Novel Method for Designing a Sequential Logic Controller with Intermediate Stop of Actuators

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Abstract- **This paper presents a powerful tree-chart method to design a sequential logic controller with or without intermediate stop of an actuator. The suggested method is more general compared with other available techniques as it can be used to design various types of circuits: simple, complex, and compound. The introduced method in this paper is a special tree chart which is drawn from the description of a physical system, and then the required logic equations are directly extracted in a simple form using a number of rules. The extracted equations are implemented using pneumatic and electro-pneumatic circuits and then simulated using simulation software. The simulated pneumatic and electro-pneumatic circuits are implemented at pneumatic laboratory.**

This paper explains the procedure of the proposed method. Different examples are used to represent many possible variations in sequential circuits design. The results show the simplicity and applicability of the new technique.

Keywords-- Fluid logic system; On-Off controller; Fluid power system; pneumatic circuit; hydraulic circuit; sequential logic circuits.

I- INTRODUCTION

Automation is the use of control systems such as fluid power system (Pneumatics, hydraulics), electrical, electronics, PLC and computers to control industrial machinery and processes, reducing the need for human intervention. Fluid power control systems are widely used in aerospace, industrial, and mobile equipments because of their remarkable advantages over other control systems [ref. 7].

An automatic sequential control system may trigger a series of mechanical actuators in the correct sequence to perform a task. Sequential logic control system is classified into asynchronous and synchronous system. An asynchronous system, or self-timed circuit, is a sequential logic circuit which is not governed by a clock circuit or global clock signal [ref. 2].

It is a well-known that there is no universal circuit design method that suits all types of synchronous sequential circuits. Some methods are more suitable for one type than others. There are four famous methods to design a sequential circuit: Karnaugh-Veitch map, step counter, combinational logic circuit design and cascading method. [ref. 8].

The presented method in this paper is useful and ideal for small to large size circuits. Also, it is powerful for designing complex, compound system and system with actuator makes intermediate stop. It self minimizes the hardware, where the logic equations can be extracted from a tree chart in more simple form by applying a number of rules. To demonstrate this method, selected practical examples are used which provides the reader with all the possible variations occurring in sequential circuit design.

II- SYSTEM DESCRIPTION

A general block diagram of an on/off control system is shown in Fig. **1**

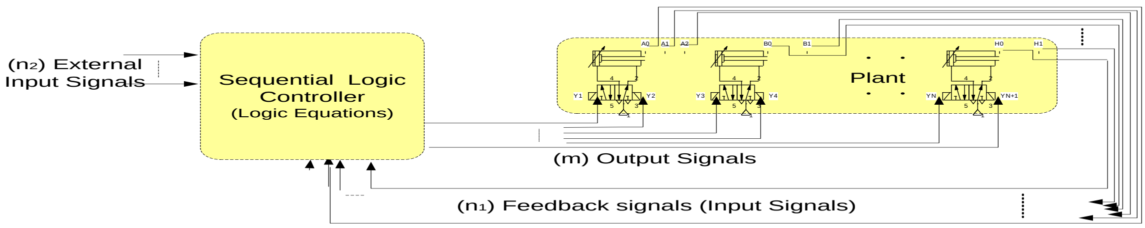

Figure 1, A general block diagram of an on/off control system

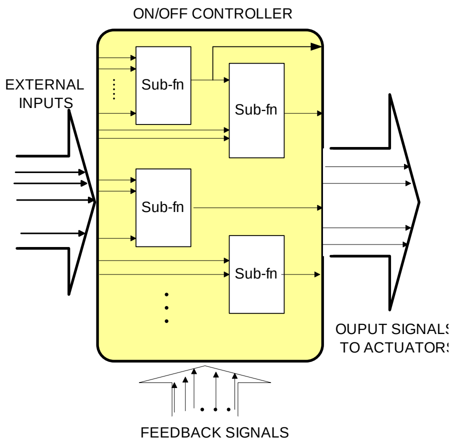

Figure 2, Sequential logic controller

Sequential logic controller is represented in block diagram as shown in fig.1. The controller sends a number [m] of outputs to the plant (actuators) and receives a number [n1] of feedback signals and a number [n2] of external signals. To define the logic equation for each output, construct a tree chart which deals with the number of related inputs. Then the controller must be disconnected into sub-functions. Each sub-function sends one output and receives the related inputs. Note that, the output of the sub-function may be output to the plant or input to another sub-function inside the controller. Then the controller can be redrawing as shown in Fig. 2. The tree chart method designs each sub-function and then defines its governing equations. Then, the controller equations are collected and implement them by pneumatic, electrical, or PLC elements.

A. Definition of some terminology of the tree chart

The modified tree chart for each actuator (cylinder) is generally drawn as in Fig.3. A tree chart is created for only one cylinder. At each level of the tree chart, the position status of each cylinder (A, A_1, A_2,…A_8) is checked by test limit switches (a0, a1, a2, ..,b0, b1, ..). Then two branches or more are created. The output of each branch must be defined as shown in table 1.

The definition of any branch is illustrated by line color in Fig.3. The setting and resetting equations of the actuator are the required equations from the chart. The setting equation term can be calculated by ANDing the variables of each output one, upward through its branch to the root of the chart. Then, the setting equation is calculated by ORing all terms of output one. Similarly, the resetting equation for the output zero is calculated [ref. 1].

TABLE 1. TREE CHART OUTPUTS

0	= True Zero (retract actuator)
1	= True one (extend actuator)
I	= Zero or One as previous output at (t-1)
I_1	= One as previous output at (t-1)
I_0	=Zero as previous output at (t-1)
R	= Redundant
stop	= Intermediate Stop
	or test another cylinder position

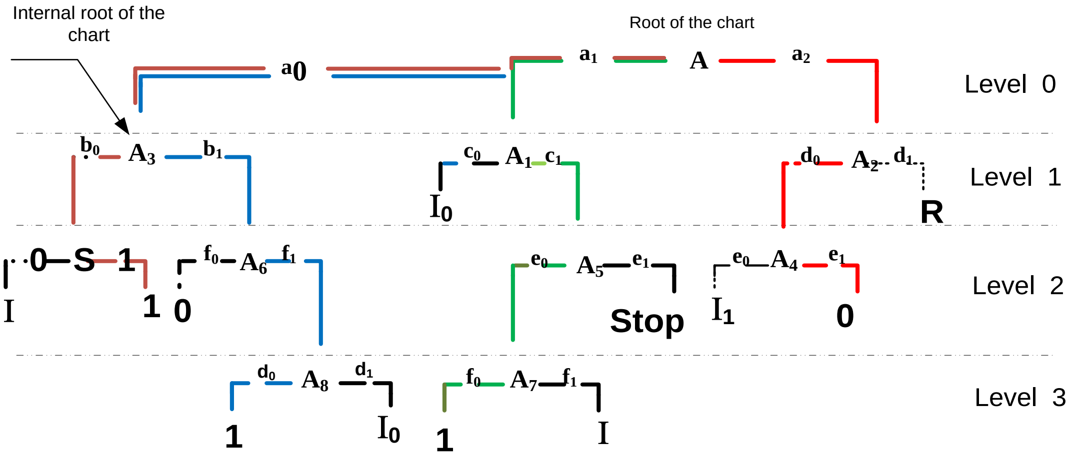

Figure 3, Definition of elements and branches of tree chart

III. THE NEW METHOD PROCEDURE

The new method procedure for designing sequential logic circuits can be summarized as the following steps:

1- From a problem description of the required controller, draw a traverse-time diagram including all the actuators (cylinders) in the sequence.
2- Determine number of input signals for the required system (External input signals, Feedback input signals, etc.…)
3- Determine number of output signals coming from the controller to the power section.
4- Discretize the function of the controller into sub-functions. Each one of the sub-function sends only one output and receives the related inputs.
5- Define similar starting conditions.
6- Determine discrimination signal/s to differentiate between similar starting conditions.
7- Draw a tree chart for each discrimination signal and calculate its logic equations.
8- Draw a tree chart for each actuator and extract the logic equations in more simple form by applying the simplification rules stated in next section.
9- Implement the logic equations by pneumatic, hydraulic electronic, or PLC elements**.**

A. Simplification Rules of the Tree Chart

1- If cylinder output gives 0 or I_0 (1 or I_1) and terminates at certain level of the branch, it does not appear in the logic equation of 0 (or 1) at lower level of the same branch.

2- For a logic term is obtained, study the sequence for certain logic signal or function occurring only one time (appeared in this term), and then cancel all other logic signals from the term.
3- The output (R) that does not defined, due to the combination of its input does not occurred , it deals as (0, $I_{0,}$ 1, I_1) except in case of the actuator moves with other in the previous step.
4- By inspection of the logic terms, the over logic variable may be defined and removed. The over logic variable is the variable when removed from the logic term does not affects the logic function.
5- It's well-known that, in case of intermediate stop of the actuator, the final control element used with that actuator is 4/3 directional valve. This type of valves doesn't latch the input signal. Thus, if the starting logic signal vanishes just after the motion of the actuator starts, it is required to latch the input logic signal using 3/2 directional valve. The setting signal is the starting condition and the resetting signal is by hitting the target limit switch.
6- For the simultaneous movement of two or more cylinders, identify the logic signal of the same movement.
7- For multiple movements of actuators, if there are repeated signals give same repeated action, start the tree chart always by this signal.

IV. CASE STUDIES

Two cases are selected to demonstrate how to design sub-function circuits and extract the more simple logic equations.

A. First Case Study:

- *Problem definition*

This example has two cylinders; each cylinder needs two signals, (one signal for extracting and the other for retracting). Thus, there are four outputs from the required controller (A_c, A_s, B_c, and B_s respectively) . Cylinder A has an intermediate stop, therefore, there are three limit switches used to define the initial, intermediate, and final positions (a_0, a_1, and a_2 respectively). Cylinder B needs two limit switch to define initial and final positions (b_0, and b_1 respectively). Thus, the number of feedback inputs is five and the external input is considered as the starting switch.

The motion of cylinder A starts to extract by pushing start switch S and stops intermediately when it reaches limit switch a_1, then, cylinder B extracts till it hits limit switch b_1, cylinder A moves to complete its extension to touch final position a_2. Then, cylinder A retracts to reaches its initial position a_0, finally, cylinder B retracts to its initial position b_0. This sequence is described in Fig.4.

- *Design procedure*

1) The similar conditions and the discrimination signal/s are determined from the displacement step diagram shown in Fig.4. The starting condition of steps 3 and 5 are the same (a_1AND b_1). These two similar conditions must discriminate. Thus a discrimination signal x is created as shown in Fig.5

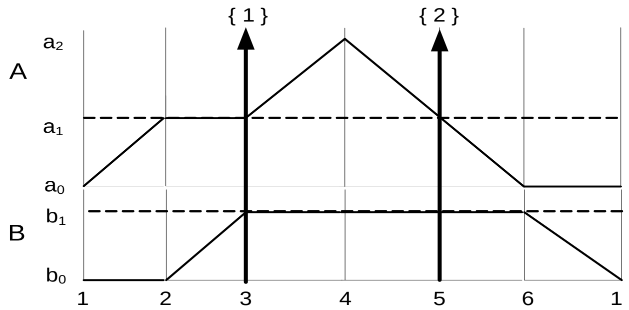

Figure 4, First case study

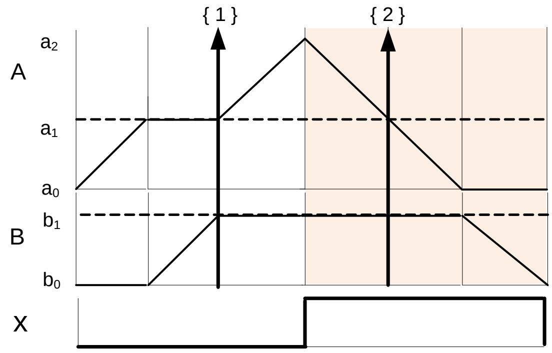

Figure 5, Discrimination signal x

2) The tree chart in Fig. 6 is drawn for x signal. Thus the equations (1), (2) for the resetting and setting are extracted from the tree chart.

$$X_c = a_0 . b_0 . S \qquad (1)$$

$$X_s = a_2 \qquad (2)$$

3) The tree chart for cylinder A is shown in fig.7.

Setting and resetting equations (3, 4) are extracted from the tree chart in Fig.7.

$$A_c = a_2 \qquad (3)$$

$$A_s = a_1 . b_1 . \bar{X} + a_0 . \bar{X} . \bar{a}_1 \qquad (4)$$

4) The tree chart of cylinder B is shown in fig.8. Setting and resetting equations (5, 6) are extracted from the tree chart in Fig.8.

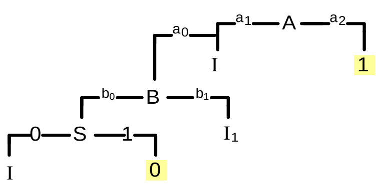

Figure 6, Tree Chart for discrimination signal x

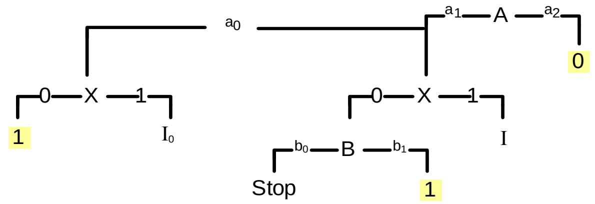

Figure 7, Tree chart of A

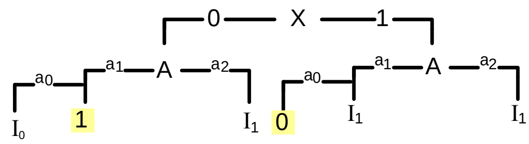

Figure 8, Tree chart of cylinder B

$$B_s = a_1 . \bar{X} \qquad (5)$$

$$B_c = a_0 . X \qquad (6)$$

5) The simplification rules are applied. In case of the retracting equations of the discrimination signal X, equation (1). From Fig.5, the logic signal b_0 can be used instead of a logic signal $a_0 . b_0$ without change of the logic action and a signal a_0 is considered as an over logic [rule 2].

$$X_c = b_0 . S \qquad (7)$$

By using [rule 2], the logic signal a_1 can be canceled from the first term of equation (4) without change the logic function. And also the second term X' a'$_1$ can be used instead of a_0 X' a'$_1$ without any change of logic action [rule 4]. Thus equation (8) can be used instead of equation (4),

$$A_s = b_1 . \bar{X} + \bar{X} . \bar{a}_1 \qquad (8)$$

The setting equations of cylinder B (equation (5)), can be simplified as in equation (9), [rule 4].

$$B_s = a_1 \qquad (9)$$

Finally, the previous control equations (7, 2, 3, 8, 6, and 9) are implemented by pneumatic or electro-pneumatic elements and simulated by using simulation program as shown in Fig 9, and Fig10. The simulated pneumatic and electro-pneumatic circuits were practically implemented at pneumatic laboratory.

B. *Second Case Study*:

This case illustrates intermediate stop of the actuator and multiple movement of actuator. It also illustrates the effect of the starting condition disappears just after the actuator moves.

- *Problem definition*

The displacement step diagram of this case is shown in Fig. 11. From the figure, the number of inputs is equal to six. There are three limit switch from cylinder A (a_0, a_1, a_2), two limit switch from cylinder B (b_0, b_1), and start switch (S). The number of outputs is equal to four. There are two outputs for cylinder A (A_s, A_c), and two outputs for cylinder B (B_s, B_c).

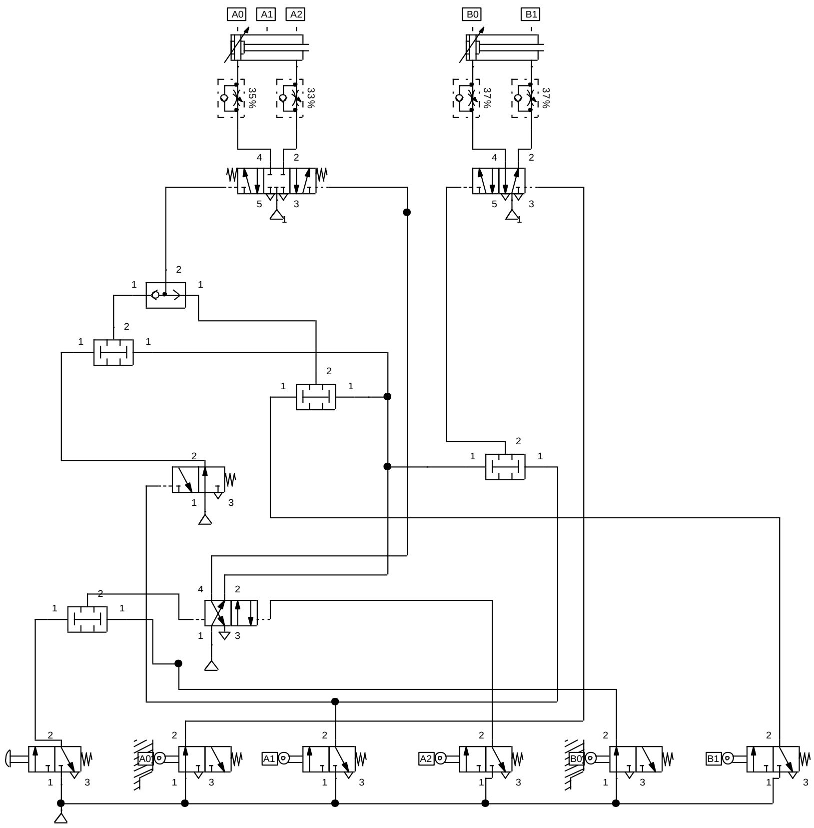

Figure 9. Pneumatic system of case study 1

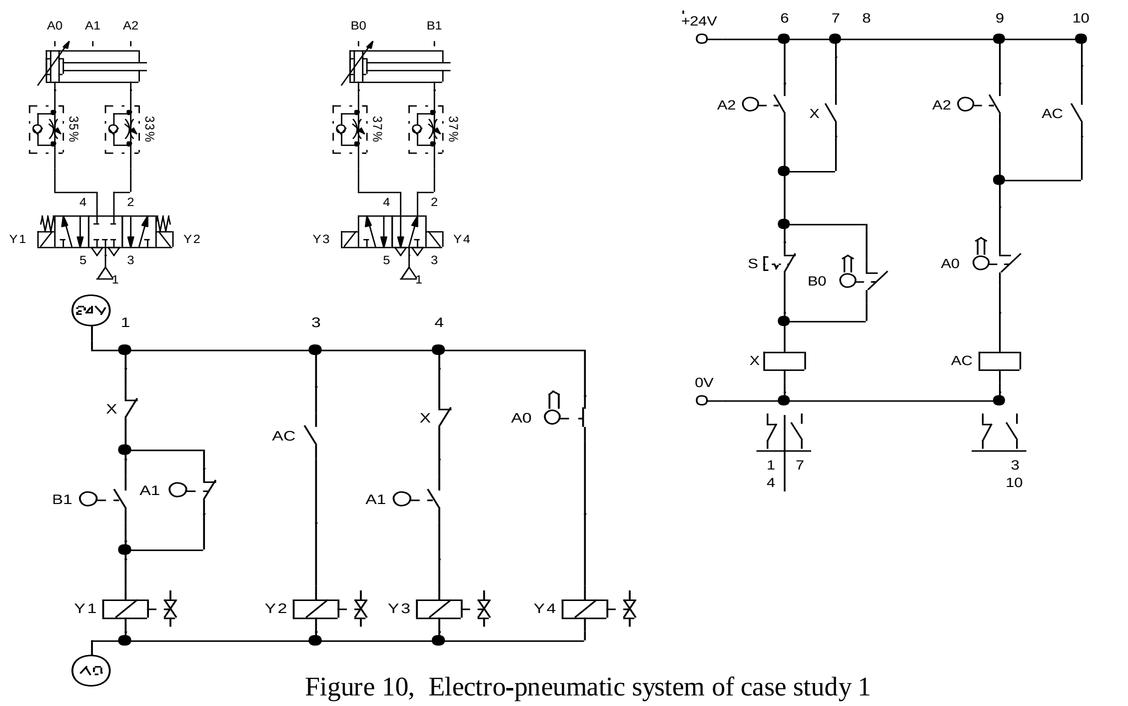

Figure 10, Electro-pneumatic system of case study 1

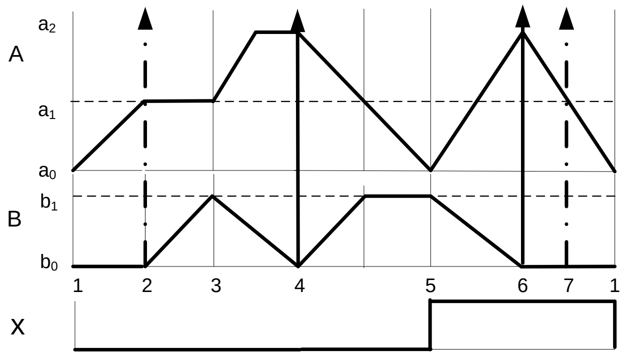

Figure 11, second case study

- *Design procedure*

1) From the displacement time diagram shown in Fig.11 the starting condition of steps 4 and 6 are the same and also steps 2 and 7 are the same. These four similar conditions must be discriminated. Then a discrimination signal x is created as shown in fig.11.

2) Tree chart for x signal is drawn in Fig. 12.

The equations of setting and resetting of signal X are extracted from the tree chart.

$$X_s = a_0 . b_1 \quad (10)$$

$$X_c = a_0 . b_0 \quad (11)$$

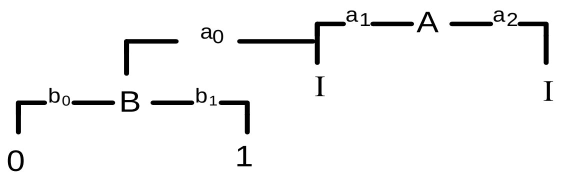

Figure 12, Tree chart of X

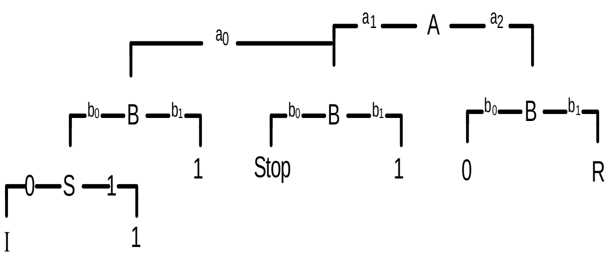

Figure 13, Tree chart of cylinder A

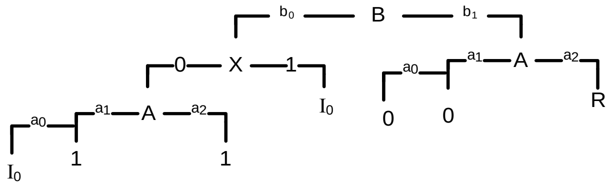

Figure 14, Tree chart of cylinder B

3) Construct tree chart for cylinder A

The logic function of the setting and resetting are shown by equations (12) and (13).

$$A_c = a_2 . b_0 \quad (12)$$

$$A_s = a_1 . b_1 + a_0 . b_1 + S . a_0 . \bar{a}_1 \quad (13)$$

4) Construct tree chart for cylinder B:

The logic function of the set and reset are as follow:

$$B_c = b_1 . a_1 + b_1 . a_0 \quad (14)$$

$$B_s = a_1 . b_0 . \bar{X} + a_2 . b_0 . \bar{X} \quad (15)$$

4) By applying the rules of simplification:

$A_c = a_2 . b_0$ (*stored this signal and cleared by* a_0 [*rule* 5]) (16)

$A_s = a_1 . b_1$ (*stored this signal and cleared by* a_2 [*rule* 5])

$+ a_0 . b_1$ (*stored this signal and cleared by* a_2 [*rule* 5]

$+ S . a_0$ (*stored this signal and cleared by* a_1 [*rule* 5] (17)

Finally, the previous control equations (10, 11, 16, 17, 14, and 15) are implemented by pneumatic or electro-pneumatic elements and simulated by using simulation program as shown in Fig 15, and Fig16. The simulated pneumatic and electro-pneumatic circuits were practically implemented at pneumatic laboratory.

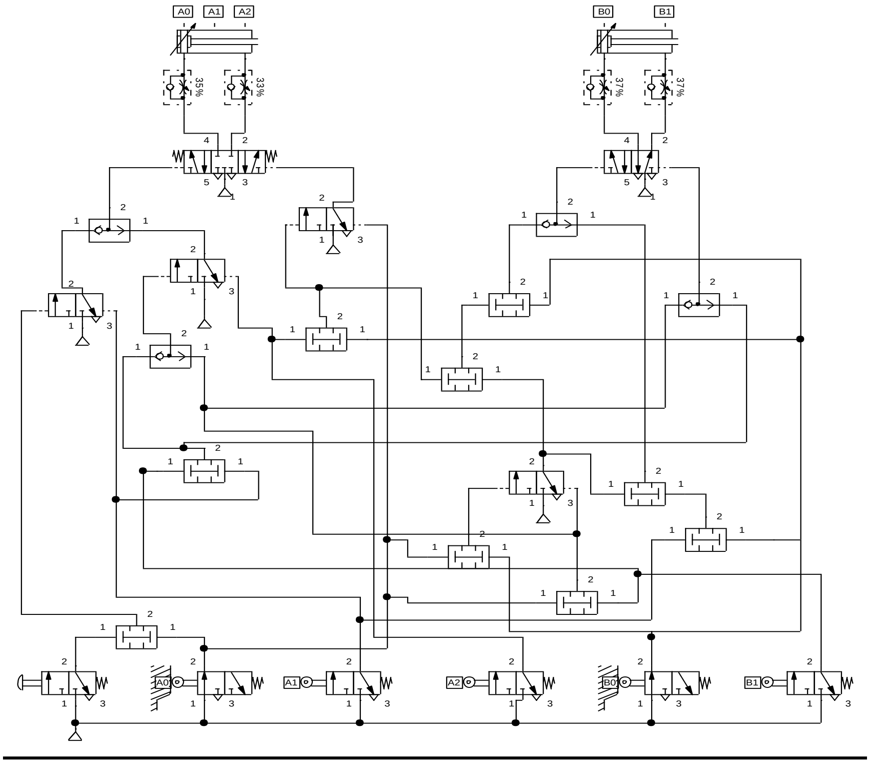

Figure 15, Simulated pneumatic system of case study

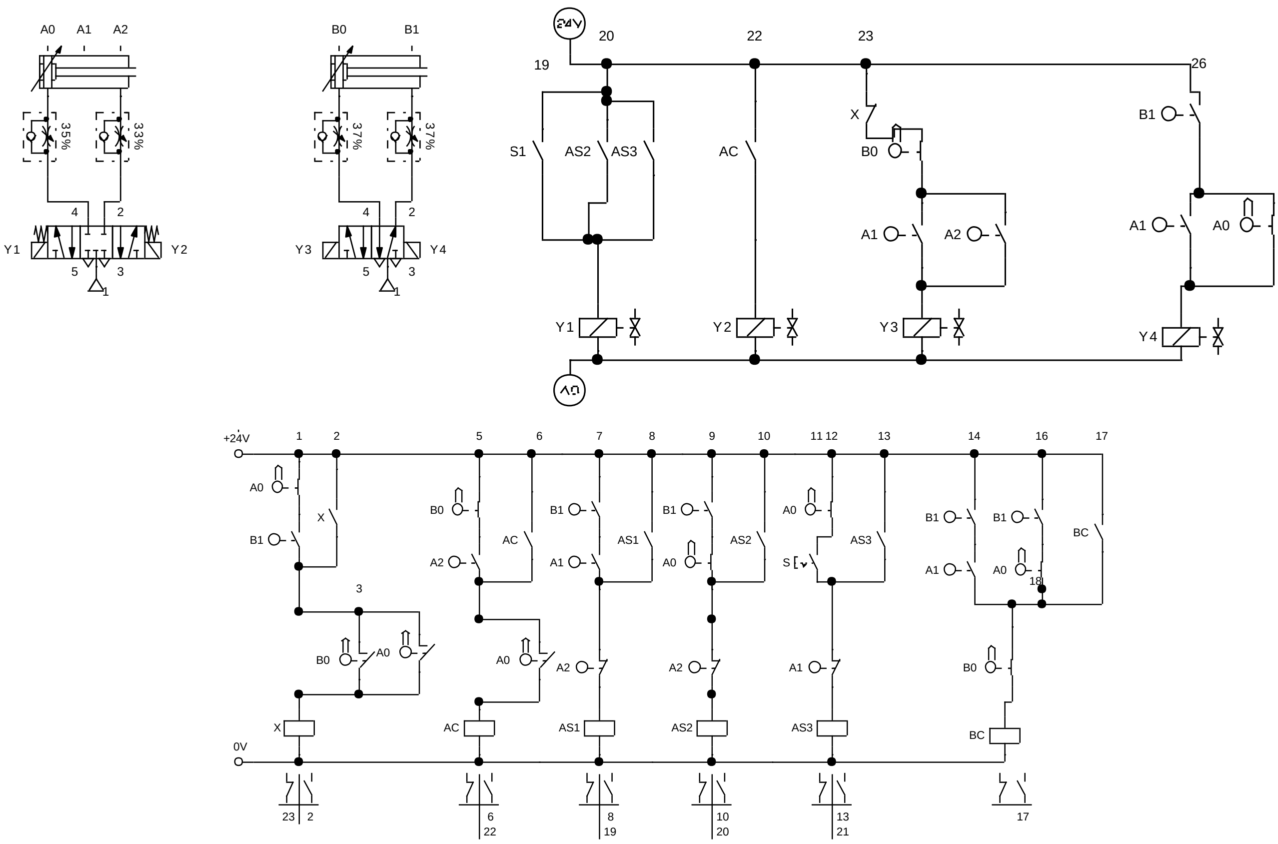

Figure 16, Simulated electro-pneumatic system of case study

V. CONCLUSION

The introduced tree chart method is suitable and powerful for designing most types of sequential logic systems, simple, complex and compound circuits.

The proposed method is able to design the systems that have an intermediate stop in the actuator operation.

Moreover, the logic equations are extracted in more simple form by applying the suggested simplification rules .

The extracted logic equations were simulated pneumatically and electro- pneumatically using simulation program. The simulated pneumatic and electro-pneumatic circuits were practically implemented at pneumatic laboratory.

This method needs some experience in case of discretizing the function of the controller into sub-functions and also chooses the discrimination signal.

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