NEW METHOD FOR DESIGNING PNEUMATIC SEQUENTIAL LOGIC CONTROLLER

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ABSTRACT

As the control functions grow in size and complexity, more effort must be paid to the design procedures. In this paper, a powerful new method is described for designing large and complex systems using fluid logic sequential circuits. This simplified procedure uses a special tree chart where the system operation or sequence is described. The logic equations that describe the system operation are extracted from this tree chart in a simple form by applying powerful special rules.

KEYWORDS

Fluid logic system, On-Off controller, Fluid power system, sequential logic circuits,

NOMENCLATURE

A, B, C, …	Cylinder
a_0, b_0, c_0, ….	Limit switch (or valve) of initial position of cylinder A, B, C,… [feedback inputs]
a_1, b_1, c_1, ….	Limit switch (or valve) of end position of cylinder A, B, C,… [feedback inputs]
$\overline{a}_0, \overline{b}_0, \overline{c}_0$	Inverted Limit switch (or valve) of initial position of cylinder A, B, C,…[feedback inputs]
$\overline{a}_1, \overline{b}_1, \overline{c}_1$	Inverted Limit switch (or valve) of initial position of cylinder A, B, C,…[feedback inputs]
X, Y, Z	Distinguished signal
$\overline{X}, \overline{Y}, \overline{Z}$	Inverted signal of distinguished signal
l_1 (1 or l)	One or initial (the previous value).
l_0 (0 or l)	Zero or initial.
S	Start switch (or valve) [external inputs]

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INTRODUCTION

There are many and different useful procedure or methods for designing sequential circuits. Some of these methods are more powerful in certain type of sequential circuits, than the others. Sequential circuits can be classified into many categories, e.g. small size non-repetitive circuits, medium size circuits and complex circuits.

The most commonly design methods are:

1- Combinational circuit design method [1,2,3].,
2- Sequential circuit design method e.g. ;
    a- Karnaugh-Veitch method, [5].
    b- Step-counter [5]..

Circuit design method with karnaugh-Veitch is useful for small to medium size and it self simplifies its output equation by applying a number of rules. But it is not ideal for both large and very large size circuits, where design experience is required. The method introduced in this paper is useful and ideal for small to large size circuits. Also, it is powerful for complex circuits. It self minimizes the hardware, where the logic equations can be extracted from a tree chart in a simple form by applying some rules.

System Description

Fluid logic networks are used to control cycles of physical events. To simplify the presentation in this paper, physical events will be considered as the extending or retracting of hydraulic or pneumatic linear actuators. A group of actuators, controlled sequentially by a fluid logic network is shown in schematically fig. 1.

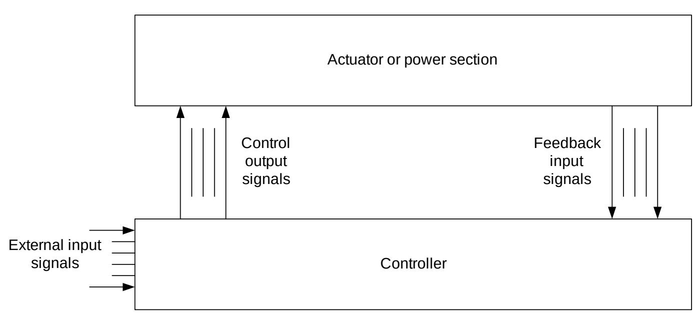


Fig. 1. Schematic of fluid logic network

The shown system can be classified into two sections. The first section is the actuators and its related valves (final control valves) which it is called the power section. The second is the control section or controller. The power section is the system to be controlled. The second section is the controller. The controller receives different types of inputs and then sends control signals to the power section or the actuators. The inputs may be a feedback inputs from the limit valves (or from limit switches in case of electro-pneumatic controller) or may be external inputs like human operator switch, start switch, .etc. Outputs from the controller (control signals) are signals to extend or retract the cylinder under the control law which is defined depending on the required sequence of the cylinders [2,3,4]..

A case study will be used to introduce the design procedure of the sequential logic circuits.

Case Study (A Simple Example Used To Illustrate The Tree Chart Method):

A selected example is introduced here for demonstrating the design procedure.

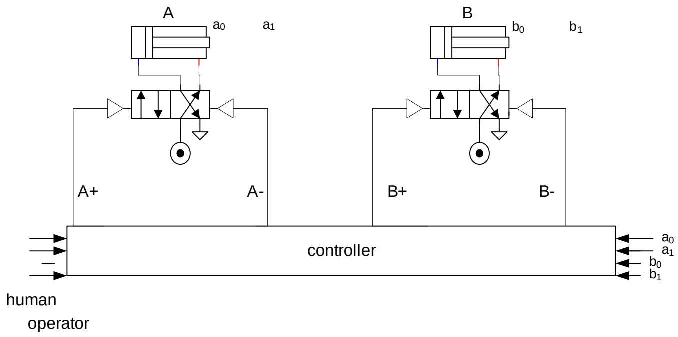


Fig. 2. Controller input output

In fig. 2 the controller receives feedback inputs from the limits of the two cylinders A,B (a0, a_1, b0, and b_1) and also receives external inputs from operated panel (start s/w). Output signals (A+, A-, B+, B-) come from controller for extending and retracting cylinders A and B (A+, A- means extending and retracting signals of cylinder A,…etc).

The following motion or sequence is the required sequence of the two cylinders.

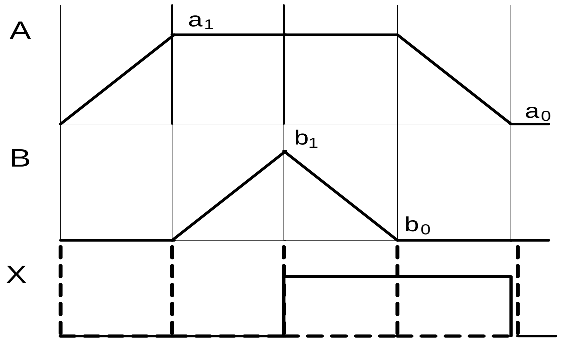


Fig.3. Required sequence

This sequence starts when the controller receives; human operator order (start switch signal) and the last limit switch signal at the last step (interlock signal). At this time, cylinder A extends until it reaches and touches limit switch at the end of stroke (a_1). Then cylinder B extends. After cylinder B goes to the maximum stroke, and touches the limit switch b_1. It returns to its initial position and touches limit switch b_0. After that cylinder A returns to its initial position.

To design a controller of any sequence like that, a design procedure must be followed for simplifying the steps of extracting the output logic equations of the power section (A+, A-, B+, B-). The following steps describe how the controller can be designed:

Determine Number of Output Signals from Controller:

The number of outputs from controller to the cylinders can be determined depending on the operation type of those final control elements related to the cylinders. If the final control element operates by fluid (or other type of signal) and returns by spring action, the output from controller is one signal for each cylinder. Otherwise, the controller outputs two signals, if the final control element is operated and returned by fluid (or other signals). Thus, the number of outputs from the controller sent to the power section can be determined by selecting the type of operation of final control element. In this selected example, number of outputs from controller are four (y_1, y_2, y_3, and y_4), where the final control valve has two signals.

Determine Number of Input Signals to the Controller:

External inputs are from human operator (start signals …), and feedback inputs are coming from limit switches. Therefore, numbers of input signals to the controller in this example are one external input (S) and four feedback input signals (a_0, a_1, b_0, and b_1).

Study Similar Starting Conditions:

Similar starting conditions for more than one step may be found in the required sequence. If there is a case like that, false signal goes to a certain actuator at a wrong time, and then a wrong action (or more) happens. So, a new signal (or more) are generated to differentiate between the similar starting conditions. In the selected example, starting condition of step 2 and step 4 are the same (a_1 AND b_0). Due to this similar starting condition, cylinder A retracts at a wrong time (step2), then the sequence fails. Therefore, a new logic signal (x) (or signals for more than two similar condition) are created to distinguish between these similar starting condition. Fig. 4   shows a tree chart for signal x .

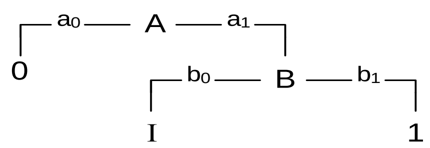


Fig. 4. Tree chart for signal x

The tree chart tests the starting signals of the previous (or more) steps and next (or more) step for one of the two similar starting condition (do not include the second similar starting condition). The logic equations of x can be calculated from the tree. Note that, the tree has three outputs (0, 1, I). Therefore, two logic equations are extracted from the tree, one for setting x and the other for clearing. Clearing signal of x can be determined by " **ANDing all inputs from the output 0 upward to the main root of the tree**".

$$X_c = a_0$$

Setting signal is:

$$X_s = a_1.b_1$$

By studying the sequence, we find that b_1 happens only one time; then signal $a_1$does not affect the setting signal. Thus

$X_s = b_1$

There are a number of simplified rules that will be represented for this tree in section .

Draw a Tree Chart:

In any sequence a different starting conditions are determined where each step starts after the last step is completed to guarantee the sequence. Extending signal and retracting signal are the required two signals for each actuator. . A tree chart is drawn for each actuator to define those two signals. The tree chart tests the position of all actuator, in the system to be controlled, which are involved in the required actuator. In the selected example, fig.5 introduces a tree chart for cylinder A. Firstly; test the condition which gives a clear signal of cylinder A. Then go through the tree to get the output of the same cylinder.

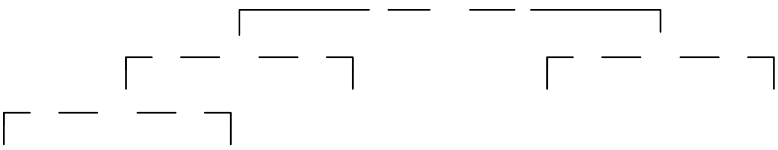


Fig. 5. Tree chart for cylinder A

The tree has output (I), which mean that there are two logic equations one for setting cylinder A (A+) and the other for clearing cylinder A (A-). Also it has I_1 one or initial (1 or I) which is used for simplifying the logic equations as described at section .The setting equation can be defined by " **ANDing the inputs starting from output 1 upward through branch until reaching the root of the tree** " as follows :

$$A+ = s.a_0.\bar{x}$$

And in the same manner the clearing signal is

$$A- = b_0.x$$

Fig. 6 shows the tree chart for cylinder B.

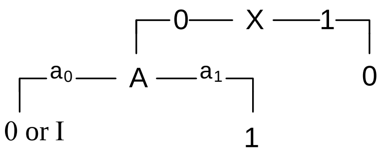


Fig. 6. Tree chart for cylinder B

0

a_0 A a_1

0 S 1 1 or I

The logic equations are for cylinder B :

$$B+ = a_1\overline{x} \qquad\qquad B- = x$$

So, we can state that, contribution of a branch ending by one (or zero) is as follows: '**AND all the inputs in the branch, starting from one (or zero) upward to the root of the tree chart**".

Draw the Pneumatic Circuit:

Implement the logic equations, which were obtained from the tree, by fluid logic elements.

The power section is

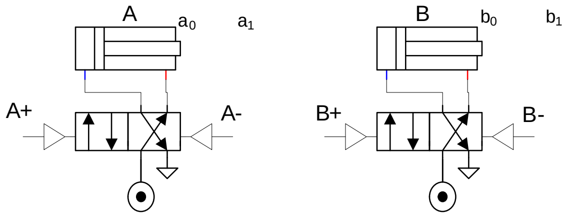


Fig. 7. Pneumatic power section

Where $x_s = b_1$ $\qquad$ $x_c = a_0$

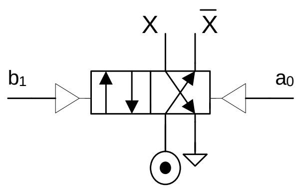


Fig. 8. Control valve

Cylinder A: $A+ = s.a_0.\overline{x}$ $\qquad$ $A- = b_0.x$

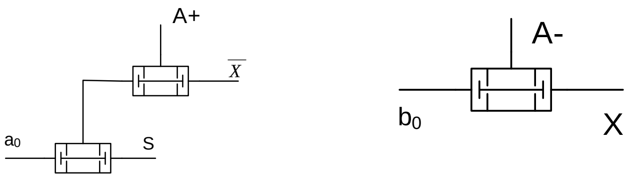


Fig. 9. Extract (A+), and retract (A-) signals of cylinder A

Cylinder B: $B+ = a_1\overline{x}$ $\qquad$ $B- = x$

Fig. 10. Extract (A+), and retract (A-) signals of cylinder A

The required circuit is :

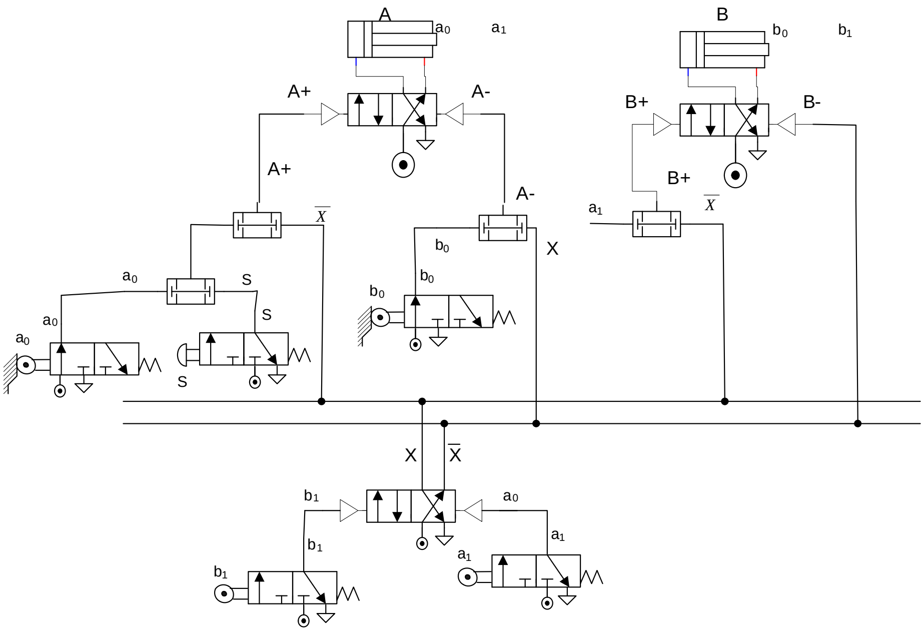


Fig. 11. Final pneumatic circuit

The New Method Procedure Can Be Summarized as the Following Steps:

1- Determine number of input signals for the required system (External input signals, Feedback input signals,…)

2- Determine number of output signals coming from the controller to the power section by defining the type of final control valve.

3- Define number of similar starting conditions.

4- Determine number of distinguished signals to differentiate between similar starting conditions.

5- Draw a tree chart for each distinguishing signal and calculate its logic equations.

6- Draw a tree chart for each output to the final control valve and find its logic equations. Start the tree chart always by testing cylinders that terminates by clearing signals (0). And write I_1 (or I_0) for the output that does not act like true 1 (or 0). Use the simplified rules to extract the simple logic equations from the tree.

7- Implement the logic equations by pneumatic circuits (controller circuits and power section).

Rules for Simplification the Tree Chart are:

1- Start always by testing the conditions of clearing signal.

2- If cylinder gives 0 (or 1) at certain level of the tree chart, it does not appear in the logic equation of 0 (or 1) at the same or lower level.

3- After the logic equations are obtained, study the sequence for certain limit switch occurring only one time, and cancel all other limit switch in its equation.

4- If cylinder gives I_1 (or I_0) at its output in certain level, cancel it from 1 (or o) at the same or lower level.

To illustrate the powerful of the represented method, the following example will be solved by the introduced method and compared with the solution by the Karnaugh-Veitch method which was introduced in [5].

Selected Example:

A control circuit is to be designed for a fully automated drilling machine that contains seven actuators (cylinders). The machine sequence is shown in fig. 12 [5]. A start valve is to be included to prevent continuous cycling of the machine.

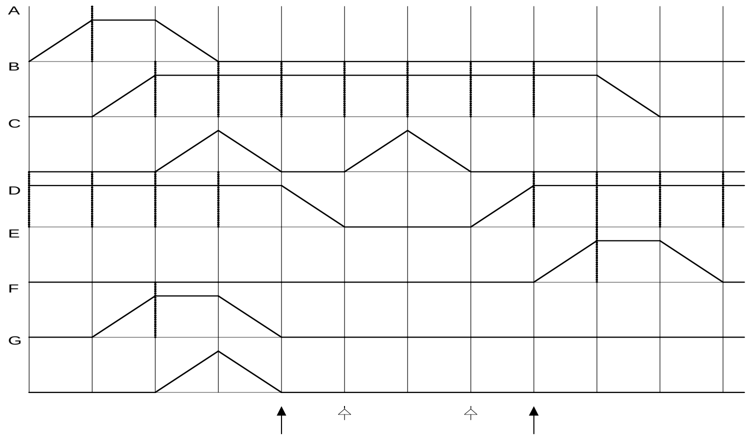


Fig. 12. Sequence diagram for a fully automated drilling machine

a) There are seven actuators (A, B, C, D, E, F and G).

b) There are 14 (a_1, a_0, b_1, b_0, c_1, c_0, d_1, d_0, e_1, e_0, f_1, f_0, g_1 and g_0) feedback inputs and one external input(s). Then the number of inputs are 15 [step 1].

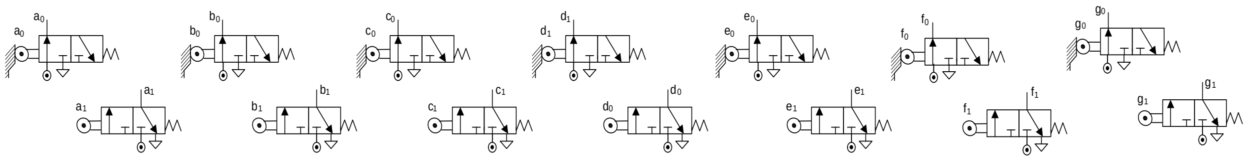


Fig. 13. Feedback inputs

c) Final control valve for each cylinder operates by two inputs. Then, there are 14 outputs (A_c, A_s, B_c, …) [step 2].

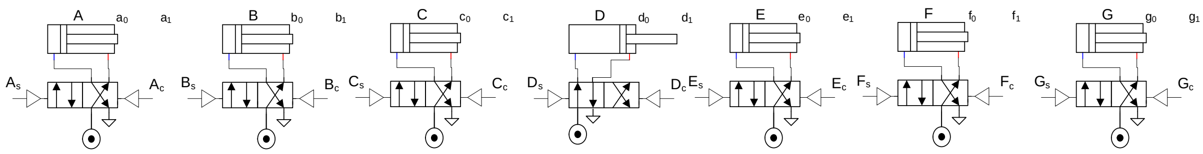


Fig. 14. pneumatic power section

d) There are two different similar starting conditions [step 3].

e) One distinguished signal is used [step 4]..

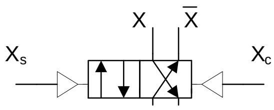
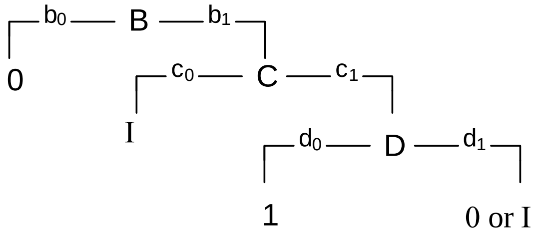


Fig. 15. Distinguished signal valve

f) The tree chart for distinguished signal X and the extracted equations are shown in forward tree [step 5,7].

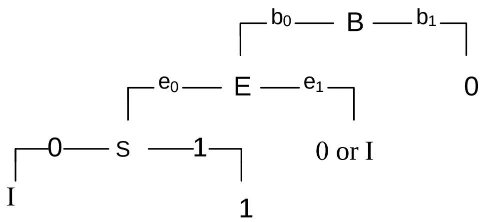


$X_c = b_0$

$X_s = c_1 \; d_0 \; b_1$

Fig. 16. Tree chart and logic equation of distinguished signal.

g) The tree chart for each cylinder A and the extracted equations are illustrated [step 6,7].



$A_c = b_1$

$A_s = S \; e_0 \; b_0$

Fig. 17. Tree chart and logic equation of cylinder A

h) The tree chart for each cylinder B and the extracted equations are illustrated [step 6,7].

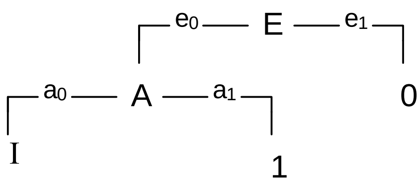


Fig. 18. Tree chart and logic equation of cylinder B

i) The tree chart for each cylinder C and the extracted equations are illustrated [step 6,7].

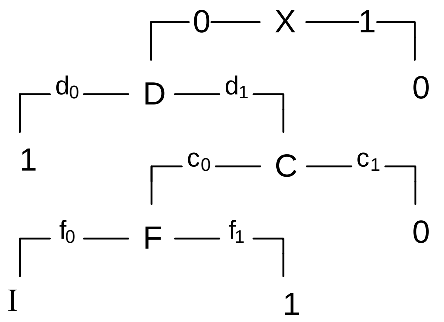


Fig. 19. Tree chart and logic equation of cylinder C

j) The tree chart for each cylinder D and the extracted equations are illustrated [step 6,7].

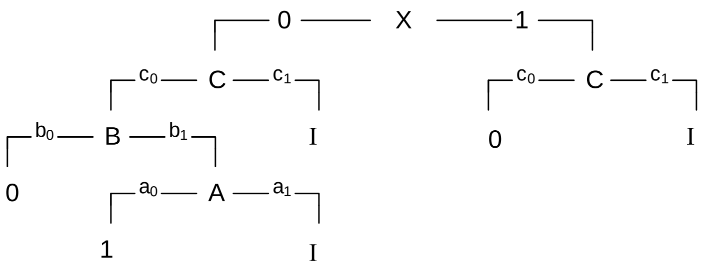


Fig. 20. Tree chart and logic equation of cylinder D

k) The tree chart for each cylinder E and the extracted equations are illustrated [step 6,7].

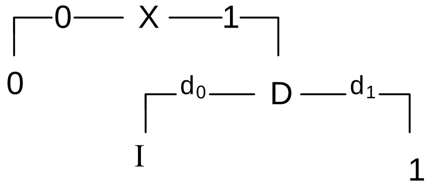


Fig. 21. Tree chart and logic equation of cylinder E

l) The tree chart for each cylinder F and the extracted equations are illustrated [step 6,7].

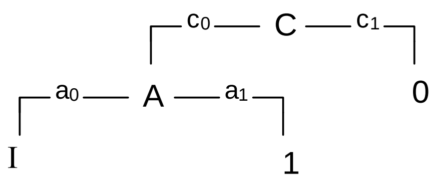
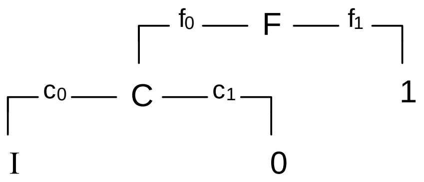


Fig. 22, Tree chart, and logic equation of cylinder F

m) The tree chart for each cylinder G and the extracted equations are illustrated [step 6,7].



$G_c = c_1$

$G_s = f_1$

Fig. 23. Tree chart and logic equation of cylinder G

Comparison between proposed method and Karnaugh-Veitch method :

The solution of the previous example using the new method and compare it with the solution of the same example with the Karnaugh-Veitch method at page 84 to 95 of [ref 5] shows that:

- The design effort required when using new method is more less than that when using the Karnaugh-Veitch method, where it need to draw 10 tables and the choose of loops in the tables of Karnaugh-Veitch method is more tedious.
- The same number of distinguish signal only one (x) are obtained from the two method, but the logic equations of X_c and X_s are more simple if using new method.
- The logic equations computed by the new method also more simple, where number of AND and OR valves to implement the controller 17 valves when using new method instead of 28 valves when using the Karnaugh-Veitch method.

The following complete pneumatic circuit of the a fully automated drilling machine.

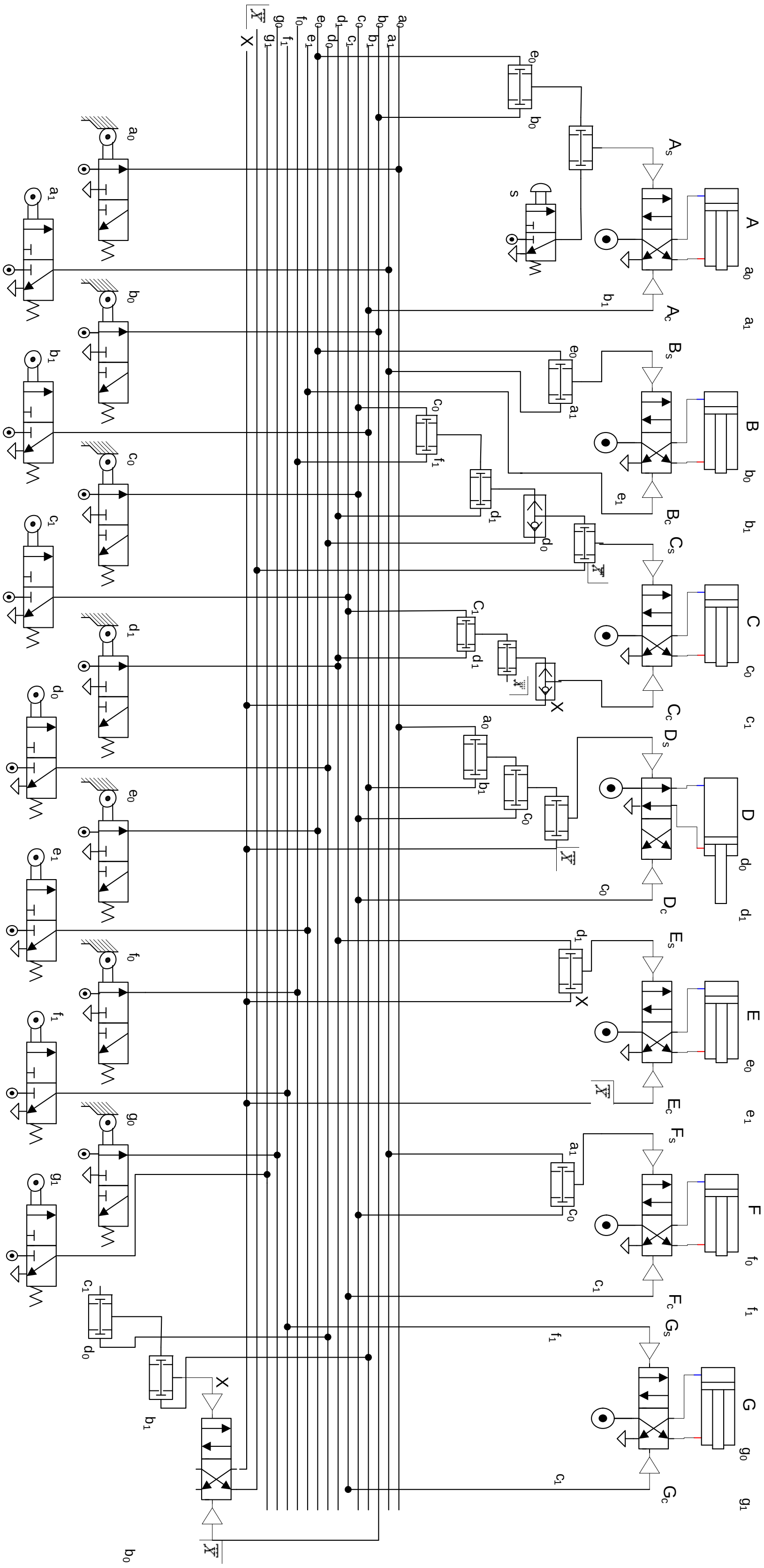


Fig. 24. Designed pneumatic circuit for the fully automated drilling machine

CONCLUSION

A systematic new method for designing fluid logic sequential networks using tree chart has been introduced. Seven steps have been presented to construct tree chart in the correct form and also, four steps to extract simplified logic equations.

Note that this method valid for small to very large complex logic circuits. A future works are preparing for compound circuits.

REFERENCES

[1] Morris Mano, M., " Digital Design", Prentice Hall, (2002).

[2] Peter Croser, Frank Ebel, "Pneumatics, Basic level", Festo Didactic GmbH & Co., D-73770 Denkendorf, (2002).

[3] Waller, D., and Werner , H.,"Hydraulics, Workbook Basic Level", Festo Didactic GmbH & Co., D-73770 Denkendorf, (2001).

[4] Frank Ebel, " Fundamentals of Pneumatics", Festo Didactic GmbH & Co., D-73770 Denkendorf, (2000).

[5] Peter Rohner, “ Fluid Power Logic Circuit Design, Analysis, Design methods, and Worked Examples”, Mecmillen press LTD., (1979).