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MATHEMATICAL MODEL OF DIAGNOSING AUTOMATIC ANALOG CONTROL DEVICES OF THE ELECTRIC DRIVE

The paper proposes a mathematical model of diagnosing automatic analog control devices of the electric drive. The model makes it possible to achieve higher quality of the electric drive diagnostics, which is implemented due to accelerated search of the measuring channel where an extreme signal level is present and by taking into account the failure parameter in each measuring channel.

Key words: *control device, diagnostics, electric drive.*

Problem statement

Development of the regulated electric drive (ED) control systems as well as methods and means of its diagnostics is a prospective trend of modern science and technology [1].

Although ED with microprocessor control systems are widely used in recent years, ED with analog and digital-analog control systems are also common. As a result of natural ageing processes and the influence of different disturbances during operation process, ED characteristics deteriorate with time. It should be noted that the quality of ED performance is greatly influenced by analog control units that are most sensitive to ageing processes and various disturbances.

Therefore, there is a need for monitoring the technical condition of ED as a whole and automatic analog control devices (ACD) of their control systems in particular, which is realized by performing continuous control and diagnostics.

Analysis of the recent research and publications

Some aspects of this problem solution are considered in [2 – 5]. Work [2] discusses 5 main approaches to electric equipment diagnostics in the process of its operation or testing: comparison of the diagnostic parameter with the given value; application of the known probabilistic relationships between a failure and the observed variations of parameters; finding the minimal number of points where diagnostic signals are observed; checking by test signals; creation of comprehensive mathematical models of the diagnosed objects. Works [3, 4] present the development of mathematical models of diagnosing closed and open ED control systems on the basis of the approach of comparing diagnostic parameters with the range of permissible values for given operation mode. The above models have limitations because they do not take into account a failure parameter in each measuring channel. Application of this parameter would make it possible to predict ED state. Work [5] demonstrates another approach to this problem – elaboration of diagnostic models in the form adaptive neuro-fuzzy networks.

Statement of the research problem

Elaboration of the mathematical model of diagnosing automatic ACD that implements accelerated search of the measuring channel, in the circuit of which an extreme signal level is present, and takes into account the failure parameter in each measuring channel will make it possible to improve the quality of diagnosing ED as a whole and automatic ACD of its control system in particular. Disregard of the failures at the beginning of their occurrence leads to inconsiderable deterioration of ED characteristics but at a later stage could result in its complete failure.

Main materials of the research

As it is known, elemental base of automatic ACD of ED is represented by radioelectronic elements and devices that in the process of ED operation are subjected to the influence of different external (climatic and mechanical) and internal factors. These factors lead to the situation when one or several parameters characterizing the operation of automatic ACD of ED exceed the permissible values [6] that are determined by the main and the limiting tolerance fields.

Operation of the device with parameters that are beyond the limiting tolerance fields is impermissible because further operation of the object could involve emergency situations. If the parameters are beyond the limits of the main tolerance field, its further intended usage is not expedient in terms of functionality, safe operation and repair work requirements.

Complexity of diagnosing closed-loop control systems is explained by the presence of feedbacks. Emergence of an impermissible parameter level at the output of any single element involves the emergence of impermissible parameter levels at the inputs of other feedback loop elements. This happens regardless of whether it is caused by a malfunction of the element itself or by an impermissible level of the signal supplied to its input from the output of another element not included into the feedback loop [7]. Therefore, in the process of diagnostics model elaboration it is necessary to provide the possibility to detect the defective ACD without creating artificial gaps in the control loops.

It is necessary to take into account the fact that each of the diagnostic parameters has its own patterns of change over time and therefore boundaries of the regions of permissible values have to be formed for each of them individually, which leads to more complex diagnosing process and, consequently, increases time for one cycle of diagnostics. In connection with this it is proposed to use the approach suggested in [4] and to switch from a direct analysis of diagnostic parameters to analyzing the signals that would characterize the accuracy of working out the input defining influences and would be expressed in relative units. This will make it possible to form uniform, unchanging in time boundaries of the regions of their permissible values.

The corresponding mathematical model of diagnostic parameters is given by

$$\begin{cases} i = \overline{1, n}, \\ \varepsilon_i(t) = \dfrac{x_i(t) - x_{nom_i}(t)}{x_{nom_i}(t)}, \\ \varepsilon_i(t) \in [-1, 1], \\ \begin{cases} \varepsilon_i > 0, & if \quad x_i > x_{nom_i}, \\ \varepsilon_i < 0, & if \quad x_i < x_{nom_i}, \\ \varepsilon_i = 0, & if \quad x_i = x_{nom_i}, \end{cases} \end{cases} \tag{1}$$

where n is the number of diagnosed automatic ACD of ED control system; ε_i – parameter characterizing the accuracy of processing the input defining influences by the $i^{\text{-th}}$ ACD at the fixed moment of time t; x_i – value of the diagnostic parameter at the output of the $i^{\text{-th}}$ ACD at the fixed moment of time t; x_{nom_i} – nominal value of the diagnostic parameter at the output of the $i^{\text{-th}}$ ACD at the fixed moment of time t.

Formation of the nominal values of the diagnostic parameters is provided by a corresponding model that represents the operation of separate ED ACD with a required degree of accuracy while a holistic model does not give the possibility to take into account real values of the parameters that are supplied to each of the diagnosed ACD.

Under the influence of various factors failures may occur in the process of ED operation. They should be traced and analyzed. Accumulation of the information on failures that occur in each measuring channel will make it possible to detect the automatic ACD that is the most sensitive to disturbances and to predict the state of ED as a whole and of its control system in particular. In this way implementation of the principle of ED servicing according to its actual technical state is provided. .

Taking the above-mentioned into account, mathematical model for diagnosing automatic ACD of ED will be given by:

$$\begin{cases} i=\overline{1,n},\ \ j=\overline{1,n},\ \ s_j=\overline{0,g}, \\ k=1,\ \ v=1, \\ i=1 \ \Rightarrow \begin{cases} j=1, \\ \varepsilon_{\max_j}=\left|\varepsilon_i\right|, \end{cases} \\ \begin{cases} i=i+1, \\ \left|\varepsilon_i\right|>\varepsilon_{\max_j} \end{cases} \Rightarrow \begin{cases} j=i, \\ \varepsilon_{\max_j}=\left|\varepsilon_i\right|, \end{cases} \\ x_j \to const\,1, \quad if \ \begin{cases} \varepsilon_{\max_j}\ge\varepsilon_{гр}, \\ \varepsilon_j>0, \end{cases} \\ x_j \to const\,0, \quad if \ \begin{cases} \varepsilon_{\max_j}\ge\varepsilon_{гр}, \\ \varepsilon_j<0, \end{cases} \\ x_j \to \mathrm{var}\,(const\,1),\ if \ \begin{cases} i=n, \\ \varepsilon_j>0, \\ \varepsilon_{\max_j}\ge\varepsilon_{доп}, \\ \left|\varepsilon_j\right|\to m,\ \ m\ge q \vee \begin{cases} \left|\varepsilon_j\right|\to m, \quad 0<m<q, \\ s_j=s_j+1, \quad s_j\ge g, \end{cases} \end{cases} \\ x_j \to \mathrm{var}\,(const\,0),\ if \ \begin{cases} i=n, \\ \varepsilon_j<0, \\ \varepsilon_{\max_j}\ge\varepsilon_{ad}, \\ \left|\varepsilon_j\right|\to m,\ \ m\ge q \vee \begin{cases} \left|\varepsilon_j\right|\to m, \quad 0<m<q, \\ s_j=s_j+1, \quad d\ge g, \end{cases} \end{cases} \end{cases} \tag{2}$$

where s_j is a current number of failures, index j characterizing that automatic ACD and, accordingly, that measuring channel where output signal is an extreme one in the given scanning cycle.; g – limiting value that determines the number of failures in one measuring channel required for forming a conclusion about the future failure in the given measuring channel; k – commutation sensor output signal that indicates the position of the switching device that supplies voltage; v – signal at the output of the power supply sensor of ED control system; $\varepsilon_{\max j}$ – current extremal value of the signal ε in the given scanning cycle that was registered in the j^{-th} measuring channel; ε_{lim} – maximum permissible value of the diagnostic parameter deviation from its nominal value in relation to limiting tolerance field ; ε_{ad} – maximum permissible value of the diagnostic parameter deviation from its nominal value in relation to the main tolerance field.; m – the number of cases when the diagnostic parameter exceeded the limits of the main tolerance field within the time given for one measuring channel diagnostics; q – limiting value that determines the required number of cases when a diagnostic parameter exceeds the limits of the main tolerance field (for detecting failures) within the time given for one measuring channel diagnostics.

Expression *const 1* (constituent of the unit) means that a constant maximally possible output signal emerges at the output of the $i^{\text{-th}}$ measuring channel

Expression *const 0* (constituent of zero) means that a constant minimally possible signal emerges at the output of the $i^{\text{-th}}$ measuring channel or that output signal is completely absent.

Expressions var *(const 1)* or var *(const 0)* have meanings analogous to those mentioned above, but the corresponding malfunction was caused by failures or by that the parameter was exceeding the limits of the main tolerance field for a long time.

In accordance with the model (2) the process of diagnostics proceeds as follows. After a scanning cycle is finished and in the case of unsatisfactory results of checking for failures of *const 1* and *const 0* types, checking for failures of var *(const 1)* or var *(const 0)* type is performed. In particular, if signal ε in the $j^{\text{-th}}$ measuring channel appears m times during the checking process with $m \geq q$, the conclusion about the failure of var *(const 1)* or var *(const)* type is made. In the opposite case, if $0 < m < q$, a failure is registered in the given measuring channel and a new scanning cycle begins. If the number of failures in the $j^{\text{-th}}$ measuring channel exceeds a certain limiting value $s \geq g$, a conclusion is made about the failure of var *(const 1)* or var *(const 0)* type.

Analysis of the given mathematical model allows making a conclusion that for technical implementation of the corresponding diagnosing device it is necessary to provide a survey of n measuring channels with the ability to recognize the signal sign as well as commutation and voltage supply sensors. Besides, it is necessary to provide processing of the information and displaying it for visual control of the investigated object state and also connection with a higher-level computer for storing and further processing of the information.

Conclusions

Mathematical model of diagnosing automatic ACD of ED is elaborated. Implementation of the accelerated search of the measuring channel, in the circuit of which an extreme signal level is present, and taking into account the failure parameter makes it possible to improve the quality of diagnosing ED as a whole and automatic ACD of its control system in particular.

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