FICA, Vol. X, No. X, MES 20XX

AUTOMATION PROCESS OF THERMOFORMING TO CREATE CHOCOLATE PATTERNS AT THE ENTERPRISE "GOLOSINAS Y ALGO MAS"

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Abstract.- *This project is about the automation process of thermal shaped to create chocolate patterns at the enterprise "Golosinas y Algo Más", through the design and building of a machine which accomplishes this goal and adds a variety of chocolate figures, reduces the elaboration time, expenses and the difficulties in the elaboration process.*

This machine was created based on an analyses of the different design choices, from which the most suitable and the one which satisfies the needs in the process was chosen. The machine is activated by an automatic electric and pneumatic system shaped with pneumatic cylinders which are controlled by electric valves and by a compressor which provides the air with a pressure no higher than 0,68 MPa to its motion. It also has a system of vacuum, which is in charge of the suction process, to shape the plastic sheet. One more advantage this machine has is the fact that it has a dashboard to visualize the process in a LCD. All of these process are controlled by a microcontroller ATmega 324, to guarantee a higher autonomy and speediness improving the flexibility of the process.

In order to design the mechanic and the control system of this machine, the manual process was the start point. The process' stages were identified and after being based on the previous designs, each one of the new stages were built by an individual form, then all of them were joined in a harmonic way.

Some considerations were taken into account before the construction process. First, the frame and panel structure which will support the heater was elaborated. Then the pneumatic cylinders were coupled, making sure the movement faces no drawbacks. After that, the heater was placed in the corresponding panel and the first chamber of vacuum was placed at its place. Finally, the electric and electronic systems with its two main stages: control and conditioning were installed. The control stage receives the signals of the system (temperature and time) and it sends signals to the conditioning stage which governs the pneumatic cylinders, the heater and the system of vacuum.

Once the building process was done, some functioning trials took place, this was done to get a high quality final product. Some test using different materials at different temperatures and with different time were developed in order to skip some fails in the final product. This was useful in order to create lists with the ideal settings for each material.

Finally a machine users' manual and a maintenance's guide were designed so the person in charge of the operating o maintenance knows enough about its use.

The functioning principle of this machine is sub divided in the next processes: heater warming stage, heating and suction, and thermal shaping. The thermal shaping process will start with the setting of the parameters (temperature, warming time) and the plastic sheet is held and heated at a right temperature, it depends on how the material is. For instance, the plastic sheet is heated at 195°C for 45 seconds. When the plastic sheet reaches the deforming temperature which was pointed before, through pressure of vacuum or suction the sheet is deformed which will take the form of the matrix previously made of wood, then, after 16 seconds approximately the new formed sheet is taken out and will be used as a matrix to create chocolate figures.

The automating of different process involved in manufacturing the plastic patterns to elaborate chocolate figures, is a searching task which will be used as a bibliographic support to other searches about future issues.

Keywords

Thermal shaping, thermoforming, heat transfer, thermal plastic, vacuum.

1. Introduction.

Nowadays, the elaborating process of patterns to chocolate at the enterprise "Golosinas y Algo Más" is being done manually, therefore, it is necessary the use of an automatic process.

It is hard to get unique patterns just on time, sometimes it is imperative to have a pattern otherwise some customers cannot be pleased. This enterprise "Golosinas y Algo Más" is raising yet the market is really wide and the owner is trying to cover the northern area of the country. If getting the patterns was easier, sells would be improved and more customers could get unique products with more creative forms, according to specific requests.

This project's aim is to improve the production in the manufacturing process of patterns to create chocolate figures. Technology is being used as a help in order to reduce the time production, easing the job and reducing expenses.

2. Development.

Some considerations must be kept in mind when designing the thermal shaping machine, for instance: machine's capacity, raw material, heating, shaping method, automating, and constitutive elements.

2.1 Machine's capacity.

This machine will create 25 x 30 cm. to 34 x 50 cm. patterns to chocolate figures. This size will depend on the requirements the customer has, and on the figures need to be created.

2.2 Raw material.

There are some polymers designed to the thermal shaping process, however, the plastic ones are better to this process. From all these materials, the PVC (Polyvinyl chloride) is more commonly used to these patterns. Vacoplast (rígid sheet of PVC) is the most suitable in these purposes, with appliances which keep in touch with food (Filmtex, 2013). Therefore, the PVC is chosen as the ideal material to create the chocolate patterns.

2.3 Heating.

At the heating stage, it was important and indispensable, to consider the temperature necessary to the thermoforming process of the PVC. It is also necessary to consider the temperature at which the PVC gets unmolded, which is at 110 °C and the thermoforming is at 135° to 175° C.

To the PVC sheet heating process, a tubular metal covered resistance is selected, it is made of an alloy of of nickel which is known as Incoloy. This has a high corrosion resistance in humid environments, high oxidation resistance at high temperatures, and it has easiness to be shaped. (Megamex, 2009). It consumes 900W and its surface temperature is 510°C on average.

2.3.1 PVC sheet heating process.

As a first step, the heat necessary to warm the PVC sheet according to Equation 1 is determined, then the heat necessary to be transmitted through the heating source is determined, and finally, a balance of energy is stablished in order to know how much heat is necessary in this process.

The amount of heat transmitted to the PVC sheet is the change in its internal energy and it is determined starting from:

$$Q = \Delta U = mc_{prom}(T_2 - T_1) \qquad (1)$$

Where:

$m = mass$

$c_{prom} = specific\ heat\ avarege$

$T_1, T_2 = initial\ temperature, final\ temperature$

After this, the next equation is set, about density relating it with mass and volume

$$\rho = \frac{m}{V} \qquad (2)$$

And as a result:

$$\rho = 0.014\left[\frac{Kg}{cm^3}\right] = 1400\left[\frac{Kg}{m^3}\right]$$

$$C_p = 0.28\left[\frac{Kcal}{Kg \cdot °C}\right] = 1.172\left[\frac{KJ}{Kg \cdot °C}\right]$$

And replacing this data in equation 1 it is got:

$$\dot{Q}_{PVC} = \frac{6510J}{15s} = 434W$$

In Figure 1, the heating time of the PVC sheet is shown based on its thickness.

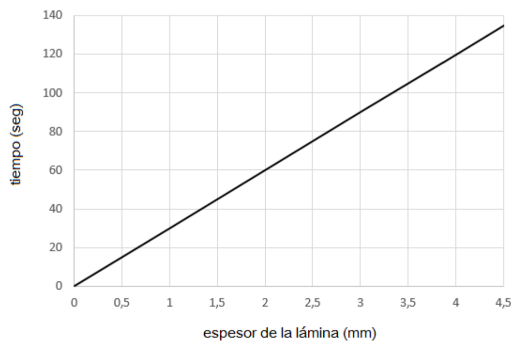

Figure 1 Thickness vs heating time of the PVC sheet.

As it can seen, in figure 1, for a Thickness of 450 micrometer the heating time necessary is of 15 seconds approximately, according to Formech International Ltd (A Vacuum Forming Guide).

Therefore, it is concluded that the PVC sheet requires 434W to be heated from 18°C to 150°C.

Once the heating level the sheet needs is determined, the heating which must be ejected by the tubular resistance is determined as well. It is necessary to determine the heating the resistance transfers, and by this, make sure if the energy produce is strong enough to this purpose. The heating transfer between the heating source and the air is given by a natural convection, and this heats by radiation and natural convection, the PVC sheet.

To determine the heat transmitted by radiation, the next equation was used:

$$\dot{Q}_{rad} = \varepsilon \sigma A_s (T_s^4 - T_{alred}^4) \quad (3)$$

Where:

$\varepsilon = surface\ emissivity$

$\sigma = constant\ of\ Stefan - Boltzmann.$

$T_s = surface\ temperature$

$T_{alred} = surrounding\ temperature$

The constant of surface emission to the metal cover tubular resistance of Incoloy (Watlow, 2003) is: ε=0.6.

The emission area of the resistance is determined by using software, Solidworks, obtaining an area of $A = 30139.7mm^2$. This area is divided by two, taking into account that the lower part of the resistance is not radiating energy to the PVC sheet, then, it is got that the emission are is $A_s = 15069.85mm^2$.

The heat transfer by radiation average of the tubular resistance was 176.29W ($\dot{Q}_{rad}$).

If the PVC sheet requires 434W ($\dot{Q}_{PVC}$)) to reach the thermoforming temperature, it means the sheet still needs 257.71W.

Therefore, the potential in total the heater has to supply is of 900W; this element will not transfer all this heat to the plastic yet, being tubular means it emits energy in many directions. If it is considered that only a half of this potential will reach the PVC, yet a 50% of the heater surface is face to face with the plastic sheet, then, it is supposed that the heat transferred average that the tubular resistance provides is 450W ($\dot{Q}_{total}$).

Then, the energy conservation law allows us affirm that:

$$\dot{Q}_{total} = \dot{Q}_{rad} + \dot{Q}_{conv} \quad (4)$$

And as a result:

$$\dot{Q}_{conv} = \dot{Q}_{total} - \dot{Q}_{rad}$$

$$\dot{Q}_{conv} = 450 - 176.29 = 273.71W$$

As the sheet only needs 257.71 W and the resistance is transferring by the air 273.71 W ($\dot{Q}_{conv}$), we have 16W extra. It allows to know the resistance will provide more energy than we need to warm the sheet.

Now, the distance between the heater and the sheet is calculated, to do this, it is considered the fact that we have 16W extra to heat the volume of the air between the heater and the PVC sheet

It is known that the box which hold the resistance is 52 cm x 36 cm. The volume, therefore, will be gotten from calculating its area and the distance between the components. So, we have

$$V = (0.52 \times 0.36 \times h)[m^3] = 0.1872h[m^3]$$

To determine this air volume, the equation 5 is used to an ideal gas.

$$PV = nRT \quad (5)$$

Donde:

$n = nomber\ of\ moles$

$P = pressure$

$V = volume$

$R = universal\ gas\ constant$

$T = temperature$

To Ibarra city, which is on 25 m.a.s.l., the atmospheric pressure is 77.31 KPa. Then, the values of equation 5 are replaced, and the number of moles is calculated $n = 5.982h\ [mol]$ per unit of volume of heating.

The average molar mass of dry air is 28.97 g/mol, then, the air mass when heating is $m = 0.1733h[Kg]$.

Air specific heat to constant pressure is

$C_p = 1007 \left[\frac{J}{Kg \cdot K}\right]$.

The specific heat which must be transferred to the volume of air is 16W, as it was analyzed yet. This heat is expressed by a time unit. Therefore, to express it in energy terms, we do it so.

$Q = 16 \cdot t[J]$

Equation 1 is used to find the distance which will allow the transference of the heat needed

So, we obtain the equation of time in function of the distance; the longer distance between the tubular resistance and the PVC sheet, the longer it will take to reach the temperature necessary to the thermal shaping according is expressed in the next formula: $h(mm) = 0.7(seg)$

In this case it is determined that in a distance of 30 mm between the heater and the PVC sheet, the heating process is of 21 seconds approximately, it is the time necessary for the control system to govern the process and it is calibrated correctly.

2.4 Vacuum process.

The shaping is done by a suction or an emptiness generated by an vacuum pump.

After doing some trials according to the information in Table 1 and according to some authors (TK560, 2009) (Benheck, 2007) (The Replica Prop Forum, 2010), it is concluded that to the vacuum stage a 3HP motor will be used. The absorption time recommended to these trials is of 10 to 15 seconds.

Table 1. Satisfying samples in function of the vacuum potential.

Power HP (W)	Satisfying samples (%)
1,88 (1400)	80
2 (1491)	80
2,5 (1864)	90
3 (2237)	100

2.5 Structure and automation.

To the analysis of the structure, the pneumatic elements necessary to its automating are measured and normalized.

2.5.1 Pneumatic system

The pneumatic system is formed by three pneumatic cylinders: one for the movement horizontal of the heating module, and two cylinders which allow the frame to be moved with the PVC sheet in a vertical direction to place the sheet in the shaping stage, and two electric valves to auctioning and controlling, as it is seen in Figure 2.

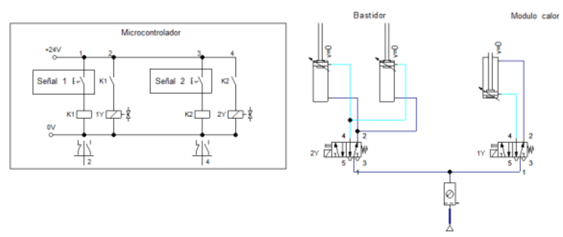

Figure 2. Initial conditions of the pneumatic system

To the cylinder 1 which is in charge of moving the heating module was considered with a charging factor of η=1, and for the cylinders 2 and 3 one of η=0.5.

With the data obtained to cylinder 1 (η=1, m=5kg, P=0.68MPa) the diameter is 10mm. To cylinders 2 and 3 (η=0.5, m=6kg, P=0.68MPa) the suitable diameter is 16mm.

According to the necessity of movement in each process, it was determined that: the race of the cylinder was 320mm, and the race of 2 and 3 was 13cm.

Therefore, a de 32mm of diameter and 400mm of moving distance double acting cylinder, two double acting cylinders of 20mm of diameter and of 150mm of race, and two 5/2 solenoid-spring valves were selected.

2.5.2 Machine structure

After selecting the pneumatic cylinders which are going to be used in the automating system, the machine structure is designed with the finals dimensions as in Figure 3.

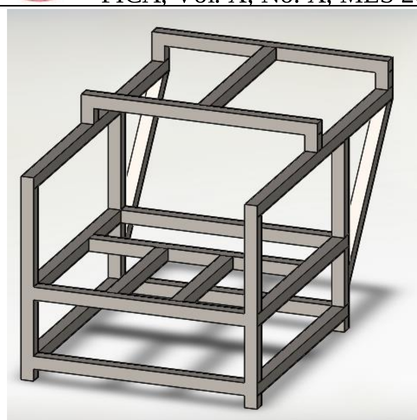

Figure 3. Machine structure.

2.5.2.1 Calculate of beams

In order to calculate the structure, how much weight will this machine have to support was analyzed first, and then how this weight will be distributed, considering a weight of 100kg for unexpected weights. To its analysis the larger beam is used (BC), because it is the critical.

In Figure 4 the dimensions proposed to its constructions are shown.

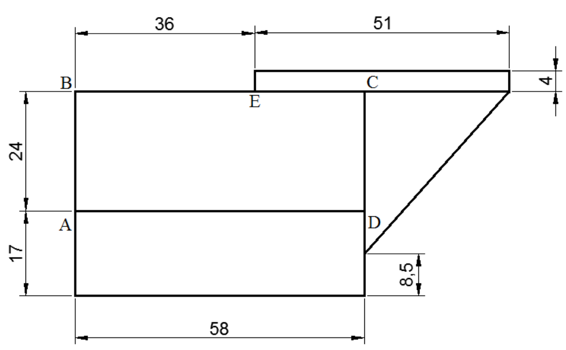

Figure 4. Wired side sight to calculate the beams.

In order to determine what profile section will be used to the blanks AB BC CD, it will be done by using the method of pending-deflection, it is called this way yet it relates the unknown pendings and deflections with the weight is on the structure. The blanks are fixed in A and D, and for this this equation is used:

$$M_N = 2Ek(2\theta_N + \theta_F - 3\Psi) + (FEM)_N \quad (6)$$

Where:

$M_N =$ Internal moment at the closer end of the blank

$E, k =$ Elastic modulus of the material and stiffness blank. $k = {}^{1}/_{L}$

$\theta_N, \theta_F =$ Pending the near and far ends or angular displacements of blanks in the supports.

$\Psi =$ Rotation rope blank due to a linear displacement.

$(FEM)_N =$ Fixed end moment in the near-end support.

The equation of the fixed ends is:

$$(FEM)_{AB} = \frac{Pb^2a}{L^2} \quad (7)$$

By solving equations with data structure, results the diagram of Figure 5:

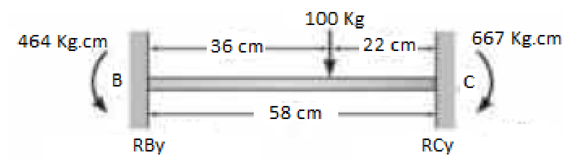

Figure 5. Forces diagram in Rafter BC

From here, it is got the flection maximum moment the rafter will support.

$$M_{max} = 775.24\ Kg.cm$$

We count with the next equations to find out the thickness of the structure tube.

$$S = \frac{M}{\sigma_d} \quad (8)$$

$$S = \frac{I}{c} \quad (9)$$

$$I = \frac{H^4 - h^4}{12} \quad (10)$$

$$c = \frac{H}{2} \quad (11)$$

Donde:

$S =$ Section modulus

$M =$ Maximum moment.

$\sigma_d =$ Design effort

$I =$ Inertia moment of the transversal area regarding its own neutral axis.

$c =$ Distance from neutral axis to the farthest fiber, in cross-section.

When linking this equations it is got that:

$h^4 = H^4 - 2.2H$

It is necessary to asume a value to find later the thickness profile. An 1¼ inches tube is chosen (3.175 cm).

Therefore, it is concluded that the minimum thickness is ½ mm. to a 1¼ inches tube.

2.5.2.2 Calculate of columns

Next the calculus to get the wide and thickness of the machine columns are done. To this analysis column CD has been chosen (see Figure 4), yeti t is the one which is supporting an overweight,. A design of elastic instability, buckling and deflection with central charge at the columns To begin with the design it is supposed the column is large, so the alternative Euler formula is used:

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} \qquad (12)$$

Donde:

P_{cr} = Buckling critical charge

E = Elastic module.

I = Inertia moment at the transversal section

K = Constant which depends on the fixed extreme

L = Real length of the column between the supporters

The elasticness module to all the carbon steels and alloyed is of 207 GPa, which means to 2110812.560 kg/cm^2. The value of K is of 0.65, according to Figure 6 (embedded - embedded).

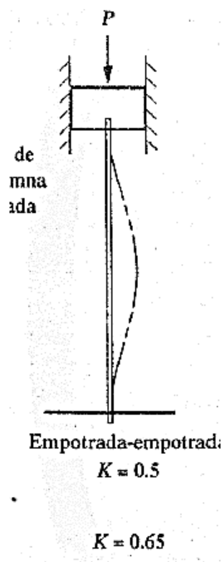

Figure 6. Values for K to get the effective lenght

It is also used the allowed charge, then the next equation is required:

$$P_a = \frac{P_{cr}}{N} \qquad (13)$$

Where:

P_a= Allowed charge.

N= Design factor

The allowed charge is the same to the maxim charge expected; in this case it would be of 100 Kg. The design factor to the fixed columns and embedded extremes is 2.

Equation 13 is replaced by 12 and equation 10 is used yet t is about a squared hole section.

$$\frac{H^4 - h^4}{12} = \frac{NP_a(KL)^2}{\pi^2 E}$$

And replacing data it is got:

$$H^4 - h^4 = 0.028\ cm^4$$

To prove if the correct design method has been chosen, the real slenderness ratio KL/r it is calculated, with the constant value of column C_C.

After calculating when comparing it is noted that KL/r (12.037) < C_C(123.246). This says the columns is short and the J. B. Johnson formula must be used

$$P_{cr} = As_y\left[1 - \frac{s_y\left(\frac{KL}{r}\right)^2}{4\pi^2 E}\right] \qquad (14)$$

Equation 13 is replaced in equation 14 and it is got:

$$P_a N = (H^2 - h^2)s_y\left[1 - \frac{s_y\left(\frac{KL}{r}\right)^2}{4\pi^2 E}\right]$$

Finally, data in this equation is replaced. It is necessary to suppose a value to find the thickness of the profile later. An 1¼ inches tube is chosen. It is got h=3.162 cm, then the thickness would be 0.1 mm. Then, to beams and columns, a 1¼ and 1.2 mm squared profile was used, warranting its stability, useful time a safeness of the structure.

2.5.3 Selecting rollings

Rollings will help the heat module to move easily accomplishing the mission of avoiding friction in the heating module at the structure. Its moving speed is 1m/s approximately and the heavy it is supporting is not that heavy, 500N, approximately. Then, selecting a rolling system is not too critical. For this, a rigid balls rolling 6201 was selected, which is possible to get it at the local market, this also can be adapted to the requirements of the machine.

2.6 Temperature sensor

To set the control of heating system temperature a type J thermocouple was selected. The type J and K thermocouples and RTD Pt100 are the most common industry temperature sensors, they are cheap and easy to replace. A thermocouple is a couple of wires of different materials which are linked in one side. When some heat is applied where they are linked, a little voltage is produced, which is proportionately increased according to the raise in the temperature. To set the thermocouple signal, and to control the heater, a Smart temperature controller was chosen, which allows set the parameters of temperature and through relays output, controls the heater.

2.7 Control system

The control systems used in this machine is shown in Figure 7. Entrance signals which come from different elements which at its time will be read and control signals will be sent to the components will let it fulfill the objective. As it was pointed earlier, two parameters are required (temperature and time) and also the current system temperature to, based on this, to control the different elements.

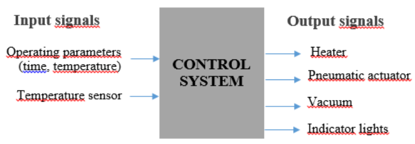

Figure 7. Diagram of inputs and outputs of control system.

An ATmega 324 microcontroller was used to control the process, yet it is one we can find at the local market with enough number of pines, (40) to control the thermal shaping process.

In Figure 8 the programming flow chart of the microcontroller which was done in the machine automating process is shown.

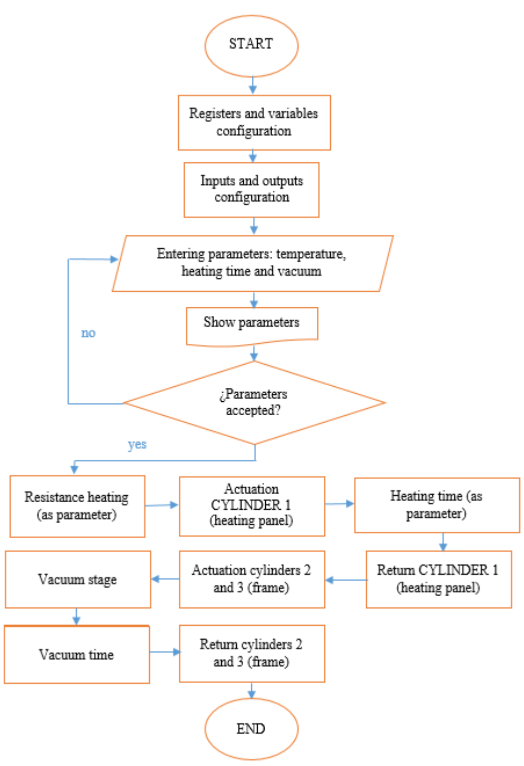

Figure 8. Programing process flow chart.

2.8 Constructing and implementing the machine.

The construction of the thermal shaping machine was developed at a metal structure workplace. It was necessary to consider the services this place offered us, for instance its machines and tools, so the construction could be done in a right and reliable way.

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The standardized elements which were used in this Project were bought at the local market keeping always to save money. In figure 9, the process is illustrated.

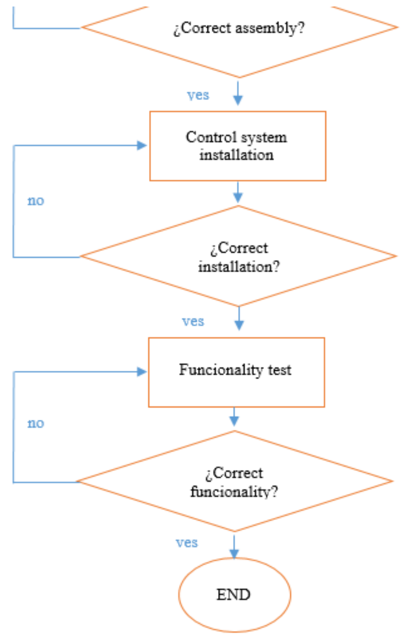

Figure 9. Flow chart of the process of construction

The control system was divided into two stages: controlling and conditioning. The control one will be centered on the microcontroller inputs and outputs, while the conditioning stage's aim is to adapt the microcontroller exits (5V) to the elements' requirements (12V, 110V). The blocks diagram in Figure 10 shows the elements of the electronic system and the relationships between them.

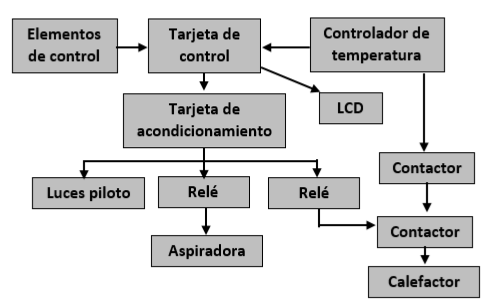

Figure 10. Blocks diagram with the stages of the electronic system.

Figure 11. Thermoforming machine (real)

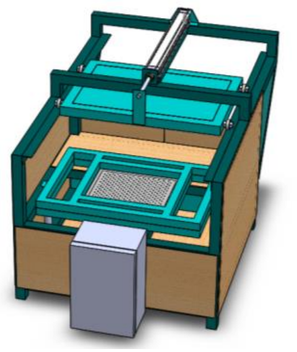

Figure 12. Thermoforming machine (design)

2.9 Result analysis

After implementing this machine, some results which are shown in Figures 13, 14 and 15 were gotten. These results, being compared with the previous thermal shaping process, show the benefits this machine offer to the enterprise “Golosinas y Algo Más”.

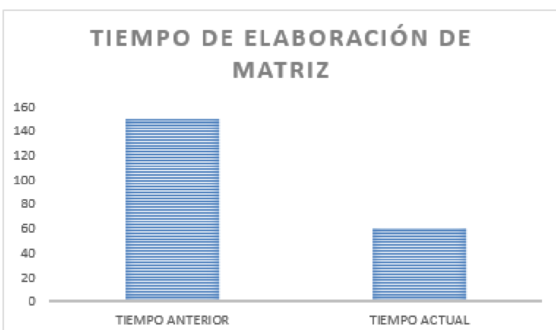

Figure 13. Time for elaboration of the patterns matrix (in minutes).

In Figure 13 the time necessary to create the manual matrix is shown. It takes 145 minutes, which is really larger than the time is taken with the automating process, it is 60 minute long.

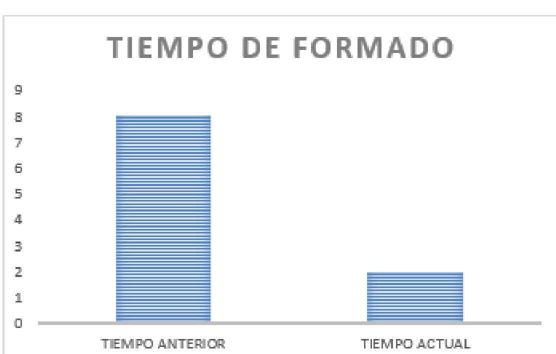

Figure 14. Time for the patterns shaping. (In minutes)

In Figure 14 the time for the patterns shaping process is shown. It can be seen that the time after automating the process is two minute long approximately, while the manual process takes around 8 minutes approximately.

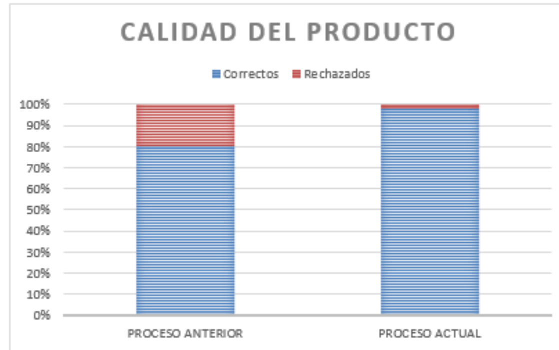

Figure 15. Final Product Quality

The product pleasant grade can be seen in figure 15. In the previous process which was completely manual this grade was around 80%, but when using this machine this grade is around 98%, so we can see the machine is reliable.

2.10 Conclusions

With implementing this automatic machine of thermal shaping, the variety of figures has been reached and the product quality has been kept.

The analytical development of the design let us to have a clear vision of the functions and necessities of each stage by separated, then each one of the process was laced, and finally it was possible to get each system of the machine, interacting between them, and accomplishing a specific function to solve a necessity.

The automating process helps us create patterns to create chocolate figures in a simple and safe way, mainly to the operator, reducing the time and effort are required to its elaboration. This machine’s design was developed by searching its operation is simple, so any person can deal with it, keeping in mind the security rules.

The design and construction of the thermal shaping machine was developed without drawbacks nor difficulties yet the human resources and materials were reachable and it eased the design and construction processes.

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