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Diagnostic system induction motor rotor eccentricity by phase current

Abstract: *Construction principle of diagnostic systems of induction motor rotor eccentricity is proposed as a source of information, which uses a phase current, where the amount of eccentricity is determined by the root-mean-square value of additional currents caused by air gap unevenness*

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Streszczenie. W artykule przedstawiono metodę analizy ekscentryczności wirnika w silniku indukcyjnym. Do analizy wykorzystywany jest prąd fazowy – jego składowa parzysta powodowana ekscentrycznością. ***System diagnozowania ekscentryczności wirnika silnika indukcyjnego***

Keywords: an induction motor, a rotor eccentricity, a diagnostics.
Słowa kluczowe: silnik indukcyjny, ekscentryczność

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Introduction

In power industry are mainly used induction motors (IM) as a drive of mechanism. One of the methods to improve their operational reliability and service life is an effective and timely diagnostics of abnormal operating modes, in particular, the rotor eccentricity [1-4]. However, by a number of reasons to develop a diagnostic system that would allow effectively identify the rotor static eccentricity during an operational process isn't possible hitherto. At the same time, as the practice of IM demonstrates, about half of them work with the rotor static eccentricity for a long time [1-4]. It is accompanied by a significant loss of power. To solve this problem diagnostics of the rotor eccentricity induction motor is proposed as follows.

Diagnostic features

Air gap unevenness in IM of the rotor eccentricity by ε magnitude causes its magnetic field modulation. Because of this fact, it gets extra magnetic fields with frequencies [2-4].

$$f_\nu = f_1(\nu \pm 1/p)\,, \qquad (1)$$

where: f_1 - fundamental harmonic network frequency, p - IM pole pairs quantity, ν - harmonic network number, $\varepsilon = d/\delta_n$; δ_n and d - nominal air gap magnitudes of IM and rotor displacement.

Additional air gap magnetic fields induce stator and EMF rotor windings in the coils with the same frequency. However, the total value of the EMF in the stator windings and the rotor phase is always zero and currents don't arise from it in these windings. These EMF and currents from them are not equal to zero in a short-circuited rotor winding. They create the magnetic field, which weakens the additional magnetic field in the air gap. This attenuation is taken into account as a damping coefficient $D_{p\pm1}$ [2, 4].

All these processes are accompanied by the appearance of I_ν additional harmonic currents with f_ν frequencies in the stator phases currents. These currents are clearly visible in Figure 1, which shows IM AO-41-6 current phase spectrograms in an idling mode. They obtained by experimental method using a spectrum analyzer based on a personal computer (PC) "Elena 2012" software, where in as an analog-to-digital converter (ADC) used a sound card (SC) [5]. In this spectrum analyzer 1812 units on the scale correspond to the measured current at 1A.

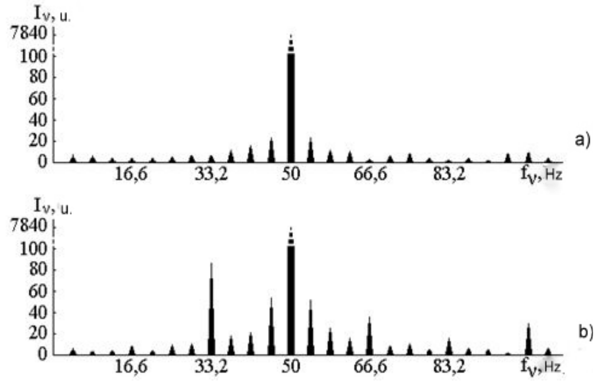

Fig.1. IM AO-41-6 phase current spectrogram at ε=0 (a) and ε=0,95 (b)

Spectrograms show that the appearance of the rotor eccentricity in IM AO-41-6 is accompanied by the appearance of additional currents stator with frequencies of 16,67 Hz, 33,34 Hz, etc. in currents of phases. Therefore, the phase current of the stator can be used as a source of information about the rotor eccentricity, and it coincides with the opinion of the authors [6-10]. For all that, I_ν additional currents with f_ν frequencies will be a diagnostic feature. The nature of the changes depending on the magnitude of the rotor eccentricity in an idling mode is given in Table 1.

Table 1. Nature of magnitude changes of I_ν additional currents with f_ν frequencies depending on the rotor eccentricity at a bias of one of bearings

ε [r.u.]	Magnitude of harmonic I_ν with f_ν frequencies [units]							I_ε [units]
	16,66 Hz	33,33 Hz	66,66 Hz	83,33 Hz	116,66 Hz	153,33 Hz	166,66 Hz	
0,00	4,38	4,51	10,52	5,69	2,94	3,97	2,06	5,49
0,25	2,98	15,33	5,97	8,30	1,13	2,09	1,72	7,14
0,50	2,10	37,56	20,20	9,66	3,67	3,61	5,66	16,79
0,75	6,77	49,35	44,08	2,20	2,62	2,05	4,03	25,30
1,00	7,47	85,11	51,01	14,46	6,82	1,88	4,43	38,05

Information about damage

The analysis of the data in Table 1 shows that growth of the rotor eccentricity is not always accompanied by an increase of I_v additional currents with f_v frequencies. As shown by numerous experiments on IM of different types, this is caused by the vibration of blood pressure and the drive mechanism, unevenness of resistance moment of its load, as well as fluctuations mains voltage and network frequency. If SC uses as ADC [5], in this case, its noise and various types of breakthroughs have a definite impact on the amount of I_v additional currents with f_v frequencies.

Significant portion of these problems can be eliminated if to diagnose IM in an idling mode and for a sufficiently long time, and to evaluate the rotor eccentricity by the root-mean-square (RMS) value of several I_v additional currents with f_v frequencies [11], which is defined as:

$$I_{\varepsilon} = \sqrt{(I_{\nu 1}^2 + I_{\nu 2}^2 + \cdots + I_{\nu n}^2)/n}, \tag{2}$$

where: n - a number of used additional currents with f_v frequencies in diagnosis.

As shown by the experimental results, the usage of I_v additional currents with f_v frequencies as information is usually limited to those which arise from the network harmonics $\nu \le 7$. Using others does not make sense, because their value is low and comparable with measurement errors. The results of I_{ε} calculation for IM AO-41-6 according to Table 1 are shown in its last column.

Implementation of diagnostics system

If the current phase of IM I_p is used as a source of information, and PC is used for processing this information, in such case, the rotor eccentricity detection should be carried out according to the scheme in Figure 2, where TA – current transformer; R_l- load of TA; ND – normalizing device; SPM – signal processing unit; IPU and ISU – information processing and storage units about rotor eccentricity; EEMU and CB – estimate of eccentricity magnitude unit and control block of diagnostics system.

Designing a simple and inexpensive diagnostic systems of IM as ADC, SC can be used [5], and elements: SPM, IPU, ISU, EEMU and CB in PC can be implemented as software. In this case, with the help of ND, harmonization of the output signal from the valid signal TA with a valid input signal of SC is implemented [11].

Mathematical software signal processing unit is a decomposition of the signal from the ADC in a Fourier series with a result as additional current value $I_{v1} \div I_{vn}$ with f_v frequencies [12]. In IPU for the information processing and signal generation I_{ε} about the presence and the rotor eccentricity magnitude the algebraic criterion in the form of their mean values of additional currents is used as a mathematical software [11]. Sometimes it is possible to use artificial neural network [13].

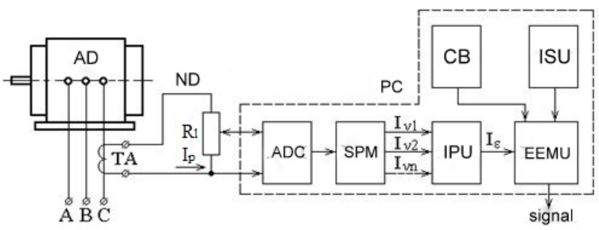

Fig.2. Block diagram of diagnostic system

Information storage unit is a database that stores information about the parameters of IM, and its current value: the additional currents values $I_{v1} \div I_{vn,}$ current of the first harmonic of the mains frequency, as well as $I_{\varepsilon}=f(\varepsilon)$ dependence and evaluation criteria of rotor eccentricity magnitude. Data is entered into the database at the time of new IM installation and used as a standard.

Estimate of eccentricity magnitude unit, according to ISU, I_{ε} calculated value at the time of IM diagnostics and evaluation criteria of rotor eccentricity magnitude determines its value and makes recommendations for the further IM exploitation.

Such diagnostic system should have modes: "Setting" and "Diagnosis", which are adjusted using CB. In the mode "Setting" filling ISU database, and in the mode "Diagnosis" one directly carries IM diagnostics.

Dependence $I_{\varepsilon}=f(\varepsilon)$ with high accuracy can be obtained experimentally at a factory and to be delivered to the consumer with IM in an annex to the passport. For large IM with a welded hull and movable supports of the rotor it is easily obtained in situ by using displacement one of support. Experimental dependence $I_{\varepsilon}=f(\varepsilon)$ for IM AO-41-6, based on data of Table 1, is shown in Figure 3. Its theoretical value when $\varepsilon<0.25$ is shown by the dashed line.

Depending $I_{\varepsilon}=f(\varepsilon)$, undertaken on methods [2-4] is less accurate, but more convenient to obtain modeling results.

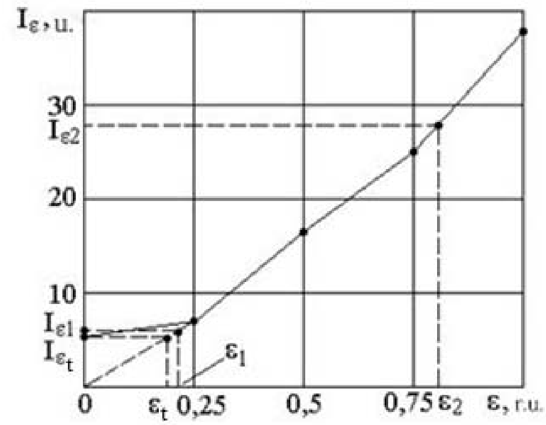

Fig.3. Criteria for rotor eccentricity estimating

Quantities ε_1 and ε_2, which defined proceeding from the value of technological eccentricity ε_t, is proposed to use as a criterion for assessing of rotor eccentricity magnitude and a decision on further IM exploitation [14]. Under technological eccentricity is meant that the eccentricity which is received by IM during the manufacturing process. For each IM it is constant, as it depends on the accuracy of manufacturing and installation of stator, rotor and bearing shields at the factory. In the general case for IM with a small air gap [14] can be taken ε_t= 0,1.

First by this criterion is ε_1 magnitude. In IM with a small air gap, its value is:

$$\varepsilon_1 = k_r \varepsilon_t , \tag{3}$$

where: k_r - is a reliability index that can be taken equal to 1,2÷1,3.

The second by this criterion is ε_2, above which one the probability of interference of rotor to stator with grave consequences for IM increases dramatically. Considering presence of technological eccentricity, it should be defined as:

(4) $$\varepsilon_2 = (1-\varepsilon_1)$$

Consequently, for IM AO-41-6 in Figure 3 $\varepsilon_2 \approx 0,8$.

The eccentricity ε is determined by dependence $I_\varepsilon = f(\varepsilon)$ in ISU and calculated value I_ε, obtained by the diagnostics. Decision on further IM exploitation given in Figure 3 accepted on the analysis basis of ε value.

Thus, when $I_\varepsilon < I_{\varepsilon 1}$, a diagnosis of the magnitude is impossible because of technological eccentricity. In this case, it is considered that it is absent.

By $I_{\varepsilon 1} < I_\varepsilon < I_{\varepsilon 2}$, information is provided that the rotor eccentricity is in IM, wherein the electricity overrun is about 0,3%÷1,5%.

If $I_\varepsilon > I_{\varepsilon 2}$, information is generated that the rotor eccentricity in IM exceeds the permissible limits. This requires immediate disabling it, because the interference probability of rotor to stator is increased sharply.

Implementation of blocks: SPM, IPU, EEMU, ISU and CB is easy and implemented in «Delphi».

Conclusion

1. Experimentally found that IM phase current components in the form of additional currents I_v with frequencies f_v can be used as the source of information about the rotor eccentricity.
2. Also it's defined experimentally, that the growth of the IM rotor eccentricity is not always accompanied by the rising of these additional currents due to fluctuations in the electrical network parameters, the electromechanical properties of IM and the load, which greatly complicates the selection of the source of information.
3. Using the root-mean-square value of additional currents can uniquely identify not only the presence, but also the value of rotor eccentricity.
4. The proposed diagnostic system of rotor eccentricity with source of information in the form of a current of one phase capable enough to effectively identify the rotor static eccentricity during IM operation.

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