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SYNTHESIS OF REGULATORS FOR ASYNCHRONIZED FAN MOTOR

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ABSTRACT

The modern development of the use of intelligent technologies in control and management systems is successfully solving the problem of replacing adaptive ACS with high-speed systems with high flexibility, functioning in conditions of uncertainty, the potential advantages of intelligent ACS. In this regard, the task of creating a series of high-speed servo drives with intelligent controllers in order to comprehensively study their properties under conditions of uncertainty...
is of undoubted theoretical and practical interest. Currently used energy-saving variable frequency drives based on asynchronous motors with wound rotor is the main type of variable speed drive. The application of the laws of vector torque control provides the required quality of regulation and significantly increases the efficiency of the electric drive.

АНОМАЦИЯ

Современным развитием применения интеллектуальных технологий в системах контроля и управления успешно решается задачи замены традиционных адаптивных САУ на быстродействующих систем с высокой гибкости, функционирующих в условиях неопределенности, благодаря потенциальным преимуществам интеллектуальные САУ. В этой связи задача создания серии быстродействующих следящих приводов с интеллектуальными регуляторами с целью комплексного исследования их свойств в условиях неопределенности представляет несомненный теоретический и практический интерес. В настоящее время используемые энергосберегающие частотно-регулируемые электроприводы на основе асинхронных двигателей с фазным ротором является основным типом регулируемого электропривода. Применения законов векторного управления моментом обеспечивает требуемое качество регулирования и значительно повышает КПД ЭП.

Keywords: fuzzy controllers, fuzzy regulator, neural network, multi-loop control structure, symmetric optimum, asynchronous valve motor, PI controller.

Ключевые слова: нечеткие регуляторы, нечеткий регулятор, нейронная сеть, многоконтурная структура управления, симметричный оптимум, асинхронный вентильный двигатель, ПИ-регулятор.

At present, with the introduction of new circuit solutions resting on the active development of power electronics, microelectronics and microprocessor control systems, automated electric drives can achieve the necessary adjusting characteristics of the machines and mechanisms used, and also significantly reduce electricity consumption [1].

In the presented diagram, an additional corrective link is introduced into the vector of input values of the fuzzy controller for the dynamics of the transient process, the nature and parameters of which are set using the functional converter FP. At the same time, changing the FP parameters allows you to correct both dynamic and static characteristics of the system. This structure of the regulator, combined with the optimal choice of the parameters of the knowledge base of the fuzzy controller, carried out using genetic algorithms, allows the developer, with a minimum of settings, to implement adaptive control systems for uncertain and non-stationary mechanisms, regardless of their structure. Among the advantages of new control methods belonging to the category of intelligent control systems is the ability to:

- implement any non-linear control algorithm required for the process;
- to have an incomplete, inaccurate description of the control object, and for a neural network and the absence of a description;
- to create a soft adaptation that ensures the robustness of the system in case of instability of parameters.

The considered methods and control systems for electronic devices make it possible to implement the whole range of problems of controlled control with the required technological process.

- requirements for high accuracy and a large control range, high speed and cost-effectiveness necessitate the use of closed-loop systems.
- There are two methods of automatic control of coordinates [2]:
- regulation on the deviation of the coordinate from the set value using negative feedback on the controlled value;

Typical control systems based on fuzzy controllers belong to the class of expert systems and are nonlinear controllers of the characteristic surface. In the field of EP, one of the options for using fuzzy logic is associated with the regulation of the operating parameters of mechanisms based on a fuzzy controller with adaptive properties. The block diagram with a fuzzy regulator (controller) is shown in figure 1.

Figure 1. The block diagram with a fuzzy regulator
• regulation by disturbance, where with the help of positive feedback the influence of disturbance on the controlled value is compensated.

The electric drive is mainly used for deviation control, since it can provide the required accuracy regardless of the nature of the disturbance. In the general case, when regulating several coordinates, a closed EP system is built according to one of three structures:

• a structure with a summing amplifier;
• the structure of the independent regulation of coordinates;
• the structure of the subordinate regulation of coordinates.

The method of sequential correction with subordinate coordinate control is a generalization of the method of sequential correction as applied to EP systems, in which the structural model is represented by a sequential connection of inertial and integrating links.

The control object has a transfer function of the form

$$W_0(s) = \Pi_{i=1}^{m} \left( \frac{k_i}{T_i p + 1} \right)$$  \hspace{1cm} (1)

where $k_i$, $T_i$ are the parameters of the $i$-th link of the structural model. The time constants $T_i$ of the control object can be conditionally divided into two groups - large and small. The links of the structure, which correspond to large time constants, determine the main dynamics of transient processes in the system, its speed[3]. To implement the idea, a multi-loop control structure with nested subordinate loops is used (in figure 2), while in each internal loop the regulator compensates for no more than two time constants. The adjustment of the regulators of such a system is performed independently in each circuit.

**Figure 2. Multi-circuit system with slave regulation**

When tuning the system to the technical optimum, a requirement is put forward as a criterion - the modulus of the closed-loop frequency response should be close to unity over the largest possible frequency range. This requirement is essentially a condition for reproducing the input signal. The transfer function takes the form

$$H(s) = \frac{a_2}{(a_0 p^2 + a_1 p + a_2)}.$$  \hspace{1cm} (2)

In order for the modulus of the frequency response at small to be close to unity, it is sufficient that the conditions of the "optimal" tuning are satisfied:

$$a_1^2 = 2 \times a_0 \times a_2.$$  \hspace{1cm} (3)

The transient response of the system tuned to the technical optimum has the following parameters:

• overshoot $\delta = 4.3\%$;
• the time of the first agreement $t_1 = 4.71 \theta$;
• the time of the transient process $t_p = 8.4 \theta$;
where $\theta = \sum T_i$ is the sum of small time constants.

In the case of tuning the closed-loop system to a symmetric optimum, its logarithmic amplitude frequency response takes the form symmetric with respect to the cut-off frequency and the maximum phase stability margin falls on the vicinity of the cutoff frequency. The closed-loop transfer function of such a system takes the form[4]

$$H(s) = \frac{a_3 + a_2 p}{(a_0 p^2 + a_1 p + a_2 p + a_3)}.$$  \hspace{1cm} (4)

The condition for the "optimal" setting in this case

$$a_1^2 = 2a_0 a_2$$
$$a_2^2 = 2a_1 a_3$$  \hspace{1cm} (5)

The transient response of a system tuned to a symmetric optimum has the following parameters:

• overshoot $\delta = 4.3\%$;
• the time of the first agreement $t_1 = 3.1 \theta$;
• the time of the transient process $t_p = 16.5 \theta$.

The transient characteristics of closed systems tuned to the technical (curve "b") and symmetric optimum (curve "a") are shown in figure 3.
The transient process of a system tuned to a symmetric optimum is characterized by significant overshoot, which can be reduced if a low-pass smoothing filter is consistently installed outside the closed loop:

\[ W_f(p) = \frac{1}{40p+1} \]  

(6)

The transient process of such a system, shown in figure 3 (curve "a") is characterized by the following parameters:

- overshoot \( \delta = 8.1\% \);
- the time of the first agreement \( t_1 = 7.6\theta \);
- the time of the transient process \( t_p = 13.3\theta \).

Using the obtained transfer functions (2 and 3) and the equations of the circuits, it is possible to construct a structural diagram of the AED with vector frequency-current control with a direct orientation along the vector of the main magnetic flux and a fixed excitation frequency \( f_2 = \text{const} \) (in figure 4).

The following variables are controlled here:

- \( \psi_s = \text{const} \);
- \( i_{sx} = 0 \);
- \( i_{sy} \).

If we do not take into account the mutual connections between the circuits, then the stator and rotor of the AED are inertial links with time constants \( T_{l_s} \) and \( T_r \), which determine the nature of the dynamic processes in the drive. Thus, an asynchronous valve motor is a complex non-linear automatic control system. To compensate for the influence of the time constants \( T_{l_s} \) and \( T_r \) in transient modes, it is necessary to use regulators of the main magnetic flux, current, torque and speed in a closed-loop control system.

Considering the following assumptions:

- excitation voltage (rotor) is sinusoidal;
- the current of the starter circuit of the motor is continuous;
- the control characteristic of the inverter is linear;
- moment of inertia, given to the motor shaft, is constant[5].
The inertia of the feedback circuits for flow, current, torque and speed is not taken into account due to its smallness, the following block diagram of the regulation of an electric drive with an AED can be proposed (in figure 5):

Optimization of the loops of the subordinate control system (in figure 4) is performed according to the condition of technical maintenance TO and symmetric CO optimum. Consider the rotor circuit first, then the stator circuit. In a single-loop excitation circuit, it is necessary to compensate for the large rotor time constant $T_r$, while the uncompensated time constant will be determined by the inertia of the valve converter $T_{	ext{II}} = T_n = T_p$, that is, the control object is represented by series-connected inertial links, one of which has a time constant that is significantly larger than all the rest[6]. Then the synthesis problem is solved by the use of a PI controller, which allows tuning the closed loop to TO. The open loop system has a transfer function

$$W_{\text{II}}(p)W_{\text{p}}(p) = \frac{k_{\text{p}}(T_{\text{II}}p + 1)}{T_{\text{II}}p + 1} \left(\frac{I_m/(R_rK_u)}{T_r p + 1}\right)$$

(7)

Let us take $T_{\text{II}} = T_r$ and using the conditions of tuning (in figure 4) of the circuit for maintenance, determine the coefficient of the PI flow controller

$$k_{\text{pII}} = \frac{T_r R_r K_u}{2T_{\text{II}} k_{\text{om}} P_{\text{om}}} T_{\text{II}} = \frac{T_r}{k_{\text{pII}}}$$

(8)

The control channel in the stator circuit consists of three control loops. In accordance with the principles of subordinate regulation, synthesis begins with an internal KT. For it, as well as for the gearbox, the adjustment for maintenance is performed in order to compensate for the large time constant of the stator under the condition $T_{\text{II}} = T_n = T_p$. As a result, we obtain a PI controller with the following coefficients:

$$k_{\text{p}} = \frac{T_{\text{II}} R_r K_u}{2T_{\text{II}} k_{\text{om}} P_{\text{om}}} T_{\text{II}} = \frac{T_{\text{II}}}{k_{\text{p}}}$$

(9)

With further synthesis, the transfer function of the closed current loop with a sufficient degree of accuracy (due to the smallness of the uncompensated time constant $T_{\text{II}} T_r$) is approximated by the expression:

$$W_{\text{II}}(p) = \left(\frac{1/k_{\text{om}}}{2T_{\text{II}} T_r p + 1}\right) \approx \frac{1/k_{\text{om}}}{2T_{\text{II}} p + 1}$$

(10)

The open loop system has a transfer function:

$$W_{\text{II}}(p)W_{\text{KM}}(p) = W_{\text{PM}}(p) \left(\frac{1/k_{\text{om}}}{2T_{\text{II}} p + 1}\right) \frac{3}{2T_{\text{II}} p + 1}$$

(11)

As a result, the control object is represented by an inertial link with a small time constant, and the synthesis problem is solved by using an I-controller. The uncompensated time constant of the KM will be determined as $T_{\text{II}} M = 2T_{\text{II}} T_r$, then the open loop will take the form:

$$W_{\text{II}}(p)W_{\text{KM}}(p) = W_{\text{PM}}(p) \left(\frac{1/k_{\text{om}}}{2T_{\text{II}} p + 1}\right) \frac{3}{2T_{\text{II}} p + 1}$$

(12)

Using the conditions of adjustment (12) of the circuit for maintenance, we determine the coefficient of the I-torque regulator:

$$T_{\text{PM}} = \frac{6k_{\text{om}} P_{\text{om}} T_{\text{II}}}{k_{\text{om}}}$$

(13)

The presence of an integral component in the KM will compensate for the static error that occurs when the moment of resistance on the motor shaft changes[7].

In turn, the torque control loop is internal to the speed control loop. Here, too, due to the smallness of the uncompensated time constant $T_{\text{II}} M$, the transfer function is approximated with a sufficient degree of accuracy by expression (13), and the uncompensated time constant is $T_{\text{II}} C = 2T_{\text{II}} T_r M = 4T_{\text{II}} T_r$. The open loop system has a transfer function:

$$W_{\text{PC}}(p)W_{\text{KC}}(p) = W_{\text{PC}}(p) \left(\frac{1/k_{\text{om}}}{2T_{\text{II}} p + 1}\right) \left(\frac{1}{T_{\text{II}} p}\right)$$

(14)
As a result, the control object is represented in the form of series-connected links - inertial, with a small time constant, and an integration link, with a large time constant. For KC, tuning is performed on CO in order to maintain the speed at a given level. Using the PI controller, we get the following open loop transfer function:

\[
W_{\text{PC}}(p)W_{\text{KC}}(p) = \left(\frac{k_{\text{PC}}(T_{\text{PC}}p+1)}{T_{\text{PC}}p}\right)\left(\frac{1}{T_{\text{PC}}p+1}\right)\left(\frac{1}{T_{\mu}}\right) \quad (15)
\]

Using the conditions for setting (1.2) of the CO loop, we determine the coefficient of the PI controller speed:

\[
k_{\text{PC}} = \frac{k_{\text{om}}}{\theta k_{\text{oC}} T_{\mu}}; \quad T_{\text{PC}} = 16 T_{\mu} \quad (16)
\]

Setting the KC to CO allows you to compensate for the static error that occurs when the moment of resistance on the motor shaft changes and thereby maintain the set speed. The KC tuned to the symmetric optimum is characterized by a significant overshoot, to reduce which it is necessary to consistently put a filter calculated according to (15) taking into account \(\phi = T_{\mu} C\):

\[
W_{\phi}(p) = \frac{1}{4T_{\phi}p+1} \quad (17)
\]

When implementing the principle of vector control, it is necessary to \(\psi_{\text{δх}} = \text{const}\), which will make it possible to control the electromagnetic moment by changing the projection of the stator current onto the longitudinal axis of the \(x, y\) coordinate system. At the same time, to ensure a constant magnetic flux, it is necessary to control the projection of the stator current \(i_{sx}\) onto the transverse coordinate axis in such a way that for any changes in the transverse component of the rotor current \(i_{rx}\), the main magnetic flux \(\psi_{\text{δх}} = \psi_{\mu}\text{const}\).

Due to the existing cross-links, a change in the projection of the stator current \(i_{sx}\) affects the longitudinal component \(i_{sy}\), which determines the electromagnetic moment. Therefore, in the vector control system, it is necessary to ensure the operation mode of the stator current control loop, at which \(i_{sx} = 0\). For this, the control system includes a component regulator \(i_{sx}=0\). Changing the current projection is carried out by adjusting the opening angle of the thyristors in the stator HT, its structural diagram is shown in figure 6.

The synthesis of the controller transfer function will be similar to the \(i_{sy}\) component of the stator current, provided that a zero value is set at the input. Based on the structure of the subordinate regulation synthesized in this paragraph, we will calculate the parameters of the regulators and build a simulation model of the control system of the ED with AED with vector control.

References: