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Research Original Article

Electromechanical Devices of Adaptive and Control-Tracking Systems

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Abstract
In the presented work, some characteristics of devices of adaptive and control-tracking control systems are considered. The characteristic features of angle sensors, methods of converting analog signals with high accuracy (for example, sine-cosine transformers) occupies a leading position among the development and research of tracking systems. The modern electronic element base opens up new possibilities - the creation of tracking digital angle converters (TDAC) using the principles of digital tracking and adaptive control in them. Stability, efficiency, load form determines the reliability, accuracy, economy, service life of electromechanical automation devices, test equipment, etc. Determining the characteristics, establishing analytical relationships between the initial data and output parameters is one of the stages of the algorithm for solving the problems of designing equipment parameters for monitoring and tracking control systems, which in turn contributes to the development of a mathematical model from a system of equations, the joint solution of which allows you to establish analytical relationships between the initial data and settings.
Keywords: electromechanical device, adaptive system, tracking system, characteristic, control, signal, input, output, digital, angle converter, electric drive, efficiency, efficiency, reliability, source, phase, amplitude.

Introduction
The unity of methods of control theory allows to synthesize control systems, has the ability to change the parameters of the controller or depending on the change in the parameters of control objects, or the ability to change the structure of the controller, depending on external influence on the control object. Such control is called adaptive and is widely used in many areas of control theory (Kerimzade, 2023). Additional possibilities for improving control processes, depending on the size of the input values and designations that come from the measuring devices to the controlled installation, make it possible to carry out non-linear control of the object's activity with a change in the structure of the control installation. In this case, combinations of the laws of a linear regulator can be applied (Y.M, 2018). For example, if, according to the regulation law, the change in the neutral installation is known to be large sequential fluctuations, and according to the law of another linear regulation - weak changes, but a smooth approach to the steady state - then at some point A - first, the connection is made according to the first law, and then - according to second law and the change in y reaches a certain value y_a (A.V, 2016). As a result, the regulation process is expressed by a curve that combines two qualities of the regulation process - the frequency and smoothness of the process. The application of this approach facilitates the control process in a short period without over-control or without control fluctuations. This is used to control a non-linear system or to control a system with variable parameters (Wei et al., 2004). Examples of such systems include asynchronous machines, magnetic bearing vehicles, magnetic bearings, etc. Mechanical systems include the inverted pendulum, lifting and transport machines, robots, steppers, submersibles, etc. Reliability, accuracy and service life of electromechanical devices of control and tracking control systems are determined by the efficiency, stability and shape of the load. For complex control and tracking equipment during testing, these features are one of the important conditions for ensuring accuracy. Monitoring equipment and systems are used to determine the values of physical parameters. Technological processes are characterized by a certain unity of such physical parameters.

Formulation of the Problem
By the nature of the change in the control influence, servo systems are a kind of automatic control system. In tracking systems, the control action is a variable parameter, but its mathematical analysis in time is not determined, since the signal source is external, and the law of its change is not known in advance (Abdullaev Ya.R., 2018), (G.S., 2010), (G. J. S. Kerimzade G.S., 2023), (H. J. I. Kerimzade G.S., 2023). The control uses the principle of adaptation, which changes all the parameters of the system by the influence of external factors and the movement of the system is subject to quality changes. At the same time, the principles of control do not allow ensuring the normal operation of the system and it is necessary to

change the parameters and even the structure of the system in the process of control. As a result of the appointment of servo systems for the execution of the control action at the output with a sufficiently high accuracy, the error is presented as a characteristic and this explains the dynamic features of the servo system (N.F, 2017), (Abdullaev Ya.R., Kerimzade G.S., 2021), (Hasibuan et al., 2021). The error in servo systems as a signal, and depending on its value, the actuator is controlled. The control influence is compared with the controlled variable, and so-called comparative elements are used to perform the comparison operation. The control action and the controlled parameter arriving at the inputs of the comparative element must initially change and be given in the form of energy and correspondence signals. These operations are performed by the measuring element from the control action. The control and tracking device consists of a structurally integral whole, not divided into separate parts of the device (for example, a spring pressure gauge for measuring pressure, a mercury glass thermometer for measuring temperature, etc.). Such a device is directly assigned for tracking when processing the incoming information signal. The control-tracking system organizes the unity of measuring instruments (measuring instruments, equipment, converters) and communication channels among themselves, combined auxiliary means, which are determined for tracking when processing signals of incoming information or for automatic processing, or transmission and use in automatic control systems (S, 2016). Each part of the control and tracking system individually plays a decisive role in the independent control process. Control and tracking systems are divided into analog and digital (Alme et al., 2010). In analog systems, indicators are functions of changing the tracking parameters, and in digital systems, indicators are presented in digital forms, automatic discrete signals of tracking information are created (Voldek A.İ., 2007), (Ueyd P., 2011), (C.Mervert, 2014), (A.S, 2019), (V.V, 2018).

Solutıon Methods

Corrective devices are used to ensure the stability of the automatic control process of the system and satisfy the quality conditions of the control process (Seborg et al., 2016). As an example, the input value (demodulated) of the shaft rotation angle error Ω with the principle of the servo microcircuit operation algorithm ie is given (Wei et al., 2004):

$$\Delta U(\Omega, \Psi) = U_0 \sin(\Omega - \Psi) \tag{1}$$

If we take into account that the tracking system implements the corresponding calculation process, that is, $\lim_{t\to\infty}\Delta U(\Omega,\Psi)=0$l, then we can apply the "first limit" property $\lim_{\Omega\to\psi}\sin(\Omega-\Psi)$ to calculate the error as a linear you can get the expression:

$$\Delta U(\Omega, \Psi) = U_0 \times (\Omega - \Psi) \tag{2}$$

Expression (2) corresponds to a narrow error range (Ω-Ψ) , since formula (1) must be used, which requires equipment, time and software resources. Such a problem is carried out by means of the devices that are part of the microcircuit, for example, using the E-operator method, the problem of the method of synthesizing an alternative algorithm for the tracking digital angle converter (TDAC) is solved. In this case, a transfer function is applied; by changing the speed and angle of rotation of the TDAC shaft, the formation of a digital output signal is taken into account; taking into account the correspondence of the tracking process, the error formation condition is written as system (3):

$$\begin{cases} \left|\Omega - \Psi\right| \le \alpha \text{ at, then } \Delta U(t, \Omega, \Psi) = \dfrac{1}{\alpha} U_0 (\Omega - \Psi) \\ then \left|\Delta U(t, \Omega, \Psi)\right| = U_0 \end{cases} \tag{3}$$

Figure 1 shows a graph of the error function, and figure 2 shows the structure of the TDAC algorithm.

$F_{in.}(p)$- input action (demodulated) proportional to the angle of rotation of the shaft; $U_1(p)$, $U_2(p)$- intermediate signals of the TDAC structure; $F_{out.}(p)$- shaft angle output value; V(p)- the output is the rate of change of the angle of rotation of the shaft. Constants included in formulas (constants):

$$W_1(p) = \frac{k(1 + T_1 p)}{(1 + T_2 p)(1 + T_3 p)} \tag{4}$$

$$W_2(p) = \frac{1}{p} \tag{5}$$

According to the block diagram in fig. 2:

$$\begin{cases} U_1(p) = F_{in.}(p) - F_{out}(p) \\ U_2(p) \xleftarrow{W_0} U_1(p) \\ V(p) = U_2(p) W_1(p) \\ F_{out} = V(p) W_2(p) \end{cases} \tag{6}$$

The first equation of system (6) corresponds to the algebraic equation:

$$U_1(t) = f_{in}(t) - f_{out}(t) \tag{7}$$

The second equation of the system (6) corresponds to the conditions (3), which are implemented programmatically in the microcontroller. The third equation of system (6) generates the output signal of the rate of change of the angle of position of the output shaft of the TDAC. Given expression (4):

$$V(p) = U_2(p) \times k \frac{(1+T_1 p)}{(1+T_2 p)(1+T_3 p)} \quad (8)$$

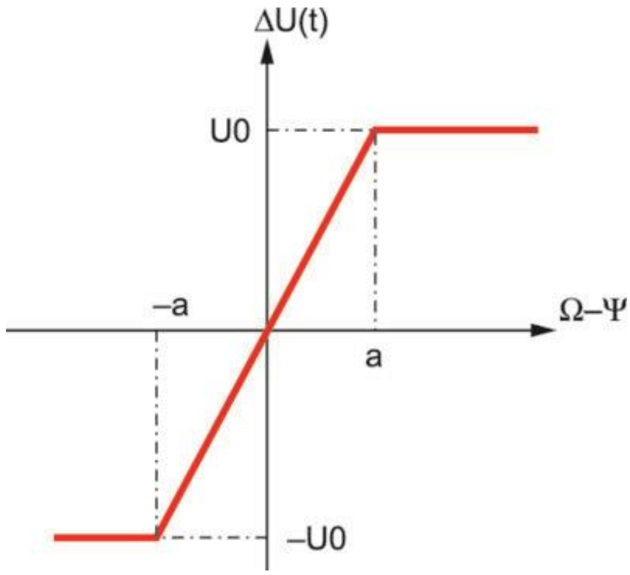

Figure 1. Graph of the error function

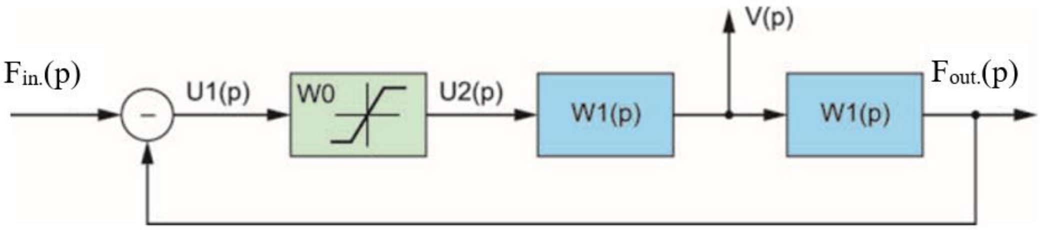

Figure 2. Structure of the tracking digital angle converter algorithm

Taking into account expression (5), the fourth equation of system (6) corresponds to:

$$F_{out}(p) = V(p) \times \frac{1}{p} \quad (9)$$

In condition (3), equations (7), (8) and (9) express the functioning of the TDAC algorithms. The synthesis of the algorithms of these formulas is applied by the algebraic E-operator method for transforming differential equations, which allows the transformation of linear differential equations, as well as their operator expressions according to Laplace. Therefore, in the transfer function, it is enough to replace the derivatives $(y)^k$ or operators $(p)^k$ with the corresponding expressions as $(1-E)^\kappa/\Delta t^k$, then express the output variable. The resulting expression expresses a linear combination of the values of the output variable that changes over time. The use of the operator E in expression (8) leads to the following equation:

$$V(t) = k_6(U_2(t) \times E \times k_1 + U_2(t)k_2 - V(t) \times E^2 k_3 + V(t) \times Ek_4 \quad (10)$$

A tracking control system is an automatic control system, which, with an unknown law of change in the controlled value, the controlled parameter, is distinguished by an arbitrary influencing feature. The dynamic features of the servo system are determined by the value of the error. In addition, in servo systems, the error signal in the regulation of the object is taken as a signal that depends on the value and nature. Systems are divided into static and astatic. Static systems are controlled by the value of the error: there is an error, there is control in the system. Astatic systems in the presence of a constant parameter error automatically perform their functions. The tracking system can be implemented by various fundamental principles of control and programs, in contrast to software control systems, in such systems, instead of program sensors, a tracking device for monitoring changes in external influences is installed. In tracking systems, the control effect is a variable parameter, but mathematical analysis is not determined in time, since the signal source as an external factor is not known in advance. The error in servo systems covers the dynamic features of the system. In servo systems, the error is received by such a signal that, depending on its value, the actuator motor is controlled. The main element of the tracking system is an error signal meter - a discriminator. To describe the discriminator and analyze the features, the discriminator characteristic (DC) is used (fig. 3).

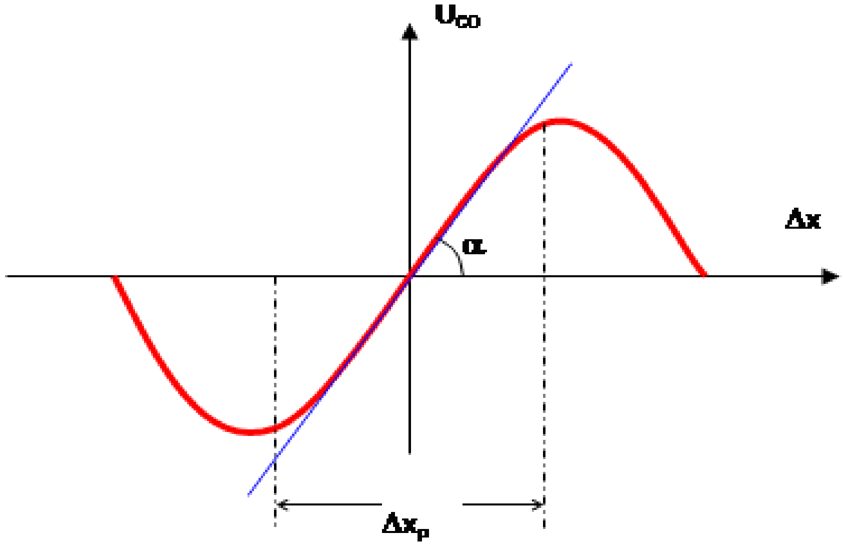

Figure 3. Discriminatory characteristic

The discriminatory characteristic (DC) is represented by two main parameters: the width of the working area D_{xp} (volume) and the steepness of the working area S=tgα. The scope DC determines the maximum allowable control errors of the servo system. The steepness DC determines the potential for accuracy in measuring the coordinates of the servo system. For the stability of the measurement accuracy under various control and measuring conditions, it is necessary to ensure the fulfillment of the condition S=const. Typically, the technical implementation of discriminators is based on the sum-difference principle of signal processing. Technically, to form DC, a phase detector FD is used, which is used for input signals (Rohde et al., 2021):

measurable: $U_{meas.}(t) = U_{meas.\max}\cos(\omega t + \psi_{meas.})$;

support: $U_{\sup port}(t) = U_{\sup port.\max}\cos(\omega t + \psi_{\sup port.})$,

here U_{max} - is the signal amplitude, ψ - is the signal phase.

The output signal FD depends on the product of the amplitude of the input signals and on the cosine of their phase difference:

$$U_{FD}(t) = U_{meas.\max} \times U_{\sup port.\max}\cos(\psi_{\sup port} - \psi_{meas.}) \quad (11)$$

Tracking system as an automatic control system, according to the algorithm of which, depending on the value of the variable signal at the input, the output signal changes. According to the structure of the tracking system (fig. 2), each tracking system has an error signal meter (discriminator). The calculation and storage of the coordinate value, the rate of change is performed in the generator of smoothing values, and in special computing devices it is implemented by the program. For the discriminator in the actuator, which is part of the tracking system, a reference signal is generated by the value of the parameter determined by the coordinate code. The signal from the output of the servo system is transferred to the input to calculate and minimize the serial error signal.

$$\begin{cases} x_{n.E.} = x_{n-1} + x'_{n-1} \cdot T \\ \Delta x_n = x_n - x_{n.E.} \\ x_n = x_{n.E.} + K_1 \Delta x + x_0 \\ x'_n = x'_{n-1} + K_2 \Delta x + x'_0 \end{cases}, \quad (12)$$

here K_1 and K_2 are the coefficients that determine the stability of the work and the time constant of the servo system, as well as random and dynamic errors; x_0 and x'_0 – are the initial values of the coordinate and its derivative in the purposeful-search mode.

In monitoring and tracking control systems, an electric motor can be noted as an implemented electric drive, by means of which, to set in motion the working mechanisms, electrical energy is converted into mechanical energy. The advantages include fast response, high starting torque, smooth speed control, simple operation, etc. The main parameters include torque, power, efficiency, rated voltage, rotational speed, moment of inertia, electrical time constant, mechanical characteristic. Depending on the type of efficiency and design, from 10 to 99% can be applied. The International Electrotechnical Commission (IEC) defines performance requirements for electric motors. According to the IEC standard, 4 efficiency classes are established for electric motors IE1, IE2, IE3, IE4 (fig. 4). Depending on the field of application, comparative characteristics of electric motors with external commutation are shown (fig. 5).

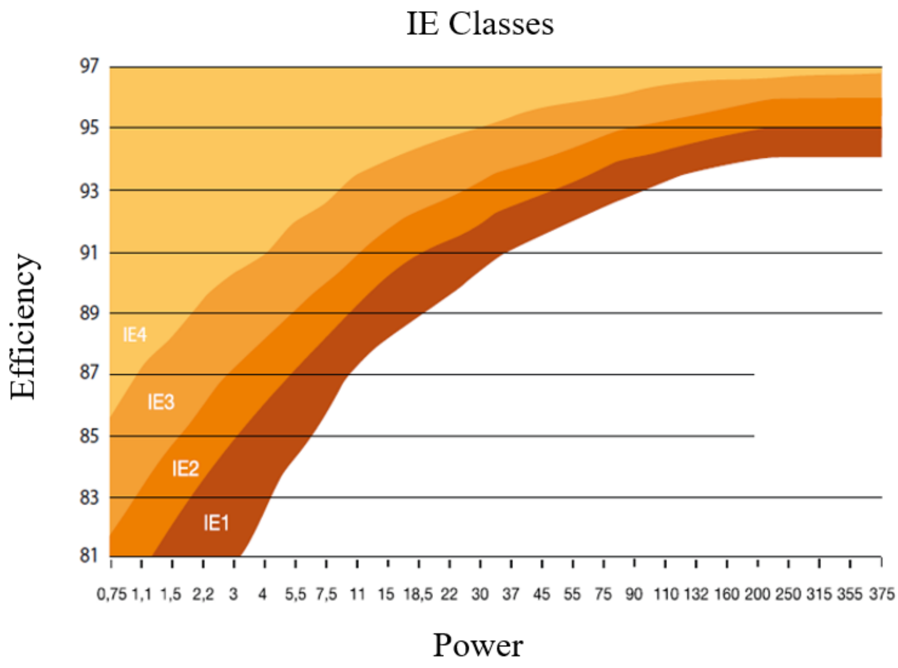

Figure 4. Efficiency and power dependencies (according to the IE standard for efficiency classes)

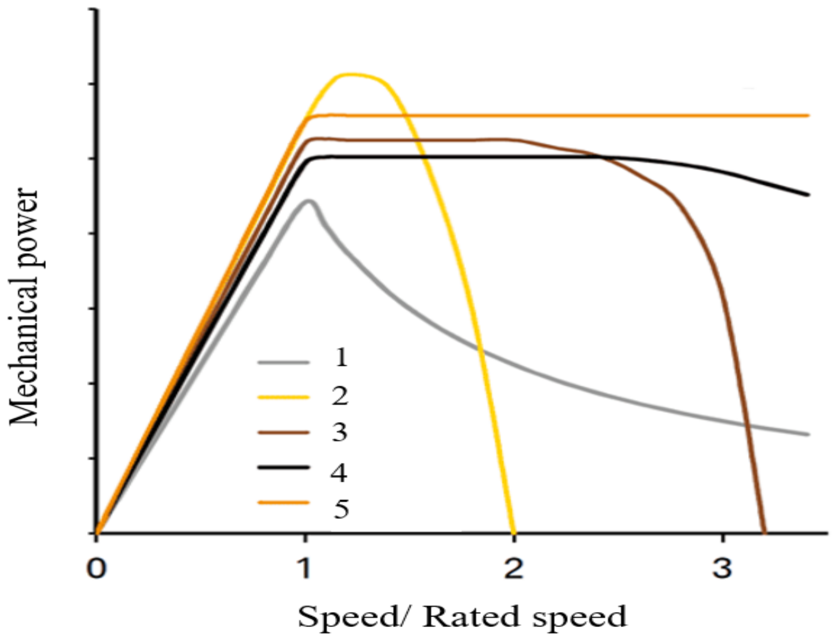

Figure 5. Dependences of mechanical power and speed/rated speed

1 - asynchronous motor with a squirrel-cage rotor;
2 - synchronous motor with fixation of magnets;
3 - synchronous motor with natural magnets;
4 - reactive synchronous motor with unique magnets;
5 - synchronous motor with excitation circuit.

Conclusions

On the basis of the scientific and technical base, according to the sources under consideration, an alternative algorithm for the tracking digital angle converter (TDAC) was synthesized. The synthesized adaptive algorithms of the TDAC of the second and third kind contribute to a targeted influence on transient processes, while narrowing or expanding the frequency band of the logarithmic amplitude characteristic from zero to the maximum cutoff frequency. Based on cheap modern controllers, the compactness of the presented algorithms allows you to create an effective calculation process using software-apparatus for accurate measurement of the shaft rotation angle. The synthesis of algorithms is carried out by the method of the mathematical E-operator, which, in turn, contributes to the creation of structures with compact algorithms for the construction of real calculation programs. Functional diagrams of control systems for simple dynamic objects, analysis of their definition, capabilities, elemental composition and implemented control principles, as well as the construction of mathematical models of automatic control systems, transformation and research are analyzed. The features and requirements for modeling parameters, the advantages and parameters of the implemented electric drive of control and servo control systems, the main elements of the servo system for the regulation of various electromechanical devices of automation systems are considered.

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