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Features of certification of electric machines with defects of main structural assemblies during repair and long-term operation

Abstract. *The methods and algorithms of defects diagnostic and parameters and characteristics of electric machines estimation have been substantiated. The structure of certification system of induction motors during repair and long-term operation taking into account a condition of the main constructive elements has been proved.*

Streszczenie. *W artykule zweyfikowano metody I algorytmy stosowane w diagnostyce defektów I oszacowniu parametrów I charakterystyk maszyn elektrycznych. Struktura systemów certyfikujących dla silników indukcyjnych podczas naprawy i działania długotrwałego przy wzięciu pod uwagę warunków pracy głównych elementów konstrukcyjnych została potwierdzona.* (***Właściwości certyfikacji maszyn elektrycznych z uszkodzeniami głównego obiektu konstrukcyjnego podczas naprawy i działania długookresowego***)

Key words: induction motor, videoidentification, stator core properties, certification system.
Słowa kluczowe: silnik indukcyjny, identyfikacja video, właściwości rdzenia statora, system certyfikujący

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Introduction

One of basic tasks of electric machines (EM) operation is to provide the required level of their reliability at as high power indices as possible. It can be fully solved only taking into account physical processes taking place in radial-flux or axial-flux [1, 2] EM under static and dynamic operating conditions.

Complexity of forecasting EM reliability indices is caused by a wide spectrum of defects and damages conditioned by faults of their production technology, operation and repair [3].

Taking into account variation of properties of basic materials and design changes in EM makes it possible to develop recommendations for to their change and restoration. Besides, estimation of the amount of expenditure and making a final decision about EM further operability are possible. If real EM indices significantly differ from the nominal ones, there appears a necessity of determination of new published data and required parameters and characteristics, i.e. its certification. It contributes to development and introduction of real approaches to energy saving as the choice of optimal working modes and sparing operating conditions with the use of real possibilities and characteristics of the machine provides the improvement of its energy efficiency and general increase of durability.

The purpose of the paper consisted in substantiation of the methods of determining the actual state of the main structural assemblies of electric machines, which can be used in their certification during repair and long-term operation as well as in determination of the degree of physical aging.

Theory

Application of two methods of determination of structural assembly state was substantiated as a result of the research. The first one can be applied at the repair stage and consists in combined use of the systems of video identification and determination of local properties of magnetic circuit electric steel.

In this case video identification system represents a suspended digital camera connected with a personal computer. It is used for making projection photographs of the analyzed assemblies.

To detect damage quickly and reliably this image during processing is divided into blocks with different level of sections detailing.

Fig. 1 contains an example of supposed sector division of the areas of possible defects of a ready-assembled induction motor (IM), and groups determined by its general geometry are indicated. Damages of the motor shaft and the key groove, changes in the structure of radial or longitudinal-transverse ribbing, damages of shield ribs on the side of the shaft free end are determined in sector 1. Sector 2 characterizes damages of the inlet device, damages of the shield ribs on the side of the fan case, damages of the frame in the area of mounting holes. Sector 3 describes damages of the fan case.

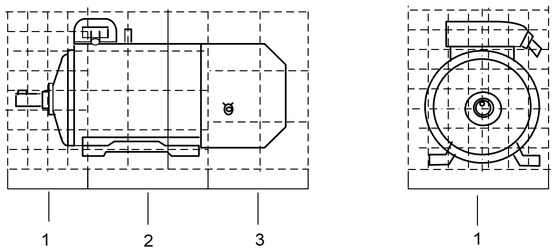


Fig. 1. Structure of a supposed sector division into areas for detecting defects

In accordance with the basic algorithm of operation of video identification system, on the basis of the existing statistical data, all the defects are conventionally divided into typical (basic) and atypical (random) ones. When the first group is analyzed, verification is made at the main local sections of possible occurrence of defects, and for the second group it is made by methods of defects detection according to general perspective with the following detailing.

Improvement of image quality is achieved by the use of nonlinear procedure of noise elimination and linear contrasting. When the initial image is directly processed and its analytical characteristics are determined, a gradient method is used.

In the case of bivariate image brightness function $f(x, y)$ the steps in directions x and y are fixed by partial derivatives $\partial f(x, y)/\partial x$ and $\partial f(x, y)/\partial y$ which are proportional to the rate of brightness change in the corresponding directions of a two-dimensional image.

In the work the use of brightness function gradient module, which is proportional to maximum (as to the direction) rate of brightness function change in the particular point and does not depend on the contour direction, is substantiated

$$(1) \qquad \left|\nabla f(x,y)\right| = \sqrt{\left(\frac{\partial f(x,y)}{\partial x}\right)^2 + \left(\frac{\partial f(x,y)}{\partial y}\right)^2} \; .$$

The functions containing discrete differences are analogous to partial derivatives and gradient module for digital images. They are of the form:

$$\frac{\partial f(x,y)}{\partial x} \to \Delta x f(n_1, n_2) = f(n_1, n_2) - f(n_1 - 1, n_2),$$

$$\frac{\partial f(x,y)}{\partial y} \to \Delta y f(n_1, n_2) = f(n_1, n_2) - f(n_1, n_2 - 1),$$

$$(2) \qquad \left|\nabla f(x,y)\right| \to \left|\nabla f(n_1,n_2)\right| = \sqrt{\left|f(n_1,n_2) - f(n_1-1,n_2)\right|^2 + \cdots + \left|f(n_1,n_2) - f(n_1,n_2-1)\right|^2}.$$

Here n_1, n_2 – numbers of the analyzed points.

Thus, when working with digital images, the procedure of contours marking is described by the function:

$$F(n_1,n_2) = \sqrt{\left[f(n_1,n_2) - f(n_1-1,n_2)\right]^2 + \cdots + \left[f(n_1,n_2) - f(n_1,n_2-1)\right]^2}.$$

The advantage of the method consists in the fact that gradient module, unlike partial derivatives, takes only non-negative values, so in the obtained image the points $n_1, n_2 - 1$ corresponding to the contours are characterized by a higher level of brightness, which, in its turn, improves the accurateness of contours marking and the quality of further processing.

When the outline of the object is obtained, the diagnostics of possible defects is made with the use of information stored in the database. Damages are correlated on the basis of the analysis of image histograms.

If such damage was not found, a new characteristic corresponding to a particular sector is added. If the defect changed its structure, the registry in the database (DB) is changed.

Such a mechanism of processing and analyzing improves the quality of diagnostics at the sections where damages are most probable and reduces the cost of time and software-hardware resources in the analysis and processing of less vulnerable areas.

The method of local testing of magnetic circuit steel is explained in Figs. 2 – 3. Its essence consists in determination of laminated core steel properties with the use of a U-type inductor with uniformly marked magnetizing and measuring windings with the number of turns, respectively, W_{mg} and W_{ms}. Inductor supplied by alternating voltage $u_1(t)$ with variable amplitude and frequency moves across the core teeth and creates the necessary magnetic flux Φ at every section. Magnetizing winding current $i_1(t)$ and measuring winding voltage $u_2(t)$ are measured values. Testing, according to Fig. 2, makes it possible to determine the losses at alternating reversal magnetization of the laminated core teeth zone for magnetic induction value equal to its value from alternating reversal magnetization of teeth in an operating machine. Testing, according to Fig. 3, besides measuring these parameters, additionally allows determining the exact location and the character of damages of the core teeth upper parts.

The results of magnetic systems local testing are formed as spatial distribution of their main electric and magnetic properties such as specific steel losses $p_{1/50}$, relative magnetic permeability μ_r and degree k_s of steel saturation. Also, as in [4], local testing makes it possible to find main defects of cores such as pressing slackening and short circuit.

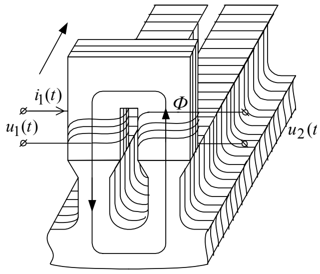


Fig. 2. Core diagnostics according to two teeth

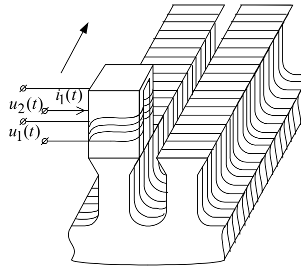


Fig. 3. Core diagnostics according to one tooth

The second method implies current estimation of electric machines condition during operation. It is grounded on the fact that, in spite of the variety of the defects, their influence on the state of the analyzed units and electric machines as a whole is reduced to deterioration of vibration characteristics and operation thermal conditions. [5]. Besides, it is proved that to identify the main defects types the integral values of thermal and vibration parameters are not enough. The most complete information for vibration parameters can be obtained as a result of spectral characteristics analysis. Electric machines thermal state is to be determined by contactless thermal imaging methods. The most informative of them, the radiation one, enables correlating temperature change with internal heat sources, i.e. determining the state of the units according to the parameters of radiation power.

It is impossible to realize the above described methods at typical testing complexes as they imply the use of complicated laws of control of power equipment and sufficiently large amount of mathematical calculations. To solve this problem the authors substantiated universal testing complexes representing computer-aided semiconductor converters structures with the possibility of programmed reconfiguration and a multifunctional measuring system.

The peculiarity of creation of such complexes consists in refusal from standard microchips of converters drivers for the benefit of universal drivers in integrated circuits of programmable logic devices (PLD). PLD application enables realizing a flexible control structure with extended possibilities. Besides, it can be easily reprogrammed within the system to control basic EM types under different diagnostics conditions. Relatively low variety of the principles of creation and control of the main types of semiconductor converters applied in IM testing substantiated the expediency of the use of matrix structure of the complex power converter (Fig. 4).

Such a structure provides the possibility of a non-contact configuration of any type power converter (thyristor voltage regulator, pulse width converter, frequency converter). To do this it is sufficient to have a 5x5 controlled key matrix. To realize the system of pulse-phase control a block of timing with the circuit is provided.

The key element in the considered structure is presented by a bidirectional gate with protection elements, controlled by a driver to convert a control signal from PLD. Such a circuit makes it possible to realize practically all the necessary commutation modes including nonsymmetrical ones.

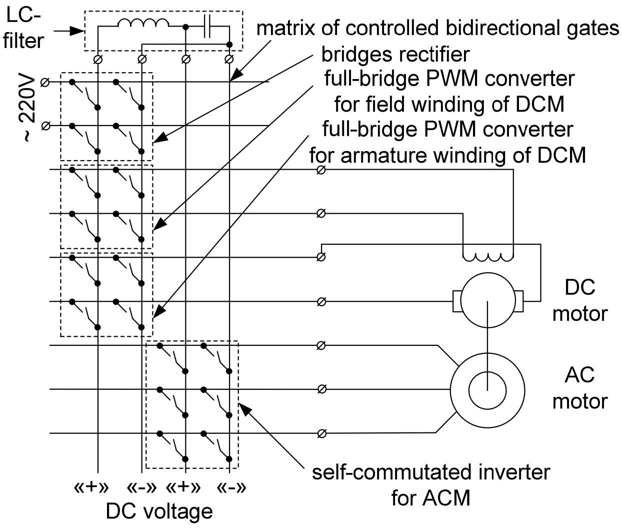


Fig. 4. Matrix structure of a universal power converter installation

The proposed methods are supposed to be used in the structure of certification system. The result of its operation consists in obtaining the IM forecast published data and characteristics. The system is to include the following components: a subsystem for determination of defects of the basic structural elements, database on the fund of the repaired machines, a mathematical core for making necessary calculations concerning parameters forecasting.

The structure of certification system varies depending on the failures statistics and ways of defects showing up, which are typical of the considered EM. Its form for an IM as an example is shown in Fig. 5.

Mathematical core of the system represents a complex of software for calculation of forecast published data, operating characteristics, equivalent circuit parameters and IM operating parameters [5, 6].

IM reliability calculation is made with the use of information about damages according to the calculation dependences of interconnection of the basic types of defects with vibration level and excess of winding temperature for the assigned operation conditions and modes of IM work.

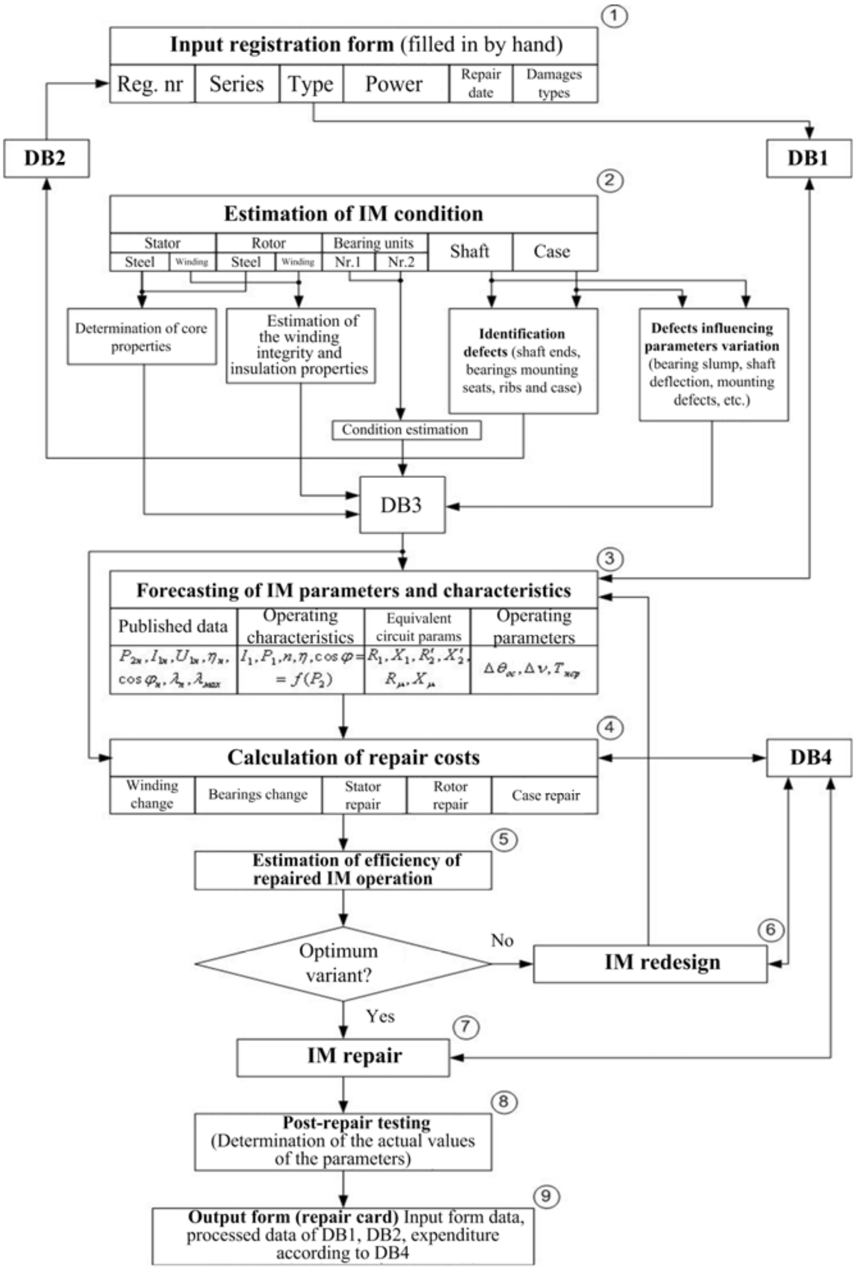


Fig. 5. Structure of IM certification system

If the estimation results do not meet the operating conditions, the system provides for a variant of IM redesign or modernization by variation of slot filling coefficient, change of winding data, improvement of insulation heat resistance etc. with the aim of search of a variant with optimum combination of power consumption and reliability under the condition of meeting the requirements of the technologic equipment.

Experimental research

The research consisted in experimental estimation of informational value of the proposed methods. Typical damages of structural units were both introduced artificially and estimated according to the results of industrial research.

Figs 6 – 7 show examples of possible damages of the IM case and shaft.

Fig. 6. Examples of IM case damage

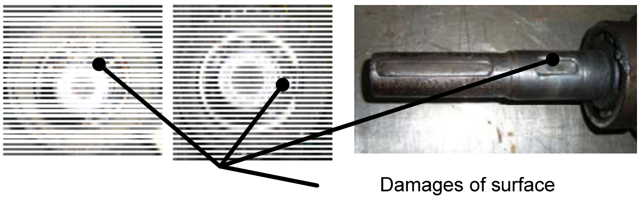
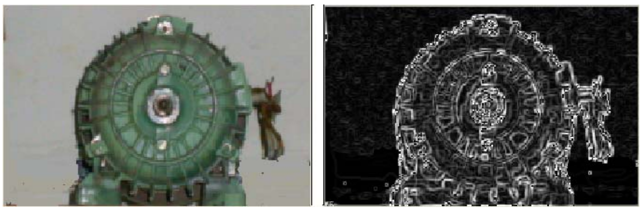


Fig. 7. Examples of IM shaft damage

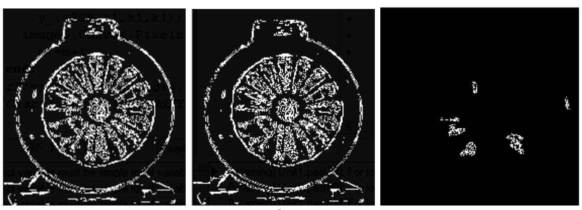
Fig. 8 shows the result of the procedure of contours marking with the use of brightness function gradient module according to relations (1) – (2).



a b

Fig. 8. Example of image processing: a – initial image;
b –processed image

Fig. 9 shows an example of using algorithm of detecting new defects, information of which is stored in DB and Fig. 10 demonstrates real distribution of magnetic induction in IM stator core in the axial direction (B_{norm} - value of magnetic induction at the healthy section).



a b c

Fig. 9. Results of image processing program operation:
a – initial countour image; b – contour image when fan case is damaged and there is a lateral dent; c – new revealed defects

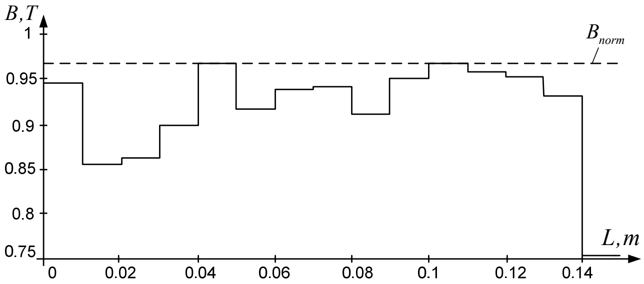


Fig. 10. Distribution of IM stator core magnetic properties in the axial direction

The rest of the obtained results correspond to theses of papers [4 – 6].

Conclusions

1. Efficiency of the developed methods for determining the defects of the main structural assemblies of electric machines during the process of their repair and long-term operation has been proved.
2. The structure of universal testing complexes for experimental research of electric machines with design defects has been substantiated.
3. Methods for taking into consideration the variation of the condition of electric machines main structural assemblies during determination of their power parameters, published data, operating characteristics and reliability indices have been developed, taking IM as an example.

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