INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2024, VOL. 70, NO. 2, PP. 495-499
Manuscript received January 22, 2024; revised June, 2024. doi: 10.24425/ijet.2024.149571

Synthesis of an electronic control module for a selected technological node with a focus on its automation

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***Abstract*—The article presents problems related to the design of sequential control systems using algorithmic design method.**

Based on a graph describing the functions of signal processing, the method of fast programming of sequential electro-pneumatic systems and systems with logic elements is presented.

The developed sequential system was verified through simulation using the FluidSim computer-aided design software from Festo.

***Keywords*—analysis of technological processes; system graph; algorithmic method; programming sequential systems**

I. Introduction

In the design of automation systems, the analysis and synthesis of the conceptual diagram of the device [1,2,3] are of particular importance. Proper implementation of the diagram shortens the time of execution, preparation, and verification of the technical documentation of the device [4,5,6].

In the design of sequential systems [7,8], a description of the system in the form of a state transition and output graph or state transition and output tables is used. These are equivalent descriptions, but the description in the form of state transition and output tables is more convenient for further transformations in subsequent stages of sequential system synthesis.

The literature [9,10] presents principles for creating state transition and output tables, minimizing internal states, and encoding state transition and output tables.

The synthesis of sequential systems using the conventional method of state transition and output tables is straightforward when the number of inputs and internal states is not large [9].

For systems with more than three inputs and eight internal states, the synthesis algorithms become complicated, and the inconvenience of using state transition and output tables significantly increases.

Taking the above into account, it seems worthwhile to seek methods that reduce the inconvenience of synthesis and principles for implementing sequential systems using digital elements [11,12,13] of small, medium, and large-scale integration.

The article presents the synthesis of a technological node with a focus on its automation.

The control system synthesis is discussed [11] using the example of a technological process related to paint production, filling cans with paint, sealing filled cans, and arranging them on paint can pallets.

The described in the literature [11] process related to filling and sealing cans is carried out using two robots located at the conveyor belt carrying the cans.

The article presents an algorithmic method applied to the synthesis of sequential, asynchronous electro-pneumatic systems using logic elements.

An algorithmic method for designing asynchronous control systems is discussed, which allows the synthesis of virtually any electro-pneumatic system used in process automation.

Algorithmic method of designing sequential control systems presents the operation of the system in a graphical way. The graph describes the signal processing functions that enable fast programming of sequential asynchronous systems [12,13].

In the technological process, the kinematic structure is formed by actuators cooperating with electrically controlled pneumatic valves [14,15,16]

II. Connection formula and graph describing the operation of the system

Based on the description of the technological process, the description of the operation of the actuators and the assumptions made [11], a formula is created illustrating the operation of the machine, i.e., the sequence of operation of the driving elements, which in the analysed process are pneumatic actuators. If two actuators operate simultaneously, their symbols in the formula are placed one above the other. The connection formula is shown below, while the resulting cycle diagram is shown in the figure.

Connection formula:

$$S^{\pm}\begin{matrix}B^{-}C^{+}\\E^{-}E^{+}\end{matrix}F^{+}\begin{matrix}C^{-}B^{+}A^{-}B^{-}C^{+}\\G^{+}G^{-}F^{-}E^{-}E^{+}\end{matrix}F^{+}\begin{matrix}C^{-}B^{+}A^{+}\\D^{-}G^{+}G^{-}\end{matrix}D^{+}F^{-}$$

The selected sequence is based on seven actuators. Actuators A, B, D, and E are actuators that are extended in the initial state.

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When S button is pressed, actuators B and E begin to retract. After the retraction of actuators B and E, actuators C and E begin to extend, and so on, according to the connection formula.

The sequence is completed after the retraction of actuator F, and the system is waiting for the S button to be pressed again to restart the sequence.

Based on the cycle diagram and the connection formula, it is possible to create a graph illustrating the operation of the system, as shown in Figure 1.

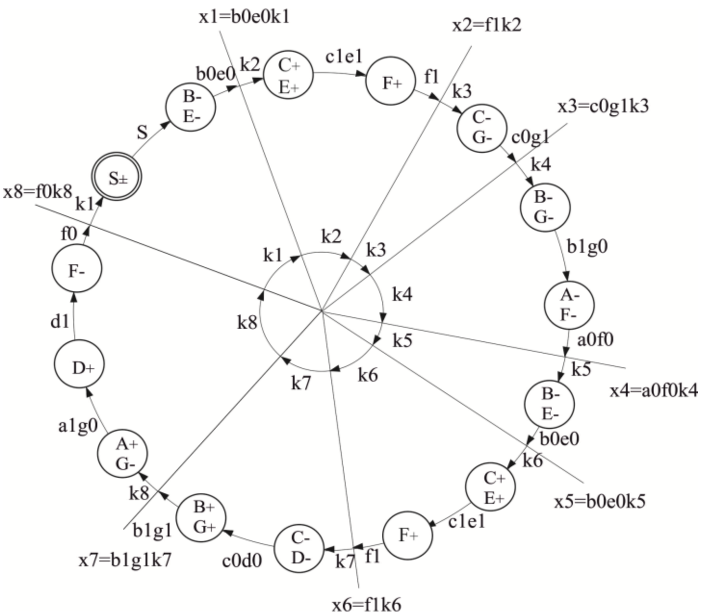

Fig.1. Graph of system operation

The graph is created by placing on its circle as many circles showing the state of the system as there are states of the elements in the connection formula. Each state circle will be the vertex of the system graph.

The system graph is described in such a way that the vertices of the graph are assigned symbols denoting a change in the state of driver elements, while the arches directed to the vertices are assigned the signals that cause this change. The arches coming out of the vertices are assigned signals informing that the desired state has been reached. The graph is divided into groups so that the change in the state of the driver element occurs only once within a group. Signals generated at the division boundary of the graph x1,x2, ... x8 are used to control the system's memory.

For example, for the graph shown, the signal coming out of vertex C+E+ is a signal c1e1 indicating the extension of actuators C and E. This signal, directed to the vertex F+, causes the extension of actuator F. The state S± (system start) is drawn in a double circle as a stable state, while the other states, as transient states, are drawn in a single circle.

Figure 2 shows the algorithm of the system, which is another form of writing the connection formula and cycle diagram.

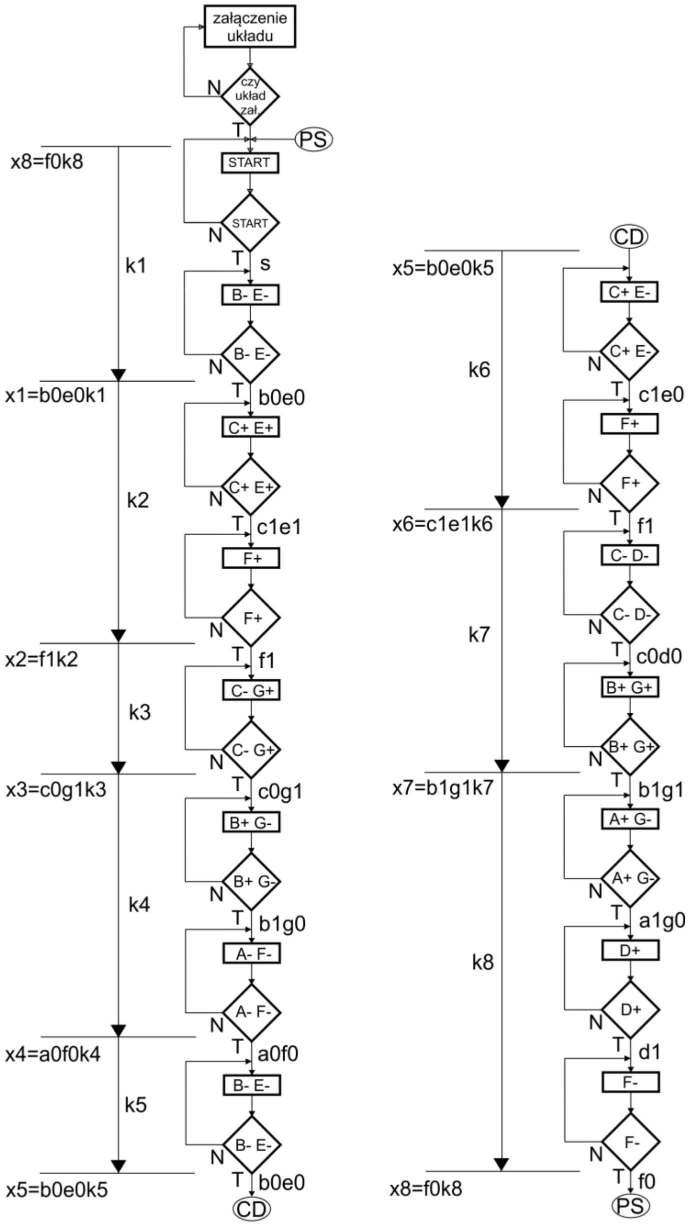

Fig.2. Algorithm of control system operation

III. Electronic diagram for the analysed technological node

Based on the presented system graph and the algorithm of system operation, it can be concluded that:

- the valve input causing the retraction of actuators B- and E- requires the implementation of the AND function sk1 (s start button signal, k1 memory state);
- the valve input causing the extension of actuators C+E+ requires the k2 memory state signal;
- the valve input causing the extension of actuator F+ requires the implementation of the AND function c1e1k2 (the conjunction of the position status of actuators C and E and the memory state k2);
- valve input causing the retraction of actuators C- and G- requires the k3 memory state signal, and so on.

From the analysis of the graph in the further states of the machine, signals for valves cooperating with actuators can be determined.

The graph contains the elements whose operation (activation, deactivation) occurs multiple times in one cycle. These are the driving elements: B-, B+, C-, C+, E-, E+, F, F+, G-, G+, which force the use of logical OR elements in the control system for the valve cooperating with the actuator.

For controlling the valve cooperating with the actuator, functions have been compiled that force their multiple actions in one cycle of the machine:

- controlled in the direction of B- is (sk1 + k5);
- controlled in the direction of B+ is (k4 + c0 d0k7);
- controlled in the direction of C- is (k3 + k7);
- controlled in the direction of C+ is (k2 + k6);
- controlled in the direction of E- is (sk1 + k5);
- controlled in the direction of E+ is (k2 + k6);
- controlled in the direction of F- is (b1g0k4 + d1k8);
- controlled in the direction of F+ is (c1e1k2 + c1e1k6);
- controlled in the direction of G- is (k4 + k8);
- controlled in the direction of G+ is (k3 + c0d0k7).

Multiple operation of the valve cooperating with the actuator in a single cycle of the machine forces the cooperation with the signalling element (limit switch) of logical AND elements. Below are the functions for multiple signals:

- signal b0 creates conjunctions: b0 k1 and b0 k5;
- signal b1 creates conjunctions: b1 k4 and b1 k7;
- signal c0 creates conjunctions: c0 k3 and c0 k7;
- signal c1 creates conjunctions: c1 k2 and c1 k6;
- signal e0 creates conjunctions: e0 k1 and e0 k5;
- signal e1 creates conjunctions: e1 k2 and e1 k6;
- signal f0 creates conjunctions: f0 k4 and f0 k8;
- signal f1 creates conjunctions: f1 k2 and f1 k6;
- signal g0 creates conjunctions: g0 k4 and g0 k8;
- signal g1 creates conjunctions: g1 k3 and g1 k7.

In the electro-pneumatic system (Fig.3), the actuators are controlled by solenoid valves.
Signals generated at the boundary of the graph division are used to control the system's memory.
The system graph shows that the memory switching takes place according to the dependencies:

x1=b0e0 k1, x2=f1 k2, x3=c0g1 k3, x4=a0 f0 k4,
x5=b0e0 k5, x6=f1 k6, x7=b1g1 k7, x8=f0 k8.

Input signals to the memory block are read from the graph, they occur at the boundary of partition into groups:

- signal x1 generates state k2 (through the memory input setting state k2), which simultaneously clears state k1 (through the memory input clearing state k1),
- signal x2 generates state k3 (through the memory input setting state k3), which simultaneously clears state k2 (through the memory input clearing state k2),

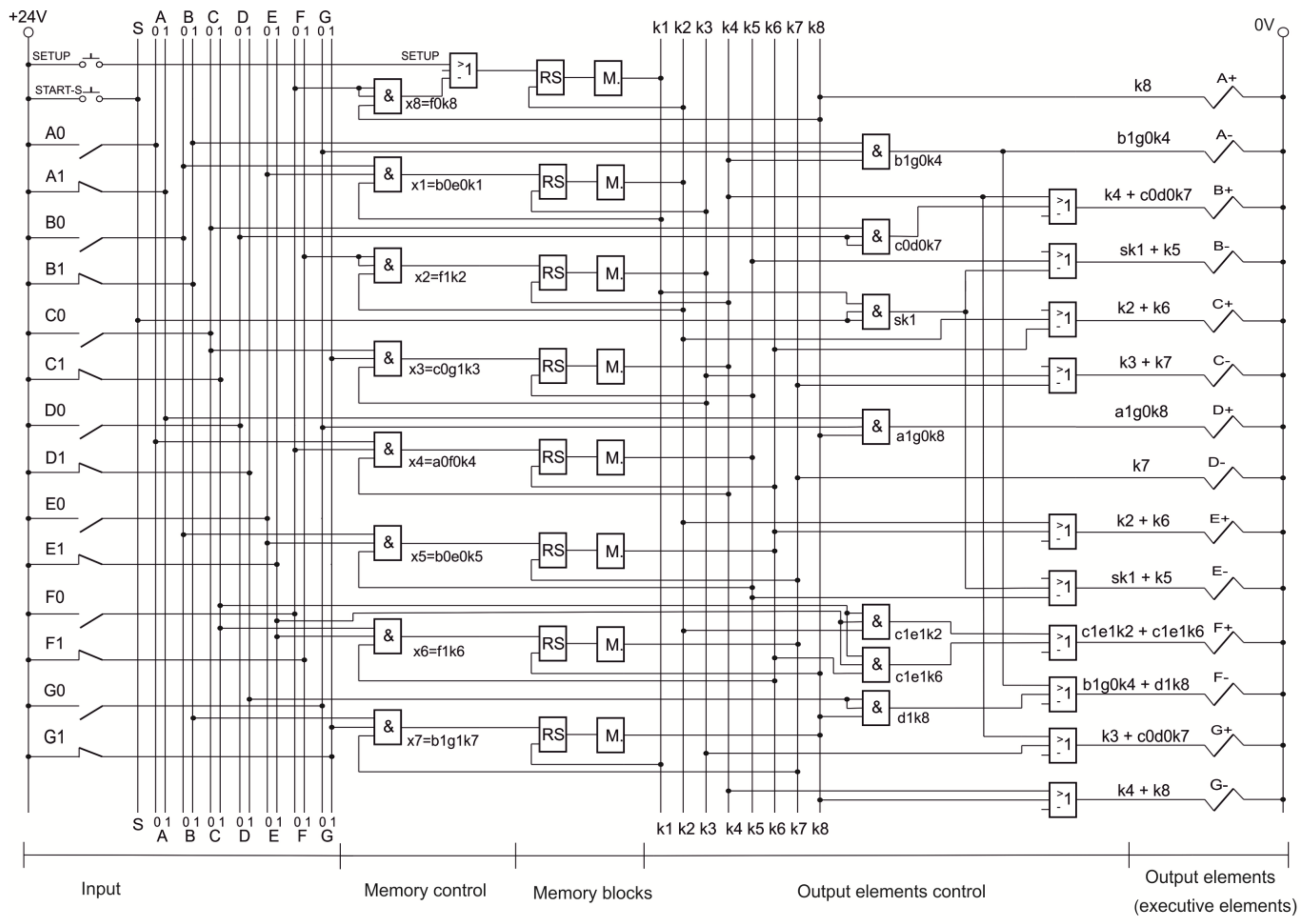

Fig. 3. Schematic diagram of the electronic system

- signal x3 generates state k4 (through the memory input setting state k4), which simultaneously clears state k3 (through the memory input clearing state k3), and so on,
- signal x8 generates state k1 (through the memory input setting state k1), which simultaneously clears state k8 (through the memory input clearing state k8).

In the designed electro-pneumatic system, 4/2 valves with electrical control were used (Fig. 3). The valve state is set by providing a voltage signal to its coil. The loss of this voltage keeps the valve in the same state. When voltage is applied to the second coil, its state changes.

IV. SIMULATION OF THE ELECTRONIC SYSTEM OF THE ANALYSED TECHNOLOGICAL NODE

A simulation was carried out for the system in which the selected state from the system operation cycle is presented below (Fig. 4).

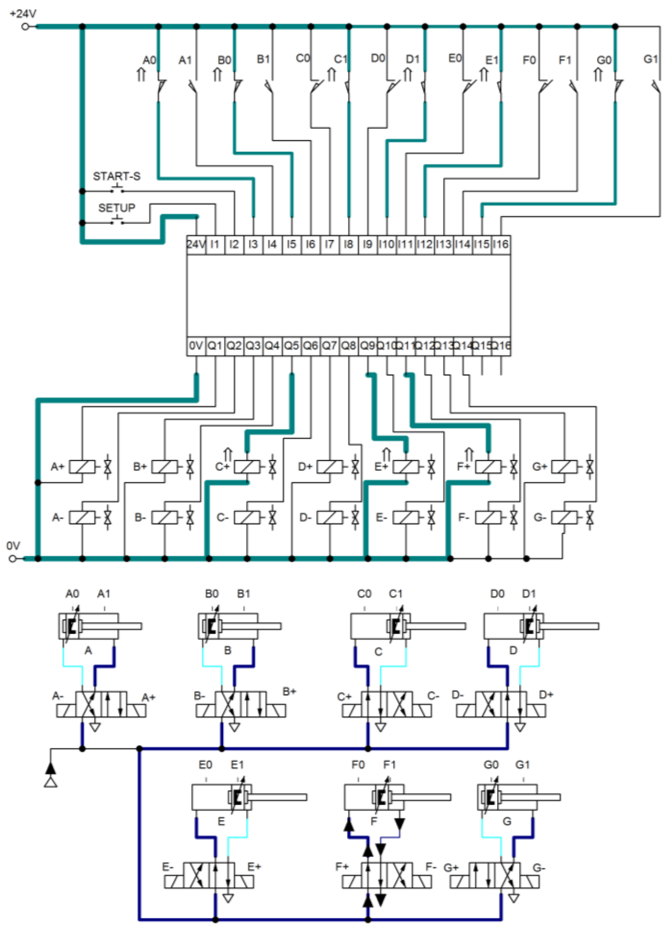

Fig. 4. Block diagram of the system during sequence execution

The system is in a state in which actuators C,D,E are extended, while actuator F is in the process of extending.
The remaining actuators A, B, and G are in the off state.
The cycle diagram of the system operation is shown in Fig.5.

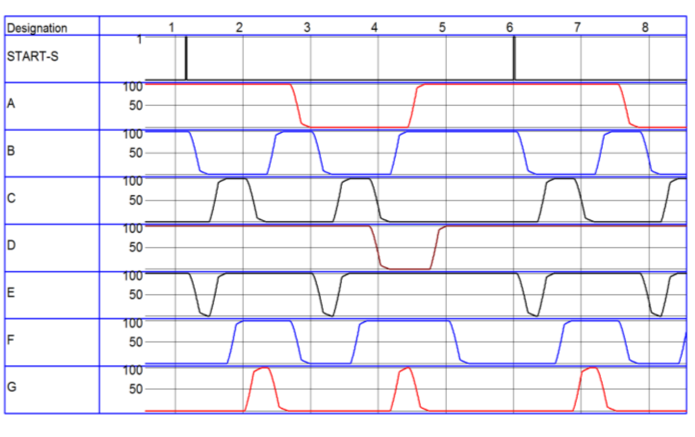

Fig.5. Cycle diagram of the system operation during the implementation of the sequence of operation of the driving elements.

The system is in the memory state k6 of the second cycle in which actuators C,D,E are extended while actuator F is in the process of extending. The digital module of the system in Fig.4, which implements the control program of the system, is shown in Fig.6. The digital module shows the internal block diagram of the system. The module shows the level of logic signals of the system in memory state k6. High level (logic 1) is indicated in light green, while the low level (logic 0) is indicated in dark green.

CONCLUSION

This article presents a generalized method for the analysis and synthesis of sequential control systems. Meeting the expectations of designers, an algorithmic method of designing sequential systems taking into account computer aided electro-pneumatic systems is presented. The procedure is outlined from recording the sequence of operation of elements in the technological process, preparing the graph, to creating the algorithm of the machine.

The generated graph describes signal processing functions, enabling rapid programming of sequential electro-pneumatic systems using logical elements. The algorithmic (graphical) method allows the design of the schematic for any sequential system that is part of the device under development.

The system designed based on the graphical method has been verified through simulation using the FluidSim computer-aided design program from Festo.

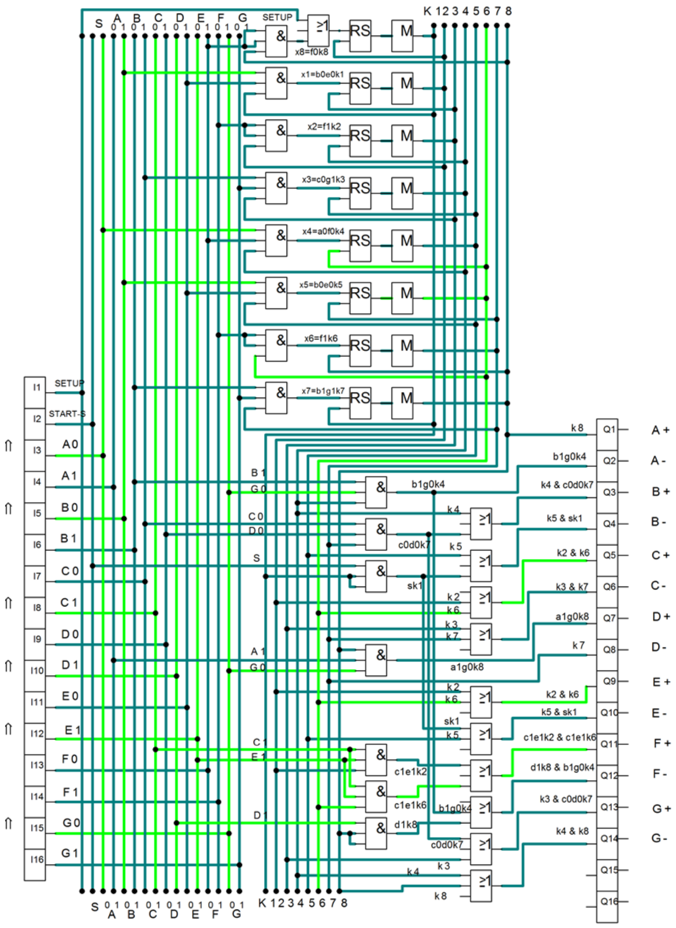

Fig.6. Digital module of the system during sequence execution – sequence of operation of driving elements in memory state k6

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