Numerical simulation of control process and operation stability predicting of traction motors

I A Menschikov\textsuperscript{1}, G G Ugarov\textsuperscript{2}, V I Moshkin\textsuperscript{3}, V A Aksyutin\textsuperscript{4}

\textsuperscript{1} Yuri Gagarin State Technical University of Saratov, 77 Politehnicheskaya Street, Saratov, 410054, Russia
\textsuperscript{2} Kamyshin Institute of Technology (Volgograd State Technical University branch), 6a Lenin Street, Kamyshin, Volgograd region, 403874, Russia
\textsuperscript{3} Kurgan State University, cost 4, 63 Sovetskaya Street, Kurgan, 640020, Russia
\textsuperscript{4} Novosibirsk State Technical University, 20, Karla Marksa ave., Novosibirsk, 630073, Russia

E-mail: slen@ngs.ru

Abstract. The article presents the results of numerical simulation of operation modes of AC traction electric motors and the diagnostic information processing in MATLAB Simulink. Predicting the stability of the electric traction motor of electric rolling stock in electric railway transport is an important practical task. Emergency operation of the traction motor can lead to a violation of the safety conditions of train traffic and serious injury-prone consequences. Most of the currently used diagnostic systems are developed on the basis of the use of the gamma-percent aging resource of the insulation of electrical machines in accordance with the theory of probability. A significant disadvantage of using the elements of a traction motor as a predicted gamma-percent resource is that, as practice shows, the operating time of real elements of electric machines to the limit state is much higher. As a result, when using the strategy of maintenance and repair on the basis of operating time, using the theory of probability, leads to a significant underutilization of the individual resources inherent in them in the design and production of most products. To reliably predict the residual life of the traction motor elements, it is necessary to perform its complete technical diagnostics. The most reliable methods for diagnosing and predicting the individual residual resource of traction motor elements in operation are statistical methods based on an objective assessment of its technical condition at the current time. The measurement and computing technologies available today have made it possible to use many previously studied physical phenomena in traction motor diagnostics systems, as well as to search for new diagnostic parameters.

1. Introduction

In the works [1–4] it is established that the best parameters for diagnosing and predicting the residual resource of the elements of the traction motor in terms of information content are the current spectrograms in the armature winding circuit.

The aim of the work is the development of a model and algorithms for the numerical simulation of traction motor operation modes using digital processing of current values. For a detailed study of the influence of external disturbances on the stability of the traction motor operation, the model (Figure 1)
based on the use of modern computer technologies implemented in the MATLAB Simulink [3–5] is proposed.

In order to test the model, the parameters of the operating modes of the 1DT.003.11 type traction electric motor are used. The input parameters are set using an AC voltage source and a rectifier.

2. Numerical simulation algorithm
As a result of simulation the output diagnostic parameters of operation of the 1DT.003.11 type electric motor, the obtained values are written in the form of a matrix, distributing the current values in the armature circuit in rows and columns in accordance with their position in the system of equations.

We write down a matrix of arrays of output diagnostic parameters of the armature current values of a working traction motor with stable operation, the form of which can be taken as a model signal:

$$d(k) = \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} = \begin{bmatrix} 311 & 316 & 319 & 323 \\ 327 & 331 & 335 & 340 \\ 342 & 346 & 352 & 389 \\ 361 & 363 & 368 & 374 \end{bmatrix}$$

The calculation shows that in the stable mode of operation of a working traction motor, as a result of dividing the matrices of arrays of armature current values, the main diagonal of the matrix coefficients is equal to one ($d = 1$), the remaining coefficients of the matrix $r$ are equal to zero ($r = 0$).
As a result of calculating the matrix coefficients of the array of diagnostic parameters obtained from dividing the two matrices, we get a visual representation (interpretation) of the matrix coefficients in the form of output diagnostic parameters, where each coefficient of the matrix is represented as a square, the color of which corresponds to the value of the output diagnostic parameter. In order to recognize the values of the matrix coefficients as output diagnostic parameters, you should use the color scale matrix [6–10]. The matrix of the array of diagnostic parameters of a working traction motor can be interpreted as an image in the program of the MATLAB package (Figure 2).

\[
e_{\beta\eta}(k) = \frac{d_{\alpha\beta\eta}(k)}{d(k)} = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}.
\]  

(1)

As a result of calculating the matrix coefficients of the array of diagnostic parameters obtained from dividing the two matrices, we get a visual representation (interpretation) of the matrix coefficients in the form of output diagnostic parameters, where each coefficient of the matrix is represented as a square, the color of which corresponds to the value of the output diagnostic parameter. In order to recognize the values of the matrix coefficients as output diagnostic parameters, you should use the color scale matrix [6–10]. The matrix of the array of diagnostic parameters of a working traction motor can be interpreted as an image in the program of the MATLAB package (Figure 2).

Figure 2. Interpretation of the division of two matrices of diagnostic parameters of the stable operation mode of the 1DT.003.11 type traction motor

The matrix of diagnostic parameters of the array of current values in the armature circuit of a traction electric motor in an emergency mode of operation, for example, an inter-turn short circuit in the armature winding, will have the form

\[
e_{\text{energ}}(k) = \frac{d_{\alpha\beta\eta}(k)}{y(k)} = \begin{bmatrix}
0.408 & 0.811 & -0.107 & -0.188 \\
-0.545 & 1.196 & 0.03 & 0.196 \\
-1.195 & 1.154 & 0.748 & 0.154 \\
-2.151 & 2.044 & -0.120 & 1.044
\end{bmatrix}.
\]  

(2)

The main diagonal of the coefficients of the matrix of arrays of output diagnostic parameters is not equal to one. The values of the remaining coefficients of the matrix of output diagnostic parameters have negative values. The interpretation of the array matrix of diagnostic parameters of the emergency operation mode (see formula (2)) of the traction electric motor of type 1DT.003.11 is presented in (Figure 3).

When comparing the two modes of operation of the traction motor, it was found that in the stable mode of operation, the main diagonal of the matrix is equal to one \((d = 1; r = 0)\), and in the emergency mode, the main diagonal of the matrix is not equal to one and the values of the coefficients of the main diagonal are negative. Based on the results of modeling the stability of the functioning of the traction electric motor, a functional scheme of the control model and forecasting the stability of the functioning of the traction electric motor is developed (Figure 4).
Figure 3. Interpretation of the division of two matrices of diagnostic parameters of the emergency operation mode of the traction motor

Figure 4. Functional diagram of control process and operation stability predicting of the traction motor

The input of the model is a parametric process that reflects information about the influence of input factors \( X(t) = I, X(t) = F, X(t) = R, X(t) = t^0 \) on the performance of the traction motor, represented in a function of time. The output \( Y(t) \) is a parametric real transient process of starting the electric drive, characterized by the control parameters:

\[
Y(t) = \frac{k_m}{y}, \quad Y(t) = n, \quad Y(t) = T_J, \quad Y(t) = T_M, \quad Y(t) = P.
\]

Outputs \( J_{pr}, N_{pr} \) – forecast curves of the current and velocity graph at discrete moments of time, depending on the current state of the parameters that characterize the performance of the electric motor [7].

3. Conclusion
The carried out numerical simulation makes it possible to conclude that in order to create an adaptive on-board system for diagnosing traction motors it is necessary to carry out digital processing of diagnostic signals and to obtain the information on the state of the traction motor armature windings. The results of the simulation of the 1DT.003.11 type traction motor and functional diagrams of the models for control and operation stability prediction give the opportunity of effective solving the problems of technical diagnostics of electric traction motors in electric railway transport.

References
[1] Richard L 1009 Digital Signal Processing: Second Edition (Moscow: LLC "Binom-Press") p 656
[2] Stepanov A V and Matveev S A 2003 *Methods of computer processing of signals of radio communication systems* (Moscow: SOLON-Press) p 206

[3] German - Galkin S G 2011 *MATLAB & Simulink. Design of mechatronic systems on personal computers* (St. Petersburg: Publishing house "Krona Vek") p 368

[4] Weinreb K 2012 Diagnostics of malfunctions of the rotor of an induction motor by the method of spectral analysis of stator currents *Electricity* 7 pp 51–57

[5] Dyakov V P 2015 *Simulink: Self-study guide* (Moscow: DMK Press) p 782

[6] Sergienko A B and Sergienko A B 2006 *Digital signal processing: Textbook for universities* (St. Petersburg: Peter) p 751

[7] Elizarov I A, Martemyanov A G, Skhirtladze A G and Tretyakov A A 2011 *Modeling systems: a tutorial* (Tambov: Publishing house of FGBOU VPO "TSTU") p 96

[8] Chernykh I V 2008 *Simulation of electrical devices in Matlab, Simulink* (St. Petersburg: Peter) p 288

[9] Chervyakov V L 2002 Comparative analysis of multiplicative weighting functions in digital signal processing *Proceedings of higher educational institutions. Electromechanics* 1 pp 61-62

[10] Baranov L D, Zlatnikov V M and Kuchernyuk I N 2004 Specialized processor for dispatching of information streams of high performance digital signal processing system *Radio electronics* 1(2) pp 87-90