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Study, Design and Production of a Semi-Automatic Pneumatic Capper in Benin

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ABSTRACT

This work constitutes a contribution to the development of the processing of agri-food products. In Benin, processors of agri-food products are facing enormous difficulties. One of the difficulties is the lack of equipment. It is to somewhat alleviate one of their difficulties that this work was carried out for fruit juice producers. Indeed, the lack of equipment affects their production capacity, because the vast majority of their production is carried out using equipment for manual use. With the intention of providing a solution to this problem of producers, through our study, we have proposed a simple tool that they can easily use and at an affordable price for the vast majority of producers. Thus, we carried out a study, design and production of a semi-automatic pneumatic bottle capper. After a study which is based on mathematical models, we made a design using the Top Solide software and proceeded to the production after manufacturing certain parts and purchasing others. We wrote a program that allowed us to automate the capper. The price of the capper is 550,000f CFA including tax. Regarding the results of our work, the capper allows a bottle to be closed between 3 seconds and 6 seconds, i.e. 10 to 20 bottles per minute, therefore 600 to 1200 bottles per hour. This study will therefore ensure rapid production and in sufficient quantity to satisfy customers and all this in record time.

Keywords: Agri-food processing; Production of fruit juices; Lack of equipment; Pneumatic bottle capper

1. Introduction

A country develops through agriculture, which plays a central role in its economy. In Benin, agriculture is among the country's main sources of income and development, contributing significantly to the Gross Domestic Product (GDP). In recent years, agriculture in Benin has undergone a revolution thanks to agricultural mechanization which is the use of machines, gear and systems in agricultural operations with the aim of increasing yield. This mechanization is observed particularly in crop production.

Thanks to agricultural mechanization, we therefore notice the use of various machines during pre-harvest, harvest and post-harvest operations. So, we come across different machines in post-harvest. Among these different machines encountered in post-harvest, we have in particular those which are involved in the packaging of fruit juices and others. However, the low level of mechanization of the agri-food sector does not allow producers to easily find the equipment they need for their production. As a result, their activities have difficulty developing.

The capping of fruit juice bottles is an operation that requires automation among the packaging operations. The study we are carrying out relates specifically to this level of production. Thus, we assisted a pineapple juice production unit. The step of capping the bottles containing juice is done manually using a manual capper; which therefore does not allow the work to be delivered within the time given by the customers. The technical solution that we propose in our study is a semi-automatic pneumatic bottle capper.

Numerous studies have already been done on cappers. Among these studies, we can cite Claire DULIEU who worked on the encapsulation of acetoacetate decarboxylase, application to brewing [1]; HENRI CHAMPUAUD who worked on finite element analysis of the crimping of sealing capsules [2];

Hollay Alexandre who worked on improving the performance of an OW line (JB4 and JB5) with a focus on the inspection and filling zone [3]; Mr. SELOUANA Mounir worked on the automation of the filling group of a soft drinks production line [4]; Assent Clément worked on monitoring discharges from a bottle filling line: study and reduction of these losses to improve the financial profitability of the line [5]; EL MAKHFI Oussama and EL-ALLAM Taoufik worked on the implementation of the FMEA method in a production chain [6]. All these studies deal with bottle production and capping lines, but do not make it possible to adapt the production rate to that of the operators. They are not suitable for production under the conditions of local producers. In our study, we will talk about a machine to cap fruit juice bottles of various sizes more quickly than manual cappers and which will allow producers to do their work more quickly depending on the speed of the operators.

2. Materials and Methods

2.1. Description of the Proposed Machine

The equipment we offer to producers is presented below:

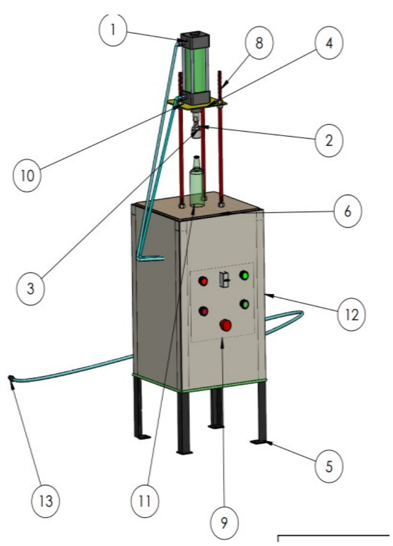

Figure 1 : The Pneumatic Capper

(1): Pneumatic cylinder; (2): Against Nut; (3): Capping Head; (4): Cylinder Support; (5): Chassis; (6): Bottle support; (7): Screw; (8): Adjustable axis; (9): Electrical box; (10): Nut; (11): Bottle; (12): Cover sheet; (13): Connection.

2.1.1 Machine Frame

The chassis is one of the most important parts of the machine. This plays a very vital role which ensures the proper functioning of the machine. It supports all the elements of the machine and must be resistant. In our case it is a mechanically welded element made from 35 mm angle iron and 3 mm thickness, a sheet of sheet metal 12/10th thick and a 25 mm square tube.

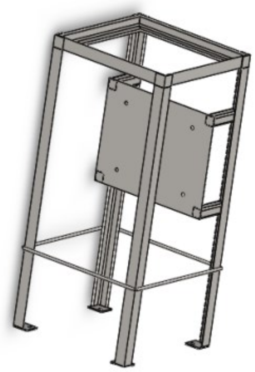

Figure 2: Machine frame

2.1.2 The Pneumatic Cylinder

It is a main element of the machine. It is he who, under the pressure of compressed air sent by the compressor, exerts the force necessary to close the bottles. In the absence of the cylinder or in the event of this element not working, the bottles cannot be capped.

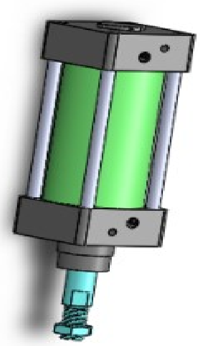

Figure 3: Pneumatic cylinder

2.1.3 The Capsule Matrix

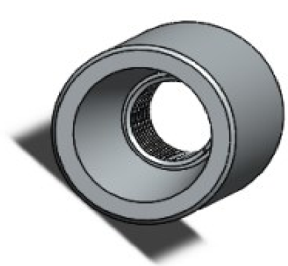

Figure 4: Capsule matrix

This member is fixed on the rod of the cylinder and allows the bottles to be closed. When the cylinder descends, the capping die descends with the cylinder and under the effect of pressure it tightens the capsules on the bottles so that there is no leakage of the product outside the bottle.

2.1.4 Cylinder Support

The role of this element is to support the weight of the cylinder and to be able to connect it to the chassis and other elements of the machine. It is a square plate with a side of 20 cm made of sheet metal 3 mm thick. Thanks to this support, the cylinder is well fixed and deprived of any movement.

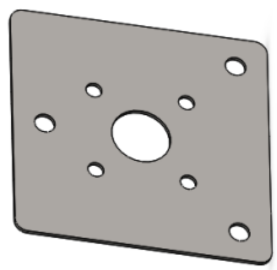

Figure 2 : Cylinder Support

2.1.5 Bottle Holder

It is a square wooden plate measuring 40 cm on each side and 3.5 cm thick on which the bottles are placed. It is placed just above the chassis.

Figure 3 : Bottle support

2.1.6 Fixing Stud

This is a round axle threaded at both ends. It first allows the cylinder and its support to be fixed on the chassis and the position of the cylinder support to be adjusted in relation to the bottle support in order to be able to adapt the height of the capper according to the height of the bottle.

Figure 7: Stud

2.1.7 Electric Box

This box contains an Industrial Programmable Controller, a pneumatic distributor with bistable electrical control, indicators, push buttons, a circuit breaker and cables. These elements are used to automate the capper.

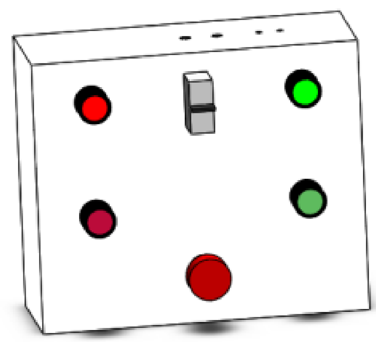

Figure 8: Electrical box

2.2 Principle of Operation

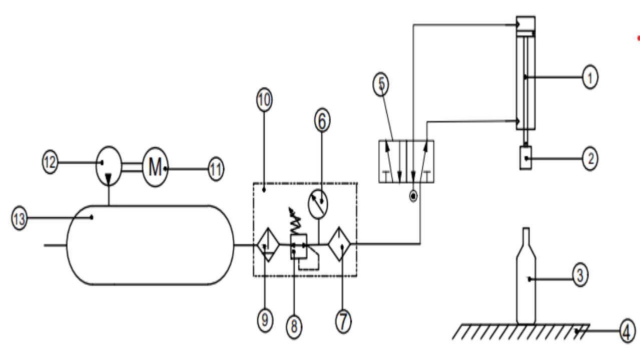

Figure 9: Operating Diagram

The bottle (3) containing juice is placed on the support (4). The capsule is then placed on the bottle. Once the engine (11) is running, via a belt pulley transmission, the latter causes the operation of the air compressor (12) which sucks in air and delivers it under pressure. This compressed air takes in a tank (13) where the air is stored; then by the air conditioning or treatment unit (10). At this level, the air first passes through the filter (9) where it is filtered and separated from impurities and then passes through the pressure regulator (8) which is used to vary the operating pressure of the fluid using the pressure gauge (6) which indicates the value of the pressure of the fluid then finally, the latter takes by the lubricator (7). The compressed air leaving the air conditioning unit therefore goes towards the distributor (6) which is of the 5/2 types (5 orifices and 2 positions) with electrical control which in turn is responsible for sending the fluid towards the entry and exit of the cylinder (1) in order to automate the capping of the bottles thanks to the cylinder via the capping matrix (2). Thus, under the effect of an electrical impulse the distributor lets the air circulate in the bore of the cylinder therefore controlling the output of the cylinder rod (1) which lowers the capping matrix fixed to the cylinder rod onto the bottle so that the capping is carried out. Finally, an electrical pulse is sent to the distributor which allows the fluid to circulate on the side of the control rod, therefore the retraction of the cylinder rod which causes the capping matrix to rise. The cycle repeats itself and therefore allows several bottles of juice to be capped per minute, thus promoting good yield. The automation of the distributor is ensured by a ZELIO type Industrial Programmable Controller (PLC) which contains six inputs and four outputs.

2.3 Modelization

This part is devoted to the identification of mathematical models relating to the different components of the capper. These models reflect the physical phenomena that govern the operation of components.

Capping force

This is the necessary force needed to properly crimp the caps on the bottles and efficiently. Studies have been carried out on determining the capping force. In our case, this force is of the order of 314 pounds [8], or approximately a force of 150 kg, or an intensity of 1500 N. We will therefore choose in our case a force of intensity 1500 N less than 2650 N.

2.3.1 The Cylinder
Theoretical Cylinder Force

Let F_{Th} be the theoretical dynamic force deployed by the cylinder, F_{ch} the real load required to cap the bottles and t the load rate, according to [9] and [10], we obtain:

gold $\boldsymbol{t} = \frac{\boldsymbol{F_{ch}}}{\boldsymbol{F_{th}}}$

so $\boldsymbol{F_{th}} = \frac{\boldsymbol{F_{ch}}}{\boldsymbol{t}}$ (1)

Diameter of the cylinder piston

$\boldsymbol{F_{Th}} = \boldsymbol{p} \cdot \boldsymbol{S}$ (2)

so $\boldsymbol{S} = \frac{\boldsymbol{F_{Th}}}{\boldsymbol{p}}$ (3)

gold $\boldsymbol{S} = \frac{\boldsymbol{\pi D^2}}{\boldsymbol{4}}$ (4)

so $\boldsymbol{D} = \sqrt{\frac{\boldsymbol{4F_{Th}}}{\boldsymbol{\pi \cdot P}}}$ (5)

With: FTh: The dynamic theoretical force;

p: the operating pressure; and S the section; D: the diameter of the cylinder bore.

Cylinder Piston Diameter

Once the diameter of the bore has been determined, that of the piston rod will therefore be determined by using the cylinder force table contained in the sizing guide below:

Piston mm	Tige mm
16	6
20	8
25	10
32	12
40	18
50	20
63	20
80	25
100	30
125	30

Figure 10: Standardized diameter [11]

Rod exit speed

For standard cylinders, the average piston speed is between 0.1 m/s and 1.5 m/s. In our case we choose a speed of 100 mm/s or 0.1 m/s. [12]

Cylinder Stroke

The stroke L of the cylinder will be chosen using the standard cylinder stroke table.

Diamètre d'alésage du vérin (mm)	Courses (mm)Tolérances $^{+2}_{0}$													
	25	50	75*	100	125	150*	200	250	300*	400	500	600	800	1000
25	•	•	•	•	•	•	•	•						
32	•	•	•	•	•	•	•	•						
40	•	•	•	•	•	•	•	•	•	•				
50	•	•	•	•	•	•	•	•	•	•				
63	•	•	•	•	•	•	•	•	•	•	•	•		
80		•	•	•	•	•	•	•	•	•	•	•		
100			•	•	•	•	•	•	•	•	•	•	•	•
125				•	•	•	•	•	•	•	•	•	•	•
160					•	•	•	•	•	•	•	•	•	•
200					•	•	•	•	•	•	•	•	•	•

* Ces courses ne sont pas reprises dans la norme NFE 48 - 059

Figure 4 : Standardized Course

Cylinder displacement

The cylinder capacity C is given by the following formula:

$$\boldsymbol{C} = \boldsymbol{S} \times \boldsymbol{L} \qquad (6)$$

with S the section of the cylinder and L the stroke of the cylinder

- Time for a race

The time of a race is given by the following formula:

$$\boldsymbol{v} = \frac{\boldsymbol{L}}{\boldsymbol{t}} \Rightarrow \boldsymbol{t} = \frac{\boldsymbol{L}}{\boldsymbol{v}} \qquad (7)$$

with v the exit speed, L the stroke of the cylinder and t the exit time of the rod.

- Flow rate $\boldsymbol{Q'_S}$ necessary to remove the rod from the cylinder

According to [13], we have:

$$\boldsymbol{Q'_S} = \boldsymbol{C}/\boldsymbol{t} \qquad (8)$$

The compressor

- Compressor Flow

According to [12], we have:

$$\boldsymbol{Q} = \boldsymbol{S} \times \boldsymbol{L} \times (\boldsymbol{n} \times \mathbf{2}) \times (\boldsymbol{p} + \mathbf{1}) \quad (\mathbf{9})$$

n: the number of cycles per unit of time;

p: working pressure (kg/cm2 or bar);

- Tank volume

According to [14], we have:

$$\boldsymbol{V} = \mathbf{0,3} \times \boldsymbol{Q} \qquad (\mathbf{10})$$

This formula is valid for screw compressors.

2.3.2 Distributer

Knowing the working pressure, we will use the pneumatic circuit sizing guide to determine the size of the cylinder tips. [10]

2.4 System Automation

System Grafcet

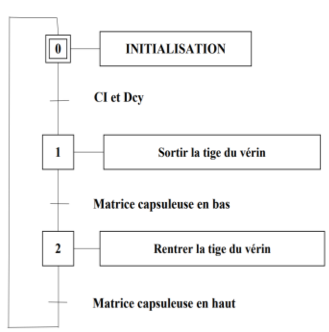

Figure 5 : Grafcet du système

For this grafcet to work, correct wiring of the different elements is required. This wiring therefore translates into the electrical diagram below:

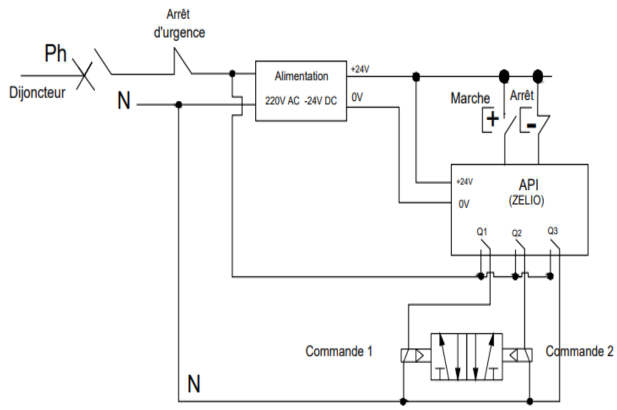

Figure 6 : Electrical diagram

2.5 Estimation of the Cost of the Machine

The selling price P of this machine will be evaluated according to the cost (Co) of the raw machine, the overall cost Cg, unforeseen events and the profit margin B. That is to say:

$$Cg = C_0 + I \qquad (11)$$

$$P = C_g + B \qquad (12)$$

3. Results and Analysis

3.1 Results

The results of the application of the mathematical models of the sizing of the components of the capper are recorded in tables 1, 2, 3, 4 and the estimated overall cost of the filler in Table 5.

Table 1: Characteristics of the cylinder

Caractéristique du vérin	
Kind	Double acting
Piston	80 mm
Stem	25 mm
Race	100 mm
Speed	100 mm/s
Output flow	0,51 L/s

Table 2 : Compressor

Compressor characteristic	
Speed	212 L/ min
Tank volume	50 L
Operating pressur	8 bars

Table 3: Distributer

Caractéristique du distributeur	
Pressure	1,5 - 8 bars
Kind	5 / 2 bistables
Order	Electropneumatique
Incoming connection	3/8 (Raccord de 10)
Outgoing connection	1/4 (Raccord de 8)

Table 4 : Correlation table

Tableau de correspondance			
Starters		Exits	
Pushbutton Green	I_1	Order 1 (Exit of the cylinder rod)	Q_1
Pushbutton Red	I_2	Order 2 (Retracted cylinder rod)	Q_2
		Green Light	Q_3

Table 5 : Estimation of the cost of the machine

C_0	I	Cg	B	P
419 950	41 995	461 945	47 000	510 000

3.2. Analyse

We wrote a program that allows us to automate the system by placing and closing a bottle in the interval of 3s to 6s, or 10 to 20 bottles capped per minute. We therefore estimate the hourly capacity of the machine from 600 to 1200 capped bottles per hour depending on the speed of the operators.

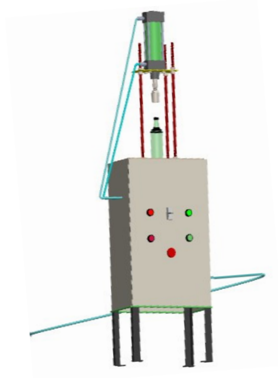

Figure 7 : Design

Figure 8 : Realization

4. Conclusion

This study aims to develop the fruit juice packaging production sector in Benin through the development of a machine for capping juice bottles to reduce the arduousness of the transformation process and increase production capacity. It allowed the design and estimation of the manufacturing of the semi-automatic pneumatic capper. This equipment has good working precision and is ergonomic. Its realization will not pose any difficulty in a mechanical workshop with adequate machine tools. The evaluation of its cost implies accessibility to any fruit juice producer although the sector is not yet on an industrial scale. However, the creation of a model and tests in size and nature will make it possible to evaluate the technical and economic performances of the semi-automatic pneumatic capper and to improve them at the same time. Indeed, the manufacturing of this equipment should have considerable socio-economic benefits for the agricultural sector which is still underdeveloped.

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