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The prediction of the residual life of electromechanical equipment based on the artificial neural network

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Abstract. This article is devoted to the prediction of the residual life based on an estimate of the technical state of the induction motor. The proposed system allows to increase the accuracy and completeness of diagnostics by using an artificial neural network (ANN), and also identify and predict faulty states of an electrical equipment in dynamics. The results of the proposed system for estimation the technical condition are probability technical state diagrams and a quantitative evaluation of the residual life, taking into account electrical, vibrational, indirect parameters and detected defects. Based on the evaluation of the technical condition and the prediction of the residual life, a decision is made to change the control of the operating and maintenance modes of the electric motors.

1. Introduction

The modern trends in an industrialization, such as the introduction of the digital technology and the growth of the population in the large cities up to 2.5 billion people to 2050, will cause an increase in electricity demand by 80% compared to 2016. The role of smart energy is critically important for the whole world. A qualitative change, based on digital technologies, in global and local energy systems will increase electrical environmental friendliness and efficiency against the background of resource base limitations. The focus on effective production, rather than on maximum productivity, will become a new development strategy for mining branch [1]. Therefore, the issues of acquiring and processing large amounts of data, obtained during the life cycle of electromechanical equipment, are very important for estimation of the current state and the residual life of the using electromechanical equipment, and also for timely diagnostics of the emergency and pre-emergency operating conditions, and, of cause, for prediction the technical state based on machine learning [6].

The methods, based on the analysis of the observed electrical parameters (for example: current, voltage, power consumption and etc.) and vibration characteristics in the different points of the machines are most effective from the point of view of the practical implementation of diagnostic systems and help to diagnose up to 90% of the defects [9]. The measurement of electrical parameters is possible without direct access to the electrical equipment being diagnosed, as well as without the installation of primary measuring transducers in the immediate vicinity of it [2, 3, 4]. The effectiveness of these methods is based on the fact that any malfunctions of electrical machines and mechanisms associated with them ultimately lead to the emergence of electromagnetic field asymmetry, and, consequently, to a change in the spectral composition of currents and voltages [5, 7, 10].

Analysis of technical and technological conditions in the emergencies in the operation of technological equipment of enterprises of the mining industry shows that when developing the foundations for ensuring safe operation, it is necessary to take into account not only the technical condition, and the non-stationary operation of the process equipment and operational parameters of technological processes [1, 8]. Therefore, the issues of acquiring and processing data are very important for estimation of the current state and the residual life of the using electromechanical equipment, for timely diagnostics of emergency and pre-emergency modes of its operation.

2. The application of neural network prediction results for residual life estimation

The emergence of powerful analytical tools, that allow to operate the accumulated data in a mode close to real time, opens up new possibilities in the area of maintenance and repair systems, and also controlling the using of equipment. In this case, each unit of electromechanical equipment is endowed with "intelligence" without the need for a unified intelligent automation system.

The proposed approach to solving problems of increasing the accuracy and quality of the assessment of the state and residual life of electromechanical equipment is based on the analysis of data of systems for recording the quality of electrical energy, operating environment, vibration and electrical characteristics with using an artificial neural network.

The determination of the probability of no-failure operation of electric motor under the condition of the retrospective database is based on the algorithm for predicting the probability of trouble-free operation of electric motor and on the work of ANN (the multilayer perceptron), that was described in the articles [11]).

After determining the probability of failure and forming the matrix of the probabilities of defects by electric and vibration characteristics with a relative error of less than 5%, the estimate of the electromechanical equipment residual life, based on work of ANN, is made:

$$\delta = K_1 \cdot P_{ih}^{pred.ANN}(h) + K_2 \cdot P_{im}^{pred.ANN}(m) + K_3 \cdot P_{ih}^{pred.ANN}(h) +$$

$$+ K_4 \cdot P_{im}^{pred.ANN}(m) = K_1 \cdot F(\sum_{i=1}^{17}(\Delta w_{ij} \cdot x_{ij} - \Delta \theta_j) + K_2 \cdot F(\sum_{i=1}^{17}(\Delta w_{ij} \cdot x_{ij} - \Delta \theta_j), (1)$$

$$+ K_3 \cdot F(\sum_{i=1}^{21}(\Delta w_{ij} \cdot x_{ij} - \Delta \theta_j) + K_4 \cdot F(\sum_{i=1}^{21}(\Delta w_{ij} \cdot x_{ij} - \Delta \theta_j)$$

K_1 is a coefficient that takes into account the states of the boundaries of the estimation of vibration parameters taking into account the detected defects at time t and depending on the normal, pre-crisis and crisis states;

K_2 is a coefficient that takes into account the states of the boundaries of the estimation of electrical parameters taking into account the onset (detection) of defects at time t and depending on the normal, pre-crisis and crisis conditions;

K_3 is a coefficient that takes into account the boundaries of the assessment of vibration parameters, taking into account the measured parameters and factors affecting the compilation of the residual resource forecast, at time t and depending on the normal, pre-crisis and crisis conditions;

K_4 is a coefficient that takes into account the states of the boundaries of the estimation of electrical parameters, taking into account the measured parameters and factors influencing the compilation of the residual resource forecast, at time t and depending on the normal, pre-crisis and crisis conditions;

$P_{ih}^{pred.ANN}(h)$, $P_{im}^{pred.ANN}(m)$ are predicted values of the probability estimate based on vibration and electrical parameters and ANN;

$$\Delta w_{ij} = \varepsilon(d_j^s - y_j^s) \cdot x_{ij}, \ \Delta \theta_j = -\varepsilon(d_j^s - y_j^s), (2)$$

Δw_{ij}, $\Delta \theta_j$ – correction for weight coefficients and threshold levels, taking into account the calculated yield and comparison of the obtained output vector y_j^s with the reference d_j^s;

ε – rate of training ANN.

3. The estimation of the residual life based on the probabilistic technical condition of electromechanical equipment

The results of the system work for diagnosing the technical condition and estimating the residual life of the electromechanical equipment are diagnostic graphs of the technical state probabilities (Figures 1, 2, 3).

Based on the results of processing parameters on the laboratory bench, the normal state of the unit was determined for all characteristics (Figure 1). The calculated value of the residual life, obtained by ANN and electrical, vibration and indirect parameters, and also the detected defects, was estimated in accordance with the limits, presented in Table 1.

Table 1. Levels of an estimation of a residual life of the AC motor.

Residual life indicator δ	Description of technical state	Release to service
1<δ≤0.9	"Reference" state, there is no effect on performance	Allow
0.9<δ≤0.8	"Normal" state, the impact on performance is not significant	Allow
0.8<δ≤0.6	"Pre-crisis" state, the periodical comprehensive diagnosis and the reducing the load on the unit are recomended	Allow after comprehensive diagnosis
0.6<δ≤0	"Crisis" state, it is the high probability of failure equipment, the maintenance and repair work are required	Prohibit

The artificial weakening of the mechanical fastening of the equipment led to the appearance of static and dynamic eccentricity and the emergence of these parameters in the pre-crisis zone, as a result, the estimation of the remaining resource corresponds to the level of the pre-crisis state (Table 1). A number of other parameters also went out the boundary of the normal probabilistic technical state.
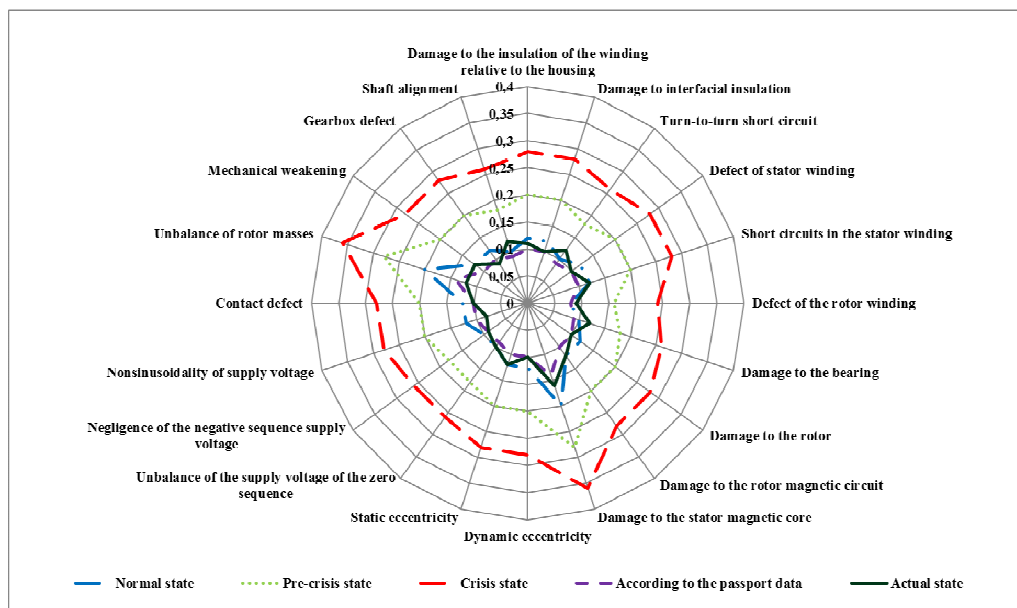
Figure 1. The diagram of the probabilistic technical state: the normal state

In addition to the weakening of the mechanical fastening, an interturn closure, an asymmetry of the supply voltage and a bearing damage were artificially created. The presence of both electrical and mechanical inherent damage of the unit led to a violation of electromagnetic symmetry, as a result static and dynamic eccentricities began to rapidly move to the critical state zone, and as a result of significant vibrations, mechanical attenuation increased. Estimation of the residual resource after a long operation of the machine with artificially created defects corresponds to the level of the crisis state. The equipment is subject to withdrawal of the electric motor for repair. In this case, this method gives an accurate knowledge of what part of the machine we need to pay attention to in maintenance and repair work.
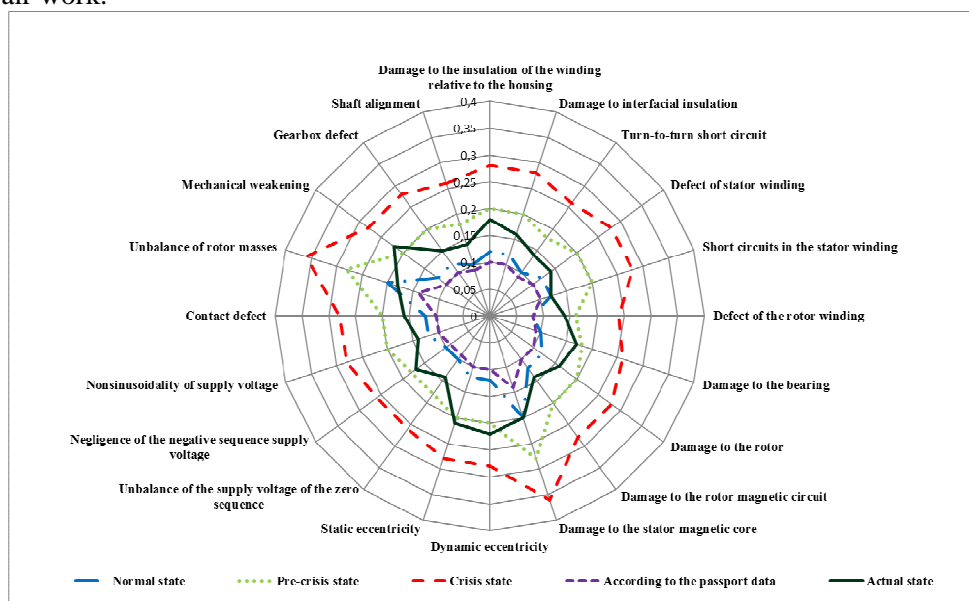

Figure 2. The diagram of the probabilistic technical state: the pre-crisis state
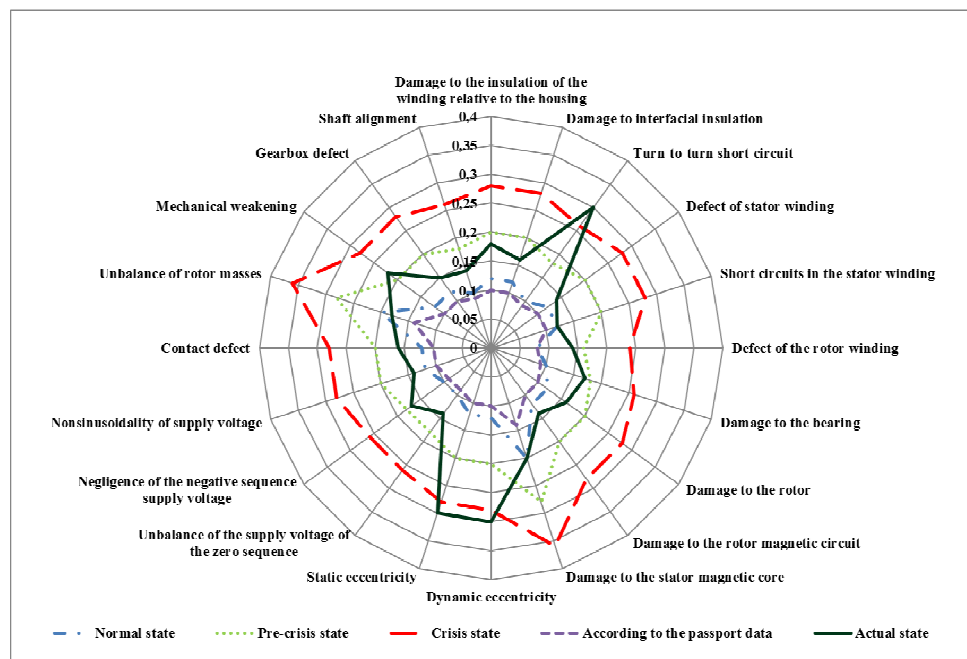
Figure 3. The diagram of the probabilistic technical state: the crisis state

4. Conclusions

The proposed method for estimating the residual resource, based on the forecast of the probability of occurrence of certain defects, will improve the accuracy of making decisions on the withdrawal of equipment for repairs, and will eliminate the costs associated with the unjustified shutdown of equipment as a result of failure or withdrawal to planned repairs in the absence of defects.

The result information of the artificial neural network, based on vibration and electrical diagnostic characteristics of an electromechanical equipment, and probability technical state diagrams can be used as a visualization tool for the work of operators or maintenance personnel.

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