Annals of the University of Craiova, Electrical Engineering series, No. 48, Issue 1, 2024; ISSN 1842-4805 eISSN 2971-9852

Pneumatic System for Compacting Food Waste Packaging

Ionel Laurenţiu Alboteanu*, Mircea Adrian Drighiciu*, Ecaterina Maria Drighiciu†, Florin Ravigan*
* University of Craiova / Department of Electromechanical, Environmental and Applied Informatics, Craiova, Romania,
e-mail: lalboteanu@em.ucv.ro, adrighiciu@gmail.com, ravigan.florin@gmail.com
† Distributie Oltenia / Department of Construction, Craiova, Romania
e-mail: drighiciu.ecaterina@yahoo.com

Abstract – **The paper presents an automatic system for compacting metal, plastic and glass waste from food consumption (boxes or empty cans). The compaction process is found in waste recycling systems. The purpose of this work is to analyze the main stages of designing an electro-pneumatic drive and automation system for a waste compactor used in food packaging, starting with the creation of the specifications document and ending with the development of a control structure in a classic version – control circuits with contacts and relays, or by using programmable logic controllers (PLCs). To design and validate the control circuits, the FLUIDSIM simulation environment was used, and the experimental validation involved building a functional small-scale model of the compaction device and analyzing its operation in laboratory conditions. Additionally, aside from the educational and research goals, which involve proposing a solution and verifying it through numerical simulation and on a small-scale experimental model, the work also aims to integrate the proposed solution into an automated packaging collection equipment within the Deposit-Return System (SGR). Packaging collection machines located in commercial centers do not have compaction modules integrated into their structure, and thus blockages often occur due to the rapid filling of the collection containers. The introduction of compaction modules would significantly reduce the waste volume and transportation costs for the collection centers.**

Cuvinte cheie: *sistem automat, compactare deseuri, automat programabil, diagrame grafcet, fluidSim, simulare. model experimental*

Keywords: *automatic system, metal waste compaction, programable logic controller, grafcet diagrams, fluidSim, simulation, experimental model*

I. INTRODUCTION

Metal is an exhaustible resource. However, it can be recycled endlessly without losing its qualities. Scrap metal is usually aluminum or steel. For example, recycled aluminum can be obtained with 74% to 95% less energy consumption than aluminum obtained through ore processing [1]. Steel can be obtained from empty cans. By recycling metal waste, the ore extraction process and the energy used for extraction and production can be reduced. Moreover, the greenhouse gas emissions, the pollution resulting from these processes, and the impact on the ozone layer are also considerably reduced. Recycling 1 kg of aluminum saves around 8 kg of bauxite, 4 kg of chemicals, and 14kWh of electricity [2].

Regarding the recycling of plastic materials, one of the most important PET waste recyclers in Europe presents the following advantages [3]:

- The production of new resources through PET recycling ensures a reduction in CO2 emissions by almost half compared to the same product obtained from raw materials derived from petroleum;
- Energy consumption is reduced by 30% compared to the energy required in the process of producing PET from virgin material;
- Fuel usage is reduced by up to 75% compared to the energy spent in the production of virgin material.

In the European Union market, with the introduction of the Deposit-Return System (SGR) [4], automated systems for collecting plastic, metal, or glass packaging from food and beverage consumption have been implemented. These machines have been installed in high-traffic areas (shopping centers, airports, etc.) for advertising purposes and to educate the public about the issue of waste recycling.

The main limitation of these machines is that they are not equipped with compaction functions to reduce volume and transportation costs.

This work presents an automatic system for compacting waste, primarily from beverage and food packaging (cans and tins).

The pressing (compacting) process of empty containers is a common function in waste recycling systems [5].

From the perspective of component elements and operation, the metal container compaction device presented as a direct application of pneumatic actuation and control systems can be considered a system where both sequential and parallel/concurrent activities can take place.

The authors have also addressed this research topic in the paper [6] but it was not developed sufficiently.

II. THE DESCRIPTION FOR THE COMPACTION SYSTEM

A. The Structure of the Compaction Device

The component elements of the compaction device are indicated in Fig. 1a.

The compactor consists of three pneumatic cylinders, C1, C2, and C3, along with the functional elements and equipment of such an actuation system (distributors, valves, stroke limiters, compressed air supply, air treatment elements, pressure switches, etc.) [6].

The pressing operation for the empty cans is carried out by pneumatic cylinder C2, which moves vertically (Fig. 1a, 1b). Cylinders C1 and C3 facilitate the complete opening and closing of the container designed to hold the empty cans during pressing. This container, specifically designed for the application, has a rigid metal parallelepiped structure capable of holding four empty cylindrical metal cans arranged in a single layer.

The empty cans are loaded into the storage container via a transport subsystem. This system includes a conveyor with either continuous or intermittent motion, combined with a gravity-based transfer mechanism (ramp) that allows the cans to roll into the container (Fig. 2).

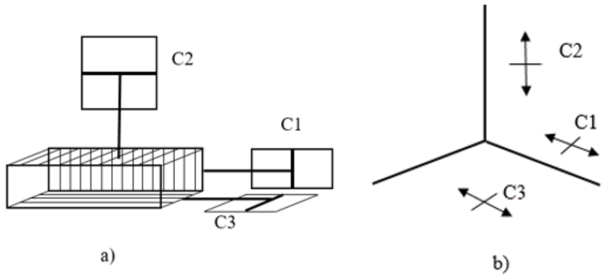

Fig. 1. The structure of the compaction device [6]: a) Representation of the arrangement of the pneumatic cylinders, b) Directions and planes of movement for the three cylinders.

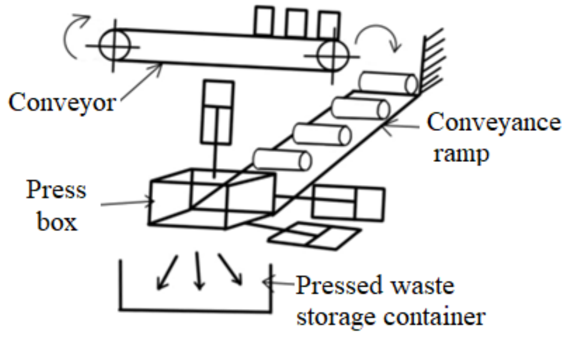

Fig. 2. Explanation of the arrangement of the components of the compaction system. [6]

The container can be dimensioned for a predetermined number of metal cans that are compacted in a complete operating cycle. The conveyor transporting the empty cans can be stopped after the agreed number of cans has been deposited in the pressing container, and restarted after the pressing cycle is completed. This prevents the accumulation of empty metal cans at the end of the transfer devices. The cans on the conveyor can be spaced by separation devices that are part of the conveyor's construction. An automatic counting device placed at the end of the conveyor determines the number of cans compacted during a complete sequence (complete cycle) of operation.

B. The Description of the Operation Protocol

A complete cycle operating scenario can be as follows [6]:

1) The conveyor transports the empty cans to the pressing container. At the end, each can falls freely onto the transfer ramp and rolls into the container – which can hold 4 empty cans. When the conveyor has transported 4 cans, it stops.

2) Cylinder C1 advances – thus, side 1 of the container is closed;

3) Main cylinder C2 advances – the operation of compacting the cans in the container is performed;

4) Cylinder C2 returns;

5) Cylinder C3 returns – its downward vertical movement from its initial position opens the space for ejecting the compacted cans;

6) Cylinder C3 advances – closing side 3 of the container;

7) Cylinder C1 returns – now side 1 of the container opens, and the device is returned to its initial state.

Another cycle can then begin, in the same sequence, after the container is refilled with another 4 empty containers.

The pneumatic actuation circuit diagram is shown in Fig. 3 Pneumatic cylinders C1, C2, and C3 are double-acting, powered from the same energy source. Each cylinder's strokes are provided by a 4/2 distributor with electrical control (solenoid valves). The extreme positions (initial and end-of-stroke) of C1 and C3 are indicated by signals from sensors S1 and S2, respectively S4 and S5. The initial position of the main cylinder C2 (with the rod retracted in the upper position) is signaled by sensor S3, with the return stroke commanded by pressure switch P (pneumo-electric transducer). Generally, the maximum working pressure in the compacting phase (advance stroke) can be adjusted according to the material being pressed.

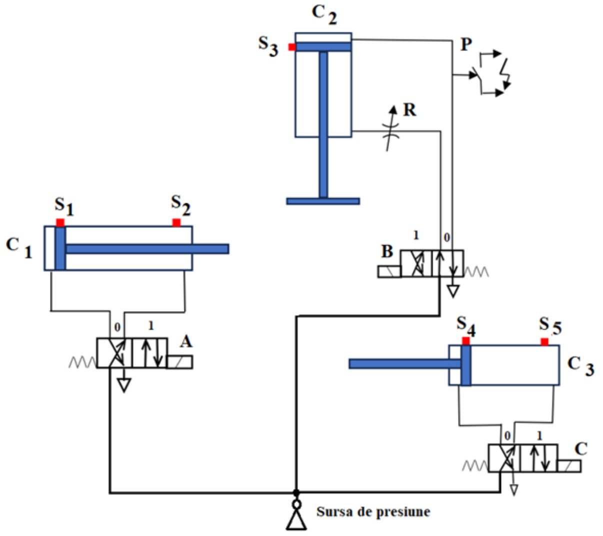

Fig. 3. Pneumatic drive diagram circuit.

In this version, the pneumatic circuit contains only one speed adjustment element for cylinder C2 (pneumatic resistor R). Thus, the piston speed of C2 can be adjusted in both strokes. Other pressure control and adjustment elements can be added later in the circuit, depending on the requirements for the most efficient operation of the entire device.

A contact and relay control circuit version is shown in Fig. 4. This ensures the specified operating sequences.

The notations in Figure 4 have the following meanings:

B1: Start button for the operating cycle;

K1…K5: Coils with associated contacts;

S1…S6: End-of-stroke sensors for the cylinders;

A, B, C: Coils of the pneumatic valves;

P: Pressure relay (pressure switch).

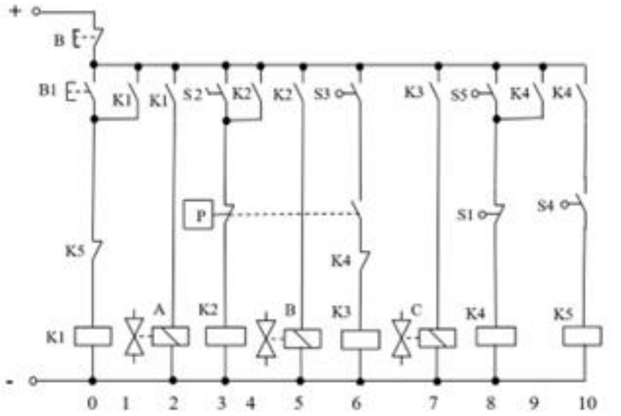

Fig. 4. Contact and relay control circuit diagram of the compaction device.

A detailed explanation of the operation of the diagram in Figure 4 is provided in [6]. A summary of the step-by-step sequential operation is presented in Figure 5.

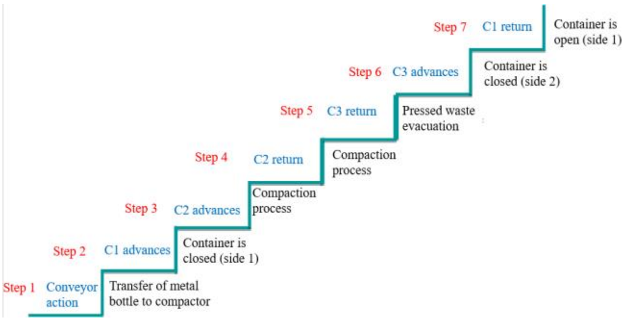

Fig. 5. Description of the sequential staged operation of the compaction system.

C. *Dimensioning of pneumatic cylinders*

The actuation circuits are supplied by a compressed air generation and conditioning system consisting of a compressor, air lubricator, dehumidifier, and pressure regulator [6].

In this setup, the operating circuit uses a pressure of

$p_r = 6\cdot 10^5$ N/m^2 = 6 daN/mm^2 = 6 bar.

For pneumatic cylinder C1 (Fig. 1), after a comparative analysis of several pneumatically actuated devices and considering that this cylinder performs a relatively short stroke and the weight of the movable vertical wall is not significant, it was determined that the static force it must overcome is Fs_1 = 10daN.

Thus, using the sizing formula:

$$D_{C1}=(15...18)\cdot\sqrt{\frac{Fs}{pr}}=(15...18)\cdot\sqrt{\frac{10}{6}}=19,35...23,22\ \ [mm] \quad (1)$$

A FESTO cylinder of type DSNU-S with a standardized diameter of D_{C1} = 25 mm can be selected [8].

Pneumatic cylinder C2 (Fig. 1) is the primary execution element of the device, responsible for the actual compaction of empty metal cans. The movement of its rod can be performed at a lower speed than that of the other cylinders, considering the specific requirements of the process. For this purpose, the pneumatic actuation circuit includes a pneumatic resistance that enables volumetric speed regulation of the cylinder rod by restricting the compressed air supply flow.

To generate the pressing force and maintain it at a maximum value throughout the technological operation, a force of Fs_2 = 60 daN is considered.

$$D_{C2}=(15...18)\cdot\sqrt{\frac{60}{6}}=43,2...51,84\ \ [mm] \qquad (2)$$

A FESTO cylinder of type DSBC, to ISO 15552, with a standardized diameter D_{C2} = 63 mm can be selected [8].

Pneumatic cylinder C3 (Fig. 1) opens side 3 of the pressing chamber after the compaction operation has been completed, performing a linear movement over a stroke equal to the length of the pressing chamber. This action enables the compacted metal cans in the chamber to be discharged into the storage container for compacted waste, driven by the vertical wall.

Although it does not actively participate in the pressing operation, the weight of side 3 of the chamber must be designed to allow the pressing process to occur without deforming the chamber. Therefore, for this cylinder, it is considered that: Fs3 = 20 daN.

Ensure:

$$D_{C3}=(15...18)\cdot\sqrt{\frac{20}{6}}=27,38...32,86\ \ [mm] \qquad (3)$$

In this case, a FESTO cylinder of type DSBC, compliant with ISO 15552, can also be selected, but with a standardized diameter of D_{C3} = 40 mm [8].

Table 1 provides a summary of the parameter values corresponding to the pneumatic cylinders used:

TABLE I.
THE MAIN DIMENSIONS OF THE PNEUMATIC CYLINDERS IN THE COMPOSITION OF THE DEVICE

Cylinders type	D_c [mm]	d_t [mm]	s_{max} [mm]	v_{med} [cm/s]
C1- double action	25	8	300	3
C1- double action	63	18	1 - 1500	10
C1- double action	40	10	1 - 1500	4

III. THE MODELING AND SIMULATION OF THE COMPACTION SYSTEM USING FLUIDSIM SOFTWARE

A. *Automatic Control Solutions for the Compaction Device based on Contacts and Relays*

The selected solution was validated by modeling the pneumatic actuation circuit in the FLUIDSIM software and simulating the operation of the control circuit in both step-by-step and continuous cycle modes. The pneumatic actuation circuit is illustrated in Fig. 5, while Fig. 6 depicts the variant of the contact and relay control circuit [6], [7], [8].

In the pneumatic circuit illustrated in Fig. 6, the three cylinders are equipped with magnetic sensors S1, S2, S3, as well as S5 and S6. The active stroke of cylinder C2, responsible for the pressing operation, extends across its entire length. A pressure switch, P, is integrated into the circuit of the active chamber downstream of the pneumatic resistance Rp. This switch deactivates the command for distributor B once the working pressure reaches the preset maximum value, enabling cylinder C2 to return to its initial position. The pneumatic resistance Rp creates a pressure drop in the supply circuit of cylinder C2 and also facilitates speed adjustment for its movement in both directions [6].

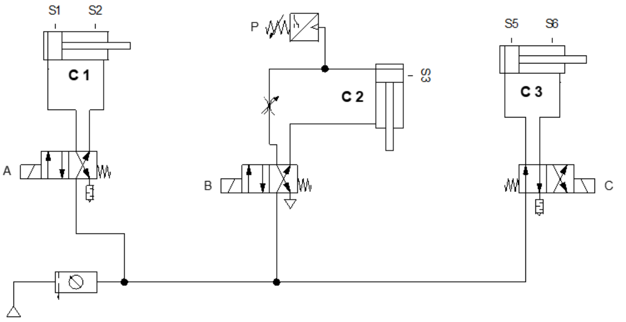

Fig. 6. The pneumatic actuation circuit built in FLUIDSIM.

The control scheme with contacts and relays ensures the sequential operation of the compacting device, according to the proposed scenario [9]. The timing relay RT in circuit 15 temporarily interrupts the power supply to coil K1 in circuit 1, thereby canceling the command of distributor A and returning C1 to its initial state. In the control scheme (Fig.7), the timing of RT is set to 3 time units, but the FLUIDSIM program allows this to be adjusted in accordance with the process specifications [10].

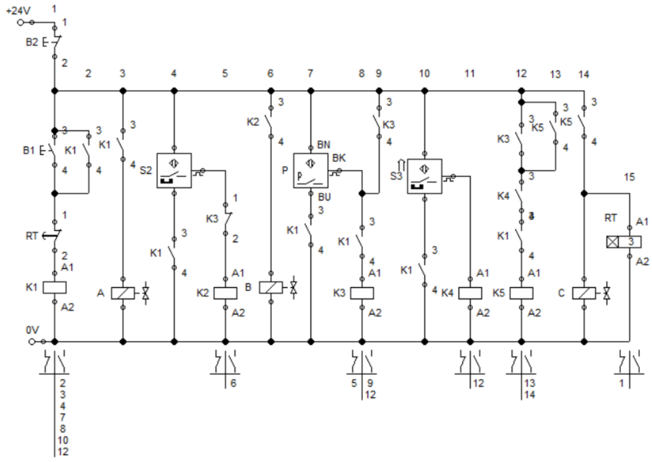

Fig.7. Contact and relay control circuit implemented in FLUIDSIM.

However, there are other solutions based on the proposed sequences, solutions that can lead to the optimization - to some extent - of the operating cycle by the simultaneous movements of some cylinders in the actuator circuit [11], [12]. One such variant is where, after the pressing is done and the main cylinder C2 returns to its initial position, the opening of wall 1 and the closing of the base 3 of the pressing tub are carried out simultaneously (Fig. 8). In this case, the forward stroke of cylinder C3 to the S4 sensor will be executed simultaneously with the return of cylinder C1 to its initial state, to the S1 sensor. This is the so-called “cycle with parallel sequences”.

Both the pneumatic circuit diagram and the control schemes created with FLUIDSIM software were verified through both step-by-step simulation and continuous simulation of a complete cycle.

In the two analyzed versions, the duration of the pressing (compacting) operation of empty cans is implicitly established by adjusting the working pressure value of cylinder C2 at which the pressure switch is activated, and which must be correlated with the pressure value of the supply source of the entire circuit. This is the so-called state-based control, knowing that pressure is a state variable of the pneumatic actuator.

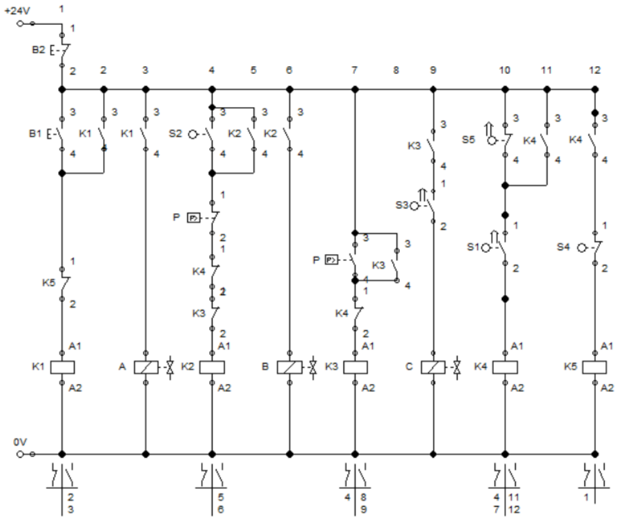

Fig. 8. Control scheme with contracts and relays – the “optimized” version

Another control possibility consists of using a time relay instead of the pressure switch P [6]. Thus, the rest of cylinder C2 at the end of the stroke for performing the pressing can be controlled by setting a time interval during which the coil of distributor B is commanded. After this duration elapses, distributor B is no longer commanded, allowing C2 to return to the initial state, to the end-of-stroke sensor.

This version is shown in Fig. 9. It can be observed that cylinder C2 is now equipped with two end-of-stroke sensors, S3 and S4 (Fig. 11a). The rest of C2 on sensor S4 after performing the pressing operation is timed by the time relay RT which has a normally closed contact with delay to open placed in circuit 4 of the control scheme (Fig. 9).

After the time set on relay RT expires, the RT contact in circuit 4 interrupts the power supply to coil K2 in circuit 4 and, implicitly, to coil B of the distributor.

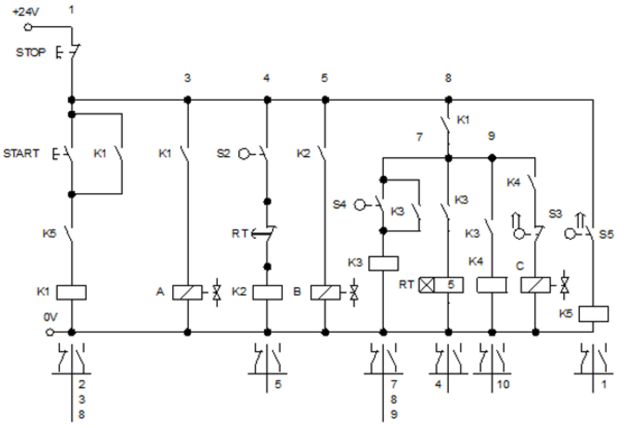

Fig. 9. Explanation for the timing of the main cylinder C2’s advance.

In the state diagram corresponding to the operating cycle, the states (activated / deactivated) of the three distributors A, B, and C are also indicated. (Fig. 10).

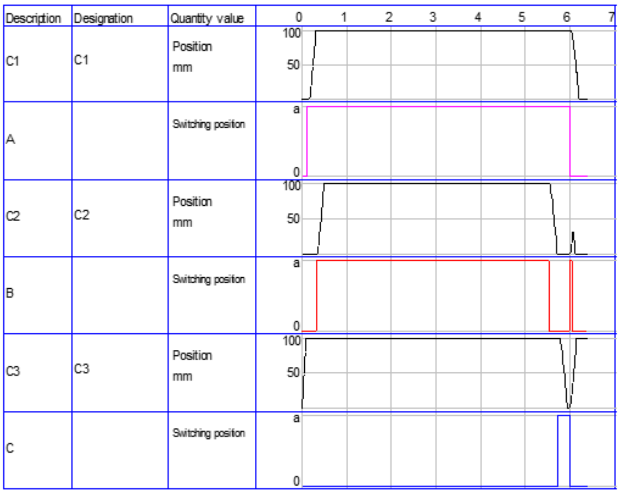

Fig. 10. The state diagram during an operating cycle for the variation presented in Fig. 9.

B. The Automatic Control of the Compacting Device with PLC

The FLUISIM program easily allows the modification of the control architecture configuration of the pneumatic actuator circuits, from the basic variant - control with contacts and relays - to a programmable controller (PLC - Programmable Logic Controller) structure [14], following the defining aspects of creating a GRAFCET structure [15].

Thus, in Fig. 11 is presented a structure of the pneumatic actuator circuit of the three cylinders C1, C2, and C3, controlled by the same distributors as in the previous variants where the operating scenario is ensured by a programmable controller.

The programmable controller (in the GRAFCET IN / OUT program) is equipped with two process communication ports (Fig. 11 b). The IN port connects the six sensors that equip cylinders C1, C2, and C3, as well as the START button - B1 for commanding an operating cycle.

The OUT port connects the coils of the distributors A, B, and C that control the cylinders.

The IN / OUT structure and the level I GRAFCET in images 11 b) and 11 c) are created without considering the timing of cylinder C2 at the end of the stroke when performing the pressing operation of empty boxes.

FLUIDSIM allows inserting timers in the GRAFCET IN / OUT component that allow evolution to another state after fulfilling the conditions (introduced in the model through transitions) ONLY after the time interval implemented by the timers elapses.

Proceeding exactly as in the contact and relay control version, it was introduced a timing of cylinder C2 at the end of the stroke (S4 = 1), associated with the duration of the pressing operation (Fig. 11 d).

The resulting GRAFCET (Fig. 11 d) contains another state (state 4), identical to state 3, in which the process remains “anchored” until the timing of the transition elapses. In other words, cylinder C2 retracts to its initial position not immediately upon reaching the end of the stroke, but only after the pressing has been executed.

In Fig. 12 is presented the resulting state diagram from the simulation in FLUIDSIM.

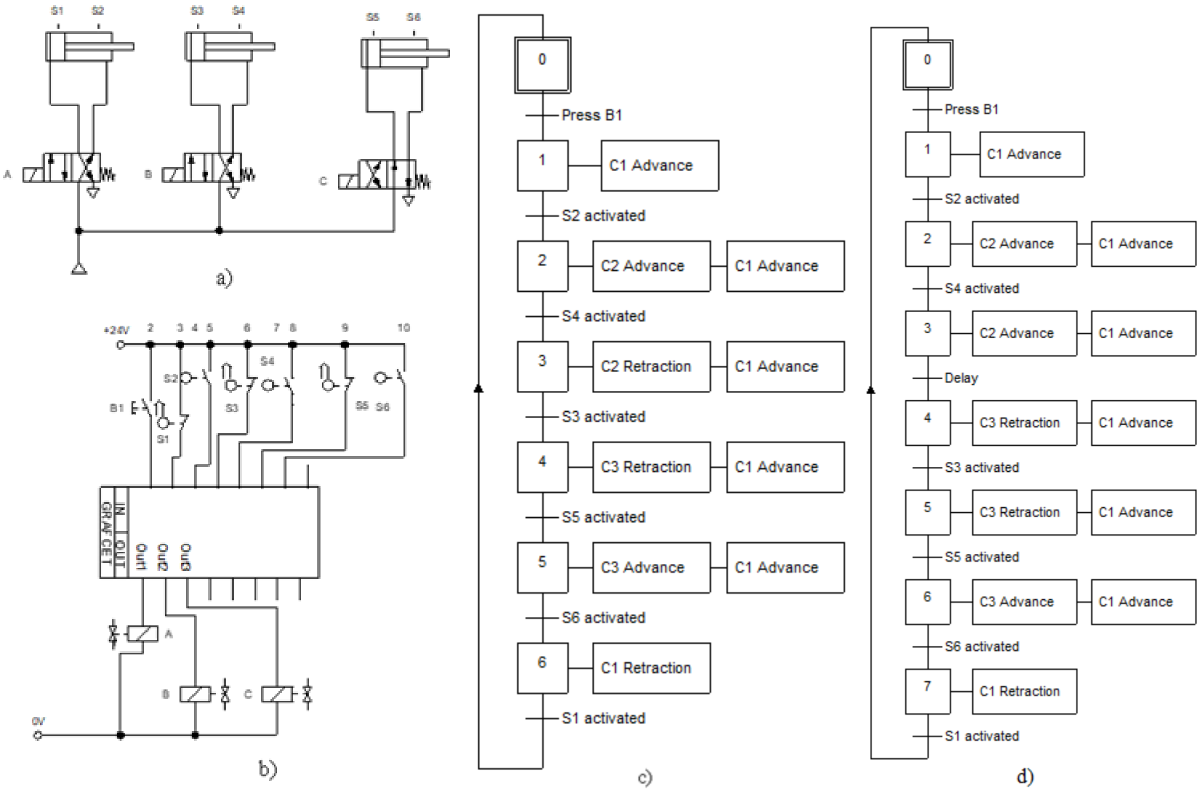

Fig. 11. The control structure with a PLC for the pneumatic actuation: a) Pneumatic actuator circuit; b) GRAFCET IN / OUT configuration; c) GRAFCET corresponding to the sequential cycle of the three cylinders; d) control structure of the compacting device with a timed GRAFCET model.

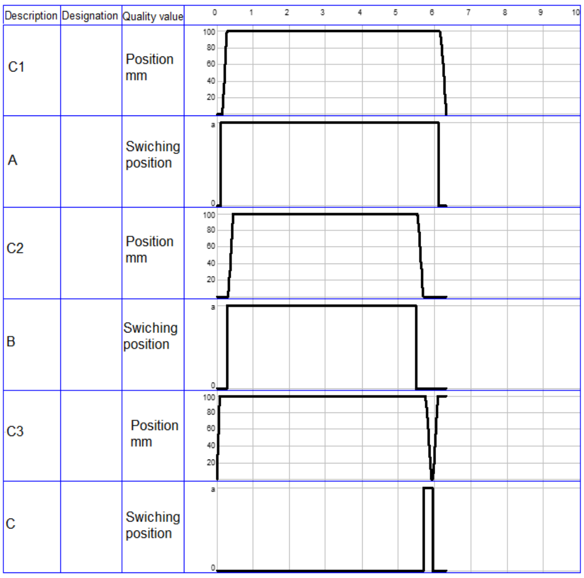

Fig.12. The state diagram corresponding to an operating cycle of the compactor.

The cylinder C2 remains at the end of the stroke on sensor S4 for an interval equal to 5 time units (value assigned to the timing of the transition between states 3 and 4 - Fig. 12) and only then, after distributor B is deactivated, it returns to the initial state.

IV. SOFTWARE DEVELOPMENT FOR PLC

Both the simplification of the hardware and the use of as few components as possible, as well as the ease of programming the system, were key aspects considered during the design of the control system. [16], [17], [18], [19]

For the automatic control of the compaction process, it is proposed to use an Easy 719-AC-RC PLC, manufactured by EATON [20].

The Eaton Easy AC-RC-719 programmable logic controller was chosen due to the features it offers, namely: compact size; direct connection to the 230 V power supply; presence of a keyboard and screen; 6 outputs; and 14 inputs.

The Eaton Easy 719 is a programmable logic controller with built-in logic, a timer, counter, stopwatch, and arithmetic functions. It performs multiple tasks across various engineering fields.

The number of inputs and outputs can be expanded up to a maximum of 24 inputs and 16 outputs, with the possibility of connecting a single extension device.

The circuit diagrams are connected using LADDER diagrams, and each element is entered directly through an easy-to-use display.

Figure 12 shows the wiring diagram for connecting the PLC to the pneumatic drive.

For the development of the PLC program, it was used a dedicated software for Eaton Easy PLCs, called Easy Soft [21].

EASY-SOFT is a PC program that allows the creation, storage, simulation, and documentation of Easy connection diagrams, which can then be transferred to an Easy device prepared for operation

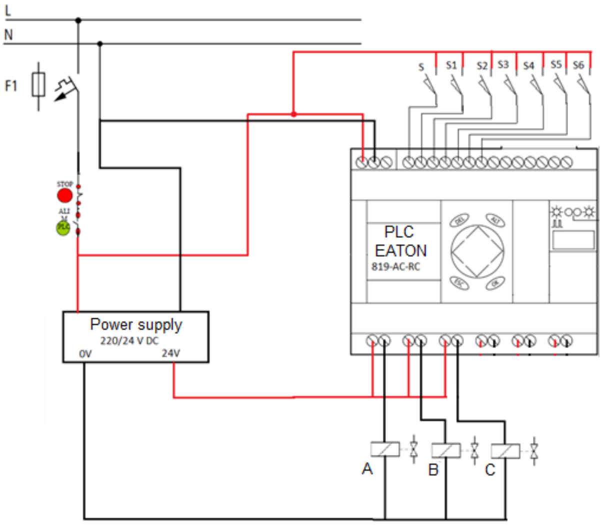

Fig. 13. Electrical wiring diagram of the PLC connections.

The program developed is shown in Figure 14 and represents the implementation of the timed version according to the GRAFCET diagram in Figure 11 d.

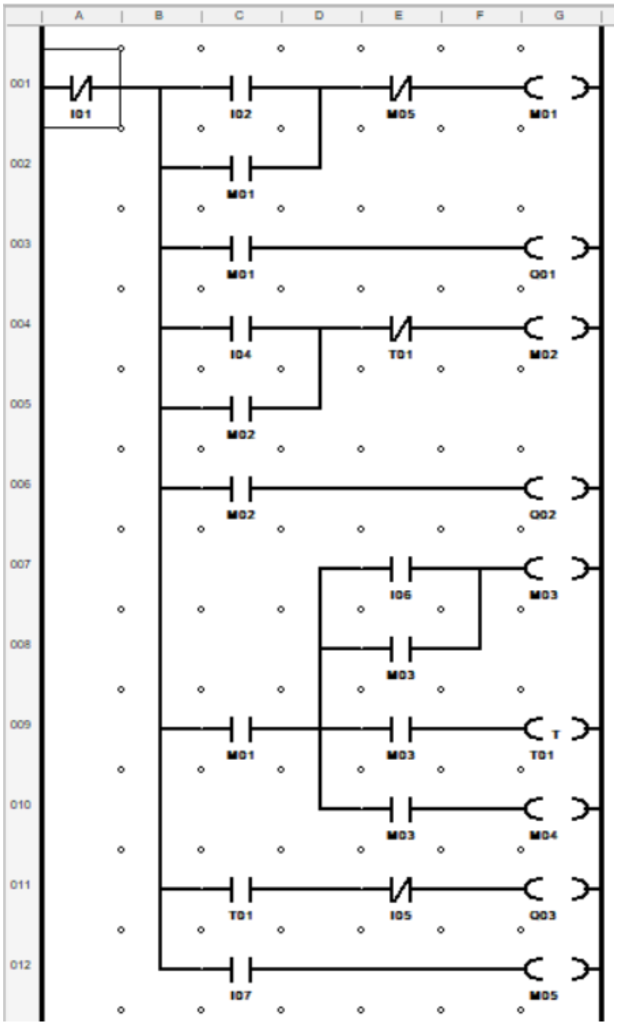

Fig. 14. Program developed for the PLC.

Notation meaning:

- I01 – input associated with sensor S;

- I02...I07 – inputs associated with sensors S1...S6;
- Q01...Q03 – outputs associated with coils A…C;
- M01...M05 – markers (elements for storing commands);
- T01 – timer element.

The correct operation of the program was verified through simulation. This feature is provided by the Easy Soft software in an intuitive and suggestive manner.

V. DEVELOPMENT OF A SMALL-SCALE EXPERIMENTAL MODEL

To experimentally validate the proposed solution for the metal waste compaction device, it was created a small-scale experimental model.

For the purpose of optimization and cost reduction, a solution was designed and implemented, featuring a minimal structure, while still respecting the basic function.

Simplifying considerations:

- The number of containers compacted in one working cycle is minimized;
- The feeding process for the compaction device is done manually;
- The pneumatic actuation for the compaction process includes two pneumatic cylinders;
- The control of the compaction process is done in a traditional manner using buttons for each step of the process.

The experimental model, shown in Figure 15, includes the following basic elements: 1. Collection container for compacted boxes; 2. Pneumatic cylinder for compacted box evacuation; 3. Pneumatic circuit distributor for compacted box evacuation; 4. Compaction device; 5. Control panel; 6. Pneumatic cylinder for compaction; 7. Pneumatic circuit distributor for box compaction; 8. DC power supply for powering the distributors; 9. Compressed air source (compressor, air preparation unit).

The pneumatic part of the experimental model consists of the pressure source, the compressed air storage tank, the air preparation unit (GPA), two distributors for directing the pneumatic fluid, two pneumatic cylinders, as well as the apparatus for regulating the pneumatic energy. These pneumatic components are produced by the company Festo [22].

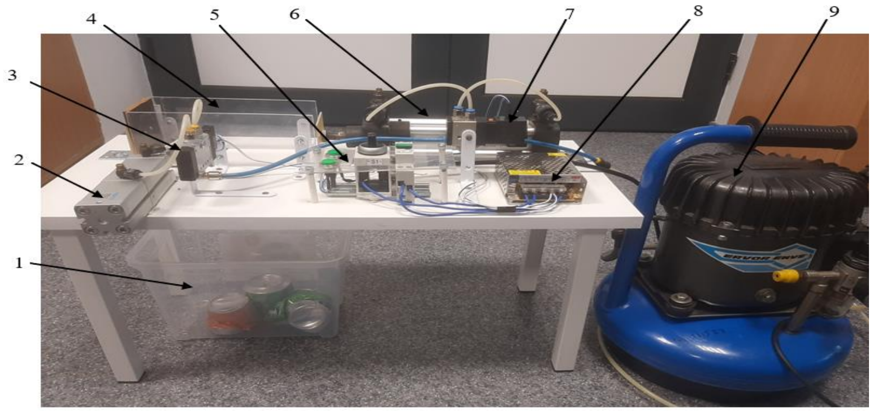

Fig. 15. Experimental model of the pneumatic compaction system.

After constructing the experimental model, its functionality was tested. Figure 16 shows an image taken during the process of compacting a metal waste resulting from the consumption of a beverage.

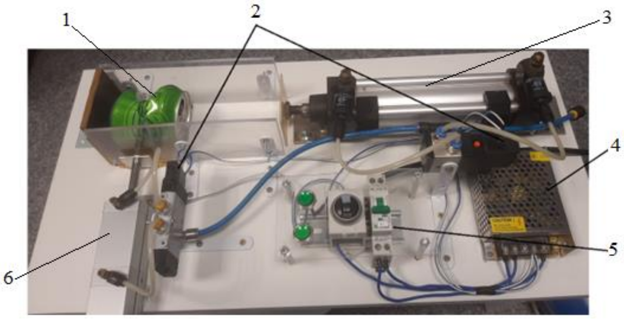

Fig. 16. An image from the compacting process: 1 - compacted container; 2 - distributors; 3 - cylinder for compaction; 4 - DC power supply; 5 - control panel; 6 - cylinder for ejecting the compacted waste.

The verification of the functioning of the experimental model was also done through the acquisition of the command signals. Thus, the graph in figure 17 shows the supply voltage signals for the valves that control the two pneumatic cylinders. The signal on the CH1 channel represents the supply voltage for the valve corresponding to the compaction cylinder, and the one on the CH2 channel for the valve of the compacted box discharge cylinder.

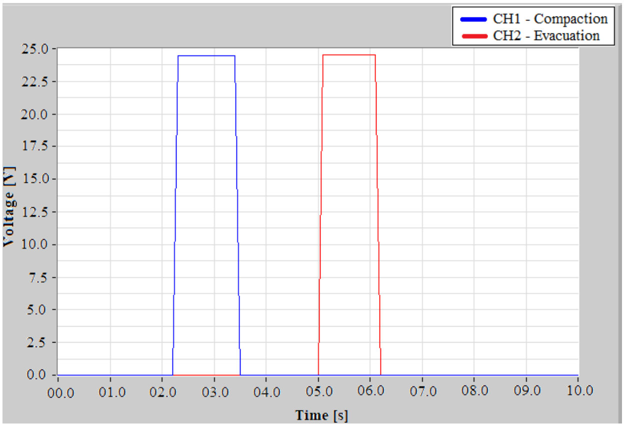

Fig. 17. Control signal diagram for pneumatic actuation.

As can be seen from the signal diagram, the time required to execute each operation within the compaction process is approximately 1.5 seconds. This can be modified by adjusting the execution speed of the pneumatic cylinders.

VI. CONCLUSIONS

The compacting device discussed in this paper can be utilized in residential settings, restaurants, specialized companies, or as part of larger waste recycling systems. Currently, the automated waste collection centers for glass bottles, metal cans, and plastic bottles, recently introduced in Romanian supermarkets, lack compacting capabilities. This device could be modified and integrated into such centers. Its inclusion would greatly decrease the volume of collected waste, thereby reducing transportation costs to regional recycling facilities.

As a result of the comparative analysis between the main types and structures of drives within electromechanical systems, it was concluded that pneumatic actuation meets the requirements imposed by the operation of various devices in high-cycle, repetitive automatic processes.

To properly configure the pneumatic actuation and automation circuit options, it is essential to use an initial stage involving modeling and simulation software. This approach enables users to identify the simplest and most efficient solutions for implementation. One such program, widely used in both educational settings and industrial applications, is FLUIDSIM.

In this paper, FLUIDSIM was utilized to design various pneumatic actuation and automation schemes for the compacting device. After configuring the circuits by connecting components available in the program's libraries, the proposed solutions were validated through step-by-step cycle simulations followed by continuous cycle simulations.

The authors used the FLUIDSIM software for the simulation of other automatic systems [6], [11], [12], [13], the validation of the simulations being also done experimentally on small-scale physical models.

The solutions found through the simulation of several drive circuit variants in FLUIDSIM led to the creation of a functional laboratory model, with a simplified structure compared to the initially designed one, but which meets the intended purpose very well.

Future research objectives:

- Completing the experimental model by adding additional drive modules;
- Automating the process by adding the PLC presented with the already developed program and equipping the execution elements with various types of position sensors;
- Integrating the device into a more complex electromechanical system, which would include an automatic system for feeding the compactor with empty cans and an automatic system for collecting the waste resulting from the compaction process.

ACKNOWLEDGMENT

Source of research funding in this article: Research program financed by the University of Craiova.

Contribution of authors:
First author – 40%
First coauthor – 30%
Second coauthor – 20%
Third coauthor -10%

Received on September 5, 2024
Editorial Approval on November 25, 2024

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