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The determination of the current state and the reliability indices of synchronous motors with long time between failures

***Abstract.** The paper deals with the approaches to the assessment of the current state and the forecast of the indices of reliability of synchronous motors with a long time between failures in the presence of defects of their basic structural units. We substantiated the structure of the neural network including a set of informative parameters and the specific features of its teaching. We carried out experimental research of the synchronous motor aiming at obtaining the initial data required for teaching the neural network.*

Streszczenie.** W artykule przedstawiono podejścia do oceny stanu bieżącego i prognozy wskaźników niezawodności silników synchronicznych z długim czasem pomiędzy awariami przy istniejących defektach w ich elementach konstrukcyjnych. Wprowadzana jest sieć neuronowa, zawierająca zespół parametrów informatywnych i specyficzne właściwości jej uczenia. Przeprowadzono badania eksperymentalne silika synchronicznego, mające na celu otrzymanie danych początkowych wymaganych w procesie uczenia sieci neuronowej.* ***(Określanie stanu bieżącego i wskaźników niezawodności silników synchronicznych z długim czasem międzyawaryjnym)

Keywords: synchronous motor, structural unit, defect, neural network, forecasting, reliability indices.
Słowa kluczowe: silnik synchroniczny, element konstrukcyjny, defekt, sieć neuronowa, prognoza, wskaźniki niezawodności

Introduction

One of the basic problems of electric machines (EM) operation consists in the impossibility of accurate determination of their current technical state (TS) limiting the possible conditions and modes of operation as a part of technological equipment [1].

Basically, it is explained by the fact that for the identification of EM TS it is necessary to know both electromagnetic parameters that later determine all the main indices of EM control quality and structural and operational deviations from the regulated operation characteristics (excess of the windings temperature, increased vibrations level, etc.), directly determining the ultimate operation life [2].

While it is possible to determine the required parameters of most low- and medium-power EMs during the control-diagnostic tests, practically, there is no such possibility for high-power EMs because of the absence of relevant testing equipment and load.

The range of these EMs, first, includes synchronous motors (SM). They are widely applied in the drives of mills, pumps, compressors, smoke exhausters and superchargers. Due to their big mass and other technological features, their repair, as a rule, is performed at the place of their installation, which additionally reduces the possibilities for the account of their TS.

As SMs are often parts of responsible mechanisms providing either direct basic technological process or the support of the necessary technological conditions, the problem of the TS prediction is important from the point of view of minimization of production losses.

Thus, the purpose of the paper consisted in the solution of the problems of the determination and prediction of SM TS under the conditions of absent of incomplete information about the alteration of their basic parameters and characteristics.

Theory

The peculiar features of high-power SM include the individual approach to their design. First, it means that every EM of this type is unique as to its design and its specific electrical and magnetic loads.

Besides, due to high unit capacity, the design of most SMs implies increased voltage of 6 or 10 kV, which essentially influences the cost and quality of the used winding materials. High inertia of the rotor and the presence of big rotating masses cause the increased requirements to the rigidity of the shaft and the quality of the bearing units.

The magnetic system, especially of the stator core, should also meet certain requirements. The presence of a big mass of laminated steel at a high level of magnetic loads determines its sensitivity to short-circuit sections capable of provoking mechanical deformations and in some cases they may result in so-called “fire in iron” (Fig. 1).

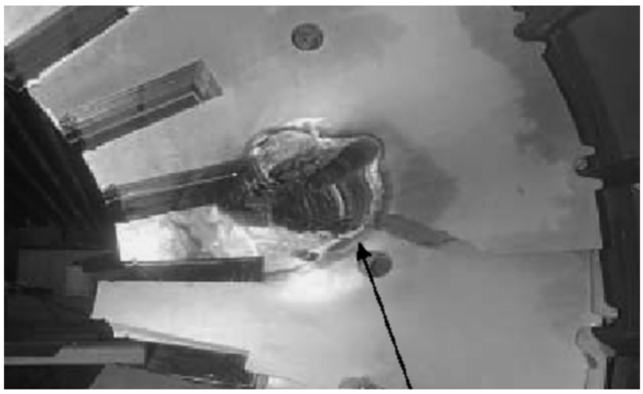

Fig. 1. An example of a broken stator core

Generalizing, one can conclude that the considered peculiarities of high-power SM determined by the deviation from the similarity theory used in the design of low- and medium-power EMs prevent the transfer to SM of the methods and approaches developed for these machines.

Because of the absence of the efficient test methods, there is only one possible way of the solution to the posed problem. It is the determination and prediction of TS at the level of the main structural units (SU) with the following transfer of the results to SM overall by the development of corresponding mathematical models and methods of parameter calculation.

In this case, the developed models are to take into account the fact of aging of SM structural units and elements during long-term operation.

According to the existing statistical data (Fig. 2), most SM damages occur in the stator and rotor windings and bearing units, which determine the importance of the comprehensive analysis of these SUs [3].

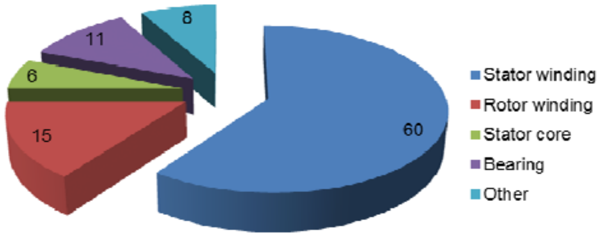

Fig. 2. The statistical data of SM failures

Their elements that are most vulnerable to aging are:

– winding insulation (breakdown resulting from fatigue aging);

– laminated steel sheets insulation physical and chemical aging during the repairs and long-term operation);

– structural steel (fatigue aging under the action of temperature, vibration, mechanical efforts and voltages);

– bearings (due to hard operation conditions and improper lubrication);

– steel cores laminated packages (magnetic aging caused by the influence of vibration and temperature).

When developing mathematical models of SM reliability we substantiated the approach based on dependences reflecting the interrelations between the alteration of the properties of these elements, taking into account the influence on the system of the external factors describing the alteration of the SMs load and the parameters of their supply.

Taking into consideration the posed problem, it can be successfully realized based on neural networks (NN) with back propagation of error (Fig. 3, a) [4].

Such a recurrent network realizes reverse links from the output of the internal neurons. In the considered case, it allows taking into account the history of the change of the state of the basic structural units and accumulating information for correct reliability indices forecasting.

The input informative parameters include the average value of radial component of vibrovelocity ν, temperature θ_b of the bearing unit, coefficient F_I of SM overload by stator current and separate components of the direct spectrum of vibrovelocity $\nu_i,...,\nu_j$ in the radial and axial direction.

Under the condition of the absence of defects in all the other units of EM the developed model is to determine such structural defects as bearing damages (def1); the presence of short-circuited turns in the stator winding (def2); the presence of critical damages of the stator core (def3); breaks or short circuits in the rotor winding (def4).

The principle of model structure implies the determination of these defects with the following forecasting of mean time *T* between failures as the main index of SM reliability.

We used mathematical package [5] to create and research the model. This package makes it possible independently design the necessary network not limiting oneself by the templates set by the neuro-simulator. Here the basic parameters of the network are assigned at the determination of the form of the realized model (Fig. 3, b)

In this case, the aging processes that result in irreversible alterations of the properties of the materials and elements and are the main cause of the time variation of the machine initial parameters can be represented as a first approximation in the form of simple analytical or empirical dependences.

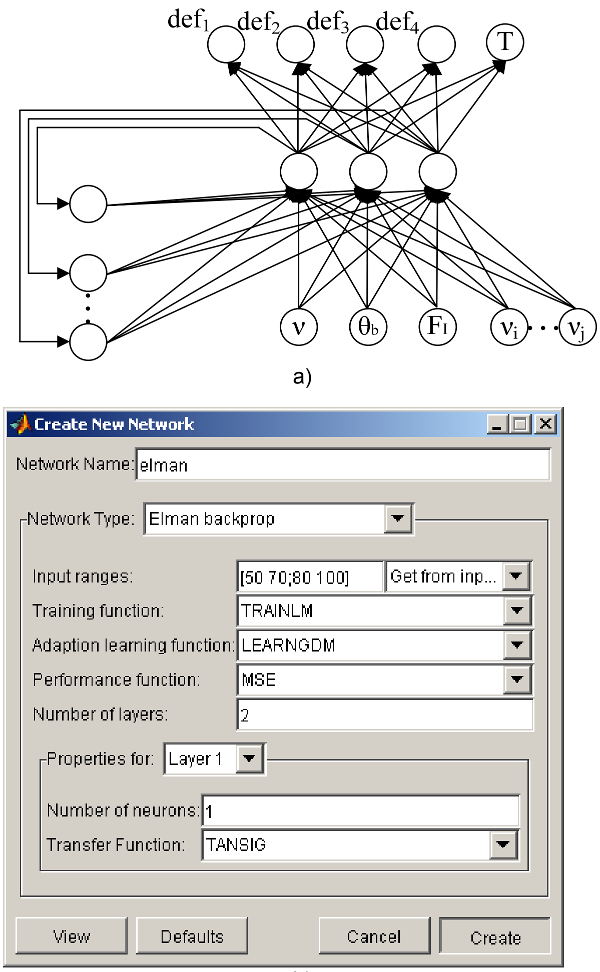

Fig. 3. Neural network: a – structure;
b – the determination of the type of the realized model

On the whole, they represent the trends of the alteration of corresponding parameters, obtained based on the experimental research and enable the prediction of the aging process, the assessment of the possible ways of its progress and finding out the most essential factors influencing its intensity.

The existing regularities of EM winding insulation aging are a typical example of such dependences [3]. In its turn, complicated interrelations of SU and SM states overall are described by preliminarily taught NN.

Experimental research

The experimental part of the work was directed to the research and substantiation of processes of aging of main SU and obtaining the initial data for NN education.

DSZ-170/74-4 SM with long time between failures was researched. It underwent a complete overhaul under the conditions of PJSC “Azovstal iron & steel works”.

The following was assessed during the research:

– the state of the stator core magnetic system;

– the state of the bearing units;

– the presence of the rotor eccentricity.

Due to the specific features of the occurrence of the defects of SM stator laminated core, we assessed the local change of its electrical and magnetic properties. With this purpose, we used a mobile variant of a system for automatic diagnostics (SAD) of electric steel [4]. Its structure and operation principles are explained in Fig 4, a and b.

Fig. 4, a shows that guide 1 is the basic part of the device. A plate with a complex inductor 2 moves in its longitudinal slot. It moves by means of a screw pair including screw 3 and a slide of nut 4 with a multiple thread.

To reduce the load from the friction in the screw pair we used radial ball bearings5 located in front cap-fixator 6 and in the end boring of the slide. Screw 3 is set in motion by flange magnetic-stepping motor (MSM) 7 mounted on the side of case 8 via a worm pair 9-10.

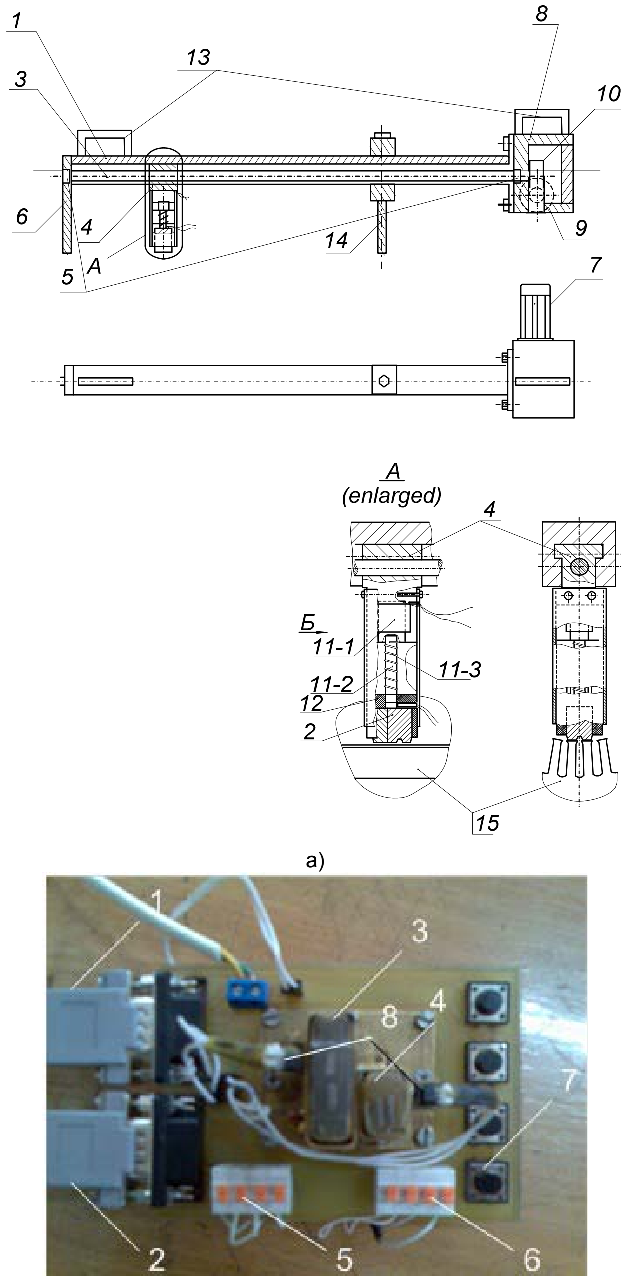

Fig. 4. The mobile variant of the system of automatic diagnostics of electrical steel:
a – general structure; b – the appearance of the measuring head

The actuator consists of the above mentioned slide-nut equipped with non-unified control unit 11 by means of a guiding pair and consisting of electromagnet 11-1, connecting pin 11-2 and spring 11-3. In the lower part of the head the pin is equipped with a slip bushing made of nonmagnetic material 12. In every particular case, the size of the bushing depends on the maximal size of inductor 2 and on the properties of the steel of the diagnosed stator core. The wires are taken out of the control unit 11 and of the inductor via preventive bushings.

After the installation of the stator the actuator is taken inside the core by means of handles 13, is mounted on it by means of clip 14 after taking the inductor to stator 15 teeth in its unbroken part with the air gap of 1 ± 0.5 mm.

Then the actuator automatically moves to the edge sheets of the core steel by means of a longitudinal motion MSM. In this case, the inductor can come close to the teeth of the core controlled section and move from them by means of turn on/off of the control magnet.

Fig. 4, b shows the appearance of the actuator measuring head.

Here 1, 2 – the seats to connect the measuring head to the control block and for measurement; 3, 4 – the measuring inductors for testing by one and two teeth in corresponding bushings providing their accurate movement; 5, 6 – the seats to connect respectively magnetizing and measuring windings of the inductors; 7 – a number of buttons for MSM manual control aiming at setting the initial position of the actuator; 8 – the sensors of the actuator final positions, made based on the Hall generators.

The core local diagnostics resulted in obtaining the spatial distributions of the alteration of magnetic induction ΔB_i and specific steel losses Δp_{sti} .

As the bearings were changed during the complete overhaul, the assessment of the state of the bearing units consisted in the assessment of the value of possible slackening of bearings fit Δb_1 and Δb_2 into caps as the initial cause of the occurrence of the static eccentricity.

The rotor eccentricity was assessed at its balancing as an absolute value of flexure later related to the variation of the air gap width $\Delta\delta_i$ by the length of the rotor active part.

Therefore, during the experimental research we confirmed the presence of many short-circuit sections with the excess of the average level of losses in the core steel by 12-87 %. At the same time, the deterioration of the magnetic properties at these sections, determined by the decrease of the magnetic induction, is within the limits of 9-43 %. The performed heat monitoring at these sections confirmed the presence of the anomalies of the excess of the core average temperatures by 4-49 %, which may cause more rapid damage of the analyzed SM.

The static eccentricity caused by slackening of the bearings fit did not exceed 2 % of the value of air gap δ , and the rotor eccentricity, in this case caused by its flexure under the action of gravity – 6 % of δ . Thus, the total asymmetry of the air gap was within 8 %, which is admissible for the researched motor.

The presented values were used in calculation models to obtain the ranges of the excess of temperatures and vibroparameters corresponding to the considered structural changes. The obtained calculated results were formed as a teaching sample for the corresponding NN.

Conclusions

1. We have substantiated the special features of the determination and prediction of TS of SM with long mean time between failures based on the information about the change of the parameters and characteristics of their basic SU.

2. We have proposed a structure of a recurrent neural network allowing the prediction of the presence of the typical defects of the structural units and the indices of SM reliability.

3. We have experimentally approbated the proposed approaches to obtaining the informative parameters for teaching the neural network.

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