DEVELOPMENT OF A SYSTEM FOR PREDICTIVE DIAGNOSTICS OF TRACTION ASYNCHRONOUS ELECTRIC DRIVE FOR TRAINS

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The paper describes the concept of improving the efficiency of the process of monitoring the technical condition and evaluating the service life of an asynchronous electric drive of promising trains based on the analysis of diagnostic information of various physical nature, taking into ac-count different types of diagnostic signals generated by individual drive elements and measured using vibration and current sensors. The implementation of the project provides an increase in the effectiveness of monitoring the technical condition of the electromechanical equipment of trains, allows to move from scheduled maintenance of high-speed rail transport to service according to the actual condition, to increase safety, as well as to the introduction automatic monitoring systems. Functional purpose of the system: monitoring the technical condition of electromechanical equipment and predicting the residual life of its nodes through the use of an intelligent decision-making unit based on a neural network. A scheme of hardware for data collection and analysis, an algorithm for collecting and processing data based on a registrar, and a predictive diagnostics algorithm have been developed.

KEYWORDS

monitoring, diagnostics, electric drive, forecasting, remaining service life

1 INTRODUCTION

With the growth of automation of modern production (Industry 4.0) and high-speed transport, the requirements for its reliability are increasing [Turygin 2018]. Therefore, the diagnostics and assessment of the technical condition of electromechanical equipment and mechatronic systems has become an important direction in the development of modern mechanical engineering, in particular, high-speed vehicles [Yan 2015, Bozek 2021, Nikitin 2022].

Currently, the theoretical foundations for assessing the technical condition of electric drives are not well developed due to the complexity of the processes occurring in them, the complexity of the mathematical formalization of the description of these processes and defects, with the limitedness of the measured diagnostic parameters, with measurement errors [Cacko 2014, Zhou 2020, Kuric 2021].

Due to the above reasons, there are no descriptions of regularities between diagnostic parameters, such as vibration, electric current, electromagnetic field and states of electric drives [Hartansky 2017, Jancarik 2019]. Therefore, there is no possibility to systematically solve the problems of diagnosing them and evaluating the residual life, planning maintenance and repair [Peterka 2020].

In the last two decades, state-based maintenance has been developed (condition-based maintenance (CBM)), which recommends the maintenance and repair of an object based on online monitoring data and algorithms for their processing, the procedure for making a decision about the state of the object and calculating the time to failure [Cheng 2020, Stepanov 2021]. State-based maintenance allows avoiding unjustified costs for maintenance and repair of train drives, taking the necessary actions if repairs are necessary before an accident occurs [Chen 2020a and 2022]. Predictive-based maintenance, which is a typical predictive maintenance model, has gained momentum in recent years [Chen 2019a].

Despite the fact that diagnostics and forecasting of the residual life are associated with the assessment of the state of the equipment and are usually considered together, the goals of decision making are different [Chen 2019b]. The results of diagnostics are usually used to make decisions about passive maintenance, and the results of prediction are used to make decisions about proactive maintenance [Cheng 2021a]. The purpose of forecasting is to minimize the risk of equipment failures and accidents, increase the service life of drives. By predicting failures, it is possible to estimate the right moment for maintenance of equipment that has various conditions: from a small defect to a functional engine failure [Cheng 2021b].

The failure rate of the entire mechatronic system or some of its elements can be different, so the prediction of the residual life is an urgent scientific problem [Ding 2019]. Currently, fault prediction methods are divided into three categories: fault prediction based on an analytical model, fault prediction based on data, and fault prediction based on knowledge [Chen 2019c and 2020b]. In forecasting research, AI-based algorithms are the most common data-driven method [Nikitin 2013]. Prediction provides basic information for the maintenance management system, where the decision on maintenance is made by predicting the time when the reliability or residual life of the object reaches a threshold value [He 2022]. Incorrectly calculated maintenance times can lead to significant costs. Therefore, an urgent task is to increase the accuracy of predicting the residual life of an electric motor or its individual elements [Abramov 2015, Li 2022].

The asynchronous electric drive is widely used in industry due to a number of advantages: high reliability, low cost. In many works, the issues of diagnostics of a drive based on electric motors are considered. The main goal of the conducted research is to increase the efficiency of diagnosing the states of the electric drive through the use of an integrated approach based on the analysis of data on vibration and current consumption [Stepanov 2013 and 2014a]. In the electric drive, electrical processes occur, which are characterized by electric current, and mechanical processes, which are characterized by vibration. Therefore, the choice of these diagnostic parameters is obvious [Stepanov 2014b and 2017]. The works [Stepanov 2014c] study the selected diagnostic features, which are obtained by the method of discrete wavelet transform of vibration acceleration and vibration velocity, as well as the current consumption of the drive motor.

The objective of this work is to increase the efficiency of the process of monitoring the technical condition and assessing the service life of electromechanical equipment based on the analysis of diagnostic information of various physical nature, taking into account different types of diagnostic signals generated by individual drive elements (vibration and current).

2 MATERIALS AND METHODS

2.1 Development of the architecture of the block for data collection and processing

On the basis of the task set, the architecture of the recorder was designed, which is shown in Figure 1. It uses vibration transducers and current sensors as diagnostic sensors. The sensor connection diagram is shown in Figure 2.

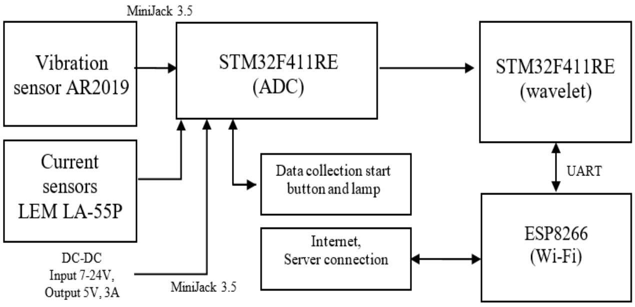

Figure 1. Structural diagram of the block for collecting and processing data (registrar)

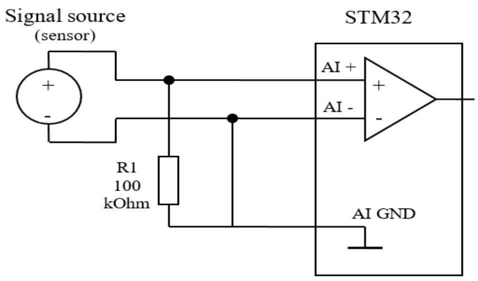

Figure 2. General scheme for connecting sensors

The developed architecture and components of the prototype data acquisition and processing unit correspond to the specified characteristics.

The STM32F411 series of microcontrollers is based on a 32-bit ARM Cortex-M4 core with a clock frequency of up to 100 MHz. The main feature is the presence of a digital signal processing unit (DSP). STM32F411 contains high-speed memory: up to 512 KB of non-volatile memory and 128 KB of RAM, has one 12-bit ADC with a sampling rate of 2.4 M sample/s and support for up to 16 data acquisition channels, as well as a real time clock.

This controller fully provides data collection with a maximum sampling rate of up to 40 kHz, connection of 4 analogue inputs and measurement with a relative measurement error of no more than 15%.

2.2 Data Acquisition and Processing Unit Software

In general, the software of the system should be software on the server (remote or local), which receives pre-processed data from the registrar, performs additional pro-cessing of these data (based on a set of digital signal processing methods), decides on the current technical condition of the control object and / or predicts the remaining resource of its work (based on a neural network), and also sends the result (technical state and / or resource of the object) to the interface block for display by the end user.

As part of the work, an algorithm was developed that makes it possible to implement the established requirements (Figure 3).

The registrar's algorithm consists in taking an analogue signal, converting, and also transferring the necessary characteristics to the server for further processing. The signal acquisition is performed using the built-in ADC (analogue-to-digital converter) of the STM32 microcontroller of the F4 series that supports signal acquisition from multiple sources (multiple ADC inputs). The signal is removed asynchronously with the help of an auxiliary module DMA (Direct Memory Access Controller). With the help of the DMA module, data is placed in temporary buffers. In this case, various preliminary transformations can be performed on the data (including the wavelet transform, as well as the discrete Fourier transform). The captured and processed data is transferred asynchronously from a pre-allocated buffer using UART to the ESP32 series microcontroller, which transmits data to the server when connected to the Internet.

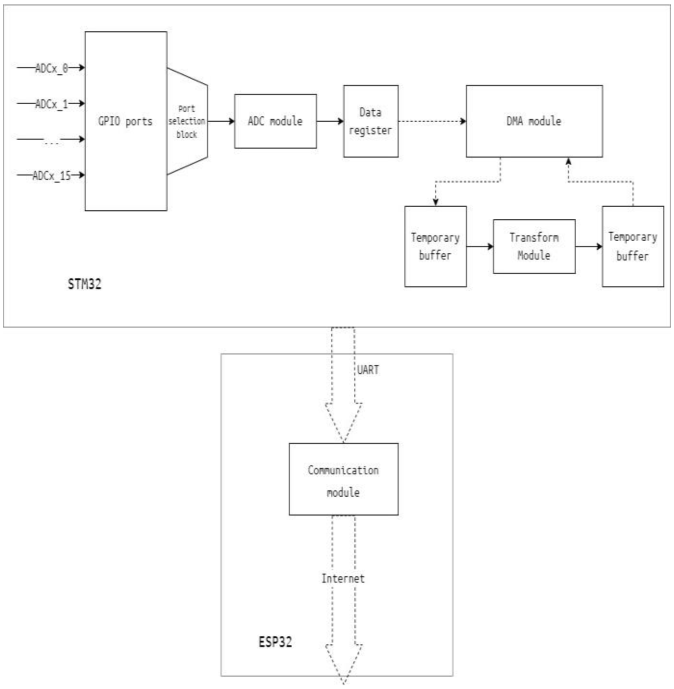

Figure 3. Algorithm of the software prototype for the data acquisition and processing unit (registrar)

3 RESULTS

3.1 Algorithm for predictive diagnostics

Let us note the main features of the assessment of the technical condition (TC) of vehicle equipment using the example of railway transport:

1. A large number of wheel-motor units (WMU) with the same power and composition;
2. Constant changes in the modes of operation of the WMU, as well as uneven work-load;
3. Checking of the WMU TC is carried out in accordance with the system of preventive maintenance (at the depot);
4. The use of vibration analysis for electromechanical equipment (EME) of railway transport (WMU) is associated with additional filtering of the signal from many interferences.

With that in mind, the following algorithm for evaluating the TC of vehicle equipment should be adopted:

1. Collection of data on the current consumed by the drive motor of each WMU should be carried out with a certain frequency during the operation of the railway transport. As a result, a trend is fixed showing all changes in the EME TC, reflected in the diagnostic signs of the consumed current, between routine maintenance;

2. Acquisition of data on the vibration of bearings, gears and other critical units must be carried out at the depot (or at the entrance to the depot). As a result, a discrete trend of changes in the diagnostic signs of vibration acceleration and vibration velocity is fixed before and after routine maintenance;
3. The final assessment of the EME TC in the depot based on a comprehensive analysis of the diagnostic signs of current and vibration;
4. Using the algorithm for estimating the residual life of equipment based on the analysis of the received trends.

In accordance with the algorithm, a software prototype was developed for the data acquisition and processing unit, which currently allows displaying the processed data in accordance with the model of additional digital processing of diagnostic signals. An example of this data is shown in Figure 4.

From the resulting decomposition, root-mean-square (RMS) and maximum values (PEAK) are determined, and these two values for each diagnostic feature (d1, d2, etc.) are sent to the server.

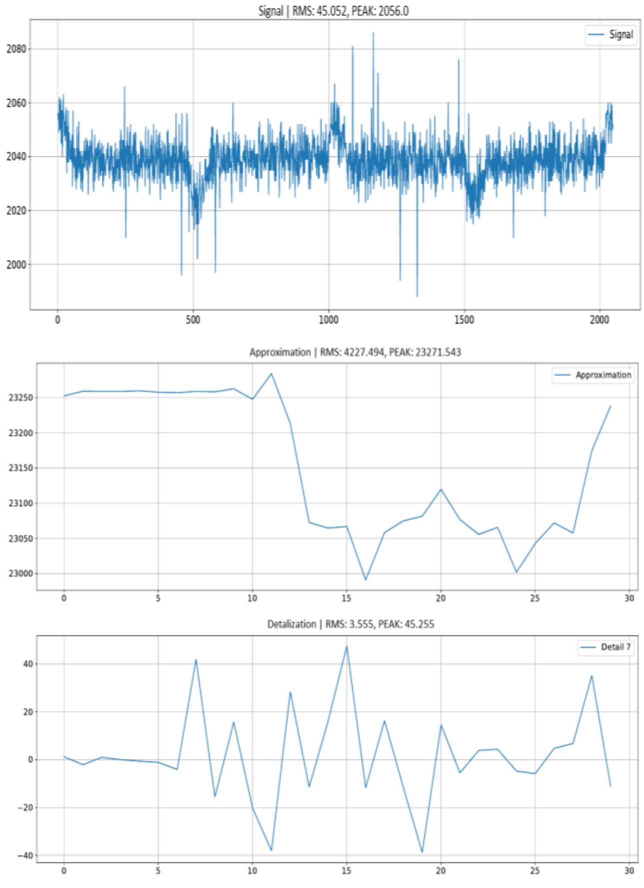

Figure 4. An example of a signal from a sensor obtained after processing (in relative units): the general level and the coefficients of the wavelet decomposition a8, d7

Figure 5. Generalized algorithm for predictive diagnostics of an asynchronous drive of promising trains

A generalized algorithm for estimating TC is shown in Figure 5. To implement the developed algorithm for evaluating the TC of EME vehicles and extracting diagnostic features from the collected data, a discrete wavelet transform is used to analyse the stator current of the drive motor and vibration. After applying this method of digital signal processing, the most sensitive diagnostic features are identified, and using the decision block described in [Stepanov 2021], the TC of mechanical and electromechanical units of EME is evaluated.

4 CONCLUSIONS

Thus, based on the results of this work, the following main provisions should be distinguished:

On the basis of theoretical and experimental research, the urgent problem of creating a predictive diagnostics system that differs from similar systems by a joint analysis of mechanical and electrical parameters has been solved. Thus, the efficiency of technical condition monitoring increases in the form of an increase in the reliability index up to 96% [Stepanov 2021].

For the automated collection and processing of the results of an experimental study, a prototype recorder was developed and implemented, including algorithms, a hardware platform and software products for collecting, processing, outputting and saving data.

Implemented a decision block based on a neural network (multilayer perceptron) with an error backpropagation algorithm. The results of the study [Stepanov 2021] showed the possibility of improving the efficiency of control through the use of an integrated approach (increase in the number of diagnostic features), which speeds up the setting (by 1.5 times), reduces the error and increases the reliability of the decisions made.

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