CONSTRUCTION ALGORITHM AND ANALYSIS OF DIAGNOSTIC COEFFICIENTS TABLES FOR VIBRATIONAL DIAGNOSTICS OF THE ATD-5000 INDUCTION MOTOR ROTOR

Geraskin O.A., Ph.D., associate professor, Bazarov O.O., Moroko O.A., undergraduate students
Igor Sikorsky Kyiv Polytechnic Institute, electromechanics department

Introduction. Algorithms for the analysis and diagnosis of damages in induction motors (IM) are the intellectual basis for the functioning of vibrational diagnostic complexes. In powerful IM determining the fact of damage based on the appearance of certain diagnostic features is not sufficient, since it is not possible to determine with sufficient accuracy the nature of the damage of the short-circuited rotor winding (SCRW) and its degree of development.

To determine the nature of SCRW damage and the degree of its development in the powerful IM, it is necessary to determine quantitative indicators - diagnostic coefficients. For example, in the case of a breakage in the IM of the 1 or 3 rods, the diagnostic signs will be similar, but the magnitude of the winding damage and the recommendations regarding the timing of its repair will be significantly different. Therefore, it is relevant to develop [1], use and analyze a system of diagnostic coefficients that allow quantitative assessment and comparison of the SCRW damage degree, taking into account different variants of damages. This approach to vibrational diagnostics enhances its reliability and extends its functionality. This article is a continuation of the article [1]. The dedication of the vibroperturbing forces studying in IM is also devoted in articles [2-3].

The purpose of the work. The purpose of the article is to develop an algorithm of construction and analysis of diagnostic coefficients tables for systems of vibrational diagnostics of IM rotor damages.

Material and results of the study. The article investigates three-phase IM of ATD type by 5000 kW with short-circuited rotor operating in the rated regime and the parameters of which are as follows: rated voltage 6 kV, stator current 545 A, efficiency 94,8%, power factor 0,89, rated speed 2985 rpm, number of pole pairs - 1; air gap - 6 mm; the diameter of the stator bore is 675 mm.

The analysis of electromagnetic vibroperturbing forces [3] is based on the calculation and spectral processing of the vibration sensor signal, which is proportional to the distribution of the Maxwell magnetic tension tensor (fig. 1), which characterizes the density of the electromagnetic force applied to the unit surface.

An algorithm for constructing tables of calculated diagnostic coefficients.

For a particular motor, this algorithm includes the following steps.

1. In one of the software packages designed to simulate the electromagnetic field, for example, Comsol Multiphysics develops a mathematical model that is solved numerically by the finite element method, in particular:

1.1. the geometry of the computational zone of the IM is constructed, the physical parameters of various materials (electrical conductivity, magnetic permeabilities, for the cores – magnetization curves, etc.) are set, magnetic field sources (currents in the stator winding) are specified;

1.2. the rotating area is selected – the rotor relatively to the fixed stator;

1.3. on the surface of the stator tooth the point of the conditional location of the vibration sensor (vibrational acceleration sensor) is selected;

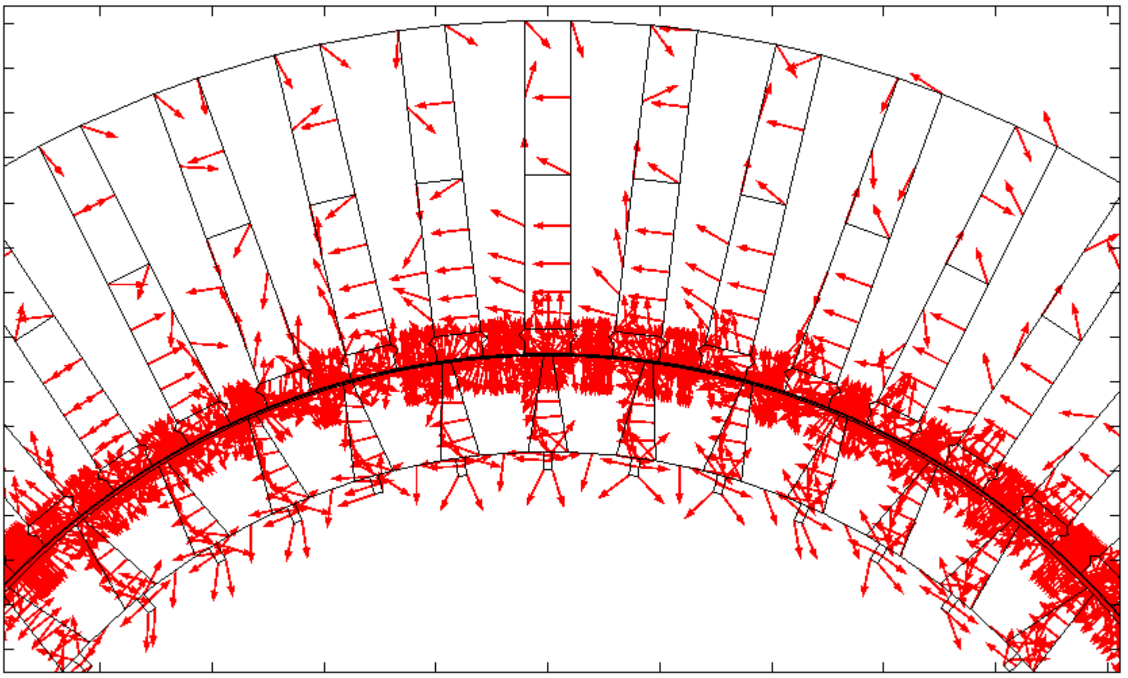

Figure 1 – Distribution of Maxwell magnetic tension tensor vectors in ATD-5000

1.4. specifies the type of damage of the IM rotor: breakage of the rods, breakage of segments of the short-circuiting ring (SSCR) or static or dynamic eccentricity (SE or DE, respectively).

2. The problem of calculating the electromagnetic field in Stationary mode (quasi-stationary time-harmonic task) or Time-dependent (time-dependent task) is solved.

3. At the point of conditional location of the vibration sensor for the time interval corresponding to one rotation of the rotor, the normal component of the tensor of magnetic tension is calculated, which on a certain scale reflects the sensor signal at one complete rotation of the rotor.

4. Using the method of numerical simulation of the vibrational acceleration sensor signal over the full period of the amplitude-phase modulation of the "signal of damage" [2], the signal of the vibration sensor for the entire modulation period is calculated.

5. Spectral processing of the received calculation signal is performed.

6. According to the formulas from [1], the calculated diagnostic coefficients are calculated for different types and volumes of damage of the IM rotor.

7. For another variant of the IM damage, the calculation process is completely or partially repeated.

According to the results of the carried studies, table 1 is about the diagnostic coefficients on the example of the investigated IM for different variants of the rotor damage, including the breakage of several SCRW rods, the breakage of two rods displaced relative to each other at different angle, the breakage of the SSCR, the presence of SE and DE were made.

These coefficients are calculated not only for different variants of damages of the rotor, but also for different amounts of damages, and the tables consider the variants of damages that are characteristic for the initial stage of defect development, for example, when the number of damaged rotor rods is equal to 1 ... 3 (1,6 ... 6,6% of the total number of SCRW rods). These variants of damages are the most interesting and important for diagnostics, since their timely detection allows to prevent further accidental destruction of the IM rotor. With a greater damage degree, for example, with a larger number of damaged rods, the vibration of the motor becomes unacceptably high and the IM is subject to an emergency stop.

Table 1 – Diagnostic coefficients of ATD-5000

Kind of damage	**Diagnostic coefficients**						
	$k_{СКЗ\_a}$	$k_{СКЗ\_v}$	k_0	k_{100}	k_Z	$k_{ОБ}$	$k_{ОБ\_Б}$
undamaged IM	1	1	1	1	1	0	0
1 rod damaged	1,05	1,07	1,06	0,94	1	0,23	0,15
2 rods nearby damaged	1,45	1,77	1,21	0,83	1	0,73	0,48
3 rods nearby damaged	2,47	3,31	1,36	0,72	1	1,50	1,01
2 rods displaced by an angle of 46,9° were damaged	1,21	1,33	1,18	0,96	1	0,46	0,22
2 rods displaced by an angle of 86,1° were damaged	1,16	1,25	1,15	0,92	1	0,39	0,10
2 rods displaced by an angle of 180° were damaged	1,09	1,14	1,12	0,89	1	0,23	0,05
1 SSCR damaged	1,39	1,23	1,10	0,97	1	0,44	0,32
2 SSCR damaged	1,47	1,35	1,15	0,94	1	0,51	0,36
SE, $\varepsilon = 0,26$	1,07	0,95	1,23	0,90	1,77	0	0
SE, $\varepsilon = 0,52$	1,66	0,85	1,75	0,84	3,85	0	0
DE, $\varepsilon = 0,26$	1,12	1,16	1,03	1,04	1,19	0,25	0
DE, $\varepsilon = 0,52$	1,26	1,57	1,07	1,12	1,77	0,55	0

Diagnosis of the IM rotor damages based on the analysis of the diagnostic coefficients system.

Diagnosis of damages of the IM rotor is based on the analysis of table 1.

1. As the number of damaged rods of the SCRW increases, the total vibration level (coefficients $k_{СКЗ\_a}$, $k_{СКЗ\_v}$) increases. The vibrations at a frequency of 100 Hz are reduced, which is explained by the distortion of the magnetic field in the air gap and, as a consequence, the decrease of the amplitude of the first magnetic flux density harmonic, which causes vibrations at a frequency of 100 Hz. The increase in the total

vibration of the SCRW damage is explained by the appearance of rotational frequency harmonics and their lateral harmonics (coefficients $k_{ОБ}$ > 0 and $k_{ОБ\_Б}$ > 0).

2. As the shear angle between the two damaged rods increases, the overall vibration level decreases (compared to the vibration in the case of two adjacent SCRW rods damage). For two damaged rods at an angle α = 180°, the coefficients $k_{ОБ}$ and $k_{ОБ\_Б}$ are unequal to zero, which is explained by their calculation as the root mean square of the all harmonics set of rotational frequency and their lateral harmonics.

3. Damage of one segment of the short-circuiting ring causes higher vibration compared to damage of one rod.

4. The diagnostic coefficient $k_{СКЗ\_v}$ is the most sensitive of all coefficients before any type of damage occurs.

5. In the case of SE, the coefficient $k_{СКЗ\_v}$ becomes less than one, which is explained by the decreasing of the frequency 100 Hz harmonic amplitude, which is the largest in the vibration velocity spectrum. When the SCRW is damaged, the level of vibration from the tooth harmonics practically does not change (coefficient k_Z), but the contribution of the tooth harmonics significantly increases in the presence of SE and DE. This feature can also be used in diagnostics to separate one injury from another: the damage of the SCRW and the occurrence of SE or DE.

6. With any damage of the rotor, the constant component of the spectra (coefficient k_0) is always increased, which is explained by the decreasing in the electrodynamic repulsion forces of the stator and rotor windings due to the SCRW damage and an increasing of the magnetic attraction force between the rotor and the stator.

Conclusions. The technique of IM rotor damages diagnostics on the basis of the diagnostic coefficients system is developed, which allows to determine the degree of each type damage development. Joint use in the diagnostics process of the diagnostic features system and the diagnostic coefficients system significantly improves the accuracy of the IM rotor damage diagnostics.

References

1. Geraskin O.A. Vibrational diagnostics of the induction motor ATD-5000 rotor damages on the basis of diagnostic coefficients analysis / O.A. Geraskin, O.O. Krechyk // Міжнародний науково-технічний журнал молодих учених, аспірантів і студентів "Сучасні проблеми електроенерготехніки та автоматики" – Київ: «Політехніка». – 2018. – № 1. – С. 309-313.

2. Гераскин А. А. Алгоритм численного моделирования сигнала датчика вибрации с учетом вращения ротора / А. А. Гераскин, А. И. Турчин // Доповіді за матеріалами Міжнародної науково-технічної конференції молодих учених, аспірантів і студентів. Сучасні проблеми електроенерготехніки та автоматики. – Київ: «Політехніка», 2010. с. 236-238. – 600 с.

3. Васьковський Ю.М. Діагностика кутового ексцентриситету ротора асинхронних двигунів на основі аналізу вібрознуджуючих сил / Ю.М. Васьковський, О.А. Гераскін, Н.В. Беленок // Вісник Національного технічного університету «ХПІ». Збірник наукових праць. Серія: Електричні машини та електромеханічне перетворення енергії. – Харків : НТУ «ХПІ». – 2016. – № 11 (1183). – С. 30-35.