Design of a Semi-Automatic Hydraulic Extruder Machine for the Manufacture of Pastry Bricks Using VDI 2221

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Abstract. The main objective of this research work is to design a semi-automatic hydraulic extruder machine to produce pastry bricks for Bricks Imperio. The aim is to achieve a production rate of 700 bricks per hour at a maximum cost of 12,000 dollars. For this purpose, an interpretative theoretical framework of similar products is carried out, and simulation software is used to test the theoretical concepts in real-world conditions. Following the methodology recommended by the German Engineering Association VDI 2221, a detailed list of requirements is drawn up, existing technology is analyzed, and mechanical, electrical, and hydraulic functions are designed. The design is verified with CAD software, and a technoeconomic analysis is carried out. As a result, the successful design of the semi-automatic hydraulic extruder machine for the manufacture of pastry bricks is achieved, with a cost of 11,992.00 dollars and a production capacity of 700 bricks per hour.

1 Introduction

In the city of Cusco, the district of San Jerónimo, and the community of Sucso Aucaylle, industrial and artisan brick factories are located in a total of more than 120 establishments. It is these factories that supply bricks, blockers, and tiles to meet the requirements of the brick industry [1].

Within this requirement is the need to manufacture pastry bricks from the company Ladrillos Imperio, which to date are manufactured manually. Given the increase in orders, the brick businessman has chosen to hire a greater amount of labour to comply with the existing demand. However, by mid2020, the demand continued to grow and production was limited to the amount that one person could produce. Once again, in his desire to provide a solution, the brick businessman, in his desire to provide a solution, began to pay overtime to staff and increase benefits. This solution was viable for a while, but the staff got tired and began to ask for more benefits, which became unsustainable over time [2–3].

Then arises the need for technological equipment that replaces labour and has an acceptable efficiency compared to the stated needs: a machine capable of forming a pastry brick of commercial measures, 20 cm long, 20 cm wide, and 3 cm high, which exceeds the production of 700 bricks per hour, is easy to transport, is comfortable in its maintenance, is semiautomatic in such a way that it can be operated by a single person, has security elements that prevent accidents, and its cost does not exceed 12,000 dollars.

2 Methods and Materials

The design will be based on the methodology recommended by the German Association of Engineers (VDI), VDI 2221, entitled "Mechanical Engineering Design Methodology", from which we will extract the structure, guidelines, recommendations, and others for the realisation and obtaining of an optimal solution that has to fulfil the client's requests [4]. The VDI 2221 methodology is used to help determine the best solution design so that the result meets expectations [5].

The design process using the VDI 2221 method consists of several stages; among the most important is the development of a morphological matrix where functions must be fulfilled for each mechanism. In addition, mathematical calculations are used to understand and know the forces and reactions. Involved in the production of the brick. Likewise, a mechanical and electrical-hydraulic design is carried out to obtain an optimal solution for the design, as shown in Fig. 1.

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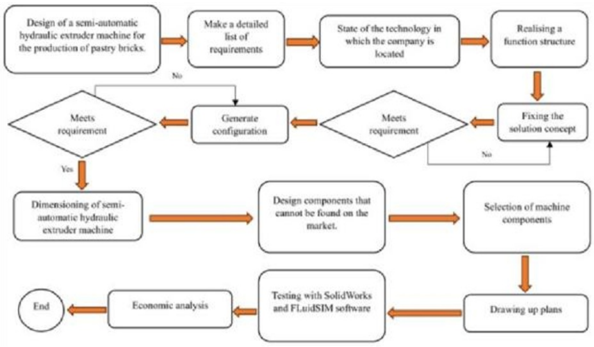

Fig. 1. VDI 2221 Methodology

2.1 Morphological Matrix

The morphological matrix is a popular conceptual design tool. Although concept design methods based on morphological matrices are effective in creating the concept design, it is difficult to determine the optimal concept design by combining these solution function principles [6–7]. The matrix is quantized in such a way that each decision principal uses decision variables and formulates an optimisation problem [8], as shown in Fig. 2.

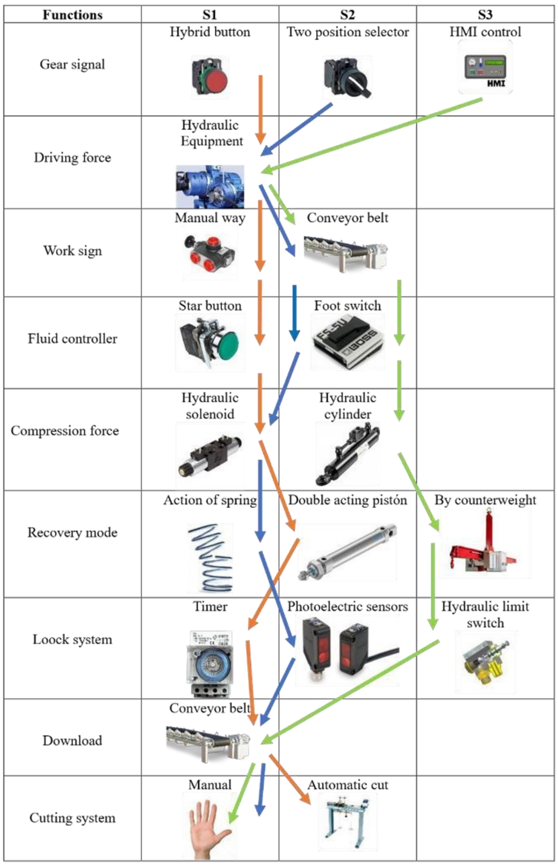

Fig. 2. Morphological Matrix

2.2 Black Box

We present a new approach for black-box simulation models called the probability distribution-based posterior box model [9–10], as shown in Fig. 2. An element that allows us to study the system from the point of view of the inputs that affect it and the inputs that respond to those inputs, the interesting thing about the black box is that it doesn't care about events, processes, or how. We are only interested in the results obtained.

Fig. 3. Black Box

Likewise, there is a description of the black box. First, there is the description of hydraulic energy and kinetic energy, as shown in Table I.

Table 1. Description Of The Electrical Signal

Entrance	Exit
Hydraulic energy	***Kinetic energy***
It is the force that will be injected into the extruder machine so that it can do the work of pressing and shaping a brick.	The energy released causes rectilinear displacement, friction, heat, and pressure.

Thirdly, there is the description of the material and the bricks according to the black box.

Table 2. Description Des Briques

Entrance	Exit
Subject	***Bricks***
The raw material is a mixture of clay and sand with percentage proportions of 70 and 30, respectively. The material that enters the machine is processed and transformed inside.	Final product of good texture and with the appropriate measurements.

2.3 Mathematical Calculations

To understand and learn about the forces and reactions involved in the production of pastry bricks, it was necessary to observe in detail the work of the personnel involved in this activity and analyse step-by-step occurrences of the process of forming pastry bricks.

For this reason, the design of the mould will take into account the measurements of the brick, the pressure to which the metal material will be subjected, with which the brick mould will be shaped, and then the characteristics that the material must have to guarantee its correct functioning over time.

Table 3. Description Des Briques

Data	
Measurements of a pastry brick	20cm x 20cm x 3cm

System pressure	2.5Mpa

With this data, it is assumed that the inner dimension of the mould should be 20 cm wide and 3 cm high, and the steel to be used should withstand at least 2.5 MPa. Then a drawing of the brick mould is made, followed by a free body diagram, as shown in Fig. 4.

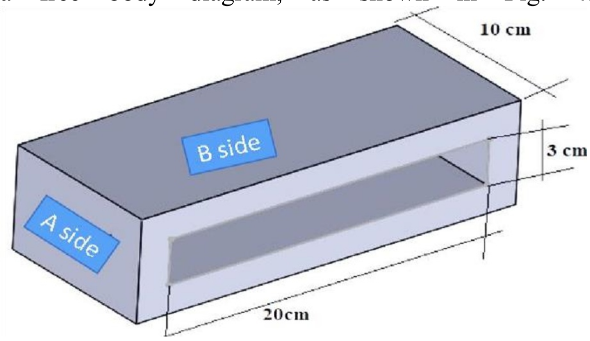

Fig. 4. Brick Dimensions

Developing we have.

Table 4. Mathematical Data

Pressure	=	2.5 MPa
Distance B	=	20 cm (0.2 m)
Width (C)	=	10 cm (0.1 m)

Formula 1:

$$Area=BxC=0.02\ m^2 \quad (1)$$

We will rely on the formula.

$$P=\frac{F}{A} \quad (2)$$

Replace the values in the formula (1), where 2.5 x 106 N/m^2x = F /0.02 m^2 and we obtain the results of the force Fb = 50000 N. With this result we can find the value of the thickness of the metal plate. Calculating the thickness of the plate with the following formula.

$$\sigma=MxC/I \quad (3)$$

Where:
σ = Effort
M = Bending moment
C = Neutral axis distance
I = Moment of Inertia
By finding the bending moment with the following formula.

$$Mb=Fxd \quad (4)$$

Replacing the values in the formula to obtain the bending moment, where the result is Mb = 50000 N x 0.1m and the bending moment is Mb = 5000 N x m.

For this mould to be correctly mounted on the machine, it must have a clamping mechanism. This mechanism must have the exact geometry of the extrusion chamber to which it will be attached. Also, as stipulated in the requirements, it must have a design that allows efficient assembly and maintenance, as shown in Fig. 5.

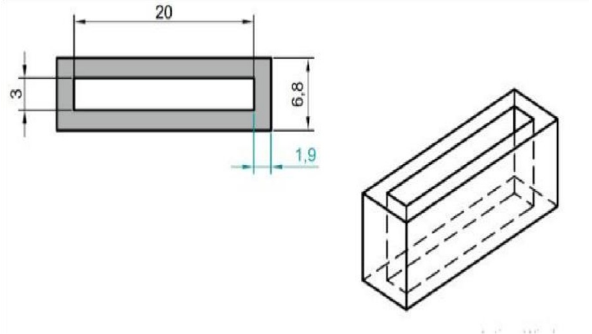

Fig. 5. Brick Dimensions

2.4 Mechanical Design

The following is a graphical representation of the optimal mechanical design solution. This graph does not include measurements or dimensions, but some parts can be described, which are listed as follows: (1) the metal base of the hydraulic extruder machine, (2) the hopper, (3) the extrusion chamber, (4) the double-acting hydraulic cylinder, (5) the brick mould, and the electrical and hydraulic systems, as shown in Fig. 6.

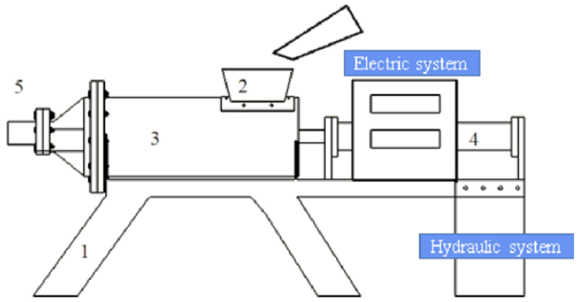

Fig. 6. Mechanical design

2.5 Considerations of the brick baker's brick making machine

For the execution of our design, it is important to recognise the elements that have to be manufactured and acquired. Then, TABLE VI and TABLE VII are made, where we name those elements that have to be manufactured inside the workshop and those elements that have to be bought in the market either locally or nationally. Quantitative quantities are considered that will serve as a reference for a list of acquisitions in the future.

Table 5. Item To Be Manufactured

Elements to be Manufactured	***Quantity***
Mould for pastry bricks.	1
Extrusion chamber	1
Feeding hopper	1
Base, extruder machine support	1

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Table 6. Selected Element

Elements to Select	*Quantity*
Hydraulic equipment (incl. electric motor, hydraulic pump, 4/3 valve)	1
Elements to Select	*Quantity*
Double-acting hydraulic cylinder	1
High pressure hose	2
Electric timer	2
Electrical power and control components	1
Bolts and Turks	25
Washers	25

2.6 Electrical Elements

Due to the customer's requirements, the machine must operate semi-automatically, which implies selecting control elements that allow the operator to give start and stop signals, elements that can detect position and interact with the system, and elements that can close or open contact and control large loads.

Likewise, the selection of electrical elements was carried out, as shown in Table 7.

Table 8. Electrical Elements

Description of electrical elements	*Quantity*
Thermomagnetic key Schneider Acti 9 IC60N bipolar	1
Schneider thermal magnetic motor guard type GV2ME	1
Three-pole contactor D series + auxiliary contact CAD50M7	1
Timer to NO + NC contact connection	1
Schneider run push button series 9001K green colour NO contact	2
Schneider operating push button series 9001K red colour NC contact	1
Emergency mushroom head push button Schneider 9001K series NC contact	1
GPT cable N° 16 AWG indeco flexible red colour	1
NLT 3x14 AWG indeco flexible cable	1
½ inch cable gland	2
½ inch hose clamp for flexible pipe	2
Signalling lamps	3
Airtight 30 x 30 x 10 cm metal cabinet	1

3 Results

Within this chapter, we will use the technology to check the calculations that have been previously performed using the finite element analysis method in SolidWorks 2020 SP5 [11]. We will check whether or not the material that has been chosen is correct for the applications required by the semiautomatic hydraulic extruder machine for the manufacture of pastry bricks.

SolidWorks Corp. describes its software as a 3D CAD design tool, which in Spanish translates as "computer-aided design" [|12], in which it is possible to model and assemble parts in 3 dimensions and drawings in 2 dimensions. This platform offers the possibility to design, simulate, manufacture, publish, and manage the data from the design process.

We will also use Festo's FluidSim 4.2 software to simulate the semi-automatic sequences to be carried out by the hydraulic and electrical systems.

The company Festo, known worldwide for providing pneumatic electric, hydraulic electric, or pneumatic or hydraulic automation solutions, is the creator of the FluidSim software, a simulator of pneumatic or hydraulic processes or a combination of the two options with the electrical and/or electronic system, thus guaranteeing the correct selection of the components to be acquired. The simulations performed are shown below [13–14].

In Fig. 7, the simulation in CAD SolidWorks 2020 SP5 shows the extrusion chamber subjected to a pressure of 2.5 MPa in the internal part of the part. In the results obtained by the software, it is observed that the Von Mises stress has an elastic limit of 5.3 x 108 N/m2. The designed system works at 3.188 x 107 N/m2. Therefore, the choice of material is correct.

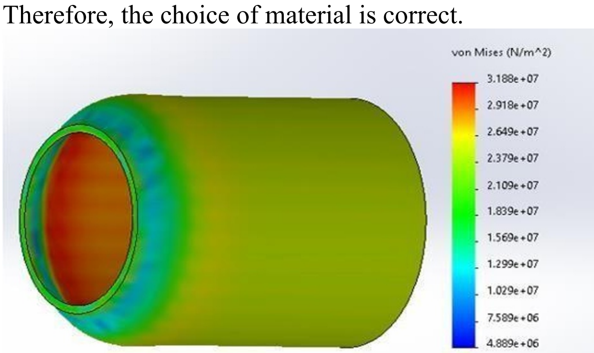

Fig. 7. Extrusion chamber

Also, in Fig. 8, the cake brick mould is subjected to an internal pressure of 2.5 MPa, the yield strength of the material is 5.3 x 108 N/m2, and the maximum stress to which the brick is subjected is 1.03 x 108 N/m2. Therefore, the choice of material that has been made is correct.

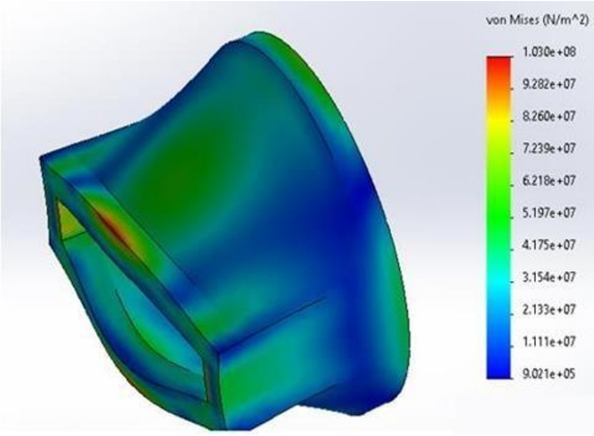

Fig. 8. Brick-formed mould

We also find in Fig. 9, the sample of the pastry brick mould, subjected to an internal pressure of 2.5 MPa, the results obtained by the software show that the Von Misess stress has an elastic limit of 5.3 x 108 N/m2, the designed system works with 8.8 x 107 N/m2, therefore, the choice of the material is good.

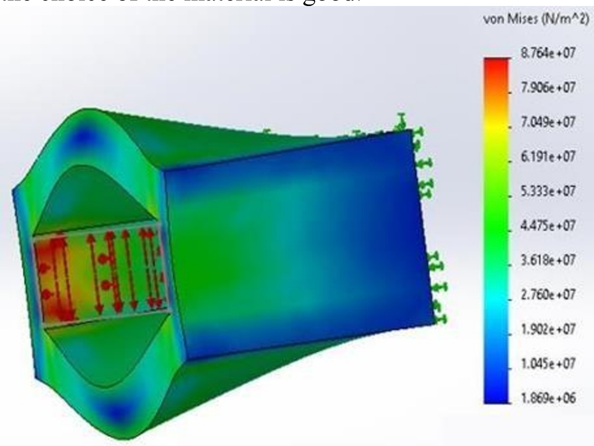

Fig. 9. Brick mould

In the following Fig. 10, the machine is subjected to a flow analysis where we first study the speed with which the material will come out; this speed must be according to the needs and congruent with the amount of bricks to be produced. According to our calculations, we need to advance 38 cm in a time of 5 seconds to ensure 700 bricks per hour. In the calculation made by the software, we can see the average advance of 16 cm per second, which added in 5 seconds would be a total of 80 cm. Therefore, the design is capable of achieving the goal of 700 bricks per hour.

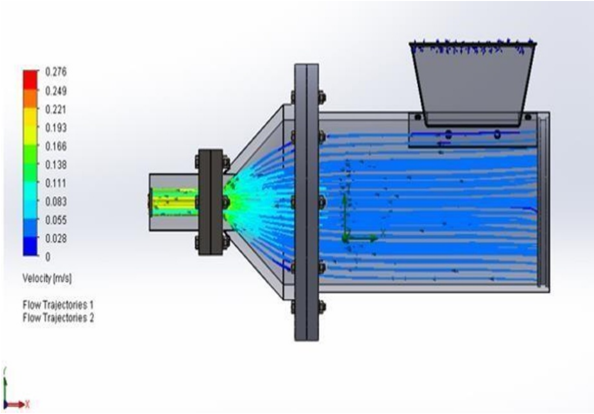

Fig. 10. Flow Analysis 1

Finally, Fig. 11 shows the value of the pressure with which the brick is going to come out: 102457.94 Pa as the maximum value and 97545.50 Pa as the minimum value. With these values, we have improved the compression with which the pastry brick is going to be formed; in this way, the qualities of the final product are improved.

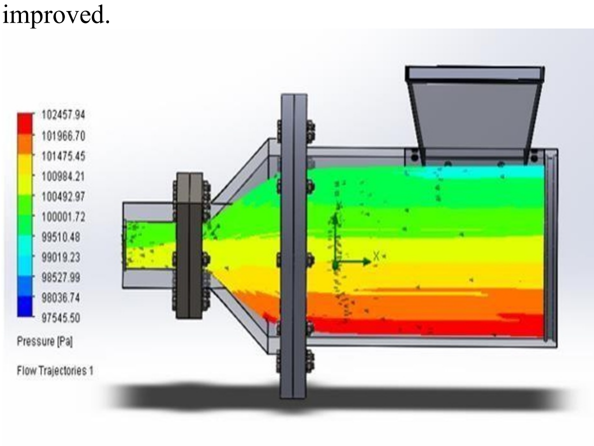

Fig. 11. Flow Analysis 2

The respective drawings of the hydraulic and electrical circuits are made using the tools of the FluidSim 4.2 hydraulic software. Once the circuit is completed, the corresponding simulation is made. Fig. 12, shows the start of the machine in a vacuum state. For this, it is necessary to unlock the emergency button represented by the letter E. Then, it is necessary to press the button P1, which activates the contactor K1. In this way, the motor of the hydraulic group is energized. At this stage, the piston does not produce any movement since the tandem valve is not yet activated and there is no passage of fluid into the cylinder.

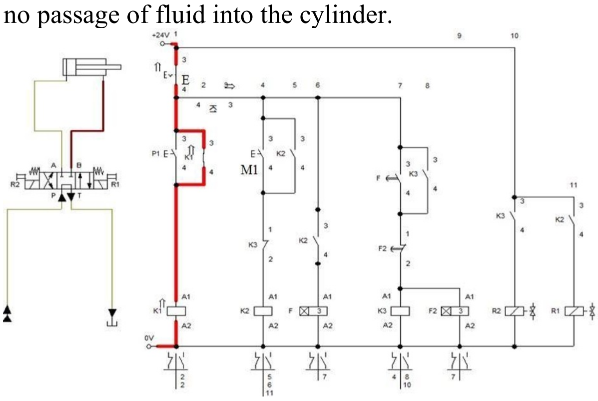

Fig. 12. Electrical and Hydraulic System

In the next step, in Fig. 13, the contactor K2 is activated; for this, it was necessary to press the start button M1, which gives the signal and allows self-locking with a normally open contact, thus giving way to a timer F, which energizes one of the coils of the tandem valve in this way, opening a passage to the fluid so that it enters the cylinder and the extrusion process occurs. The F timer has the function of controlling the travel time that the piston will have; once the time has elapsed, it cuts off the fluid supply and gives way to the return process.

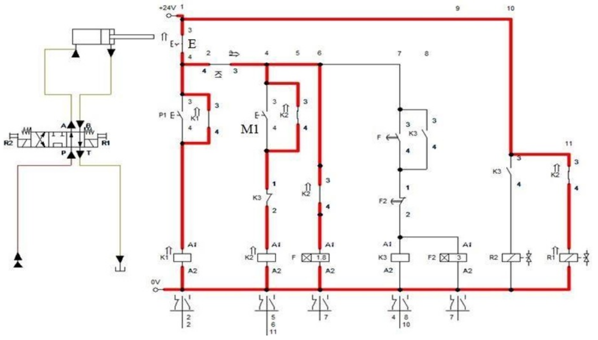

Fig. 13. Electrical and Hydraulic System

4 Discussion

The design of a semi-automatic hydraulic extruder represents a significant advance in improving the production of pastry bricks. Despite its benefits, it is important to recognize that there are opportunities for future research, such as advanced automation, materials innovation, and continuous process optimization. In addition, constraints such as cost, access to components, specialized maintenance, and adaptability to changes in the industry must be addressed. A balanced approach in these aspects will allow to maximize the potential of this technology in the future.

5 Conclusion

The design of the semi-automatic hydraulic extruder machine for the manufacture of baking bricks in the company bricks Imperio meets the request to produce 700 baking bricks in one hour; it is semi-automatic, reduces labour, and processes a better product than the handmade one. Its approximate cost is US$11,992.00.

Customer requirements, safety standards, ergonomics, and the environment present a list of demands that guarantee an optimal and friendly design in an environment where people and industry can coexist. The morphological matrix was also used to identify the many possible solutions and alternatives, which in turn were subjected to a rigorous technical and economic analysis, resulting in an ideal optimum solution.

Calculations were carried out to find the material characteristics for the brick mould, the extrusion chamber, the hopper, and the selection of electrical and hydraulic components. Finally, with the knowledge and mastery of CAD software, enormous advantages were found in the desire to design machines and electrical and/or hydraulic circuits, reducing construction times and costs, facilitating the modification of parts, increasing and decreasing dimensions, positioning and simulating functions, and using CAD software.

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