Building an expert system for diagnosing traction electric motors of rolling stock

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Abstract. This article is devoted to the development of an expert system for diagnosing traction electric motors of rolling stock. The article describes the process of selecting diagnostic parameters, allowing to assess the quality of machining and assembly of the traction motor. The process of formation of a fuzzy model of diagnosing a traction motor based on the Takagi-Sugeno algorithm is shown. Selected diagnostic parameters are taken as input linguistic variables of a fuzzy model. As an output linguistic variable, a complex indicator of the quality of mechanical processing of the collector of a traction motor was adopted. The article presents the membership functions for the input and output linguistic variables and the rules for fuzzy products for the model being implemented. The hypersurface of the output linguistic variable in the space of various attributes is shown. Based on a fuzzy model, a neural fuzzy network has been developed, which allows to evaluate the quality of mechanical processing of a collector of a traction motor, and presents the results of its training. The developed neural fuzzy network is recommended to be used as one of the components of a comprehensive expert system for diagnosing traction electric motors of rolling stock.

1. Introduction
Railway transport in Russia is one of the main types of ground transportation and transports up to 20\% of all cargo. The development and implementation of innovative rolling stock diagnostics and monitoring systems is a priority for the development of science and technology. Russian Railways holding company is pursuing this avenue of research for the period up to 2020 and has plans to continue up until 2025. Traction electric motor is the key element, ensuring the safety, reliability and energy efficiency of rolling stock.

Traction electric motor is a complex technical system. Reliable diagnosis of the traction motor is carried out using expert diagnostic systems. The results of diagnostics allow for determining the most effective set of repair measures, taking into account costs minimization, as well as ensuring the required benchmarks of rolling stock reliability.

A large amount of research by scientists is dedicated to the issues of diagnosing traction electrical machines [1 – 6]. Currently, the technical condition of the traction motors is diagnosed in the locomotive depot conditions during the implementation of individual technological operations of the approved technological process. The diagnostic approach used allows controlling a limited set of mechanical and electrical parameters, while the numerical values of the parameters do not always allow to obtain reliable information about the technical condition of the traction motor as a whole. Thus, it is difficult to assess the reliability and residual lifespan of the object of diagnosis. The use of a
A diagnostic system allows gathering of detailed objective information about the technical condition of the traction motor and its elements.

To date, various systems have been developed for diagnosing units of a traction motor: a collector-brush unit, a magnetic system, insulation, and others. The developed systems do not carry out a comprehensive assessment of the technical condition of the traction motor. Thus, the urgent goal is to create an intelligent expert diagnostics system, which allows a comprehensive assessment of the technical condition of the traction motor. The expert system will allow to further determine the reliability parameters and estimate the residual lifespan based on the obtained diagnostic data. The purpose of this article is to choose a method for constructing a diagnostic system, as well as to create a fragment of an intelligent expert system for diagnosing the technical condition of a traction motor.

The correct choice of the expert system construction method is the foundation of the said system’s ability to effectively solve the complex problem, which is the diagnostics of a traction motor. Modern traction motor technical diagnostics systems draw a conclusion about the state of a certain element according to the values of a set of diagnostic features. Diagnostic indicators are chosen based on the information about the parameters of the processes in the traction motor and about its modes of operation. Thus, to create an expert diagnostic system, it is necessary to establish sets of diagnostic parameters for each element of the traction motor.

2. Methods

The construction of intelligent expert diagnostic systems is carried out using the methods of mathematical analysis and modeling.

The technical condition of the object being diagnosed at the enterprises (including railway enterprises) is described by qualitative rather than quantitative characteristics. For the description of an object, the concepts of “good condition”, “healthy state”, “non-working state”, “limit state” are used.

Such an approach to the analysis of the technical condition of an object allows the use of neural fuzzy networks to create an expert diagnostic system. Neural features of fuzzy systems are: their ability to handle fuzzy membership functions and rules of the knowledge base of a fuzzy neural model; the ability to determine knowledge from a sample of source data using neural learning methods.

Let us consider the creation of a fragment of an intelligent diagnostic system using the example of a collector-brush unit of a traction motor. The required set of parameters was determined based on the refined graph model for diagnosing a collector-brush assembly of a traction motor when carrying out acceptance tests. The parameters of the model are the components of a nonlinear differential equation that describes the switching process in a traction motor. We have constructed the correspondence graphs showing correlation between the defects and diagnostic parameters in order to create an effective set of diagnostic parameters. From the obtained effective set of diagnostic parameters, we select a group of parameters that allow us to estimate the quality of machining and assembly of the traction motor \{A_1, A_2, \sigma_h\}. For the presented group of diagnostic parameters, a fuzzy model was compiled and a neural network was created (Table 1).

| № | Linguistic variable                                           | Value range x |
|---|-------------------------------------------------------------|---------------|
| 1 | Standard deviation of the relative heights of the collector plates, \(\sigma_h\) | 5 … 25 \text{um} |
| 2 | Amplitude of the first harmonic component of the collector profile, \(A_1\) | 3 … 35 \text{um} |
| 3 | Amplitude of the second harmonic component of the collector profile, \(A_2\) | 0 … 20 \text{um} |

The neural network is implemented in the ANFIS editor (computer mathematics system MATLAB), which allows the creation of an adaptive network of fuzzy inference. In the theory of fuzzy logic, two methods of fuzzy inference are most common: Mamdani and Takagi-Sugeno [7, 8]. The implementation of the fuzzy model is based on the Takagi-Sugeno fuzzy inference method, since
this method provides high accuracy in the identification of nonlinear dependencies [9]. The ANFIS editor allows to build a neural network based on Takagi-Sugeno's fuzzy inference system.

The quality control of machining can be assessed using the complex repair quality indicator (CRQI) proposed by the authors earlier. Since in this article we consider only the quality of machining, the response of the fuzzy inference system will take one of the components of the CRQI – a comprehensive measure of the quality of mechanical processing (CMQMP).

3. Results and Discussion

To implement the Takagi-Sugeno algorithm, we distinguish the following linguistic variables: “amplitude of the first harmonic component of the collector profile”, “amplitude of the second harmonic component of the collector profile”, “standard deviation of the relative heights of the collector plates”, “comprehensive measure of the quality of mechanical processing”. For each linguistic variable, term sets are composed and membership functions are formed. For input variables, we selected Gaussian functions as membership functions (Figure 1), and constant values for the output variable (Figure 2).

Within the framework of the implementation of the Takagi-Sugeno fuzzy inference algorithm for the system under consideration, we formulate the fuzzy product rules.

Rule 1. IF “σₕ has a normal value” AND “A₁ has a normal value” AND “A₂ has a normal value” THEN “high-quality mechanical processing”.

Rule 2. IF “σₕ is not normal and not large value” AND “A₁ is not normal and not large value” AND “A₂ is not normal and not large value” THEN “middle-quality mechanical processing”.

Rule 3. IF “σₕ has a large value” AND “A₁ has a large value” AND “A₂ has a large value” THEN “low-quality mechanical processing”.

In the model under consideration, the logical operation “AND” is implemented by the minimum method, “OR” – by the maximum method, the weighted average is chosen as the defuzzification method.

The analysis of the activity of the fuzzy inference algorithm is performed on the hypersurfaces of the resulting linguistic variable, and the space for constructing the response surface is multidimensional. The hypersurface of the linguistic variable CMQMP in the feature space CMQMP = f(A₁, σₕ), CMQMP = f(σₕ, A₂), CMQMP = f(A₁, A₂) attributes is shown in Figures 3–5, respectively.
A neural fuzzy network that implements an element of an expert diagnostic system using the Takagi-Sugeno algorithm is formed in the ANFIS editor (computer mathematics system MATLAB) on the basis of a fuzzy model [7].

Studies of traction motors TL-2K1 were conducted in the locomotive depot and training samples were formed. During tests of traction motors, profilograms of traction motors collectors were obtained with the PKP-4M device at various stages of repair: before repair, after depot repair in the volume of “TR-3”, after carrying out acceptance tests. The generated files are processed in the program for the construction and analysis of collectors profilograms in the DC machines. Software data processing allowed to determine the numerical values of diagnostic parameters, which are the input linguistic variables for the developed fuzzy model. For all values of diagnostic parameters, the value of the output linguistic variable CMQMP is determined using the generated fuzzy model. The result of defuzzification of the CMQMP linguistic variable for the diagnostic parameters of the traction motor before carrying out the repairs is presented in Figure 6.

As a training sample for the developed neural network, the values of diagnostic parameters and variable CMQMP for traction motors before repair, test sampling for traction motors after repair, control sampling for traction motors after acceptance tests are taken. The size of the training sample was 38 values, the test - 22 values, the validation - 14 values.
The original fuzzy inference system of the developed neural fuzzy network is created on the basis of the fuzzy model that implements the Takagi-Sugeno output. When teaching a neural fuzzy network, a hybrid network training algorithm was used, combining the methods of back propagation of error and least squares. The accuracy of the training of the neural network is set at 0.05; the number of learning iterations is assumed to be equal to the size of the training sample - 38. The structure of the neural fuzzy network formed is shown in Figure 7.

The test results of the neural fuzzy network are shown in Figures 8–9. The error in learning the neural fuzzy network in the control sample was 0.12, which indicates the adequacy of the generated neural fuzzy network.
4. Conclusion

As a result of the research conducted using a fuzzy logic apparatus, a fuzzy mathematical model of the CMQMP complex indicator that implements the Takagi-Sugeno fuzzy inference algorithm has been formed. The paper describes the creation of a neural fuzzy network based on a generated mathematical model and shows the use of training, test and control samples for training a network.

The conducted research allowed creating an element of an intelligent expert diagnostic system, which allows a comprehensive assessment of the technical condition of the traction motor. The expediency and adequacy of the previously proposed complex indicator CMQMP, which can be used for qualitative and quantitative assessment of the technical condition of the traction motor, is confirmed.

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