AUTOMATIC FORMATION OF MATHEMATICAL MODELS OF CIRCUITS WITH SWITCH ELEMENTS BASED ON STRUCTURAL AND OPERATOR-RECURRENT APPROACHES

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***Abstract:* Mathematical simulation of electromagnetic process in circuit of coils electro mechanic control system with switch elements is represented.**

***Keywords:* electromagnetic process, electro mechanic control system, coils, switch elements, structural matrix, operational recurrent method.**

I. INTRODUCTION

The study of electromagnetic processes in electro mechanic control system containing the switch elements in the circuits of the windings of electrical machines is actual task with point of view of their analysis and design [1]. These systems are characterized by a difficult topology, a wide variety of electromagnetic structures, the ambiguity of the conditions of their formation and the difference in time intervals of existence.

II. STRUCTURAL METHOD

Let's set up a system of equations of electrical balance for the m-phase winding

$$\mathbf{R}_{\text{ф}} i_{\text{ф}} + \mathbf{L}_{\text{ф}} \frac{d\mathbf{i}_{\text{ф}}}{dt} + \frac{d\boldsymbol{\psi}_{\text{ф}}}{dt} = \mathbf{u}_{\text{ф}}$$

where $\mathbf{R}_{\text{ф}}$, $\mathbf{L}_{\text{ф}}$ - are respectively, the matrix of phase resistances and inductances, size $m \times m$, $\mathbf{i}_{\text{ф}}$; $\frac{d\mathbf{i}_{\text{ф}}}{dt}$, $\frac{d\boldsymbol{\psi}_{\text{ф}}}{dt}$, $\mathbf{u}_{\text{ф}}$ –, are respectively, m-dimensional vectors (the matrix-columns) of phase currents, their time derivatives, derivatives of flux linkages of phases and phase voltages.

In this type of system can not be solved because of unknown voltages of vector $\mathbf{u}_{\text{ф}}$. Now we turn to the system of equations composed by mesh current method.

$$\mathbf{R}_K \mathbf{i}_K + \mathbf{L}_K \frac{d\mathbf{i}_K}{dt} + \frac{d\psi_K}{dt} = \mathbf{u}_K$$

where $\mathbf{R}_{\text{K}}$, $\mathbf{L}_{\text{K}}$ – are respectively, the matrix resistance and inductance, size $k \times k$, k – the number of independent circuits; $\mathbf{i}_{\text{K}}$, $\frac{d\mathbf{i}_{\text{K}}}{dt}$, $\frac{d\psi_{\text{K}}}{dt}$, $\mathbf{u}_{\text{K}}$ – respectively, k-dimensional vectors of loop currents, their time derivatives, derivatives of flux linkages and circuits supplied to the contours of the voltages.

For transition we use the structural matrix **C**, whose rows are selected by independent circuits, and the columns to the branches of the scheme (i.e. in this case to the phases of the windings). If a conditionally positive direction of the current branch coincides with the direction of the contour, then the corresponding element of the matrix was taken to be 1; if the opposite is **-**1 if the branch is not included in the circuit is equal to 0. Then the parameter matrix, the matrix effects of the derivatives of flux linkages and circuits take the form:

$$\mathbf{R}_K = \mathbf{C} \cdot \mathbf{R}_{\text{ф}} \cdot \mathbf{C}^T;\ \mathbf{L}_K = \mathbf{C} \cdot \mathbf{L}_{\text{ф}} \cdot \mathbf{C}^T;\ \mathbf{u}_K = \mathbf{C} \cdot \mathbf{u}_{\text{ф}};$$

$$\frac{d\psi_K}{dt} = C \cdot \frac{d\psi_{\text{ф}}}{dt}.$$

After calculating the vector of loop currents, the vector of phase currents is located at the matrix expression

$$\mathbf{i}_{\text{ф}} = \mathbf{C}^T \cdot \mathbf{i}_K.$$

Closed loop can be made for the winding scheme of multibeam stars of any two connected phases. Applied voltage of obtained contours depending on the direction of the circuit will be equal + $U_{\text{пит}}$ or – $U_{\text{пит}}$ for phases that are connected to different terminals of the power supply, or will be 0 for the phase connected to one terminal. Number of made this way independent contours k = l – 1, where l is the number of included sections.

Below there is a structural matrix and the corresponding vector of the voltage applied to the contours, for a 6-phase winding (m = 6), power on a positive 1, 2, 3 phases, and the fifth power on a negative (l = 4). In this case, a three linearly independent circuits (k = 3)appear, one of which power on power supply:

$$\mathbf{C} = \begin{pmatrix} 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & -1 & 0 \end{pmatrix};\ \mathbf{u}_{\text{K}} = \begin{pmatrix} 0 \\ 0 \\ U_{\text{пит}} \end{pmatrix}$$

To determine the structural elements of the matrix we list of numbers power on sections. We introduce a function to determine the number included in the section number of its position in this list. Numbers included in the list of sections can be in any order, the calculation results are not changed, despite the fact that the values of the elements of the structural matrix will be different. For the example provided above, this list will look like $\{1 \quad 2 \quad 3 \quad 5\}$, with the values $\xi(1)=1$, $\xi(2)=2$, $\xi(3)=3$. Then the expression for determining the elements of the structural matrix will be as follows:

$$C_{i,j}=\begin{cases}1, \xi(i)=j\\ 0, (\xi(i)\neq j)\cap(\xi(i+1)\neq j),\\ -1, \xi(i+1)=j\end{cases}$$

where i = 1,..., k - number of rows of **C**, j = 1,..., m - number of the column of the matrix **C**.

To calculate the vector $\mathbf{u}_\text{К}$ corresponding to the composed matrix $\mathbf{C}$, we define the state vector of phases $\mathbf{v}_\text{сост}$ as follows: $\mathbf{v}_\text{сост}(i)=1$, if the i-th phase included a positive, $\mathbf{v}_\text{сост}(i)=0$, if the i-th stage is turned off, $\mathbf{v}_\text{сост}(i)=-1$, if the i-th stage is connected to the negative terminal of power supply. Then, the vector $\mathbf{u}_\text{К}$ can be determined by the following expression:

$$\mathbf{u}_\text{К}=\frac{U_\text{пит}}{2}\cdot\mathbf{C}\cdot\mathbf{v}_\text{сост},$$

where $U_\text{пит}$ is voltage power supply.

The method of structural matrices allows the formulation of a universal algorithm for determining the equations of the mesh current for any number of phases and the control method. The problem for the equations is reduced to determining the matrix elements and the corresponding vector u..

III. Operational-recurrent method

To solve the system the most efficient is to use of operator-recursive approach (RR-method) [3], which fits well with the method of structural matrices.

In accordance with the OR-method system of equations

$$\mathbf{Ri}+\mathbf{L}\frac{d\mathbf{i}}{dt}+\frac{d\psi}{dt}=\mathbf{u}$$

Are converted to the form

$$\frac{d\mathbf{i}}{dt}=\mathbf{L}^{-1}\left(\mathbf{u}-\frac{d\psi}{dt}\right)-\mathbf{L}^{-1}\mathbf{Ri}$$

Here we represent the system of equations in the form

$$\frac{d\mathbf{i}}{dt}=\mathbf{a}-\mathbf{Bi}$$

denoting vector $\mathbf{a}=\mathbf{L}^{-1}\left(\mathbf{u}-\frac{d\psi}{dt}\right)$ and matrices $\mathbf{B}=\mathbf{L}^{-1}\mathbf{R}$.

We consider this non-linear continuous system as a quasi-discrete variables with parameters **B**, defining the influence of a discrete and interval **T**.

On an operator under the PR-method, assuming that $\mathbf{B}=const$ we obtain

$$\mathbf{i}(p)=\frac{1}{p}\left(\mathbf{a}(p)-\mathbf{Bi}(p)\right)$$

Replacing the operator of integration p of the linear z-form

$$\mathbf{i}(z)=\frac{T}{2}\frac{z+1}{z-1}\left(\mathbf{a}(z)-\mathbf{Bi}(z)\right)$$

expressing this equation $z\mathbf{i}(z)$ and denoting the matrix $\mathbf{B}'=\left(\mathbf{E}+\frac{T}{2}\mathbf{B}\right)^{-1}$ and $\mathbf{B}''=\left(\mathbf{E}-\frac{T}{2}\mathbf{B}\right)$ we obtain

$$z\mathbf{i}(z)=T\mathbf{B}'\frac{z\mathbf{a}(z)+\mathbf{a}(z)}{2}+\mathbf{B}'\mathbf{B}''\mathbf{i}(z)$$

Turning to the originals, we obtain a differential equation of first order:

$$\mathbf{i}_{[k+1]}=T\mathbf{B}'\frac{\mathbf{a}_{[k+1]}+\mathbf{a}_{[k]}}{2}+\mathbf{B}'\mathbf{B}''\mathbf{i}_{[k]}$$

In the calculation of this formula at each step there are substituted the current values of the matrix of variable coefficients **B** and they are determined by currents in the circuits on the assumption that the structure of the contours remains constant throughout the integration step. Step inside which, according to a given control law, should happen to switch keys, divided into two intervals (before switching and after switching keys), each of which is calculated with the corresponding structure matrix.

If the shift occurred within the calculated interval, then from the condition that the currents of ideal diodes in the switching moment must be equal to zero, the estimated calculation error due to the assumption that all of the identified switch occurred happened at the end of the interval. If the error exceeds the permissible value, the integration step is reduced, and the calculation of this interval is repeated. After calculating the interval with a specified accuracy, the previous value of the integration step is recovered. In the process of decision it is important to consider the control law rectifier elements.

IV. References

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