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Mathematical Model of Automatic Control System for Asynchronous Multimotor Drive

S. S. Issenov, I. A. Pyastolova
Energy School, Department of Electrical Equipment Operation, Saken Seifullin Agricultural University,
Main Building, Zhenis Ave. 62, Astana, 010000 Kazakhstan, phone +7 7172 317526
isenov_sultan@mail.ru

***Abstract*—The work contains the findings of the application of the finite automata theory that resulted in the development of mathematical models of automated control system for the asynchronous multimotor drive using Mealy apparatus. The work also proposes how to vividly describe the sequence of logical operations - underlying the creation of a programming language - of a digital control device with the use of an algorithm language and Boolean algebra for the automated operation of a microprocessor device, which allows raising the level of automatization of the asynchronous multimotor drive control system.**

***Index Terms*—Automatic control, algorithm design and analysis, Boolean algebra, mathematical model.**

I. INTRODUCTION

Recent intensification in manufacture increased the scale of transportation and handling operations. It necessitated enhancement of performance and automation of control over lifting and handling operations.

Crane mechanism operations are defined by the crane function and manufacturing process conditions. In some cases, it is expedient to use an asynchronous multimotor drive for translation mechanisms of crane installations accounting for process requirements and operation modes. Such phenomena as creeping of drive wheels, jamming of wheel flanges against railheads, difference in wheel diameters due to uneven wear are possible in the operation of such cranes. Uncoordinated rotation of motors is quite possible since the static loads on the supports are generally different and occasional, while the mechanical characteristics of the movement of mechanism's motors are not strictly identical [1].

To update such performance indicators of general industrial mechanisms as the stability and accuracy of the technological cycle, performance increase and control automation it is necessary to improve their electric drives.

One of the possible up-to-date solutions to that, provided the above mentioned shortcomings are rectified, is the automated pulse control of the asynchronous multimotor drive with the use of semiconductor means, which allows raising the technical level in the operation of electrical equipment.

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Based on the above, we have developed a method of automated pulse control of a multimotor asynchronous electrical drive with the use of bidirectional shift register and resistance boxes in order to provide coordinated rotation of electrical motors [2].

II. METHOD OF AUTOMATIC PULSE CONTROL OF TWO-MOTOR ASYNCHRONOUS ELECTRICAL DRIVE

The circuit diagram for the developed method in Fig. 1 contains: three-phase network; asynchronous motors with a phase-wound rotor – M1, M2; rectifiers – UZ1, UZ2; chokes – L1, L2; resistances – R1, R2; switches – S1, S2; bidirectional shift registers – BSR1, BSR2; resistance boxes and a galvanic isolation as an optocoupler – RB1, RB2; microprocessor control system – MCS; input port – IP; analog-to-digital converter – ADC; central processor – CP; timer – T; output port – OP; internal memory – IM; read-only memory – ROM; pulse-width modulator – PWM; internal bidirectional bus – IBB; liquid crystal display – LCD; control buttons – CB; stator circuit current sensors – SCCS1, SCCS2; stator currents matching unit – SCMU1, SCMU2; voltage sensors – VS1, VS2; voltages matching units – VMU1, VMU2.

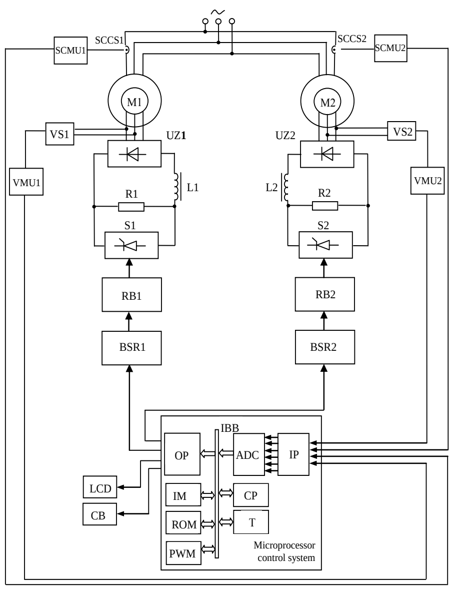


Fig. 1. Circuit diagram of method of automated pulse control of a multimotor asynchronous electrical drive with the use of bidirectional shift register and resistance boxes.

The concept of the developed method is as follows: the microprocessor control system receives analogue information on the operation process of the electromechanical system from the stator circuit and speed sensors. If the system's motors rotate with a deviation from the reference value, resistances are input with certain higher or lower values, which allows, depending on the actual operation mode, aligning the speeds for synchronous rotation of drives and leading them to the rated operation mode in accordance with the set operation program [3].

This method must be a base for development of an algorithm and a mathematical model of the multimotor asynchronous drive using a microprocessor device, bidirectional shift registers and resistance boxes as a control system.

Based on the analysis of the existing mathematical solutions, we have chosen the methods of automata theory in developing the model and the operation process of the digital device to ensure visualization and practical value [4].

III. Design of Mathematical Model of Automatic Control System for Asynchronous Multimotor Drive using Mealy Automaton

The mathematical model of any digital device is an abstract automate. The abstract automaton has one input and one output. It operates in discrete time having positive integer values $t = 0, 1, 2, \ldots$. At each moment t of the discrete time the automaton is in one state $a(t)$ out of the whole range of the states of the automaton, while at the reference time $t = 0$ it is always in the reference state $a(0) = a_1$. At the time t, being in the state $a(t)$, the automaton is capable of receiving a letter of the input alphabet at the input

$$z(t) \in Z. \tag{1}$$

In accord with the inputs' function, it will produce a letter of the output alphabet at the same time t

$$W(t) = \lambda[a(t);\, z(t)] \tag{2}$$

and will transit to the following state in accord with the function of transition

$$a(t+1) = \delta[a(t);\, z(t)]. \tag{3}$$

If some sequence of letters of the input alphabet $z(0)$, $z(1)$, $z(2)$, … – input word is fed letter by letter to the input of the automaton set in the reference state a_1, the letters of the output alphabet $z(0)$, $z(1)$, $z(2)$,… – input word will consistently appear at the output of the automate.

Basically, two automaton types are considered in the class of synchronous automatons: the Mealy automaton and the Moor automaton named after American scientists who had contributed to this field of research. There is a correspondence between Mealy and Moor automatons that allows transforming the function law of one of them into the other or vice versa. The Moor automaton may be considered as a special case of the Mealy automaton, which means that the sequence of the output states of the Mealy automaton is one tick ahead of the sequence of the output states of the Moor automaton. Thus, the difference between the Mealy and Moor automatons lies in the fact that the Mealy automaton's output state appears simultaneously with the input state causing it, and the same of the Moor automaton appears with one tick delay. The most common digital automaton is the Mealy automaton, and its function law is defined by the following equations:

$$\begin{cases} a(t+1) = \delta(a(t), z(t)), \\ w(t) = \lambda(a(t), z(t)),\; t = 0, 1, 2, \ldots . \end{cases} \tag{4}$$

The synthesis of the digital finite Mealy automaton is reduced to the following actions: 1) building the graph of the finite automaton; 2) building a structured table of transitions for the defined graph; 3) creating the logic chart of the automaton [5].

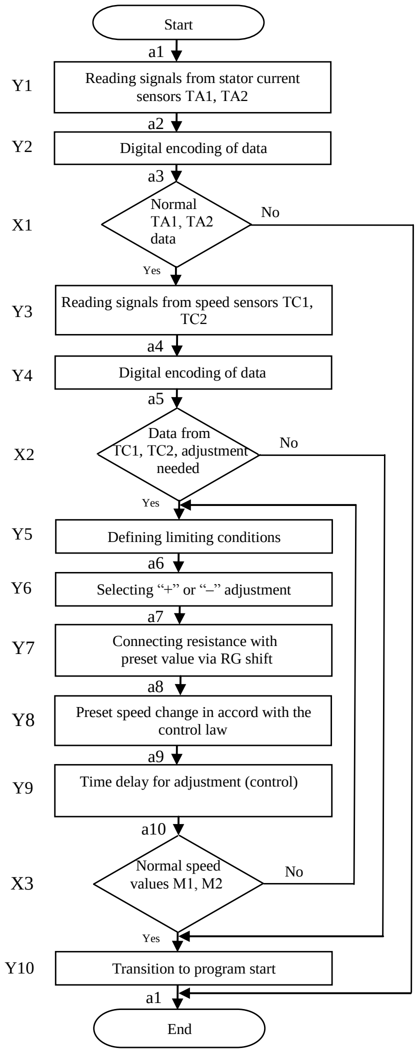
The flow-graph of the algorithm reflects the set of rules for automaton's transitions from one state into the other depending on the input information and the internal states of the automaton. When building the algorithm's flow-graph, a certain set of graphic symbols interconnected by lines is used. The symbols denote performed operations, while the arrow lines reflect their sequence.

There can be finite, operator and conventional symbols. An operator symbol is designated by a rectangular, inside which the legend of the operator realized at the current step of the algorithm is written. The operator symbol means performance of an operation or a set of operations for information processing.

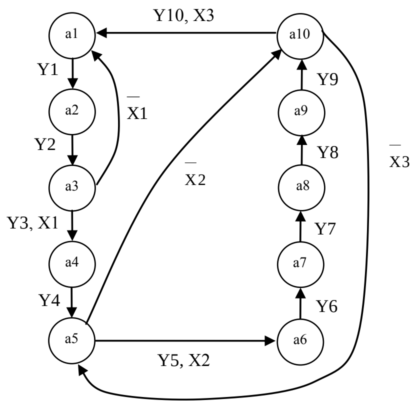
A logic symbol denotes the selected direction of the algorithm performance depending on observance or non-observance of a certain logic conditions, the designation of which is written into a rhomb. If the condition is observed, the fork will be on the output line designated as "1" or the "Yes" symbol, otherwise it will be on the output line designated as "0" or "No".

Based on the circuit diagram, we have developed the flow-graph and the graph for the Mealy automaton of the automatic pulse control device for the multimotor asynchronous drive with the use of bidirectional shift registers and resistance boxes (Fig. 2).

Since the number of states in the graph of the synthesized model of the controlling microprogram Mealy automaton is high we have drawn up the structured transition table for the Mealy automaton for automated pulse control of the multimotor asynchronous drive with the use of bidirectional shift registers and resistance boxes (Table I). Each row of the table contains state a_m wherefrom the transition is performed in the automaton; state a_s to which the automation transits from state a_m; $X(a_m, a_s)$, $Y(a_m, a_s)$ – input and output signals under the transition (a_m, a_s).



a)



b)

Fig. 2. Flow-graph of algorithm and graph of mealy automaton of automatic pulse control device for the multimotor asynchronous drive with the use of bidirectional shift registers and resistance boxes.

TABLE I. STRUCTURED TABLE OF TRANSITIONS FOR CONTROLLING MICROPROGRAM MEALY AUTOMATON OF AUTOMATIC CONTROL DEVICE FOR THE MULTIMOTOR ASYNCHRONOUS DRIVE WITH THE USE OF BIDIRECTIONAL SHIFT REGISTERS AND RESISTANCE BOXES.

A_M	$K(A_M)$	A_S	$K(A_S)$	$X(A_M, A_S)$	$Y(A_M, A_S)$	$\tilde{F}(A_M, A_S)$
A_1	0000	A_2	0001	1	Y_1	Φ_4
A_2	0001	A_3	0010	1	Y_2	Φ_3, Φ_4
A_3	0010	A_4 A_1	0011 0000	X_1 $\bar{X}_1$	Y_3 –	Φ_4
A_4	0011	A_5	0100	1	Y_4	Φ_2, Φ_3, Φ_4
A_5	0100	A_6 A_{10}	0101 1001	X_2 $\bar{X}_2$	Y_5 –	Φ_4
A_6	0101	A_7	0110	1	Y_6	Φ_3, Φ_4
A_7	0110	A_8	0111	1	Y_7	Φ_4
A_8	0111	A_9	1000	1	Y_8	Φ_1, Φ_2, Φ_3, Φ_4
A_9	1000	A_{10}	1001	1	Y_9	Φ_4
A_{10}	1001	A_1 A_5	0000 0100	X_3 $\bar{X}_3$	Y_{10} –	Φ_1, Φ_4

The structured table of transitions of the controlling microprogram Mealy automaton of the automated pulse control device for the speeds of the multimotor asynchronous drive with the use of bidirectional shift registers and resistance boxes allowed us to determine the:

– system of Boolean equations of output functions:

$$\begin{cases} Y_1 = \bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3 \bar{\tau}_4, \\ Y_2 = \bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3 \tau_4, \\ Y_3 = \bar{\tau}_1 \bar{\tau}_2 \tau_3 \bar{\tau}_4 X_1, \\ Y_4 = \bar{\tau}_1 \bar{\tau}_2 \tau_3 \tau_4, \\ Y_5 = \bar{\tau}_1 \tau_2 \bar{\tau}_3 \bar{\tau}_4 X_2, \\ Y_6 = \bar{\tau}_1 \tau_2 \bar{\tau}_3 \tau_4, \\ Y_7 = \bar{\tau}_1 \tau_2 \tau_3 \bar{\tau}_4, \\ Y_8 = \bar{\tau}_1 \tau_2 \tau_3 \tau_4, \\ Y_9 = \tau_1 \bar{\tau}_2 \bar{\tau}_3 \bar{\tau}_4, \\ Y_{10} = \tau_1 \bar{\tau}_2 \bar{\tau}_3 \tau_4 X_3, \end{cases} \tag{5}$$

– system of Boolean equations of excitation functions of elementary memory automatons:

$$\begin{cases} \varphi_1 = \bar{\tau}_1 \tau_2 \tau_3 \tau_4 \vee \tau_1 \bar{\tau}_2 \bar{\tau}_3 \tau_4 X_3, \\ \varphi_2 = \bar{\tau}_1 \bar{\tau}_2 \tau_3 \tau_4 \vee \bar{\tau}_1 \tau_2 \tau_3 \tau_4 \vee = \bar{\tau}_1 \tau_3 \tau_4, \\ \varphi_3 = \bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3 \tau_4 \vee \bar{\tau}_1 \bar{\tau}_2 \tau_3 \tau_4 \vee \bar{\tau}_1 \tau_2 \bar{\tau}_3 \tau_4 \vee \\ \vee \bar{\tau}_1 \tau_2 \tau_3 \tau_4 = \bar{\tau}_1 \bar{\tau}_2 \tau_4 \vee \bar{\tau}_1 \tau_2 \tau_4 = \bar{\tau}_1 \tau_4, \\ \varphi_4 = \bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3 \bar{\tau}_4 \vee \bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3 \tau_4 \vee \bar{\tau}_1 \bar{\tau}_2 \tau_3 \bar{\tau}_4 X_1 \vee \\ \vee \bar{\tau}_1 \bar{\tau}_2 \tau_3 \tau_4 \vee \bar{\tau}_1 \tau_2 \bar{\tau}_3 \bar{\tau}_4 X_2 \vee \bar{\tau}_1 \tau_2 \bar{\tau}_3 \tau_4 \vee \\ \vee \bar{\tau}_1 \tau_2 \tau_3 \bar{\tau}_4 \vee \bar{\tau}_1 \tau_2 \tau_3 \tau_4 \vee \tau_1 \bar{\tau}_2 \bar{\tau}_3 \bar{\tau}_4 \vee \tau_1 \bar{\tau}_2 \bar{\tau}_3 \tau_4 X_3 = \\ = \bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3 \vee \bar{\tau}_1 \bar{\tau}_2 \tau_3 \bar{\tau}_4 X_1 \vee \bar{\tau}_1 \tau_3 \tau_4 \vee \\ \vee \bar{\tau}_1 \tau_2 \bar{\tau}_3 \bar{\tau}_4 X_2 \vee \bar{\tau}_1 \bar{\tau}_3 \tau_4 \vee \bar{\tau}_1 \tau_2 \tau_3 \vee \bar{\tau}_2 \bar{\tau}_3 \bar{\tau}_4 \vee \\ \vee \tau_1 \bar{\tau}_2 \bar{\tau}_3 \tau_4 X_3 = \bar{\tau}_1 \tau_4 \vee \bar{\tau}_1 \bar{\tau}_2 \bar{\tau}_3 \vee \bar{\tau}_1 \bar{\tau}_2 \tau_3 \bar{\tau}_4 X_1 \vee \\ \vee \bar{\tau}_1 \tau_2 \bar{\tau}_3 \bar{\tau}_4 X_2 \vee \bar{\tau}_1 \tau_2 \tau_3 \vee \bar{\tau}_2 \bar{\tau}_3 \bar{\tau}_4 \vee \tau_1 \bar{\tau}_2 \bar{\tau}_3 \tau_4 X_3. \end{cases} \tag{6}$$

The system of equations of minimized functions of output signals and excitation signals of memory elements serves a basis for building a logic chart (Fig. 3) of the digital Mealy automaton of the automated pulse control device for the speeds of the multimotor asynchronous drive with the use of bidirectional shift registers and resistance boxes.

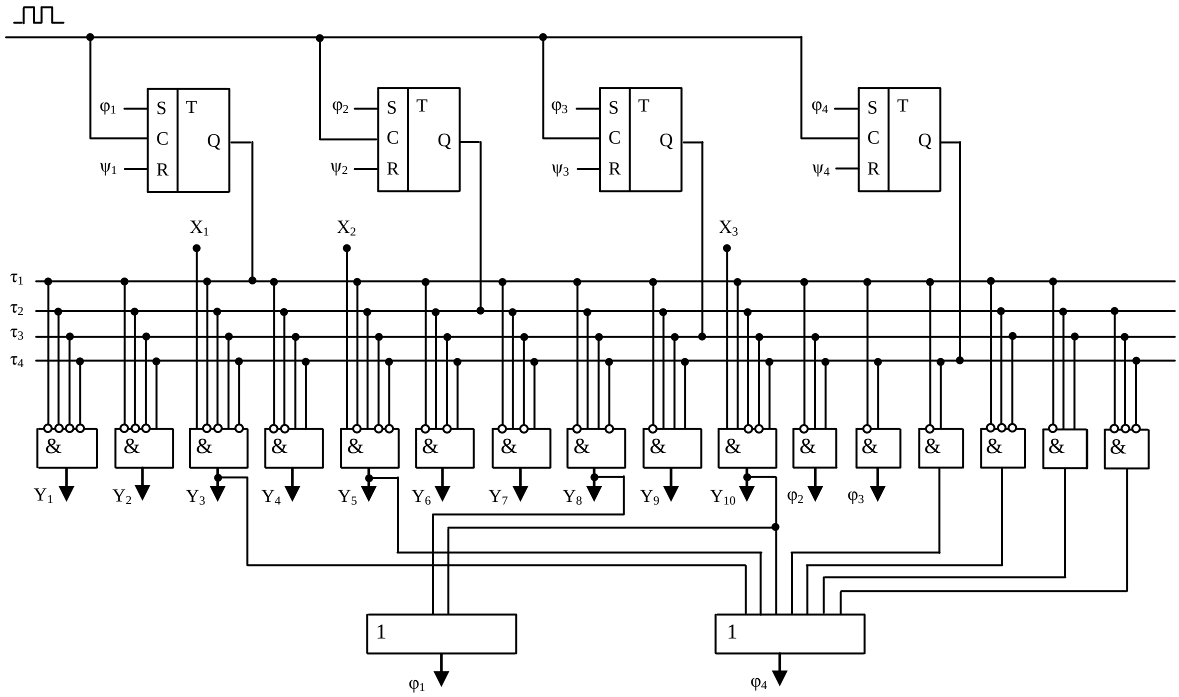


Fig. 3. Logic Chart of controlling microprogram mealy automaton of automatic control device for the multimotor asynchronous drive with the use of bidirectional shift registers and resistance boxes.

The accomplished research that allowed us to develop the operation algorithm and the graph of the Mealy automaton as well as the mathematical model of automated control of the multimotor asynchronous drive are the basis for creation of the operation program for the microprocessor control device that ensures enhanced automation level for electrical drives control and results in coordinated drive rotations.

IV. Conclusions

The work proposes the use of finite automata method – Mealy apparatus – in describing the logical processes within a microprocessor device control-ling an electromechanical system. It results in the design, based on a functional circuit, of the operation algorithm, the Mealy graph-automaton and the mathematical models of the automated control system of the asynchronous multimotor drive.

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