Improvement of efficiency of monitoring and diagnosing electromechanical systems by automating recognition parameters

I A Menshikov\(^1\), V A Kargin\(^2\), A V Volgin\(^2\), A P Moiseev\(^2\)

\(^1\) Saratov state technical University named after Gagarin Y.A., 77 Politehnicheskaya street, Saratov, 410054, Russia
\(^2\) Saratov State Agricultural University named after N.I. Vavilov, 1, Theatralnaya Square, Saratov, 410012, Russia

E-mail: saratov-79@list.ru

Abstract. Evaluation of operating modes of electromechanical systems on vehicles with traction DC motors based on a combination of values of several signs of recognition of the technical condition will increase the probability of detecting failures of traction motors by minimizing the influence of factors that are irregular. The results of the evaluation of the modes of operation and the technical condition of electromechanical systems with traction DC motors of an AC electric train of the ER-9\(^3\) series are presented. The problem of recognizing the modes of operation and the technical state of electromechanical systems has been solved with the help of mathematical processing of the parameters of recognition features used in an automated system for adaptive monitoring and prediction of failures of elements of electromechanical systems.

1. Introduction
Evaluation of the modes of operation of electromechanical systems (EMS) on vehicles with traction DC motors (DCM) based on a combination of values of several technical condition recognition signs will increase the probability of detecting DCM failures by minimizing the influence of factors that are irregular [1, 3, 4].

It is established that the best signs of informativeness are the following signs of recognition of the technical state of the EMS: the maximum amplitude of the current in the DCM armature circuit of electromechanical system; the ratio of the minimum current amplitude in the armature circuit to the maximum current amplitude; dispersion of current amplitude in the armature circuit; the average ratio of the neighboring amplitudes of the armature current; the maximum ratio of adjacent amplitudes and the average amplitude of the current in the circuit of the armature of DCM. This indicates that one of the parameters of recognition features should be used as the main one, with the average current amplitude being more preferable [2, 5].

When searching for optimal algorithms for processing diagnostic signals, a block diagram of an adaptive digital filter has been proposed, which helps the diagnostic system to adjust to the statistical parameters of the input signal, without requiring any model tasks.

The most important feature of adaptive diagnostic signal processing is the presence of an exemplary or reference signal \(d(k)\) [5].
The adaptive filter compares the reference signal \( d(k) \) with the output diagnostic signal \( y(k) \) and outputs the signal “Failure” \( e(k) \).

2. The object and method of research

The structure of the adaptive filter of the strategic identifier of diagnostic parameters of the on-board automated system for monitoring and predicting the stability of the operation of the DCM electric train of the ER-97 series is presented in Fig. 1.

![Figure 1](image1)

**Figure 1.** The structure of the adaptive filter strategic identifier of diagnostic parameters

The principle of an optimal filtering diagnostic signal is considered. Let the input diagnostic discrete signal \( x(k) \) from the measurement unit be processed by a discrete adaptive filter of order \( N \) with coefficients \( \{ \omega_n \}, \ n = 0,1,\ldots,N \) (Fig. 2). The output signal of the adaptive filter can be determined by the formula:

\[
Z(k) = \sum_{n=0}^{N} \omega_n x(k-n).
\]  

(1)

The «Failure» signal when comparing the reference \( d(k) \) and the output \( y(k) \) diagnostic signals is calculated as follows:

\[
e(k) = d(k) - y(k) = d(k) - \sum_{n=0}^{N} \omega_n x(k-n).
\]

(2)

The main task of creating an adaptive filter is to determine the filter coefficients \( \{ \omega_n \} \) that ensure the maximum proximity of the output diagnostic signal to the model specified diagnostic signal \( d(k) \), i.e. minimize the error of the accidental distorted diagnostic signal “Failure” \( e(k) \) [6, 7, 8, 9, 12].

![Figure 2](image2)

**Figure 2.** The formation of the signal “Failure” with the help of discrete adaptive filter
In order to study in detail the influence of external disturbances on the stability of DCM functioning, a simulation model was proposed (Fig. 3) based on the use of modern computer technologies implemented in MATLAB & Simulink [10, 11, 13, 14].

Figure 3. Simulation model DCM of type RT-51M with a pulse voltage regulator in MATLAB & Simulink

3. Results and discussion
As a result of the simulation of a stable DCM operation process, an array of output controlled parameters $I_a$ - current values in the armature circuit — was obtained.

Fig. 4 shows the dependencies of current values in the DCM armature circuit on time in stable and unstable modes of operation.

Figure 4. Dependencies of current values in the DCM armature circuit on time in stable and unstable modes of operation

Fig. 5 shows a graph of dependency of rotation frequency of the DCM armature on time in stable and unstable modes of operation.

As a result of modeling the diagnostic parameters of DCM by changing the input parameters on the elements of the simulation model in various operating conditions, we have compiled a table of the output diagnostic parameters of the current values in the armature circuit, arranging them in rows and columns in accordance with their position in the system of equations. As a result of numerous measurements of
current values in the armature winding circuit, we construct a matrix of arrays of DCM output diagnostic parameters with stable operation \( d(k) \), which can be taken as an exemplary signal:

\[
d(k) = \begin{bmatrix}
y_{11} & y_{12} & y_{13} \\
y_{21} & y_{22} & y_{23} \\
y_{n1} & y_{n2} & y_{n3}
\end{bmatrix} = \begin{bmatrix}
1500 & 350 & 180 \\
1200 & 200 & 180 \\
800 & 200 & 180
\end{bmatrix}.
\] (3)

To build an automated DCM technical condition monitoring system, one should perform digital processing of diagnostic parameters and obtain information on the technical state of the DCM armature windings. For mathematical digital signal processing, in the strategic identifier block, analog time-continuous input signals \( x(t) \) are converted to \( d(k) \) binary code for the stable operation mode or to binary code \( y(k) \) or unstable DCM operation mode.

Using an arithmetically logical device located in the strategic identifier block, we will divide the two values of the matrixes of the arrays of diagnostic parameters \( d(k) \). The quotient from their division is the output diagnostic parameter \( e(k) \), mathematically processed by the filter.

When the DCM mode of operation is stable the diagonal coefficients of the matrix of arrays of diagnostic parameters are \( d=1 \), the remaining coefficients of the matrix \( r \) are 0.

\[
e_{\text{stable}}(k) = \frac{d_{\text{pos}}(k)}{d(k)} = \begin{bmatrix}
1.0 & 0 & 0 \\
0 & 1.0 & 0 \\
0 & 0 & 1.0
\end{bmatrix}.
\] (5)

The array of diagnostic parameters for the stable functioning of the DCM of the RT-51M type can be interpreted as an image in the software package MATLAB 2014 (Fig. 6, a).

Each element of this matrix is represented in the form of a square, the color of which corresponds to the size of the element. In order to recognize such match, you should use the color scale matrix, which is located to the right of the image matrix [6, 7, 15, 16].
Figure 6. Interpretation of the division of two matrixes of arrays of diagnostic parameters in stable (a) and unstable (b) modes of operation with DCM of RT-51M type

In case of an unstable DCM operation mode:

\[ e_{\text{unstable}}(k) = \frac{d_{\text{pos}}(k)}{y(k)} = \begin{bmatrix} -0.262 & 0.108 & 1.002 \\ 0.567 & 0.242 & 0.0862 \\ 0.606 & 0.670 & -0.358 \end{bmatrix} \]  \hspace{1cm} (6)

Diagonal coefficients of this matrix of arrays of diagnostic parameters are \( d \neq 1 \). The values of the coefficients of the main diagonal of the matrix of arrays of diagnostic parameters are negative [6, 7, 9, 11].

Interpretation of the array of diagnostic parameters of an unstable operating mode of DCM of PT-51M type is presented in Fig. 6, b.

4. Conclusion
As a result of the interpretation of the array of diagnostic parameters for different operating modes, we get a visual representation of the coefficients of the main diagonal of the diagnostic parameters array (Fig. 6, a, b), which can be used to build automated onboard DCM parameter monitoring systems.

Comparing the coefficients of the arrays of diagnostic parameters, it was found that in the steady-state operation mode, the DCM has the main diagonal of the coefficients \( d = 1 \), and \( r = 0 \) with an unstable mode of operation \( d \neq 1 \) and the values of the coefficients of the main diagonal are negative. This is necessary to know when designing an adaptive automated system for monitoring and diagnosing DCM.

References
[1] Parkhomenko P P 1981 Fundamentals of technical diagnostics (Moscow: Energy)
[2] Volkov A K 1988 Increasing the operational reliability of traction engines (Moscow: Transport)
[3] Diakov V P 2002 MATLAB 6: training course (Saint-Petersburg: Peter)
[4] Chernykh I V 2001 Simulink: environment for creating engineering applications (Moscow: Peace)
[5] Sergienko A B 2006 Digital signal processing: A textbook for universities (Saint-Petersburg: Peter)
[6] Diakov V P 2015 Simulink: Tutorial (Moscow: DMK Press)
[7] Richard Lyons 2009 Digital Signal Processing (Moscow: LLC «Binom-Press»)
[8] Volkov A K 1988 Improving the operational reliability of traction motors (Moscow: Transport)
[9] Dmitriev A K 1981 Recognition of failures in electrical systems (Moscow: Energoatomizdat)
[10] Neyman V Yu, Rogova O V 2016 New construction types of a linear electromagnetic motor with the active teeth-slot zone Proceedings of IFOST-2016 11th International Forum on Strategic Technology 2 28-31
[11] Neyman L A, Neyman V Yu, Shabanov A S 2016 Simulation of processes in an electromagnetic converter with energy loss in the massive magnetic core. *17th International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM-2016) Conference Proceedings* 2522-525

[12] Shabanov A S, Neyman V Yu 2016 The effect of the structure of the magnetic circuit on the traction characteristics of the electromagnetic press *Science. technology. innovation is a collection of scientific papers in 9 parts ed. by E. G. Gurova* 94-95

[13] Moshkin V I, Ugarov G G 2015 The concentration of magnetic energy in the working clearances pulse linear electromagnetic engine at the stage of its electromagnetic conversion *Journal of Electrotechnics* 4(9) 20-26

[14] Moshkin V I, Ugarov G G 2014 Main dimensions and their ratios for the magnetic system of the pulsed linear electromagnetic engine *Journal of Electrotechnics* 1(2) 71-78

[15] Moshkin V I, Ugarov G G 2016 Electromechanical characteristics of pulse linear electromagnetic engines of the longitudinal magnetic field as movement *2016 International Conference on Actual Problems of Electron Devices Engineering (APEDE)* 2 1-8

[16] Usanov K M, Ugarov G G, Moshkin V I. 2006 *Linear pulse electromagnetic drive of machines with autonomous power: monograph.* (Kurgan: Publishing house of Kurgan state University press)