95	380	1.77	140	2.81	73	9.1	1359	3.12

The results of calculations of relative deviations of power losses are shown in Fig. 6.

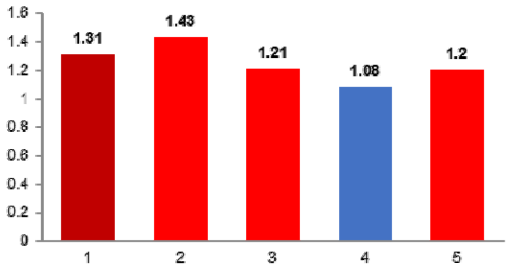

Fig.6. Relative deviations of power losses in the event of a short circuit in the stator winding, bearing wear and rotor rod breakage ($1 – \delta_\Sigma$; $2 – \delta_1$; $3 – \delta_2$; $4 – \delta_3$; $5 – \delta_4$)

From the given results (Fig. 6), it can be seen that the relative deviation of the amount of power losses exceeds the permissible value (1.31 > 1.19), therefore the electric motor is faulty and needs to be repaired. The node of the electric motor in which the largest relative deviation of power losses (43%) is observed is the stator winding. This is explained similarly to the case 2. The next node with an increase in the observed relative deviation of power losses (by 20%) is the bearing node. This is explained similarly to the case 3. Another node where the relative deviation of power losses increased (by 21%) is the stator winding. This is explained by the increase in the current in this winding as a result of the fault introduced into it. The slight increase in the relative deviation of the power losses in the magnetic line (by 8%) is explained by the same as in the case 3. The increase in the relative changes of the power losses in the stator winding, mechanical losses, and losses in the rotor winding is greater than the increase in the relative deviation of the power losses in the magnetic line (43 %, 20% and 21% vs 8%). Therefore, it is most likely that there are malfunctions in the stator winding, the bearing unit, and the rotor winding, and there is no malfunction in the magnetic circuit.

Case 4 – short circuit in the stator winding, wear of the bearing, breakage of the rotor rod and violation of the inter-sheet insulation of the stator magnetic conductor. To imitate the short circuit in the stator winding, the wear of the bearing and the breakage of the rotor rod introduced in the case 3, the violation of the inter-sheet insulation of the stator magnetic conductor was added. Violation of the inter-sheet insulation of the stator magnetic conductor was introduced by combing several teeth of the stator magnetic conductor with a file (Fig. 1).

After that, idling and short-circuit experiments were conducted, the current values of power losses in the electric motor and their relative deviations were determined. The results of the experiments are shown in Table 5.

Table 5. Test results for shorting in the stator winding, wear of the bearing, rotor rod breakage and violation of the inter-sheet insulation of the stator magnetic conductor

$U_{it(1)}$, V	$I_{it(1)}$, A	$P_{it(1)}$, W	$U_{it(2)}$, V	$I_{it(2)}$, A	$P_{it(2)}$, W	r_{1it}, Ohm	U_{sc}, V	I_{sc}, A	P_{sc}, W	r_{1sc}, Ohm
220	1.37	101	380	1.86	156	2.82	73	9.2	1382	3.14

The results of calculations of power loss relative deviations are shown in Fig. 7.

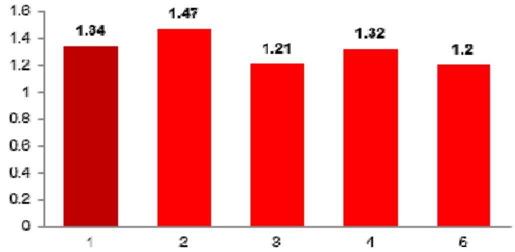

Fig.7. Relative deviations of power losses in case of a short circuit in the stator winding, wear of the bearing, breakage of the rotor rod and violation of the inter-sheet insulation of the stator magnetic conductor ($1 – \delta_\Sigma$; $2 – \delta_1$; $3 – \delta_2$; $4 – \delta_3$; $5 – \delta_4$).

From the given results (Fig. 8) it can be seen that the relative deviation of the amount of power losses exceeds the permissible value (1.34 > 1.19), therefore the electric motor is faulty and needs to be repaired. The node of the electric motor in which the largest relative deviation of power losses (47%) is observed is the stator winding. This is explained similarly to the case 3. The next node with an increase in the observed relative deviation of power losses (by 20%) is the bearing node. This is explained similarly to the case 3. Another node where the relative deviation of power losses increased (by 21%) is the stator winding. This is explained similarly to the case 4. The last node, where an increase in the relative deviation of power losses (by 32%) is observed, is the magnet wire. This is explained by the increase in eddy currents in the magnetic circuit as a result of the fault introduced into it. The increase in the relative changes of power losses in the stator winding, mechanical losses, losses in the rotor winding and losses in the magnetic field are significant (47%, 20%, 21% and 32%). Therefore, it is most likely that there are malfunctions in the stator winding, the bearing unit, the rotor winding and the magnetic circuit.

3. Discussion

A diagnostic method was developed with the use of the relative deviations of power losses in an asynchronous motor and the method of their determination. This method is recommended for malfunction detecting during the electric motor operation and establishing the need for its removal for repair. In contrast to [18-23], this method makes it possible to establish not only that the induction motor is faulty, but also to determine in which node the fault occurred. The technical implementation of the method compared to [18-23] is simpler and does not require specific equipment and significant calculations. The disadvantage of the method proposed in the article is that it can be used only for asynchronous motors with six output terminals. One way to eliminate this shortcoming may be to describe the asynchronous motor idle mode characteristics at one point taken at the rated voltage. The authors are already working in this direction. The boundary element methods, due to their versatility of application and high efficiency of simulation, is another direction could be to try to develop an motor simulator. It could reduce the cost of research and increase the eventual scope [24-26].

4. Conclusions

In the work a diagnosing method was successfully developed for an asynchronous motor with six output clamps. Experimental verification of the diagnostic method showed that it is capable to detect malfunctions that may occur during the electric motor operation. At the same time, the diagnostic method makes it possible to establish not only that the asynchronous motor is faulty, but also to determine in which node the malfunction occurred. Its technical implementation compared to the existing ones is simpler and does not require specific equipment and significant calculations.

***Authors**: Lina H. Hussienat, Suad Omar Aldaikh, Mohamed Zaidan Qawaqzeh, Al-Balqa Applied University, Department of Technical Science, Al Salt 19117, Jordan, E-mail: lina.hsainat@bau.edu.jo;: suad.aldaikh@bau.edu.jo; qawaqzeh@bau.edu.jo; Oleksandr Vovk, Serhii Halko, Serhii Kvitka, Andrii Sabo, Department of Electrical Engineering and Electromechanics Named after Prof. V.V. Ovharov, Dmytro Motornyi Tavria State Agrotechnological University, 69600, Zaporizhia, Ukraine, E-mail: oleksandr.vovk@tsatu.edu.ua; serhii.halko@tsatu.edu.ua; sergii.kvitka@tsatu.edu.ua; andrii.sabo@tsatu.edu.ua; Mykola Ostroverkhov, Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 03056, Kyiv, Ukraine, E-mail: n.ostroverkhov@hotmail.com; Oleksandr Miroshnyk, Department of Electricity Supply and Energy Management, State Biotechnological University, 61052 Kharkiv, Ukraine, E-mail: omiroshnyk@btu.kharkiv.ua, Taras Shchur, GVA Lighting, Inc, L6H6X5, Oakville, Ontario, Canada, E-mail: shchurtg@gmail.com; Paweł Kiełbasa Associate Professor, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Balicka Av. 116B, 30-149 Krakow, E-mail: pawel.kielbasa@urk.edu.pl;*

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