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# Design and Simulation of Programmed Sequences for Electro Pneumatic Paper Sealants Using Cascade Method

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**Abstract**

This article presents the design procedure using the cascade method and simulation of the programmed sequences for the pneumatic processes of a paper sealing machine. Represents multiple practices alluded to pneumatics as a fundamental principle in the execution of the project. Regarding the methodology used, development was established in 3 phases, from which the implementation of the transport, sealing and paper cutting process is obtained. Everything is immersed in the respective operation of the programmable logic controller (PLC) together with the pneumatics, giving this industrial process status to the designed solution. Each of the parts used in the execution of the project is also explained, the behavior of the process is analyzed and the transition of each one of the states is observed to finish with the final product.

**Keywords:** Pneumatics, Programmable Logic Controller, Simulation, State Diagram.

## INTRODUCTION

Implementation of pneumatics in our daily activities has contributed to the improvement and optimization of many tasks or processes that are required for transformation of the environment and acquisition of elements for a better standard of living.

In different sectors of the industry, pneumatic technology is used in the positioning of platforms and elements in general, in machining of products and control of the production of lines of work, industrial assemblies. The applications of pneumatics are very varied, ranging from food industry, automotive industry, textile industry, aeronautics, mining sector, steel industry, from manipulators to robots [1].

There are diverse applications that use this type of pneumatic mechanism, what it is essential to be clear about the importance of knowing this type of energy transmission different from those used on a daily basis [2].

The article is divided into 3 main sections, where the first section is called "Materials and Methods", containing pneumatics, the programmable logic controller, cascade method. The second section called "Work development" refers to phases of the work, , and finally “conclusions”, where the findings are exposed after the development of the article.

## MATERIALS AND METHODS

### Pneumatics

Pneumatics is the technology that uses compressed air as a way of transmitting the energy needed to move and operate mechanisms. The air is an elastic material and, therefore, when applied a force is compressed, maintains this compression and returns the accumulated energy when it is allowed to expand, as dictated by the law of ideal gases [3].

### Pneumatic controls

Pneumatic controls consist of signaling elements, control elements and work input. The signaling and control elements modulate the execution phases of the work elements and they are called valves. The pneumatic and hydraulic systems are constituted by:

- Elements of information.
- Work elements.
- Signaling elements.

For handling of control information, it is necessary to use devices that control and direct the fluid in a pre-established manner, which requires having a series of elements that perform the desired functions related to the control and direction of the flow of compressed air [4].

The great evolution of pneumatics and hydraulics has, in turn, evolved the processes for the treatment and amplification of signals, and therefore, now we have a very extensive range of valves and distributors that allow us to choose the system that best suits the needs [5].

The valves in general terms, have the following missions:

- Distribute the fluid

- Regular flow
- Regular pressure

The valves are elements that command or regulate the start-up, stop and direction, as well as the pressure or flow of the fluid sent by the compressor or stored in a tank. This is the definition of DIN / ISO 1219 according to a recommendation of the CETOP (European Committee for Transmission of Hydraulic and Pneumatics) [1].

Depending on their function, the valves are subdivided into 5 groups:

- Valves of roads or distributors
- Blocking valves
- Pressure valves
- Flow valves
- Shut-off valves

### Programmable Logic Controller

Programmable Logic Controller (PLC), is a computer used in automatic engineering or industrial automation, to automate electromechanical processes, such as the control of factory machinery in assembly lines or mechanical attractions [6].

PLCs are used in multiple industries and machines. Unlike general-purpose computers, PLC is designed for various types of input and output signals, among the advantages of using PLCs are: extended temperature ranges, immunity to electrical noise and resistance to vibration and impact. The programs for the control of operation of the machine are usually stored in backups in non-volatile memories. PLC is an example of a "hard" real-time system, where the output results must be produced in response to the input conditions within a limited time, otherwise it will not produce the desired result [7].

### Cascade Method

It is a method used to design automatic or electro-pneumatic circuits in a methodical way to eliminate the blocking conditions presented in the operation diagram, and to realize what is necessary, order of the opposite movement of the same cylinder [8]

The procedure consists of:

- Identificate elements of the work (Stem or engines).
- Identificate movements of the elements for the work (initial position, rest)
- Relationship Phase-Sequence
- Group formation.
- Switching valves.
- Formation of horizontal pressure lines and connection to the commutating valves.
- Connect sensors.
- Connect power valves.

It´s important to know that in a group can´t be two movements of the same actuator, the movements can't be changed according to the defined sequence. The smallest possible number of pressure groups must be generated, the activators of the groups must be fed by the previous pressure groups and the last group must start energized.

## WORK DEVELOPMENT

Figure 1 shows phases implemented in the design of the solution, each of them ends with the product that enables the development of the next phase.

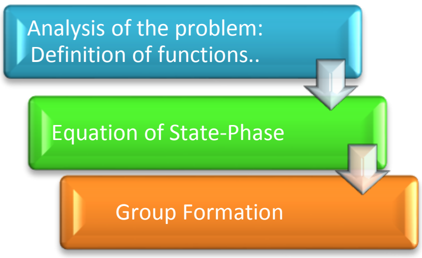


**Figure 1.** Graphic description of development work

Source: Authors

### Phase 1: Analysis of the problem

Now, first phase begins, identifying and analyzing the problem, the paper sealing machine is used to generate the labels of products of different nature, which include, among others, price information, production batch date, expiration date; all this information must be contained in a strip cut from a roll of adhesive paper, which is installed in the dispenser of the sealing machine. It is then required to perform 3 processes represented in: Transport the paper strip, seal the paper strip and finally perform the cut of the paper strip with a standard size.

Phase 1 of the design generates as a product the parameterization of the 5 double effect cylinders implemented in the design, below they relate each of them and the function they fulfill:

A = Paper conveyor cylinder.

B = Cylinder holding the paper.

C = Cylinder dispenser of the ink

D = Cylinder that contains the seal

E = Cylinder containing the shear

Table 1. Specifies each of the movements to be implemented.

**Table 1.** Description of the movements of the double-acting cylinders

| Cylinder | Movement | Resulting Action |
|---|---|---|
| A | * | THE CYLINDER ADVANCES HALFWAY |
| A | + | THE CYLINDER ADVANCES TO THE END OF ITS TRAVEL |
| A | - | THE CYLINDER CONTRACTS COMPLETELY |
| B | + | THE ROD COMES OUT AND HOLDS THE PAPER STRIP |
| C | + | THE STEM COMES OUT TO IMPREGNATE THE SEAL WITH INK |
| C | - | THE ROD RETRACTS TO STOP IMPREGNATING INK |
| D | + | THE STEM COMES OUT TO PUT THE SEAL ON THE PAPER STRIP |
| D | - | THE ROD RETRACTS TO STOP PUTTING THE SEAL |
| E | + | THE ROD COMES OUT AND CUTS THE PAPER WITH THE SHEAR |
| E | - | THE ROD RETRACTS TO FINISH THE CUT |

The problem of the design is represented by the need to find the synchrony in the movements of the pneumatic cylinders, in such a way that each one of them makes the displacements of entry and exit of their shanks without colliding with the other cylinders, in the required time and with the precision that corresponds to each task of transportation, sealing and cutting of paper. For this, the mass flows of the cylinder chambers must be considered, which are represented in Figure 2.

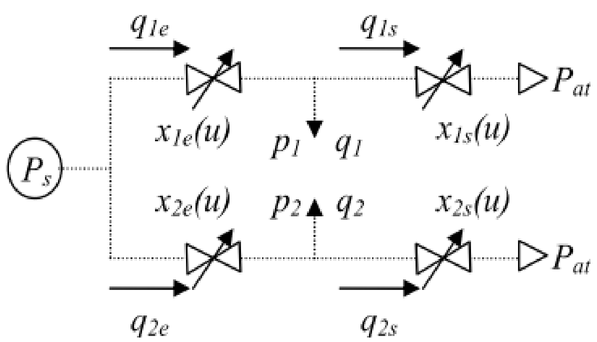


**Figure 2**. Representation of the flows through the valve orifices

Source: Authors

At the moment of starting the system, the air flows to and from the cylinder are zero: q1 = q2 = 0 and those that circulate through the holes of the valve are equal: q1e = q1s and q2e = q2s.

The mass flow of air through the orifices of the valve, depends on the area of the orifice and the inlet and outlet pressures: qm = f (x, pent, psal) and is calculated according to ISO-6358 (ISO-6358 , 1989) that establishes according to equation (1)

$$qm = \begin{cases} K\,X\,Pent\sqrt{\frac{273}{T}} & \frac{0<r<rc}{r\geq rc} \\ KX\,Pent\sqrt{\frac{273}{T}} * \sqrt{1-\frac{(r-rc)}{(1-rc)^2}^2} & \end{cases} \qquad (1)$$

Where

X= Effective area of the hole ($m^2$)

Pent= Input pressure to the hole(pa)

Psal= Orifice outlet pressure (Pa)

K= Proportional constant of adjustment of units given in($^{kg}/_{m^2 * Pa}$)

r= Pressure reason (Pent/Psal)

rc= Critical pressure ratio that delimits the sonic flow of the subsonic. Determined for FESTO valve by Kawashima in, rc = 0.3 [9].

The mass flows to the cylinder chambers, according to Figure 2 and equation (2) result:

$$q1 = q1e(x1e, ps, p1) - q1s(x1s, P1, Pat)$$
$$q2 = q2e(x2e, Ps, P1) - q2s(x2s, P2, Pat) \qquad (2)$$

The design poses the challenge of finding a motion equation, making a phase-state diagram of the motion equation, constructing an electro-pneumatic circuit, parameterizing a PLC and programming it with the required sequence so that its inputs and outputs control the process.

**Phase 2: MOVEMENT EQUATION AND STATE-PHASE DIAGRAM**

Each letter in upper case represents a cylinder; therefore 5 cylinders were used for the simulation of the automated pneumatic process. The resulting equation of motion is the following is represented by Equation (3):

A* B+ C+ D+ C- B- D- A+ E+ E- A- (3)

**Phase – State Diagrama**

State-phase diagram graphically shows the transitions of the 5-cylinder rods during a single execution cycle, cylinder A has special consideration for having three prosing sensors A0, A1 and A2, which serve to sense the initial positions, intermediate and final of said cylinder. Figure 3 shows stage state diagram for a single cycle of the process, note that it shows that step 10 will be equal to the initial step P0 [10].

The initial trigger action is executed when the AND condition established by the sensor A0 and normally open button (start) that activate a relay with its self-locking circuit are met.

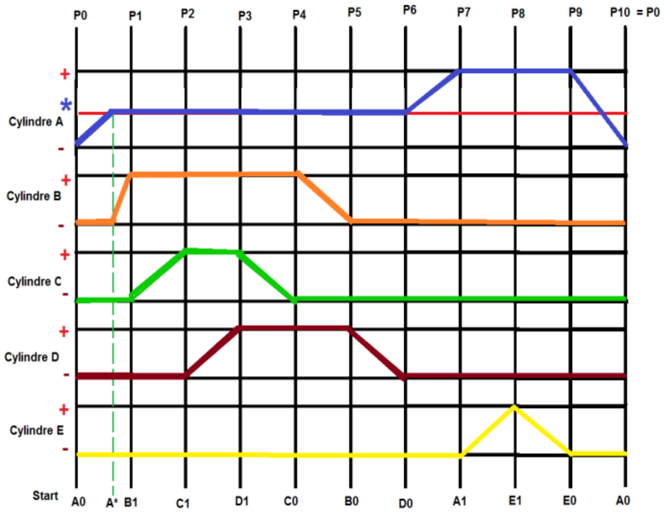


**Figure 3.** Diagram State Phase of the process for a single work cycle
Source: Authors

### FASE 3: GROUPS FORMATION (CASCADE METHOD)

Process was performed by the cascade method, and assigned groups and movements can be seen in Table 2.

**Table 2.** Description of the movements of the double-acting cylinders

| Group | Group equation |
|---|---|
| 1 | A* B+ C+ |
| 2 | C- B- D- A+ E+ |
| 3 | E- A- |

Equation (4) identifies the groups within the movement equation, it is important to clarify that the cascade method does not allow having double the cylinder in a group.

A* B+ C+ D+ / C- B- D- A+ E + / E- A- (4)

Sign " + " represents stem going out.

Sign " – "represents stem going in.

Sign " * "represents stem in the middle.

**Start circuit:** It is the circuit required for the System to start working (Figure 4). It´s important to note that a retention is implemented so that it can work with a normally open pushbutton.

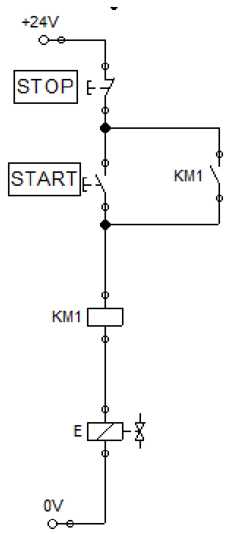


**Figure 4**. Control circuit, start circuit
Source: Authors

Once defined control, it proceed to implementation of pneumatics by the cascade method, as shown in Figure 5

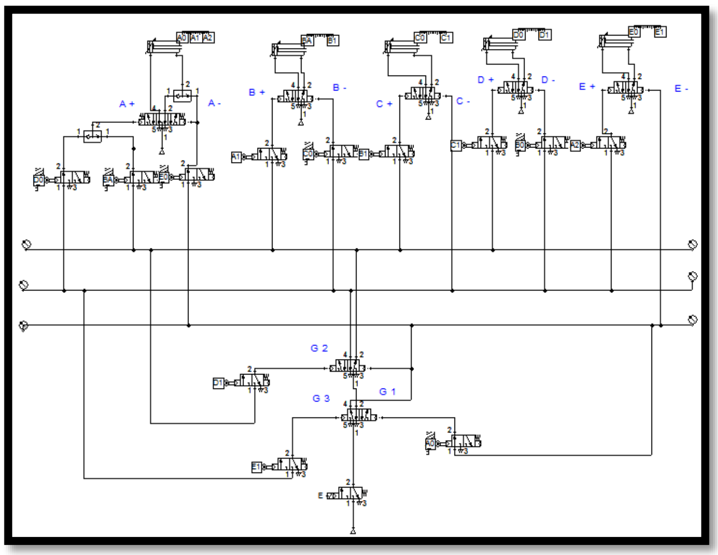

**Figure 5.** Circuit designed with the cascade method

Source: Authors

### Phase 3: OPERATION OF THE STATE-PHASE EQUATION

First the process of each of the cylinders is explained and finally the equation of state is obtained.

For control, the pneumatic part is executed. It starts and what can be seen in Figure 6 occurs.

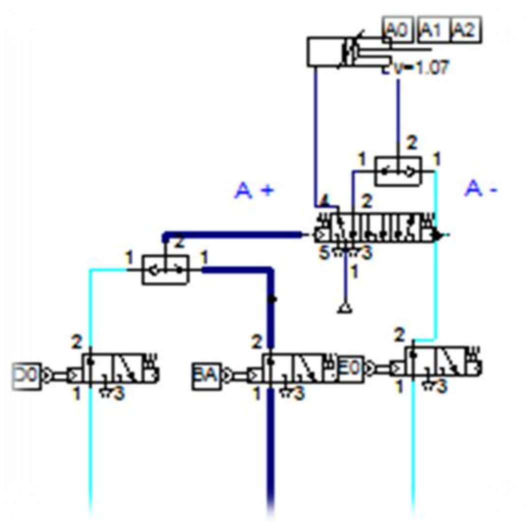


**Figure 6**. The first shank (A) transports the paper halfway
Source: Authors

Figure 7 shows the activation of cylinder B, responsible for keeping the paper strip fixed, its displacement ends when the position sensor B1 is activated.

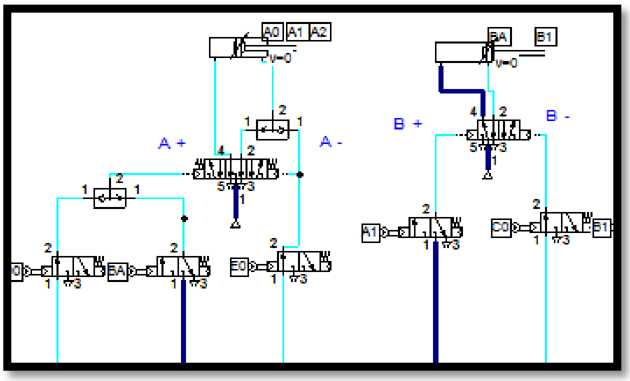

**Figure 7.** The second shank (B) holds the paper
Source: Authors

Figure 8 shows the activation of the cylinder C, responsible for impregnating with ink the seal with a pad its path ends when the sensor C1 is activated.

$$R_{z(\beta)} = \begin{bmatrix} \cos\beta & -\sin\beta & 0 & 0 \\ \sin\beta & \cos\beta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

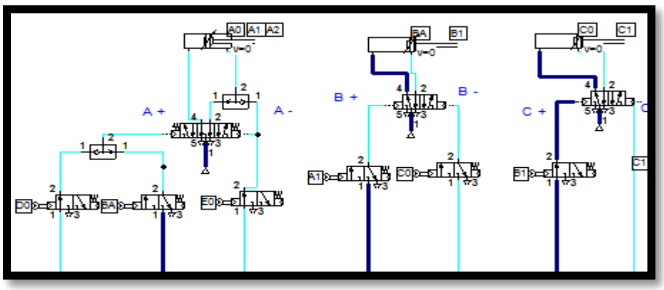

**Figure 8.** Cylinder movements C, transports the ink
Source: Authors

In Figure 9, when the ink shank is picked up, the stamp stem continues its normal course until the stamp is impregnated in the paper.

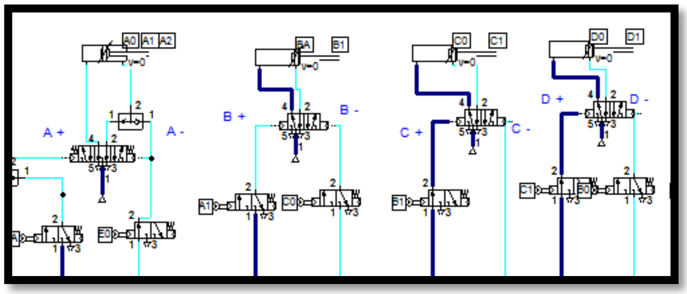

**Figure 9.** The fourth shank (D) the seal reloads ink when it meets the ink shank.
Source: Authors

Figure 10 shows cylinder C when it returns after impregnating with ink the seal connected to cylinder rod D,returns to its position and then returns the shank B (the one that holds the paper).

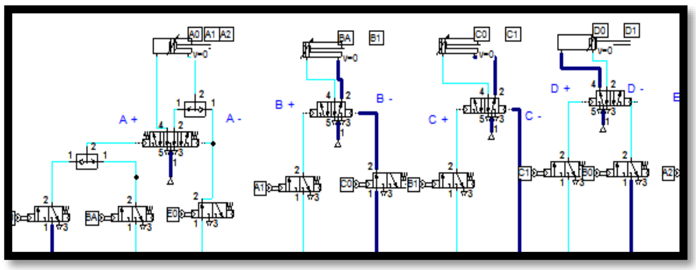

**Figure 10.** Cylinder movements C and B, return ink pad
Source: Authors

In Figure 11 the movement of the cylinder D is observed when it returns, at that moment the sensor D0 is activated, Stem 4 (D) returns to its initial position. The shank 1 (A) comes out completely and transports the paper to the trimming section.

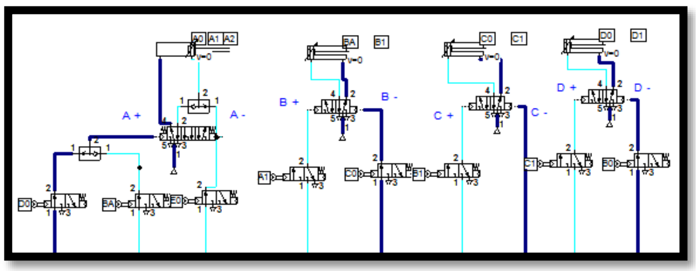

**Figure 11.** Transfer of paper strip to cutting area
Source: Authors

Figure 12 shows the deactivation of cylinder E after cutting the paper strip. When the rod 1 (A) completely transports the paper the rod 5 starts with the cut.

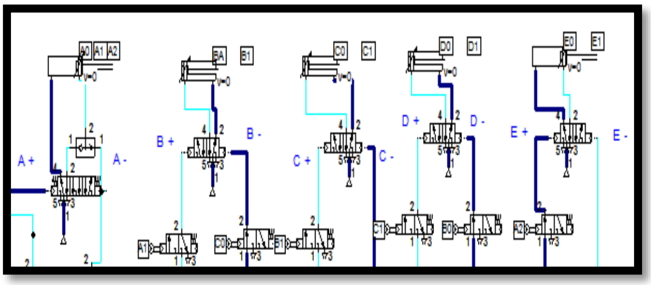


**Figure 12.** Deactivation of cylinders A and E starts with the cut.

Source: Authors

Once again it executes the process without any inconvenience; the only way to stop the process is with the button (STOP).

The final result of pneumatic circuit can be seen in Figure 13, but Figure 14 shows oscillogram of the state diagram phase for 10 work cycles.

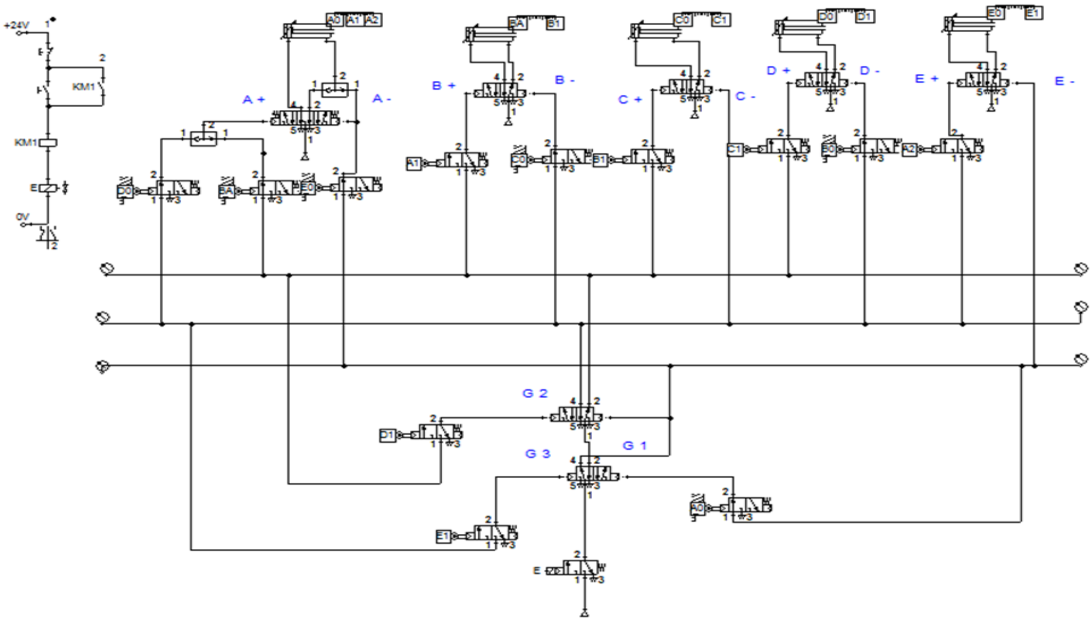


**Figure 13.** Final simulation of the automated pneumatic process for the transport and sealing of paper OFFSET
Source: Authors.

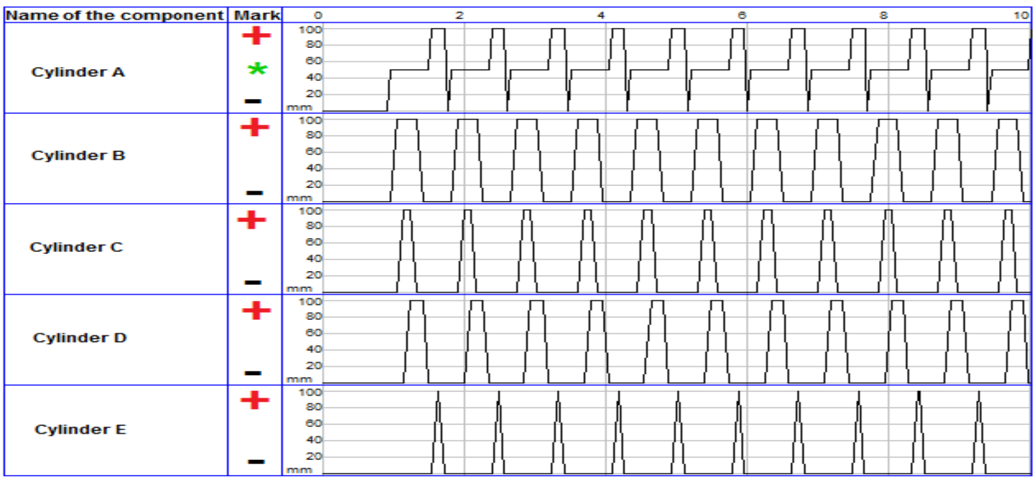


**Figure 14.** Diagram of the equation State-Phase (Final Result)

Source: Authors

Once the electropneumatic design has been completed, sequence programmed can implemented in PLC, for that Siemens S7200 reference will be used.

Parameterization of the inputs and outputs is shown in table 3.

**Table 3.** Parameterization of PLC inputs and ou tputs

| Symbol | Direction | Symbol | Direction | Symbol | Direction |
|---|---|---|---|---|---|
| Off | I0.0 | A0 | I0.2 | B0 | I0.5 |
| Start | I0.1 | AX | I0.3 | B1 | I06 |
| Inicio | Q0.0 | A1 | I0.4 | C0 | I0.7 |
| C1 | I1.0 | E0 | I1.3 | Amenos | Q0.2 |
| D0 | I1.1 | E1 | I1.4 | Bmas | Q0.3 |
| D1 | I1.2 | Amas | Q0.1 | Bmenos | Q0.4 |
| Cmas | Q0.5 | Dmas | Q0.7 | Emas | Q1.1 |
| Cmenos | Q0.6 | Dmenos | Q1.0 | Emenos | Q1.2 |

The program implemented in Ladder language is shown in Figure 15, it consists of 12 Networks, initial Network a trigger circuit is available to enable the System, later the networks are activated according to the detection sequence of the sensors, starting by the sensor A0 that acts as a normally closed contact, allowing to activate the electrovalve that activates the action Amas, extending the rod of the cylinder A, which when reaching the middle of its path is detected by the position sensor AX, which activate the Bmas action in addition to disabling the action that was running, the sequence continues in the order established by equation 1, which is known as the equation of motion described graphically in Figure 14 or diagram State Phase.

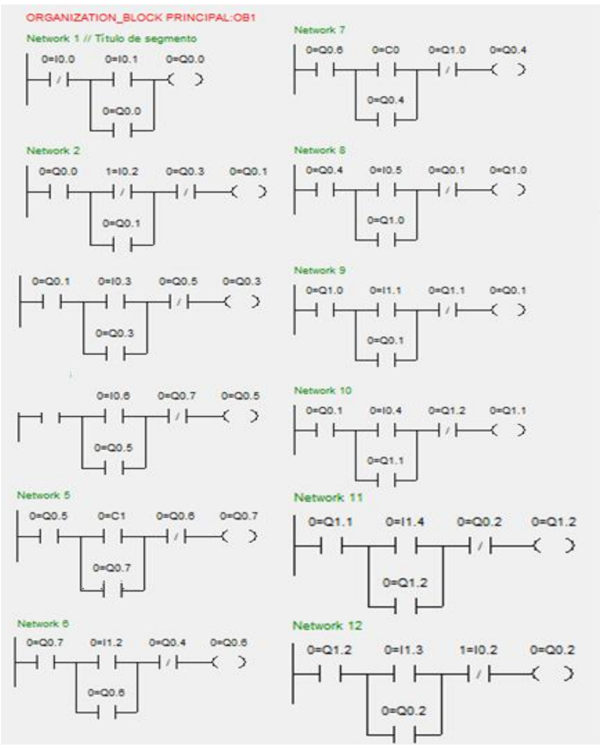


**Figure 15.** Diagram of the equation State-Phase (Final Result)

Source: Authors

## CONCLUSIONS

Implementation of cascade method for a simulated electropneumatic process is confinable against the guarantee of a correct execution to the sequence of development to the motion equation [11].

The development times of a Project implemented with the cascade method are short, which offers an advantage by shortening the testing and start-up periods of a solution.

Be able to implement the sequence of development to the motion equation in PLC, guarantees the power to monitor the states of sensors and outputs, required to identify failures due to errors in the wiring and hardware elements. [12].

Monitoring the evolution of the work flow through a diagram State phase is an advantage because it includes the visualization of the outputs, the path of the rod of each cylinder and the status of each of the sensors [13].

The economic and industrial needs start from the reduction of production costs and automation of processes, which emphasizes the importance of pneumatic processes in the midst of human needs.

The importance of pneumatics and its easy comprehension make possible the development of large industrial projects that undoubtedly automate and improve the quality of the products and the development time [14].

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