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MODELING AND RESEARCH OF RELAY AUTOMATIC CONTROL SYSTEMS

Sh.R. Ubaydullaeva- c.t.s., associate professor
R.T. Gaziyeva - c.t.s., associate professor
Tashkent Institute of Irrigation and Agricultural Mechanization Engineers

Abstract

This article discusses the construction of a graph model of a relay automatic control system. Based on the graph model, relations are derived for calculating transients in a relay system. To describe and analyze relay systems of automatic control, a specific feature of the relay element is used, consisting in the fact that its output value can take only certain constant values. The maximum possible set of structural states for relay elements is three. Accordingly, the relay element introduces a structure discretization effect into the system. This feature makes it possible to study relay systems with relatively simple means and makes it possible to develop methods for their calculation to a certain extent similar to methods for calculating linear systems. In developing the graph method for the description and analysis of relay automatic systems, this position was primarily taken as a basis. This method can be successfully used if any of the typical relay elements is included in the system. A two-dimensional relay system is considered as an example. Based on the graph model, the output coordinates of the system are calculated and their graphs are constructed.

Key words: graph model, multidimensional relay system, macrostructure, calculating processes.

Introduction. In many sectors of the economy, including agriculture, automatic systems are used in which the control object is described by nonlinear equations.

The object of this study is relay systems of automatic control. Relay systems of automatic control are one of the classes of nonlinear systems; they have been actively and widely used in various stationary and non-stationary, moving control objects, in measuring and regulatory complexes for a long time. They are distinguished by simplicity of execution, settings, high reliability, resistance to the influence of non-stationary parameters and better dynamic properties compared to continuous systems.

At present, when thanks to modern control theory it is possible to create digital control systems of any complexity, relay systems should seem to take a back seat. However, interest in them has not only not weakened, but in recent years has even increased. This can be confirmed by a review of works on this topic and the achievements of digital technology, in particular, the appearance of contactless keys, operating amplifiers on chips, microcontrollers, as well as theoretical developments in the field of relay systems in various fields of technology [1-9].

From a theoretical point of view, relay systems are essentially non-linear, which, on the one hand, was the limiting factor of their use due to the complexity of the calculation, and on the other hand, caused the development of theories created specifically for this class of control systems. The list of issues related to the theory of relay systems, as well as to the theory of automatic control as a whole, is very wide. First of all, these are the features of their mathematical description, behavior in statics and dynamics, stability issues, special modes of relay systems of automatic control, etc. [10-15].

Thus, the urgency of the problem is determined by the widespread use of relay control systems and the need to study the dynamics of these systems in a wide range of parameters, the need to develop accurate methods that allow basic research and numerical calculations of specific nonlinear systems of automatic control. In this regard, the task of developing methods and algorithms for studying the dynamics of the functioning of relay systems of automatic control today is timely.

The purpose of this study is to develop, on the basis of graph models, a topological method for modeling and researching relay systems of automatic control.

To achieve this goal, the following tasks were solved: a complex of graph models of one-dimensional and multidimensional relay automatic control systems with various types of relay elements was developed, algorithms for studying the dynamics of the functioning of this class of systems are constructed.

In this work, a specific feature of relay systems is used, consisting in the fact that the shape of the output quantity does not depend on the shape of the input signal. This allows a mathematical analysis of relay systems by relatively simple means [16-20]. Moreover, this feature makes it possible to use methods of calculation, which, in a sense, are similar to methods of calculating linear systems. Such an analogy allows us to preserve the familiar concepts and terminology of linear control theory. For example, the concept of the transfer function, frequency and time characteristics.

Materials and methods. Consider the use of graph models to describe and analyze relay systems. In fig.1 is a structural diagram of a one-dimensional relay system. We pose the problem of finding the output signal of the system $x_1(t)$ for all time instants t ($t \geq t_0$, t_0 is the initial moment of time). The linear part of the system is represented by a m-th order dynamic link.

When developing a topological method for the description and analysis of relay systems of automatic control, a feature of the relay element is used, which consists of the fact that its output value can take only certain constant values. If the relay element is without a dead band, then the maximum possible number of structural states for it is two. For relay elements with a dead zone, three structural states are possible.

Without loss of generality, let us assume that in the system under consideration the relay element has an ideal characteristic, its output signal can take only two values + b or –b, where b is a certain constant number.

Let at the moment t0 the value of the output signal of the relay element is $Z(t_0) = b$ and the initial conditions are such that at some moment t_1 the relay element switches. On the time interval $t\ [t_0,\ t_1]$ the system is characterized by a certain structural state S_1.

We know the formation of the graph model [21-22] of the continuous part of the system, the relay element is taken into account by connecting an integrating link to the continuous part of the system.

As is known, in the study and design of control systems, the Laplace transform is used, therefore, the transfer function of the relay element is 1/p, where p is a complex variable.

The vertex characterizing the output signal of the relay element has a weight $z=bv-b$. The graph model of the system, reflecting its behavior on the interval $t \in [t_0,\ t_1]$, is presented in fig. 2.

From consideration of the graph model [23-25], it is easy to write the equation of state of the system on the time interval $t \in [t_0,\ t_1]$:

$$\vec{X}(p)=\vec{A}(p)\vec{X}(p)+\vec{B}(p)Z(t_0) \qquad (1)$$

Having performed the inverse Laplace transform, we have

$$\vec{X}(t)=\vec{A}(t-t_0)\vec{X}(t_0)+\vec{B}(t-t_0)Z(t_0) \qquad (2)$$

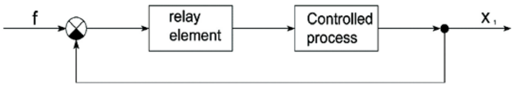

Fig.1. Block diagram of a one-dimensional relay system

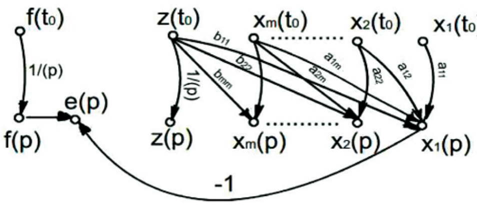

Fig.2. The graph model of the relay system

It should be noted that the switching moment t_1 of the relay element is unknown in advance and is determined from the equation $e(t_1)=a_1$ (3)

where $e(t_1)= f(t_1) - x_1(t_1)$ and a_1 is the sensitivity threshold of the relay element. In the general case, equation (3) is transcendental and is solved by one of the known numerical methods (Newton's method, iterations, etc.) Having determined the switching moment of the relay element t_1, from relation (4) we can find the values of state variables at $t = t_1$:

$$\vec{X}(t_1)=\vec{A}(t_1-t_0)\vec{X}(t_0)+\vec{B}(t_1-t_0)Z(t_0) \qquad (4)$$

These values are initial for determining the processes in the next step, i.e. on the time interval $t \in [t_1,\ t_2]$, where t_2 is the second switching moment of the relay element. The structure of the graph model on the interval $t \in [t_1,\ t_2]$, does not change, only the initial conditions change. Therefore, there is no need to rebuild the graph model; just use the formalized model shown in fig. 2.

On the time interval $t \in [t_1,\ t_2]$ the equations for calculating the processes will be as follows:

$$\vec{X}(p)=\vec{A}(p)\vec{X}(t_1)+\vec{B}(p)Z(t_1) \qquad (5)$$

where will we have

$$\vec{X}(t)=\vec{A}(t-t_1)\vec{X}(t_1)+\vec{B}(t-t_1)Z(t_1) \qquad (6)$$

To determine the second moment of switching the relay element, it is necessary to solve the equation for the input signal of the relay element $e(t_2)=a_1$. The values of the state variables at $t = t_2$, which are the initial conditions for determining the processes in the next time interval $t \in [t_2,\ t_3]$, are found from the relation

$$\vec{X}(t_2)=\vec{A}(t_2-t_1)\vec{X}(t_1)+\vec{B}(t_2-t_1)Z(t_1) \qquad (7)$$

In the general case, the ratios for calculating the processes on the segment $t \in [t_{n-1},\ t_n]$, where $n = 1, 2, \ldots$, will have the form:

$$\vec{X}(t)=\vec{A}(t-t_{n-1})\vec{X}(t_{n-1})+\vec{B}(t-t_{n-1})Z(t_{n-1}) \qquad (8)$$

Results and discussion. As an example, consider a two-dimensional relay system of automatic control. Figure 3 shows the structural diagram of this system. Figure 4 shows its graph model, where the relay elements are taken into account by opening the system and adding to the continuous part of the system of links with the transfer function 1/p. Depending on the input signals e_1 and e_2, the output signals of the relay z_1 and z_2 take the values: $z_1=- c_1\ v\ c_1$, $z_2=- c_2\ v\ c_2$. That is, with the known signals z_1 and z_2, the processes can be considered directly according to this graph model after replacing the transfers of arcs $a_{ij}(p)$ by their originals $a_{ij}(t)$. However, the switching moments of the relay elements are not known in advance and should be determined in this case from the solution of the equations

$$e_1 = f_1 - y_1 \qquad (9)$$

$$e_2 = f_2 - y_2 \qquad (10)$$

for τ_1 and τ_2 (τ_1 and τ_2 are the switching moments of the 1st and 2nd relay elements). This can be done using well-known methods for solving transcendental equations (iteration, Newton, chord method, combined method, etc.).

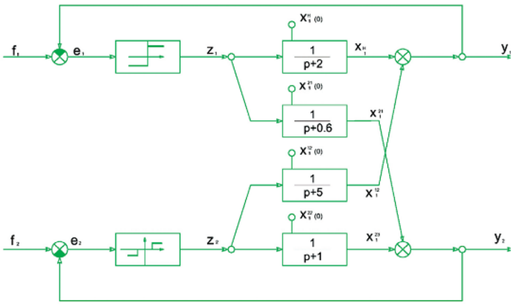

Fig.3. Block diagram of a two-dimensional relay automatic control system

After solving the equations for τ_1 and τ_2, the smallest of them is taken into account and the values of the variables $x_1^{11}, x_1^{21}, x_1^{22}, x_1^{12}$ for this switching moment are determined. They are the initial conditions for the next step in calculating the dynamics. In the next step, the calculations are again performed in parallel on both channels. Until the determination of the minimum time

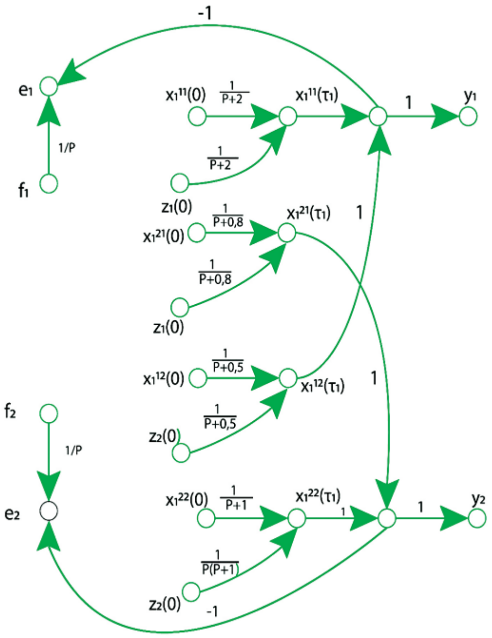

Fig. 4. Graph model of a two-dimensional relay control system of automatic control

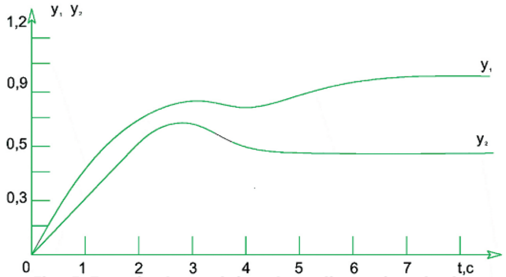

Fig. 5. Transient graph in a two-dimensional relay automatic control system

interval, after which one of the relay elements will switch. The described procedure is repeated for all steps of the process calculation, is transferred to the general case of multidimensional relay systems, and is convenient from the point of view of computer simulation of processes.

For multidimensional relay systems, an algorithm for calculating transients based on a graph model can be formulated as follows.

Algorithm 1.

2. At the input of the relay elements, the macrostructure of the system are separated. Dynamic integrating links are introduced into all separate and cross channels. A dynamic graph model of the system is being built.

3. Based on automatic models of relay elements and solving transcendental equations, it is relatively τ_i=*1,2.., N* determined. $\tau_{\min} = \min\{\tau_i\}$

4. All state variables are calculated taking into account τ_{min} and the transition of the system to the next structural state is determined.

5. The state of finite state machines with memory is fixed (in the presence of relay elements with a hysteresis loop).

6. The return to paragraph 2 of the algorithm.

For the considered illustrative system, Fig. 5 shows the curves obtained on the basis of the above algorithm.

Conclusions. From the considered example, we can conclude that modeling based on dynamic graphs is an effective method for solving problems of analysis of one-dimensional and multidimensional relay systems. We got a simple and convenient algorithm for calculating transients for multidimensional systems with various relay elements in the control channels.

The next stage of research is the use of graph modeling for the calculation of multidimensional relay systems with delay in individual channels. In such systems, there is a temporary delay of control signals. This phenomenon introduces difficulties in the calculation of such systems.

We also note that the proposed approach is convenient from the point of view of solving the synthesis problem of relay automatic systems: the synthesis problem can be considered as determination among the set of admissible trajectories S_t, optimal in one sense or another, of the trajectory $S_{ti} \in S_t$. The optimal trajectory can be realized by choosing the mode of operation of the relay part, or by changing the characteristics of individual structural states.

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