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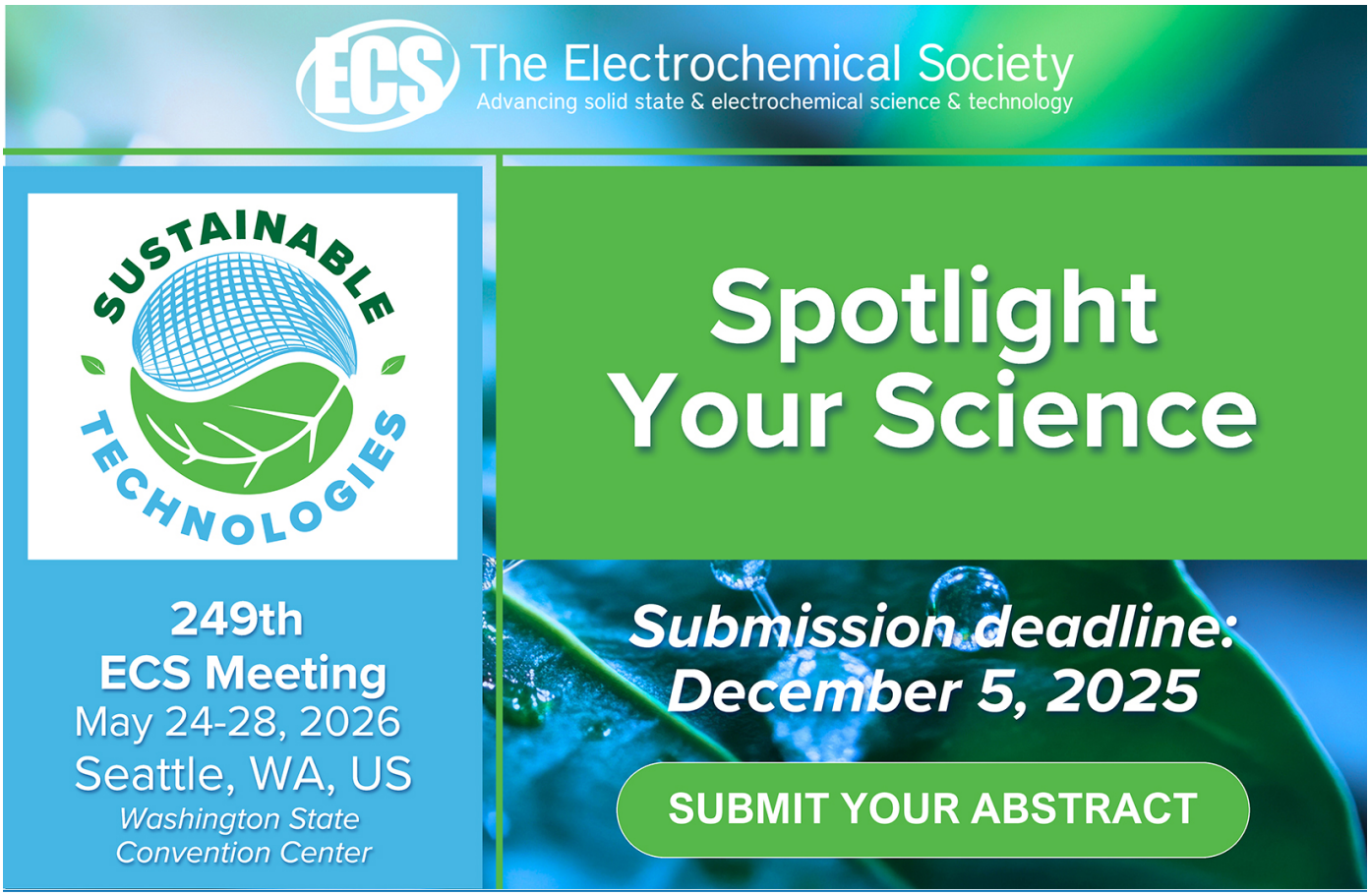
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Analysis of a molding machine using methodologies and theories of design

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Abstract. The objective of this work was to design a milk "Panelitas" molding machine, which can provide process technification and quality of life of workers of this industrial sector, which will achieve higher production and thus guarantee an inventory of the products elaborate handmade using methodologies and theories of design. Finally, the results calculated mathematically are supported by the finite element analysis that corroborates the excellent performance of the material selected for the machine, specifically the hopper, which is the most important element. In anything case, the materials exceed the mechanical properties of the material and element selected under the real operation conditions.

1. Introduction

The modern design of machinery requires high specifications from the design group, improving the quality of the components of the machines, increase useful lifetimes, and meet the needs of the customers. The mechanical design process is a useful tool for the developed design of mechanical components; also, in some studies, quality function deployment (QFD) and quality house (HoQ) are used to determine the most relevant parameters and problems for the execution of a design project [1].

Nowadays, the protractor belt has been used increasing because it is a means of transport that widely satisfies these requirements; compared with other systems, it has proved to be the most economical, even because it can be adapted to the most different working conditions [2]. Also, it is not only used for horizontal transport or in climbs, but also in curves, in light descents, and with relatively high speeds. Since the second half of the seventeenth century, conveyor belts have been an inevitable part of the transportation of material and food. But it was in 1795 when the conveyor belt became a popular medium for transporting bulk materials. At first, they are used only to move grain sacks over short distances. The transport and work system were simple in the first days [2]. More than 30 years ago, the conveyor belts entered the industrial sector, providing an adequate solution when it is required to transport food products having more excellent reliability than conventional systems. In this way, in the design of facilities for the processing and handling of raw materials or finished products, the choice of means of transport must favor and satisfy needs, reduce maintenance costs, significantly increase production, and in turn, possess sufficient flexibility to adapt to a wide variety of transport capacities or momentary overloads [3,4]. In Colombia, various varieties of candy base milk are manufactured, in which the cooking technique differs slightly; an example is the milk "Panelitas" to improve the quality

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and safety during the production applied methodologies and theories of design [1,5]. Automatic process control is used, mainly because it reduces the cost of industrial processes, which more than offsets the investment in control equipment. Besides, there are many intangible gains, such as eliminating passive labor, which causes an equivalent demand for skilled labor. The elimination of errors is another positive contribution to the use of automatic control. On the other hand, the maintenance of the desired value within a quantity or condition, measuring the current value, compared with the desired value and using the difference to proceed to reduce it. Consequently, automatic control requires a closed-loop of action and reaction that works without human intervention [6,7]. The present work proposes to design a prototype of a molding machine with the use of a conveyor belt and forming rollers to increase the production of sweet of milk "Panelitas". For this purpose, the methodologies and theories of the design were applied; also, the results were analyzed using the finite elements with the aid of the software Solidworks to corroborate the good performance of the material and geometry selected for the machine.

2. Materials and method

Any mechanical design must consider the four phases of the life cycle of a product. The first phase corresponds to the development of the product; the second phase describes the production, manufacture, and installation, the third phase contains all the important considerations for the use of the product, and the fourth phase is in charge of the useful life of the product. Besides, for the development of this project, an investigation of descriptive depth was applied because were used specific topics about methodologies and theories of design that are used in different careers of engineering. Also, the relevant mechanical and thermal properties a material were used for the development of the finite element analysis. In this way, it was used the mechanical design process according to the specifications and requirements of the clients. Figure 1 shown the mechanical design process; generally, mechanical design projects are part of the need required by the client. The first step is to select the project to be developed, which arises through an agreement with the design team. There are various tools in the study of the alternative to select; this phase of the design is known as product discovery. Subsequently, a plan for the mechanical design process is generated, once the need to be satisfied and the project planning has been selected, the customer requirements are gathered, taking into account all the phases/steps involved directly or indirectly with the product. In this phase, the engineering specifications are generated, and thus, establish the design concepts, which must satisfy the customer requirements, to establish the product design goals; at the end of this step, the product is developed applied mathematical calculations for machine design theory and drawings were carried out in computer-aided design (CAD), where the conceptual design product is obtained. Also, the support of the product is evaluated to develop operation and maintenance manuals for customers. In this way, when the specifications are not accomplished in a step, the design team should be refining the conditions and specifications according to the clients requested. In the opposite case, when the specifications are no refined and are not according to the customer requirements, the project is canceled. On the other hand, the software Solidworks, CAD, was used to perform the conceptual design of the machine. Also, the package of finite element analysis was developed to corroborate the correct design of the machine in the stage of the conceptual design, taking into account the references.

2.1. Clients considerations

Understanding the design problem is the fundamental basis in the design of a quality product; this means, convert the client's requirements into a technical description of what you need for the conceptual development of the product, that are the requirements obtained from the customer must be converted, by the design team, into engineering specifications [6]. The surveys and interviews were used to establish the requirements of the clients for the design of the machine, among the most important were low cost, simple operation, not many elements, commercial elements in the market, resistant elements, easy maintenance, Ability to manufacture a large number of "panelitas" and easy to clean after each period of operation.

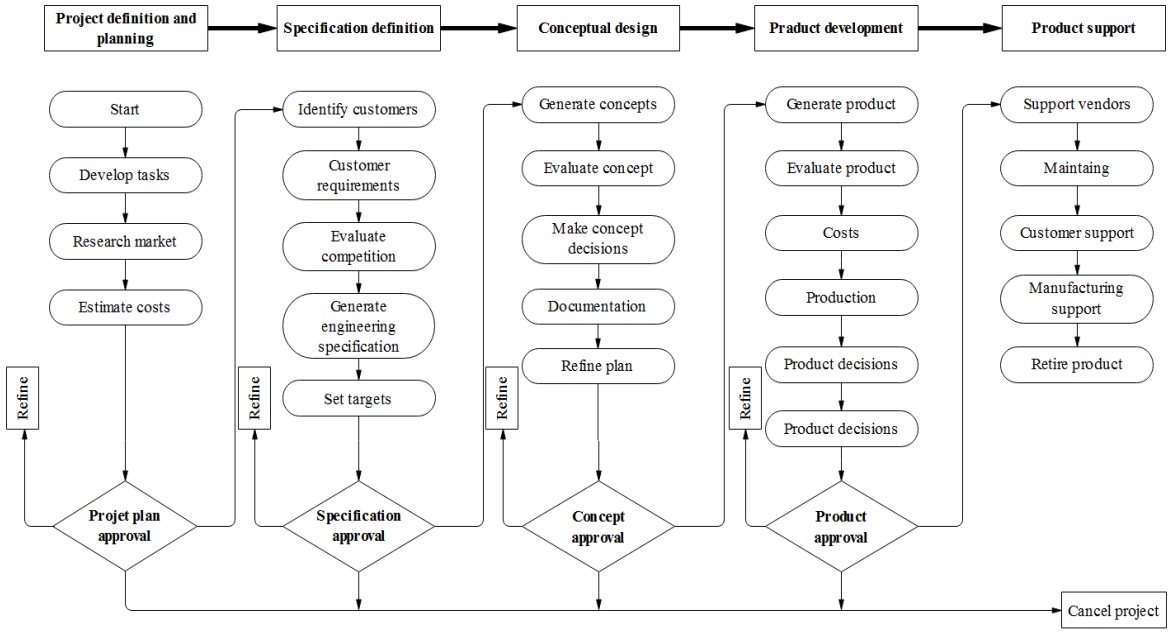


Figure 1. Mechanical design process [6].

2.2. Conceptual design

Figure 2 represents the geometrical model of the proposed machine for the optimization of the "Panelitas" molding system using the software Solidworks, which has a height of 96.4 cm, 127 cm long, and 45.4 cm wide. Besides, after 10 working hours of the machine, it is possible to obtain a total of ~9,000 "Panelitas" per day, under a correct and safe operation.

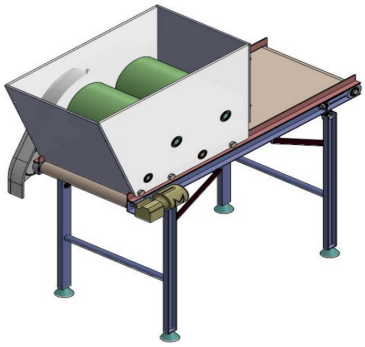


Figure 2. Conceptual geometry design of the machine.

After having selected the design of the machine, were calculate each one of the constitutive elements to establish its commercial use according to the requirements of the client. A qualitative approach was used because the variables that influence the geometric design will be taken into account for the respective subsequent calculations in Computer-Aided Design [6]. In the design of the machine, the following specifications of the manufacturers in the region and client were taken into account: Thickness of the "Panelitas" 0.06 cm by 3.50 cm diameter, with a weight of ~7 gr, the initial mass is viscous with a temperature of approximately 100°C, and the final mass is consistent with a temperature of 30°C, the ideal temperature to be able to mold. Subsequently, under these conditions, the roller had a capacity to form around 63 "panelitas" per each cycle or 360 degrees of rotation, which need a total mass of 0.44 kg for obtaining this amount of "panelitas" [8].

Theories of the mechanical design [9-11] were used to calculate the principal elements of the machine, obtaining that the optimal pressure on the mold is around 30 Psi, with a Final speed of 0.01 m/s of the gear system, and a safety factor of two for mechanical applications. The characteristics

of the engine calculated the design of the transmission because machines with the same characteristics have a motor of 0.5 HP, with the following specifications: 4-pole motor $1LA7/070/4YA60$, $HP = 0.5$, $KV = 0.4\,kW$, $n = 1590\,rpm$, $cos\varphi = 0.81$, $T = 2.24\,Nm$, $Fs = 1.15$, gear ratio $m_g = 2$, nominal coefficient $440\,V - 220\,V$; $1.9\,V - 0.95\,V$, efficiency $\eta = 63.6\%$, starting torque $Ts = 1.3 \times (T_a/T_n)$, net weight $IMB3 = 4.7\,kg$ and bearings $62022ZC3/62022ZC3$.

The commercial AISI 1020 steel material was selected for the structure and elements of the machine due to the optimal mechanical and thermal properties (Table 1), according to Shigley [9]. This material has a lot of applications in mechanical parts (manufacture of machinery and construction of structural parts) that are not subjected to significant mechanical stress such as low power shafts, pins, screws, railroad nails, and staples; cemented parts such as gears, pinions, endless screws, and bolts. Also, the low carbon content allows the easy to machine and excellent weldability.

Table 1. Principal mechanical and thermal properties of the AISI 1020 [9].

Property	Value
Young modulus	205 GPa
Hardness	1.23 GPa
Yield strength	0.34 GPa
Tensile strength	0.42 GPa
Shear modulus	80 GPa
Thermal conductivity	51.9 W/mK
Thermal expansion co-efficient	11.7 µm/m°C

In this way, for the conveyor belt: The material selected for the design of the hopper and the rollers was polytetrafluoroethylene (Teflon) due to his excellent heat resistance is insulating and does not corrode easily. More specifically, it is resistant to acids, hydrocarbons, various organic solvents, sunlight, humidity, and even temperatures up to 300°C [3]. All this without forgetting other of its main hallmarks such as that it is inert, that it has a low coefficient of friction, or that its average melting point is 342°C. Because of its thermal resistance, also used to coat cables, hoses, ducts, and even aircraft. On the other hand, the material can be used in dentistry and medicine in general for the manufacture of prostheses. Also, they have a magnificent picture of mechanical properties, very high tenacity, and excellent sliding characteristics and resistance to wear [3]. Depending on the type of material, the polyamides absorb different amounts of moisture, influencing mechanical characteristics, and dimensional accuracy.

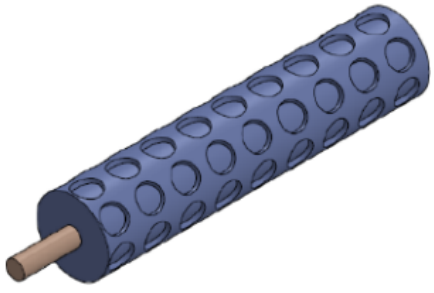


Figure 3. Roller for the molding of "panelitas".

The roller is the most important component because it is the one that shapes and molds the "Panelitas" according to the specifications requested by the clients; this roller has a length of 55 mm and a diameter of 2.5 mm, which is supported by a 2.5 mm shaft such as shown in Figure 3, that rotates between 6.6 m/s y 0.7 m/s which are agreed with the recommendations taking into account [8].

3. Results and analysis

Figure 4 shows the simulation results for the hopper design using the finite element analysis [12-15] meet the size requirements established by the client, which has the following dimension (60 cm × 37.36 cm × 45.72 cm) and a minimum front height of 10 cm. The volume or volume of the hopper was calculated from the software SolidWorks according to the dimensions and geometry, with a value of 18,2000 cm^3. The weight of the "panelitas" on the designed conveyor belt (selected by catalog) can support a maximum load of 60 kg. After, the mass was calculated to determine the total weight of the "panelitas" on the roller. Taking into account that the machine was designed for 10 working hours per day, the mass (Raw material) will weigh 18 kg, the machine will have a performance of $\eta = 11.32\%$, for the ideal conditions of operation, and torques less than 300 Nm.

For the development of the finite element analysis, 40 Psi loads with the interaction on the roller were applied to estimate the estate of stresses on the hopper. Figure 4(a) shows the use of a standard solid mesh; this mesh was selected by default in the software. Note that present 18,235 nodes and 8,793 elements. After that, Figure 4(b) shown the deformation equivalent for the structure of the hopper; the deformation is related to the change of the area of a material, this revels an indicator of a good design of machines, in this case, related with the mechanical properties of the AISI 1020 steel [9].

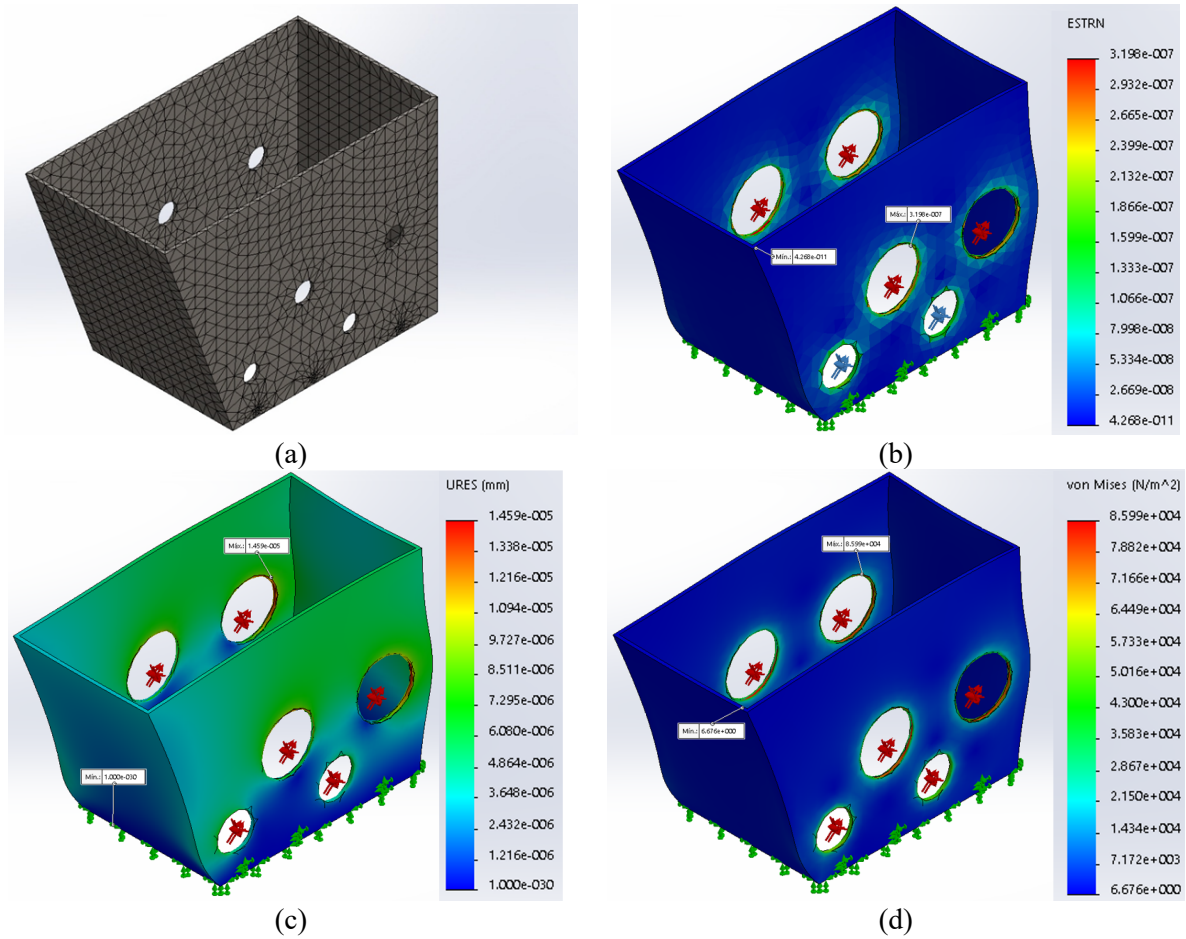


Figure 4. Simulation results for the hopper (a) Mesh, (b) Deformation equivalent, (c) Total displacement, and (d) Total elastic limit.

In this way, minimum and maximum values of equivalent unit deformation are represented in the analysis which is 4.27×10^{-11} mm and 3.20×10^{-7} mm, respectively; the values no affect the mechanical behavior of the material due to the yield strain [14,15]. The displacements are shown in

Figure 4(c), in this is higher than 1.46×10^{-6} mm, which is the maximum value in the node 17,392. In this case, these values are not significant for the excellent performance of the machine. Finally, Figure 4(d) shown 6.67 Pa and 8.59 Pa, for the nodes 16,879 and 151, respectively [15]; note that these values not exceed (are depreciable) the Young modulus of the material, which is 205 GPa from Table 1. The other constituent mechanical elements of the machine were selected by catalogs taking into account safety, costs, and health characteristics. Besides, the calculations made are following the provisions of the bibliographic references and have fair values for the correct operation of the machine. Finally, the total cost of this machine with the elements and materials used in this project is around $11,609,255.00 COP included the manufactured stage. According to the economic analysis, the recovery of the investment is in 2 years with the assumption that the machine is working 5/7 days per week.

4. Conclusions

The specific calculations were made for the constituent elements of the molding machine using mechanical design theories and finite element analysis, with which it was possible to define the optimal design according to the needs of clients and producers of the industrial sector. In this way, was possible validate the good performance of the machine using the mechanical design process. Mechanical design is a very complex process, including demand analysis, conceptual design, technical design, and detailed design according to the need of the clients. This process depends on the experience of the design group for the development of the specifications in a real product. The design theory and methodologies promote innovative practices and products aid the market competitiveness for specific industries. The design of the gears was made with a commercial steel AISI 1020 for better performance because they are straight gears for their excellent ease of transmitting low speeds and medium speeds. Bearing in mind that the straight ones are of the great application when it is required to transmit the movement from one axis to another parallel, and near, on the other hand, they offer a constant and stable speed ratio for the proper functioning of the proposed model.

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