Design of a nozzle for Stratasys uPrint SE Plus 3D printer

Diseño de una boquilla para impresora 3D de la marca Stratasys uPrint SE Plus

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Abstract

The work is supported by the comparison of conventional metrology methods and the use of virtual optical comparison technologies virtual optical comparison technologies, these methods are used for the design of a nozzle for the Stratasys the design of a nozzle for the Stratasys 3D printer analysis by means of CAE and the Finite Element Method (FEM) Finite Element Method (FEM) to be able to evaluate some more adequate parameters that will serve as the serve as the main basis for the development of the same nozzle. On the other hand, it is also based on the CFA analysis with the type of polymer used to verify if the design is feasible, taking into account the necessary configurations for the use of the most appropriate manufacturing. The difference between using a conventional metrology method is the decrease of the error in obtaining geometries of a certain model, on the other hand, when using an optical comparator, it was taken as a main point that it is only to obtain geometries of smaller elements, this makes that with the use of new technologies it is not 100% accurate in obtaining a perfect geometry.

Engineering and Technology, Mechanical Engineering, Others

Resumen

El trabajo se sustenta con la comparación de los métodos de metrología convencional y uso de tecnologías virtuales de comparación óptica, dichos métodos son usados para realizar el diseño de una boquilla para la impresora 3D de la marca Stratasys, asimismo se pretende tomar como soporte el tipo de análisis mediante CAE y el Método de Elementos Finitos (MEF) para poder valorar algunos parámetros más adecuados que sirvan como base principal para el desarrollo de la misma boquilla. Por otra parte, también se sustenta en el Análisis de CFA con el tipo de polímero usado y así poder verificar si el diseño es viable, tomando en cuenta las configuraciones necesarias para el uso de la manufactura más adecuada. La diferencia entre usar un método convencional de metrología precisa la disminución del error en la obtención de geometrías de cierto modelo, por otra parte, al hacer uso de un comparador óptico se tomó como punto principal que es solo para obtener geometrías de elementos más pequeñas, esto hace que con el uso de nuevas tecnologías no se precise al 100% en la obtención de una geometría perfecta.

Ingeniería y Tecnología, Ingenierías Mecánicas, Otras

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Introduction

New technologies in manufacturing are developing very fast in the application of new methods of 3D modeling and rapid prototyping.

According to (Ortega) the process of creating a mathematical representation of surfaces using geometries is called 3D modeling, this can be represented in two ways: on screen as a two-dimensional image through a process known as 3D rendering or as a physical object, through a 3D printer or numerical control manufacturing tool.

On the other hand, additive manufacturing is the technical name that encompasses all 3D printing technologies, it is the manufacture of three-dimensional objects by adding material instead of subtraction in order to model and prototype.

With the application of these technologies so far it has not been possible to obtain a 100% perfect replica in the manufacture of prototypes and 3D models, each of these techniques that are applied have different application methodologies when developing a model; today we can say that manufacturing plays great roles, such is the case of additive manufacturing, as a proposal and application support in this project, with the design of a 3D printer nozzle using CAD design methods and conventional metrology to apply reverse engineering to a sample object.

Finally, different materials are required for its application and design of the nozzle to support internal and external variables when manufacturing a model, for these variables it is intended to make use of a CAE software for the analysis of CFD fluid simulations of the nozzle and thermal resistance of the same to opt for the best design material proposal.

In this project we took as main points, the lack of acquisition with suppliers because they are obsolete equipment, the acquisition time and cost, as fundamental factors to take as main idea the design of the nozzle and to have in existence a model to be able to manufacture it in the future.

Introduction to Prototyping

The conception of the manufacturing of a model starts by analyzing its characteristics and attributes of design, ergonomics, costs, etc. To date, the design of a mold was made in a CAD software to be taken to a machine that could be an injection molding machine and see the results of that model. The costs of product design and development increased drastically when a product did not meet specifications, so it was necessary to redesign the mold, manufacture it and test the product again. All these costs, which are charged to the cost of the finished product, can be considerably reduced if the part is first designed at the prototype level and then the mold of that product is generated for mass production. This advantage is offered by the new technology that performs a three-dimensional printing called 3D printer. (Costa, 2018)

What is a 3D printer nozzle?

The nozzle is the last step where the filament is extruded, after heating in the melter. As in most 3D printers, the nozzle can be changed, depending on different properties such as the material to be printed, the diameter, or the utility of the nozzle.

The inner diameter of the nozzle affects the amount of plastic extruded per second, the flow, the quality and the maximum extrusion speed. Specifically, the nozzle diameter determines the layer height, which as a general rule will be 1/2 of the nozzle diameter. Smaller diameters allow thinner layers and thinner walls to be printed. Nozzles for 3D printers are available in various diameters between 0.2mm, 0.25mm, 0.3mm, 0.35mm, 0.4mm, 0.5mm, 0.6mm and 0.8mm. This determines the layer height and therefore the printing speed.

In 3D printing, we usually say that the maximum layer height given by a nozzle, to avoid problems in printing, is 80% of the nozzle diameter, so we would find the following maximum layer heights per nozzle diameter:

0.2 mm: 0.2*0.8 = 0.16 mm
0.4 mm: 0.4*0.8 = 0.32 mm
0.6 mm: 0.6*0.8= 0.48 mm

These characteristics can have a big impact on the time it takes for the part to print, as well as the quality of the final object.

Generally, the most commonly used diameter in desktop 3D printers is 0.4. A nozzle diameter that gives us a good finish in terms of resolution and speed. The layer height for this type of nozzle caliber is usually 0.2mm, which implies an optimal detail per layer in the final design.

You can buy 0.2, 0.15 and even 0.1 nozzles that have demonstrated great performance, since the smaller the size, the more detail, although it also depends on the level of resolution that the 3D printer can offer.

Even 0.6 nozzles are a good option for printing, although these types of nozzles are more focused to be used in industrial 3D printing.

Elements of a nozzle

The thread pitch: is the distance between the crests of the area to be threaded. Generally, and with some exceptions, this distance is 1mm. It is important because this part is screwed to the heater block, and it has to fit perfectly.

The distance from the head, or the end of the thread and the end of the nozzle. This measurement is very important, this is the part that will protrude from your hotend, so if you buy a nozzle with this section larger or smaller, you will have to modify the end of the stroke or re-level.

Thread distance: this distance usually varies depending on the brand. Most 3D printers require a nozzle with a thread distance of 5 mm. The standard Ender 3 nozzle, for example, has 5 mm.

The thread metric: most nozzles are metric 6 (M6). This is a 6 mm diameter thread. Mk8 nozzles are also metric 6. MK10 nozzles are metric 7 (M7).
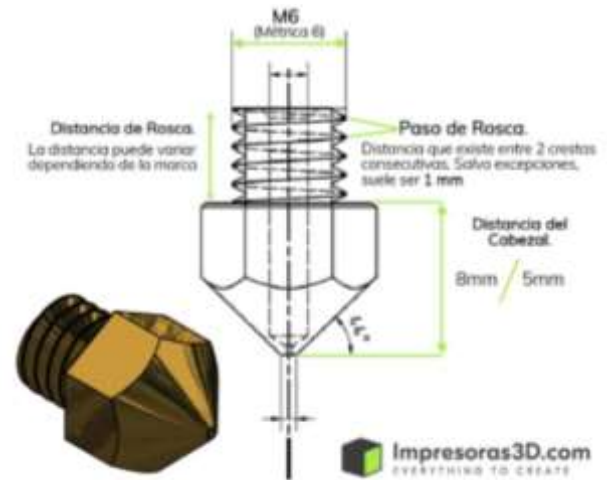

Figure 1 Nozzle elements.(IMPRESORAS3D.COM, 2021)

Types of Nozzles

When we talk about size, we are referring to the physical mass and length of the part. This is not to be confused with the nozzle diameter orifice, which is a measurement of the space inside the nozzle through which the filament is extruded.

Standard

The length of the nozzle is determined by the type and size of the fuser heater block. The current standard dimensions of these parts fit V6 and MK8 extruders, with an overall length of 12 to 13 mm.

Volcano

Volcano nozzles are designed for higher speeds and temperatures, with the ability to process at least three times more plastic than standard nozzles. Volcano nozzles require a longer nozzle, typically 21mm from end to end to promote better thermal conduction.

Supervolcano

Supervolcano nozzles are varied in both material and outlet diameters. It is one of the best nozzles that offers the best ratio of quality, detail and speed.

BondTech's CHT nozzles have a triple inlet orifice, allowing up to 30% increase in flow, ultra-precise machining, higher melt capacity, and also enjoy the advantages of nickel plating.

Figure 2 Type of nozzles according to their shape and size.(IMPRESORAS3D.COM, 2021)

Due to their relatively high thermal conductivity and tight manufacturing tolerances, 3D printer nozzles are made of different metals that affect the printing process. Let's take a look at the different materials that are used depending on the filament we are going to extrude. (IMPRESORAS3D.COM, 2021)

Nozzle type	Characteristics
Brass nozzles	– Maximum temperature: Max: 300ºC. – High thermal conductivity. – Not suitable for abrasive materials. – Low cost. – Low wear resistance.
Stainless steel nozzles.	– Maximum temperature: Max: 500ºC. – High thermal conductivity. – Not suitable for abrasive materials. – Suitable for materials in contact with food. – Low cost. – Low wear resistance.
Nickel nozzles.	– Abrasion resistant. – Greater fluidity. – Suitable for abrasive materials – More affordable than similar ones. – High wear resistance.
Vanadium nozzles	– Extremely resistant. – Suitable for abrasive filaments. – High precision. – High durability.

Nozzle type	Characteristics
Tungsten Nozzles.	– Maximum temperature: Max: 550ºC. Excellent Conductivity. – Suitable for all types of materials. – Made of tungsten carbide and copper alloy. – Uniform temperature and low friction coefficient.
Hardened steel nozzles.	– Maximum temperature: Max: 500ºC. – Medium thermal conductivity. – Suitable for abrasive materials. – High cost. – High wear resistance.
Ruby-tipped nozzles	– Maximum temperature: Max: 500ºC. – High thermal conductivity. – Suitable for abrasive materials. – High cost. – High wear resistance.

Table 1 Nozzle types and characteristics. (IMPRESORAS3D.COM, 2021)

Properties of the materials used in nozzles

Properties of brass

Brasses are binary alloys of copper and zinc combined in different proportions which, practically speaking, range from: Cu 50 - 95% and Zn 50 - 5%. These alloys are more fusible than copper; they have a high resistance to corrosion, and even in marine atmospheres they have good lubricating properties. Commercial brasses can be divided in two broad groups, cold work brasses (α) and latones for hot work (brasses α plus β).

The ductility and Mechanical strength varies with zinc content, increasing with the percentage of zinc, reaching a maximum when the zinc content is 30%, providing a good combination of mechanical strength and ductility when maximum corrosion resistance is not essential.

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As the zinc content increases above 30%, the ductility of the metal decreases, becoming brittle and hard; however, the tensile strength reaches its maximum with approximately 45% zinc. The Brinell hardness of brass ranges between 50 and 60. These changes in mechanical properties are caused by the alteration of the internal structure.

The electrical conductivity of brasses decreases as the zinc content increases. As the zinc content increases above the solid solution range α, the structure of the brasses changes to a mixture of the α and β phases. The Muntz metal composition (60% Cu and 40% Zn), brings together the mechanical strength of the α and β mixture, at room temperature and the higher ductility of a single-phase structure, at elevated temperatures. (Ledo, 2011)

Properties of stainless steel

Stainless steels are alloys based on iron, chromium and carbon, to which other elements are added, such as nickel, molybdenum, manganese, silicon and titanium, among others, which give them good resistance to some types of corrosion in certain industrial applications. The presence of each element in certain percentages produces different variations in the intrinsic characteristics of the various types. According to EN 10088, stainless steels are defined as those ferrous alloys containing chromium in a minimum proportion of 10.5%.

This good corrosion resistance is due to the ability of these alloys to form a passive layer which is a stable, adherent film of chromium oxide (Cr2O3), also called chromite, which protects the steel in an oxidizing environment. This passive film rebuilds itself when damaged, if the environment is sufficiently oxidizing, maintaining a permanent protection of the steel.

There is a wide variety of stainless steels, each of which has properties for some specific application, to improve their characteristics some elements are added: a) Increased corrosion resistance: Cr, Ni, Ti and Mo. b) Improve machinability: Se and S. c) Increase hardness: Cu, Al and Mo. d) Increase formability and weldability: Cr and Ni. e) Improve mechanical characteristics: Mn, N and C. f) Decrease intergranular corrosion: Ti, Nb and Ta.

The most common way to classify stainless steels is by the crystallographic structure or microstructure of the material, they are divided into 5 families: g) Austenitic (FCC). h) Ferritic (BCC). i) Martensitic (Tetragonal centered in the body). j) Double phase or Duplex (Austeno-ferritic and ferritic-martensitic). k) Precipitation hardened (Austenitic or martensitic base).

As the definition of stainless steel is given by the percentage of chromium, which must exceed 10.5%, the increase of this percentage and the combination with nickel determine the nature and proportion of the phases present and consequently define the type of stainless steel.

The chromium content in these steels varies between 16 and 26%; nickel and manganese contents can reach levels of 35 and 16% respectively. The austenitic structure in these steels is stabilized at room temperature by the addition of elements such as nickel, manganese and nitrogen. They are not ferromagnetic in their annealed condition and only work harden. Their cryogenic characteristics are excellent and they exhibit good mechanical strength at high temperatures. They are very resistant to impact and difficult to machine, unless they contain S and Se, and can be hardened by adding C and N.

The family of austenitic steels is divided into two groups: a) Austenitic chromium-manganese-nickel steels, designated by a three-digit number starting with 2, known as the 200 series, characterized by high mechanical strength, due to the presence of sulfur and manganese, with the last two digits depending on other elements. b) Austenitic chromium-nickel steels, designated by a number 3, 300 series, with a basic composition of 12% Cr and 8% Ni, being the most commercially successful range of steels.

For this series, the chemical composition is modified according to the type of use of the material by adding or reducing elements such as carbon and/or nitrogen and/or modifying the nickel/chromium balance. The 200 series steels acquire their austenitic characteristics through the addition of nitrogen and manganese (between 4 and 16%), while nickel is limited to below 7%. The 300 series steels contain high levels of nickel and up to 2% manganese.

Elements such as molybdenum, copper, silicon, aluminum, titanium and niobium are added to improve resistance to halide corrosion, pitting or to improve their resistance to oxidation.

They are not ferromagnetic in their annealed condition and can only be hardened by cold working. The yield strength, yield strength or yield values (σy) of the 300 series austenitic steels are comparable to those of low carbon steels.

Typical values of σy in the annealed condition vary between 200 and 280 MPa, mechanical strength varies from 500 to 750 MPa and exhibit elongations from 40 to 60%. Values of σy in manganese steels can vary from 350 to 500 MPa. These steels are not susceptible to hardening by heat treatment, but exhibit mechanical work hardening. AISI 302 (17% Cr, 8% Ni) and AISI 304 (18% Cr, 8% Ni) steels are considered basic alloys of the austenitic stainless steels.

The particular composition of these steels is due to the minimum nickel content (hence lower cost) required to retain the γ-phase at room temperature; so for low or high Cr contents the addition of more nickel is required. For example, for higher corrosion resistance, a steel is designed with 25% Cr, but it needs about 15% Ni to retain the austenite at room temperature and this means a higher cost. (Leal Alanís, 2011)

Properties of nickel

Nickel is a hard, malleable and ductile metal, which can have a high luster. It has magnetic properties below 345 °C. It has a melting point of 1,455 °C and a boiling point of 2,730 °C. Passing carbon monoxide through impure nickel forms nickel carbonyl, a volatile gas. This gas, heated to 200°C, decomposes, depositing pure metallic nickel. Steels containing between 2% and 4% nickel are used in automotive parts, such as axles, crankshafts, gears, keys and rods, in machine parts and in armor plates. (GARCÍA, 2006)

Properties of Vanadium

Vanadium is a grayish metal with a density of 6.11 g/cm3. In the periodic table, it is the first transition element of group VB, it has atomic number 23, electronic configuration [Ar] 4s2 3d3, atomic weight 50.95, melting point 1950 °C and boiling point 3600 °C. It exists in different oxidation states ranging from -1 to +5, and generally passes from one state to another by the transfer of an electron through oxidation-reduction processes. However, only the three highest states, VIII, VIV and VV, respectively, have biological functions recognized.

Similar to molybdenum (Mo), vanadium has an exceptional position within the biometals, as it participates in biological processes as an anion or cation.

Under physiological conditions VV predominates as vanadate anion (H2 VO4-) and VIV as vanadyl cation (VO2+); although, other species of cations (VO3+, VO2 +) and anions (HVO4 2-, V4 O12 4- and V10 O28 6-) of VV and anions ([(VO)2 (OH5)] -) for VIV may be present. At pH near 7 VIII is found exclusively in the form of V3+ cation and in the cellular environment in the form of complexes. Under acidic conditions of pH 3.5, the vanadyl ion is very stable, in basic solutions the orthovanadate ion (VO4 3-) predominates, which is very similar in its geometry to phosphate (PO4 3-). The coordination chemistry of vanadium is extensive and very interesting, commonly presenting octahedral, pyramid or square bipyramid geometry, where an oxygen always forms a double bond with VV or VIV, giving rise to oxovanadate or oxovanadil compounds.

A large number of inorganic vanadium compounds are known. Table I shows some of the physical and chemical properties of the most commercial compounds used in industry and which are of toxicological interest. Vanadium pentoxide (V2 O5), the most commercially available compound, is a reddish-yellow salt with a melting point of 1750 °C and a boiling point of 690 °C. It is a hazardous chemical agent and its occupational exposure limit for dusts and fumes is 0.05 mg/m3. Vanadium trioxide (V2 O3) melts at 1970 °C, is a black salt that crystallizes gradually into indigo-blue on contact with air to form vanadium tetroxide (V2 O4) and decomposes on heating to produce very toxic fumes. (Lozano, 2006)

Nozzle diameters

When selecting the nozzle, the exit diameter through which the filament will pass must be taken into account, as this will determine the maximum quality that can be obtained. When heated, the filament is pushed through the nozzle, generating an elevated pressure inside the material passage channel. This pressure must be kept constant, otherwise the extruder will not have the necessary force to push the filament. This situation results in loss of extruder motor steps and inconsistency in the amount of material deposited. To avoid this problem, it is essential to select the correct nozzle diameter in the laminating software, and to correct this parameter each time the nozzle is changed to a different size.

When using smaller diameter nozzles, the extruder deposits less filament in each pass, so it covers less surface area and must make more strokes to cover the printed layer. As a result, printing times increase considerably. As an advantage, the resolution in the X and Y axes will be much higher, so more detailed parts can be printed.

On the other hand, if we wish to print very large parts, with a medium or low level of detail, it would be convenient to use a nozzle with a larger exit diameter. In addition to covering a larger surface area per pass, thus reducing the times of each individual layer, a larger nozzle allows the height of the printed layers to be increased. As a general rule, the maximum layer height that can be printed is approximately 75% of the nozzle diameter, although sometimes it can cause problems of poor adhesion between layers and subsequent delamination of the part. It is advisable not to exceed 60%, so if we use a 0.8 mm nozzle, a maximum layer height of 0.48 mm would give us a very good relationship between speed and printing quality.

Otra forma de ahorrar tiempo en cada pieza es reducir la cantidad de paredes impresas. Lo habitual al usar boquillas estándar de 0,4 mm es establecer dos paredes de ancho en los laterales del objeto. Usando una boquilla de 0,8 mm se puede imprimir sólo una pared y lograr la misma resistencia. Debemos ajustar muy bien las retracciones para evitar faltantes de material en las paredes, ya que los defectos se magnifican al agrandar las capas.

Most laminating software includes the option to set the line width, which brings advantages in part strength or printing speed. To experiment with these parameters, this table can be of great help: (3D Solved, s.f.)

Nozzle size.	Minimum layer height.	Maximum layer height.	Minimum line width.	Maximum line width.
0.15 mm	0.04 mm	0.12 mm	01 mm	0.3 mm
0.20 mm	0.05mm	0.16mm	0.12mm	0.4mm
0.25mm	0.06mm	0.20mm	0.15mm	0.5mm
0.30mm	0.08	0.24mm	0.18mm	0.6mm
0.35mm	0.09mm	0.28mm	0,2mm	0,7mm
0.40mm	0.10mm	0.32mm	0.24mm	0.8mm
0.50mm	0.13mm	0.40mm	0.3mm	1mm
0.60mm	0.15mm	0.48mm	0.36mm	1.2mm
0.80mm	0.20mm	0.64mm	0.48mm	1.6mm
1.00mm	0.25mm	0.80mm	0.6mm	2mm

Table 2 Line width. (3D Solved, s.f.)

Process

Additive manufacturing (AM), formerly known as rapid prototyping (RP), is one such technological development. AM is defined by the American Society for Testing and Materials (ASTM) as "a process of joining materials to fabricate objects from 3D model data, usually layer by layer, as opposed to subtractive manufacturing methodologies".

Also commonly referred to as 3D printing in the public literature, this emerging technology is revolutionizing the manufacturing industry with its ability to convert digital data into physical parts. Its distinct ability to fabricate complex shapes and structures has already made it invaluable for the production of prototypes such as engine connectors for the automotive industry and tools such as investment casting molds in the jewelry and aerospace industries.

Regardless of the different techniques used in the AM systems developed, they generally adopt the same basic approach, which can be detailed as:

A model or component is modeled in a computer aided manufacturing system (CAD-CAM). The model describing the physical part to be built must be represented as closed surfaces that ambiguously define a closed volume. This means that the data must specify the bottom, the outside and the boundary of the model. This requirement will be redundant if the modeling technique used is based on the solid model.

2. The solid or surface model to be built is then converted into a file format called "STL" (stereolithography) originated by 3D Systems. The STL file format approximates the surfaces of the model using the simplest of polygons, triangles. Highly curved surfaces must employ many triangles and this means that STL files for curved parts can be large. Some AM systems also accept data in the 2D/3D vector graphics format based on the Initial Graphics Exchange Specification (IGES).

A computer program analyzes an. STL file that defines the model to be manufactured and "slices" the model into cross sections. The cross sections are systematically recreated through solidification of liquids or powders and then combined to form a 3D model.

Fundamentally, AM development can be described in four areas. The key aspects of AM are four: input, method, material and applications, Figure 3.
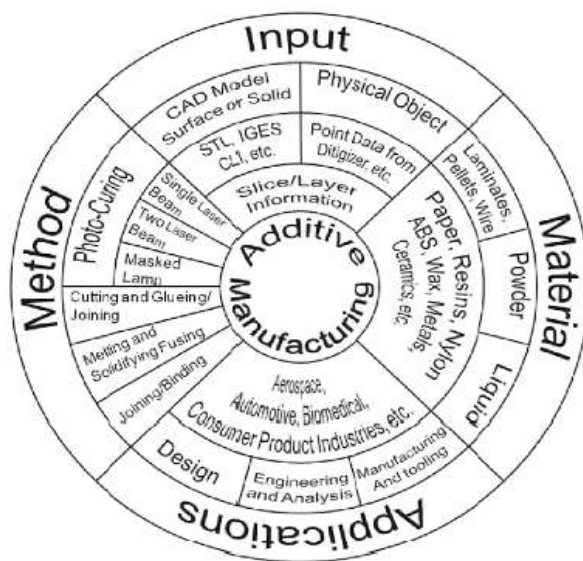
Figure 3 Key Aspects of Additive Manufacturing. (Chee Kai Chua, Kai Fai Leong. 3D Printing and Additive Manufacturing: Principles and Applications. World Scientific Publishing Co Pte Ltd. 2014)

How printers work

To create a 3D model, the first step is to design it with 3D rendering software (CAD type). The model is saved in a stereolithography (STL file). The printer software reinterprets the information in the. STL file and transforms it into 2D horizontal sections that will be printed by the printer in an additive way until the complete 3D object is formed.

There are many different techniques for printing three-dimensional models. The one used by the most common printers is fused deposition modeling (FDM) or thermoplastic extrusion. The printer has a nozzle that can be moved very precisely in three axes, through which it pours molten material in the form of wires that solidify immediately after exiting the nozzle. The most common materials used in this type of printer are various types of plastics, such as acrylonitrile butadiene styrene (ABS) and poly lactic acid (PLA).

But they can also be used with waxes, metals, ceramics, nylon, glass and even chocolate and other foods to create pastry pieces.

Components and Mechanical Positioning System

Positioning Algorithm

The design of the positioning system uses the Bresenham algorithm for its displacement, from which trajectory tracking and error minimization are guaranteed. This algorithm considers for the movement between two points in the XY plane, a line that goes from the initial point (x1, y1) to the point (x2, y2), as shown in Figure 3-1. From these points $\Delta Px=x2-x1$ and $\Delta Py=y2-y1$ are calculated, whose results are compared to establish the axis of motion; if $|\Delta Px|\geq|\Delta Py|$ X is taken as the driving axis otherwise it is the Y axis that is the driver.
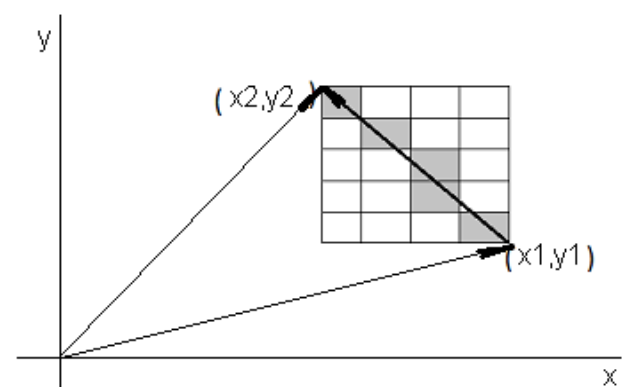

Figure 4 Movement established according to the Bresenman algorithm. (Jersson Xavier León Medina)

To determine the movement in the XY plane, we start from the real numbers provided by the G code, use absolute coordinates from which we define the initial position P1 and final position P2 of the extruder and discretize them to determine the displacement characteristics.

Within the main loop of the algorithm the coordinate corresponding to the driving axis is incremented by one unit and in the other axis, usually known as passive axis, it is only incremented as needed according to the following procedure:

The slope m of the line is calculated, which is given by:

$$m = \Delta Y / \Delta X \qquad (1)$$

The initial error, given by:

$$\epsilon = -[1 - y1 - m(1 - x1)] \qquad (2)$$

Where x1 and y1 correspond to the initial positions on the coordinate axes.

With these results, we define the beginning of the movement from the point (x1,y1), and we start advancing one unit in the movement axis, we add the slope to the initial error and we establish if the new value is greater than 0, if it is not, we continue advancing in the movement axis and we add the slope again, until this sum becomes greater than 0, at that moment we increase one unit in the other axis and the error is decreased in one unit, starting the process again until we find the arrival point (x2,y2).

The motion on the X and y axes is described by ΔPx and ΔPy according to the above algorithm; on the Z axis the motion is defined according to the thickness of the deposited material layer.

Axis Movements

X-axis motion

The selected mechanism corresponds to a pinion-gear belt motion transmission system, supported by bearings, configured as shown in Figure 5.

This movement is governed by a motor and a pinion-belt mechanism, which moves a mass determined by the sum of the components of the material extruder tool and its support structure, the movement is guided by bearings that move on longitudinal guides.
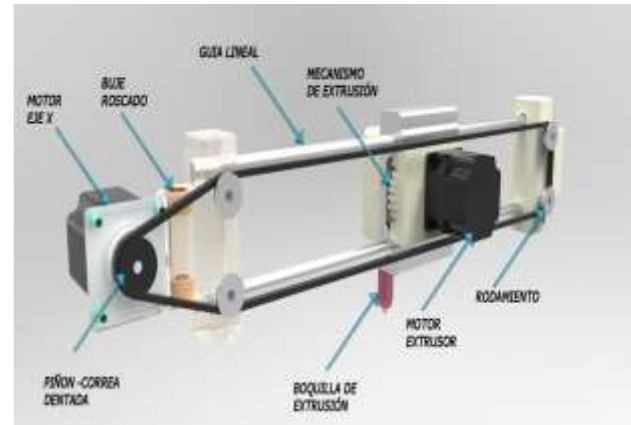

Figure 5 Actuator for X-axis motion. (Jersson Xavier León Medina)

The displacement ΔPx is determined by the number of steps per revolution of the motor and the gear ratio given by the number of teeth of the pinion and the belt pitch, the linear speed is a function of the angular velocity of the motor, and the radius of the pinion; the actuator power depends on the inertia, and the frictional losses. The mathematical models to determine the above values are described below.

$$\Delta Px = NxPc/(Pm)\,\eta \qquad (3)$$

Where:
Nx = Number of sprocket teeth for the shaft.
Pc = Belt pitch.
Pm = Number of steps per revolution of the motor.
n = Steps for the given motion.
Linear velocity of the X axis.

$$VX = w_{mx}{}^r px \qquad (4)$$

Where:
vx= Linear velocity of the x-axis.
rpx=Radius of the x-axis pinion.
ωmx = Angular velocity of the x-axis motor.
The force required to move the x-axis is calculated as follows:

$$Fcx = W/\mu \qquad (5)$$

Where:
Fcx= Force required to move the x-axis.
W=Total weight of the x-axis carriage.
μ=Coefficient of friction.
The total torque of the motor X Tcx required to move the load at constant speed is:

$$Tcx = Fcx * rpx \qquad (6)$$

The torque required to move the load at an accelerated rate is greater than that required to move the load at constant speed, due to inertial effects, and is calculated as follows: The load inertia Ja takes into account the carriage hammer X and is modeled as follows:

$$Ja = \frac{D^2 M}{4} \qquad (7)$$

Where:
D=Diameter of the pinion gear coupled to the X motor.
M = Mass to be moved of the X axis
The inertia Jb of the bearings, proper of the shaft on which the belt slides are modeled as a solid cylinder as follows:

$$Jb = \frac{\pi \rho D^4 L}{32} \qquad (8)$$

Where:
ρ=Density of the bearing material.
D=Bearing diameter.
L=Thickness of the bearing.

The total inertia is the sum of all those involved.

$$JT = \Sigma Ji \qquad (9)$$

The linear acceleration α existing at the moment of starting or braking the mechanism is given by:

$$\alpha = \frac{\partial \omega}{\partial t} \qquad (10)$$

The total torque TTx required in motor X is themes:

$$T_{TX} = T_{CXV} + JT \frac{\partial \omega}{\partial t} \qquad (11)$$

Movimiento en el eje Y

El eje Y responde al mismo tipo de modelamiento paramétrico definido para el mecanismo de transmisión de movimiento del eje X, ya que poseen el mismo mecanismo de transmisión con polea-correa dentada.

Y-axis motion

The Y-axis responds to the same type of parametric modeling defined for the X-axis motion transmission mechanism, since they have the same transmission mechanism with toothed belt-pulley.
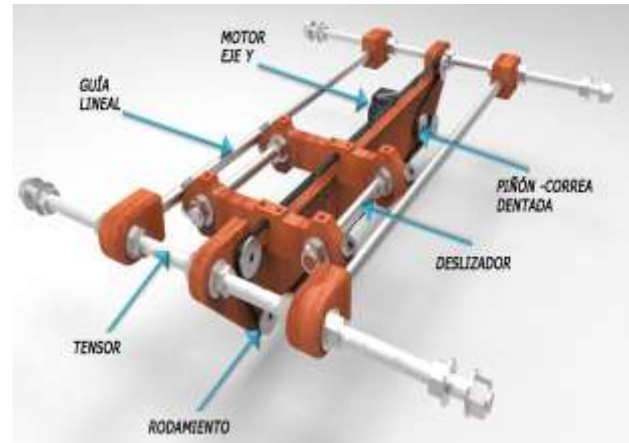
Figure 6 Y-motion actuator. (Jersson Xavier León Medina)

Z-axis motion

This motion is governed by a stepper motor, a motion transmission system integrated by two gearwheels that provide rotational motion to a transverse axis, and this through two worm-worm-crown mechanisms, located at the ends of the prototype, provides motion to two vertical threaded rods that transmit motion in the Z direction to the coupled X axis.
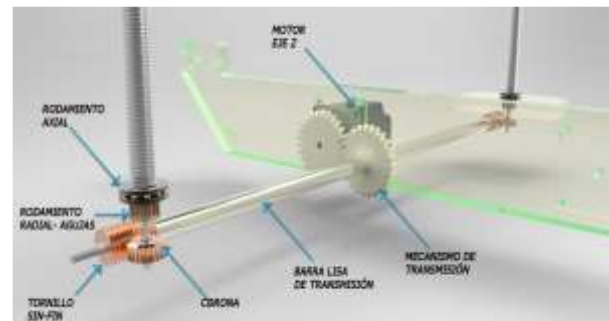

Figure 7 Actuator for Z-axis motion. (Jersson Xavier León Medina)

In this direction the change of position ΔPz is determined by the state of the coordinates delivered by the G-code, which vary according to the characteristics of the thickness of the molten layer. The displacement and speed is dependent on the number of steps per revolution of the motor, the gear ratio of the gears and the pitch of the vertical rod thread, as follows:

$$\Delta P_{Z} = \frac{Pt}{PmNz} \eta \qquad (12)$$

Where:
Nz = Number of crown teeth.
Pt = Pitch of the vertical rod thread.
Pm = Number of motor steps per revolution.
n= Number of steps for the given motion.
Z-axis linear velocity.

CORTEZ-SOLIS, Reynaldo, ARENAS-ISLAS, David, BETANZOS-CASTILLO, Francisco and FUENTES-CASTAÑEDA, Pilar. Design of a nozzle for Stratasys uPrint SE Plus 3D printer. Journal Industrial Engineering. 2023

$$V_z = \frac{1}{2\pi} \frac{\omega_{mz}}{Nz} P_t \qquad (13)$$

Material extrusion mechanism

The extrusion mechanism is composed of: the extruder motor with a pinion coupled to the driving shaft and a toothed wheel coupled to a shaft supported by two bearings and which in turn drives a small toothed wheel that comes into contact with the material filament, thus allowing the supply of the material to the heater.
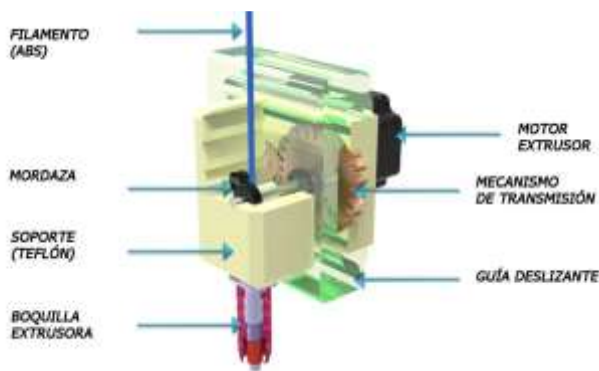

Figure 8 Extrusion Mechanism. (Jersson Xavier León Medina)

Control Design

Within the design of the printer, some control strategies are contemplated to supervise the system, in order to ensure some safety parameters and correct operation of the printer. Some of them are:

– **Open loop control**

In this control strategy there is no feedback from the plant to a control card, only the latter exerts its function on the actuators, but the final response of action is not measured.

– **Closed loop control**

In this control strategy there is a feedback to the controller so that the performance signal measured through sensors is compared with a base signal or reference signal, to establish the control actions based on the error signal to tend to be equal and thus minimize possible errors.

– **Control Proporcional Integral Derivativo (PID)**

A PID (Proportional Integrative Derivative Proportional) controller is a generic control mechanism on a closed loop feedback, widely used in industry for system control. The PID is a system that enters an error calculated from the desired output minus the output obtained and its output is used as input to the system to be controlled. The controller attempts to minimize the error by adjusting the system input:

We can highlight the following equation of the PID control strategy, it shows the model of the controller output that will serve as control input signal to the process. (Jersson Xavier León Medina)

$$u(t) = K_p\, e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (14)$$

Where:
e(t) is the signal error.
u(t) controller output and control input to the process.
Kp is the proportional gain.
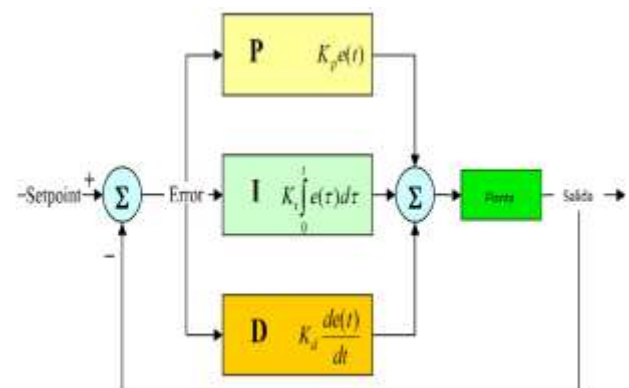Ki is the integral time gain.
Kd is the derivative time gain.

Figure 9 PID Control Diagram. (Jersson Xavier León Medina)

3D Printing

3D printing has been one of the most significant inventions in recent years. This is why the incipient creation of three-dimensional objects through additive or layer compaction techniques could surpass the development of products through the use of molds or the extrusion or subtraction of raw material.

Figure 10 3D printing appears at the top of the trend curve. (Joquera Ortega, 2016)

This revolution in the manufacture of parts has covered many areas, from engineering to medicine, bringing as a guarantee a breakthrough towards new knowledge. Today it is possible to re-transform bits into atoms, i.e. into physical objects, in homes, workshops or SMEs, thanks to 3D printers and rapid prototyping machines.

3D printing or additive manufacturing (AM) is a process of creating three-dimensional objects by adding materials layer by layer. Physical objects are produced using data from a digital model of a 3D model or other data sources, such as an AMF (Additive Manufacturing File). The personal computer plus the Internet and this new invention allow society to have the solutions to its problems at its fingertips. From this conjugation of technologies, a part is obtained, starting from a digital file (3D model), different additive processes are used in which successive layers of material are applied to create a tangible object. (Joquera Ortega, 2016)

Figure 11 3D Printer - UP Plus 2 manufactured by Tiertime. (Joquera Ortega, 2016)

From this invention, the technology was modified until today, where the printing is made of plastic material. This situation has certain advantages and limitations as shown in Table 3.

Advantages	Limitations
Complexity and freedom of design.	Higher cost of large productions.
Customization and personalization	Less choice of materials, colors, finishes
No need for tools.	Limited resistance and durability
Speed and cost savings.	Accuracy of printed objects.
Faster and less risky market access.	Most 3D printers are limited by scale and size.
Less waste, sustainability, environmentally friendly.	

Table 3 Ventajas y Limitaciones de la Impresión 3D. (Introducción a la Impresión 3D)

In the same way, the synergy between a mechanical design software with the communication to the 3D printer generates the manufacturing process of the part. This consists of the creation of a mathematical representation of surfaces using geometry, where the result is known as a 3D model, which can be represented on screen as a two-dimensional image or as a physical object, through a 3D printer.

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This process takes place inside the printer. The filament (spool of material) passes through the extruder, which pushes it through the head melting the material all the way out through the nozzle as it draws each layer onto the print tray. As the material exits, it cools to maintain its shape. The layers build up one on top of the other until the final object is obtained.

On the other hand, for SMEs dedicated to manufacturing, to be able to acquire this machine requires a strong investment, as well as papers that grant the required permits because most of them are manufactured abroad, so it is difficult to have this equipment in the workshops or production areas. From this, the idea of designing a 3D printer was born in order to guarantee the needs of any organization and the regional market. Therefore, the general objective of this research is to analyze the mechatronic design for the manufacture of a 3D printer.
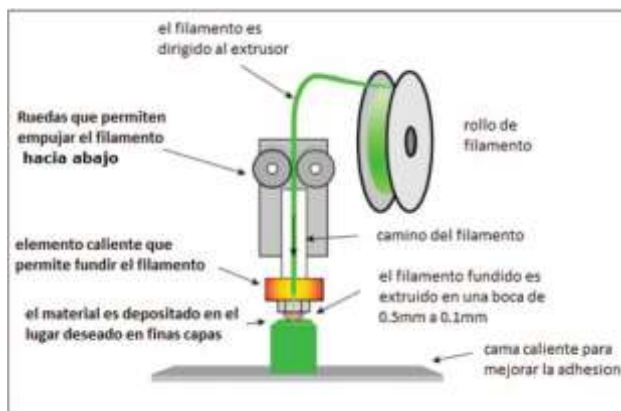
Figure 12 3D printing process. (Introducción a la impresión 3D)

3D printer application

The application of 3D printers are varied and in great quantity due to the versatility that can offer the products, because the user can manufacture the designs that guarantee the needs of the moment. From engineering, science, medicine and even education have had an answer thanks to the incorporation of parts produced by these machines.

This equipment can be used in the classroom as an educational tool in order to capture the student's attention and as a stimulator of their ideas. Table 4 details the advantages of using this technique as an educational tool in the classroom. In the same way, the fundamental material that can be used and experienced by students are thermoplastics (usually PLA or ABS) due to their versatility for being able to work with them.

Advantages	Features
Promote creativity.	The student will be able to capture their ideas in a digital context through a computer and witness how what was in their mind becomes a physical piece. From then on, their curiosity will take on infinite possibilities.
They develop spatial intelligence.	Another of the virtues offered by the "magic" of 3D printing. Children will develop their ability to recognize objects and unravel the similarities and/or differences between them, as well as improve their relationship with the space around them.
They solve problems while having fun and building knowledge.	The adaptation of 3D printers to the classroom opens up an unlimited field of possibilities for teachers. Students will be able to solve problems by creating individual pieces that break down the problem and speed up its resolution. Also, by solving this type of technological problems, they make a connection between theoretical and practical knowledge and reality.

Table 4 Advantages of the 3D printer in education. (Romero Perez)

Consequently, the development of this technology allows to improve the analysis of the parameters of various phenomena that occur in the sciences and thus provide more creative solutions to these problems. For example, in hydraulic engineering, through the design and construction of elements that are designed for specific situations, there is greater student participation due to the motivation to learn new knowledge thanks to the application of 3D printed models. In the field of medicine, it has provided answers to countless problems where solutions were difficult or highly expensive. Printing, for example, prostheses has helped to improve the quality of life of many patients. Table 5 details the use of 3D printing in the medical field.

Area	Features
Transplants.	There are two cases: you need to take skin from a part of the body and place it on the lesion, or you need to reconstruct a bone. In both cases, 3-D printers can help.
Organs.	Living cells are used as the material for printing. From these it is possible to generate an organ to be implanted in a person.
Others.	3D fabrication of corset for patients suffering from scoliosis. 3D printing of fetus in order to detect malformations in the unborn in order to follow up on the mother's gestation. 3D printing of plaster casts for fractures in the upper or lower limbs of the human body. Bone manufacturing.

Table 5 Use of printing in medicine. (Chimbo, Aveiga, Moreira y Tumbaco, 2016)

For the development of the machine, it is proposed to create a diagram that links the mechanical and electronic modules in order to respond to the design of the 3D printer. (Alex Mauricio Tipán-Suárez).
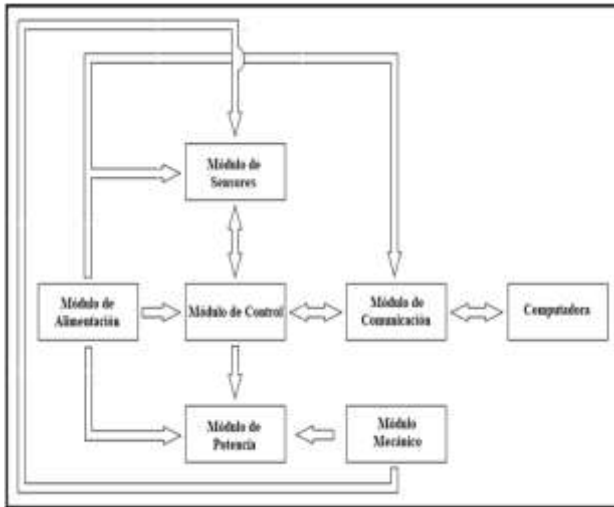

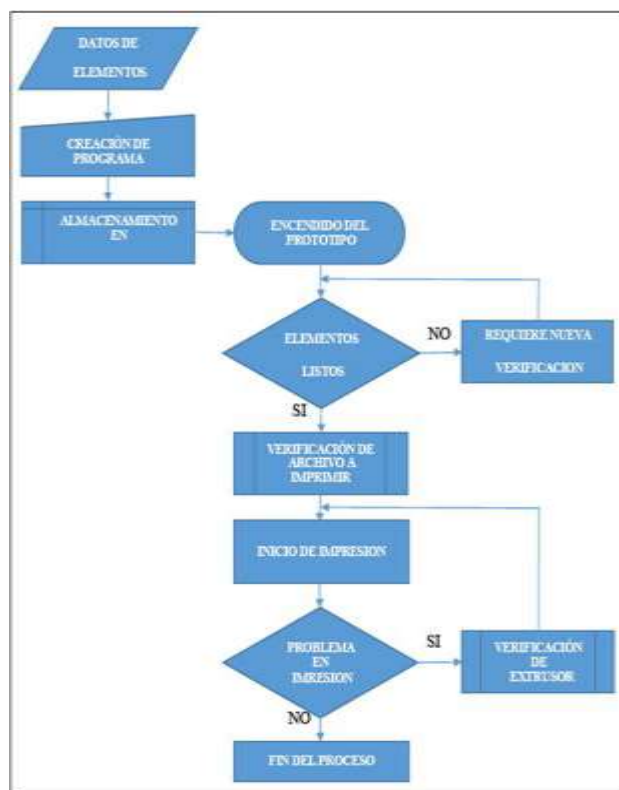**Figure 13** Diagram of the design of a 3D printer. (Naranjo y García)

Figure 14 Printer flowchart. (Cañas Masapanta)

Rheology of Polymers

In order to support the research, this information is taken into account for the rheology of the polymers to determine the best material to be able to manufacture the nozzle in the future, if desired, in a physical way.

The etymological origin of rheology refers to the study of flow (from the Greek reos: to flow and logos: treatise, science) and was proposed by Eugene Cook Bingham, professor of chemistry at Lafayette College (Easton, PA, USA) to define that branch of physics whose objective is the fundamental and practical knowledge of the deformation or flow of matter.

Polymers and Biopolymers

Polymers result from the union of several units of a monomer, resulting in a chemical compound of natural or synthetic origin based on its constituent structural units. In the field of organic chemistry, polymers are called biopolymers. There are micromolecules of biological interest such as carbohydrates and proteins that, being intrinsic to animal and vegetable raw materials used for food formulation, generate food dispersions that have certain rheological behaviors.

A very common resulting colloid is sols, a dispersion formed by a solid dispersed in a liquid, in this case the particles of the dispersed phase are constituted by large macromolecules such as proteins, polysaccharides and lipids. In the case of sols and other fluid colloids, applying a force results in a deformation flow per unit time. The resistance of the solute to flow is defined as viscosity. If for a fluid the relationship between stress and shear rate is directly proportional, it has an ideal behavior known as "Newtonian", i.e. it obeys Newton's law of viscosity. (Zambrano-Herrera, 2020)

$$\tau = \eta \left(\frac{dv}{dy} \right) \tag{15}$$

where:
τ=Shear stress.
η=Coefficient of Viscosity (Pa.s)
$\left(\dfrac{dv}{dy} \right)$ = Rate of speed or shear.

Classification of fluids

Fluids can be generally classified according to the relationship between the applied stress and the deformation ratio. We can classify fluids into 2 main groups, Newtonian fluids and non-Newtonian fluids.

Newtonian fluids are those in which the relationship between shear stress and velocity gradient is constant, the viscosity being constant.

$$\mu = \frac{\sigma}{\dot{\gamma}} \qquad (16)$$

Non-Newtonian fluids are those in which the relationship between shear stress and velocity gradient is not constant. In this case, instead of viscosity coefficient or Newtonian viscosity, we speak of apparent viscosity coefficient.

$$\eta = \frac{\sigma(\Upsilon)}{\Upsilon} \qquad (17)$$

Non-Newtonian fluids, provided there is an influence due to shear time, can be divided into pseudoplastic fluids, dilatant fluids and plastic fluids.

Pseudoplastic fluids are those products in which the apparent viscosity decreases with the velocity gradient.

Dilatant fluids are those products in which the apparent viscosity increases with the velocity gradient.

Plastic fluids are those products that require a minimum stress to start flowing. This minimum stress is known as the stress threshold or creep threshold ($\sigma 0$). Below the creep threshold, the product exhibits solid-like characteristics. Once this creep threshold is exceeded, and the flow regime is reached, these fluids can behave as Newtonian (Binham plastics) or as pseudoplastics (plastics in general). (Talens Oliag)
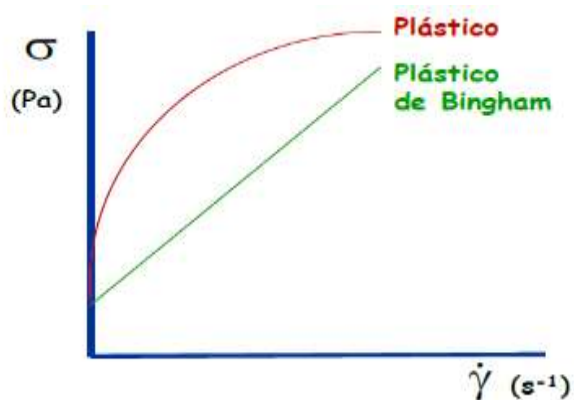
Figure 15 Flow curve or relationship between shear stress versus velocity gradient for a general plastic and Bingham plastic. (Talens Oliag)

Reverse Engineering

Parameter vs. function estimation

Inverse problems can be divided into two classes: parameter estimation and function estimation. The distinction is not always made, partly because many of the problems can be treated as function estimation problems and therefore include parameter estimation problems. Parameter estimation has a somewhat different connotation from heat transfer function estimation.

Mathematicians generally think of function estimation as the determination of an infinite dimensional solution (not just a finite dimensional discretization of a function, although the dimension can be quite large). But this is a theoretical concept and when one goes to implement the theory, one typically resorts to finite-dimensional approximations. This finite-dimensional approximation should converge to the infinite-dimensional function one is looking for. There are now some aspects that, although not exclusive to parameter estimation, are emphasized more than in the estimation of functions.

1. A limited number of parameters are estimated. In heat transfer, the number can be as small as one, it can be as large as half a dozen, and sometimes it could even go even higher.

2. The problems are usually not ill-posed, but they are usually nonlinear, even if the descriptive differential equation is linear.

3. Parameters often refer to a physical property, such as the thermal conductivity of a specific material at a particular temperature. These properties are not subject to human adjustment as, for example, a heat flow function is.

4. Parameter estimation analysis is not complete without giving an interval estimate or confidence region.

5. Model building is an important part of parameter estimation; that is, we have a physical process that we may not understand and wish to model more perfectly.

6.   Careful examination of the residuals (measured minus estimated) values of the measured variables) is done to check the adequacy of the mathematical model and to better understand the measurement errors completely. The residuals should not have a characteristic signature that persists experiment after experiment. Such a characteristic signature indicates a bias that affects parameter estimates.

7.   The sum-of-squares or weighted sum-of-squares function chosen should be selected based on measurement error.

8.   A powerful way to investigate the adequacy of the model and experiment is to estimate the parameters sequentially. These parameter estimates should approximate constant values rather than moving up or down at the end of the analysis interval.

9.   The optimal design of experiment is very important to obtain the best precision of the estimates.

10.   Perception is the primary concern, while computational efficiency may not be.

Unlike parameter estimation, function estimation generally has the following characteristics:

1.   The number of parameters to describe a function is usually large: perhaps in the hundreds or even thousands.

2.   The problems are often ill-posed and may or may not be linear.

3.   Computational efficiency is important. This may lead to avoid calculation of sensitivity coefficients. Intuition of the sensitivity of several components is usually not of interest.

4.   Confidence intervals, model building, residual analysis, optimal design of experiments, statistics and sequential parameter estimates are rarely considered. (Woodbury, 2003)

Optical comparator

Optical comparators are a type of optical measuring instrument. The measuring principle is similar to that of optical microscopes. The object is placed on the platform and a light is shone onto the object from below. This causes the object's profile, or shadow, to be projected onto the screen. A telecentric optical system is used to enable accurate measurements.

Optical comparators were originally developed to inspect the contours of objects. Models equipped with measuring functions appeared later. Some large optical comparators have screen diameters exceeding 1m.

The following are some advantages of optical comparators.

−   Non-contact measurement of the object.

−   Measurement possible even for objects with small or complicated shapes.

Unlike measuring microscopes, it is not necessary to look through an eyepiece lens, making it possible for several people to make observations at the same time.

The use of optical comparators is widespread in the inspection and measurement of items such as electronic components and precision components. Conventionally, time and effort were required to reference the data and positioning of the object. (KEYENCE, 2023)
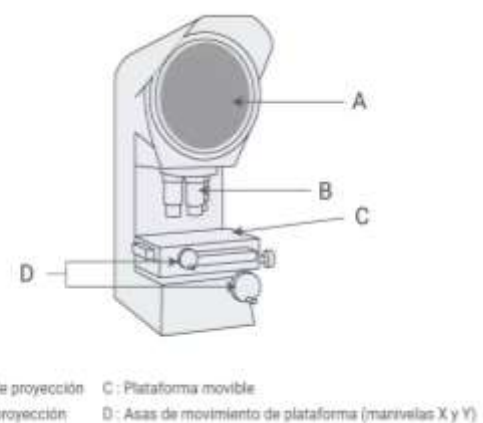

A : Pantalla de proyección   C : Plataforma movible
B : Lente de proyección   D : Asas de movimiento de plataforma (manivelas X y Y)

Figure 16 Parts of an optical comparator. (KEYENCE, 2023)

Finite Element Method

The finite element method (FEM), sometimes referred to as the finite element method (FEA), is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Simply put, a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain.

Boundary value problems are also sometimes referred to as field problems. The field is the domain of interest and most often represents a physical structure. The field variables are the dependent variables of interest governed by the differential equation. The boundary conditions are the specified values of the field. Variables (or related variables, such as derivatives) at the boundaries of the field.

Depending on the type of physical problem being analyzed, field variables may include physical displacement, temperature, heat flow and fluid velocity to name a few. The volume represents the domain of a boundary value problem to be solved. For simplicity, at this point, we assume a two-dimensional case with a single field variable (x, y) to be determined at each point P (x, y) such that a known governing equation (or equations) is satisfied exactly at each of those points.

The mathematical solution is obtained; that is, the solution is a closed-form algebraic expression of the independent variables. In practical problems, the domain may be geometrically complex as is often the governing equation and the probability of obtaining an exact closed-form solution is very low. Therefore, approximate solutions based on numerical techniques and digital computation are most often obtained in engineering analysis of complex problems.
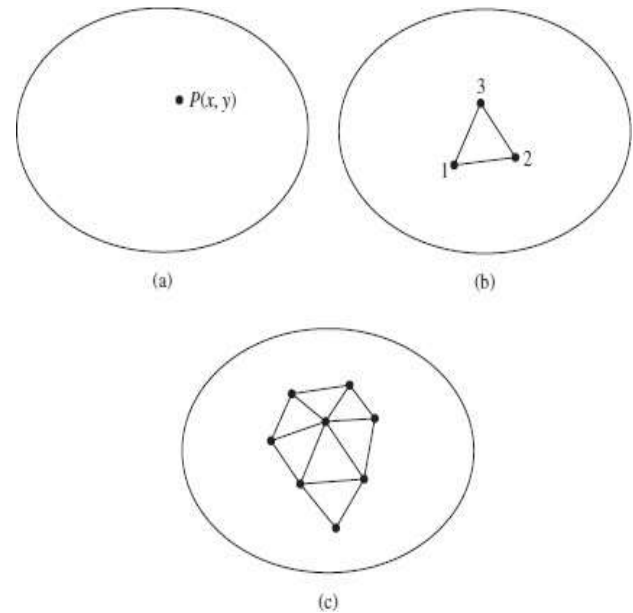
Figure 17 (a) A general two-dimensional domain of field variable (x, y)
(b) A three-node finite element defined in the domain.
(c) Additional elements showing a partial finite element mesh of the domain. (V.Hutton, 2004)

If the field variable values are computed only at the nodes, the field variable values computed at the nodes are used to approximate the values at non-nodal points (i.e., at the interior element) by interpolation of the nodal values. For the three-node triangle example, the nodes are all exterior and, at any other point within the element, the field variable is described by the approximate relationship:

$$\phi(x,y)=N_1(x,y)\phi_1+N_2(x,y)\phi_2+N_3(x,y)\phi_3 \quad (18)$$

Where ϕ_1, ϕ_2, and ϕ_3 are the values of the field variable at the nodes, and N1, N2, and N3 are the interpolation functions, also known as shape functions or mixture functions. In the finite element approach, the nodal values of the field variable are treated as unknown constants to be determined. The interpolation functions are usually polynomial forms of the independent variables, derived to satisfy certain conditions required at the nodes.

These conditions are discussed in detail in later chapters. The main point to note here is that the interpolation functions are predetermined and known functions of the independent variables; and these functions describe the variation of the field variable within the finite element. (V.Hutton, 2004)

Displacement

A typical element, e, is defined by nodes, i, j, m, etc., and straight line boundaries. Let the displacement u at any point within the element be approximated as a column vector, û:

$$u \approx \hat{u} = \sum_K N_k\, a_k^e = [N_i, N_{j,\dots}]\begin{Bmatrix} a_i \\ a_j \\ . \\ . \end{Bmatrix}^e = Na^e \quad (19)$$

Wherein the components of N are prescribed functions of position and ae represents a listing of nodal dislocations for a particular element.
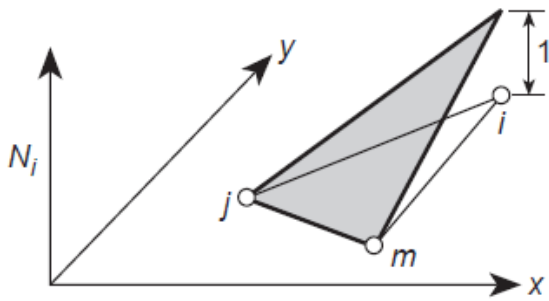

Figure 18 Form of the Ni function for an element.(O.C. Zienkiewicz, 2000)

In the case of air stress, for example, it represents the horizontal and vertical movements of a typical point within the element and the corresponding displacements of a node i.

$$u = \begin{Bmatrix} u(x,y) \\ v(x,y) \end{Bmatrix} \qquad a_i = \begin{Bmatrix} u_i \\ vi \end{Bmatrix} \qquad (20)$$

The functions Ni, Nj, Nm should be chosen such that appropriate nodal displacements are given when the coordinates of the corresponding nodes are inserted into the general equation.

$$N_i(x_i, y_i) = I \ (matriz\ de\ identidad) \qquad (21)$$

Meanwhile:
$$N_i(x_i, y_i) = N_i(x_m, y_m) = 0 \qquad (22)$$

If both displacement components are specified identically, then we can write and obtain Ni from the general equation, noting that Ni=1 at xi, yi but zero at other vertices.(O.C. Zienkiewicz, 2000)

Methodology to be developed

The type of nozzle to be used was determined, according to the existing printers in the machines laboratory of the prototyping area of the Tecnológico de Estudios Superiores de Valle de Bravo, taking into account as a reference the nozzle of a Stratasys 3D printer.

Figure 19 Stratasys 3D printer nozzle. (Own authorship)

The measurements of the nozzle were determined by metrology in order to start reverse engineering using the metrology technique.

Figure 20 Determination of the outer diameter of the nozzle
Own Authorship

Figure 21 Obtaining the general diameter of the nozzle
Own Authorship

Figure 22 Nozzle height determination
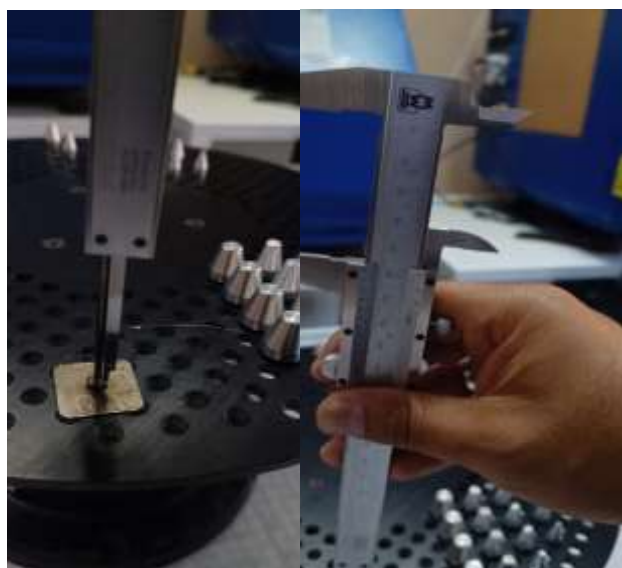*Own authorship*

Figure 23 Obtaining nozzle height (filament guide)
Own Authorship

We worked with documentary research to determine the flow and speed that will pass through the nozzle, according to the printing material, taking as a reference that waste plays a very important role for the development of this project.

Due to the fact that there are only two nozzles of this printer, it is being analyzed that the printing parameters are very weak and some factors such as the speed are preventing the material from having a correct flow.

At this stage, the metrology methodology and the use of an optical comparator are being used to determine the measurements and obtain a geometry that can be compared between both techniques.

Reverse Engineering application for nozzle modeling

Nozzle modeling in Solidworks Software

Once reverse engineering was applied to the nozzle, the modeling of the nozzle in solidworks software was started, using the conventional metrology technique.
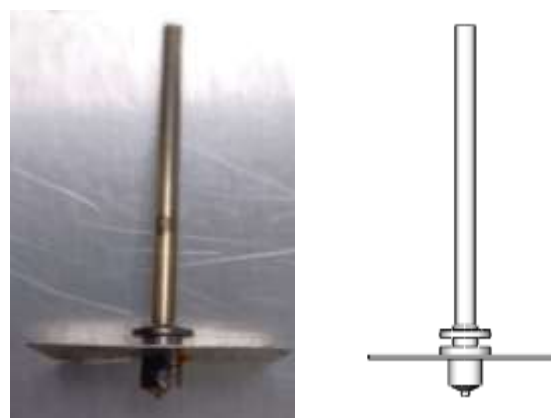
Figure 26 Stratasys machine nozzle modeling
Own Authorship

Determination of nozzle sizing, conical nozzle procurement.

Figure 27 Obtaining the conical part of the nozzle
Own Authorship
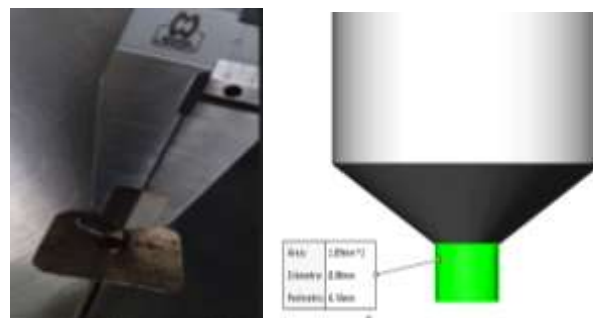
Figure 28 Obtaining the nozzle tip
Own Authorship

The nomenclature of the extruder was determined using a vernier, and the materials of which the nozzle is made were also analyzed.
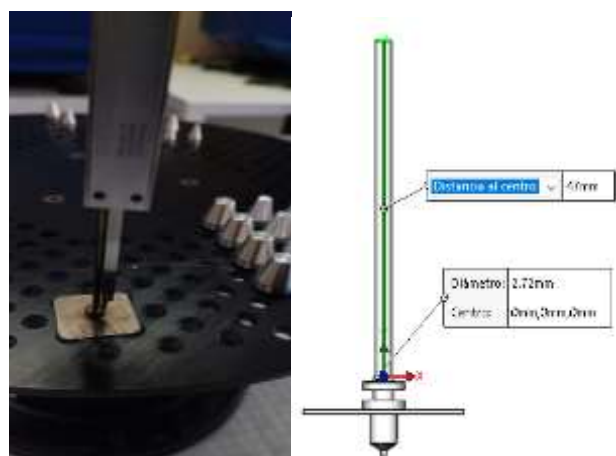
Figure 29 Determination of extruder height
Own Authorship

Determination of measurements between the two extruder supports for nozzle assembly.
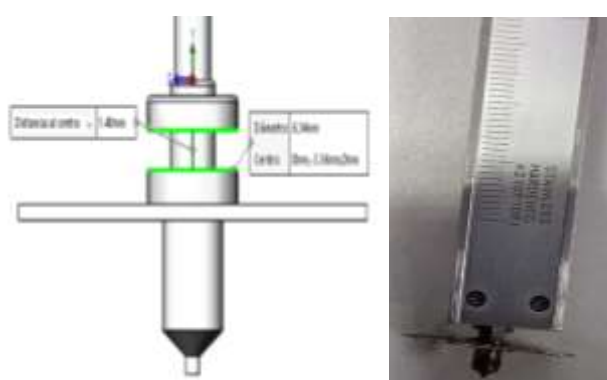

Figure 30 Determination of distance between extruder supports
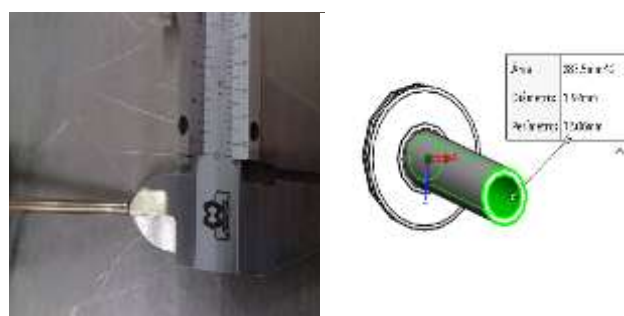*Own Authorship*

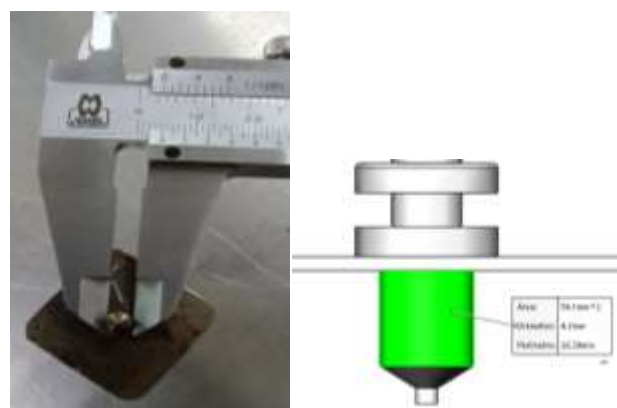**Figure 31** Obtaining the diameter of the extruder guide
Own Authorship

Figure 32 Determination of nozzle geometry
Own Authorship

Determination of geometries with optical comparator

The geometries of the nozzle were obtained using a Scarrett model 300 SERIES optical comparator, and the measurements obtained with conventional metrology and the optical comparator were compared, taking into account that there was a margin of error of 1% between the measurements with the optical comparator and those with conventional metrology instruments.

Figure 33 Obtaining geometries with optical comparator
Own Authorship

Figure 34 Obtaining nozzle geometries
Own Authorship

CORTEZ-SOLIS, Reynaldo, ARENAS-ISLAS, David, BETANZOS-CASTILLO, Francisco and FUENTES-CASTAÑEDA, Pilar. Design of a nozzle for Stratasys uPrint SE Plus 3D printer. Journal Industrial Engineering. 2023

Figure 35 Obtaining digital parameters
Own Authorship

Figure 36 2D design of nozzle/comparison with conventional metrology
Own Authorship

Modeling of the nozzle in Ansys Workbench software

By means of SpaceClaim in the Fluid Flow library of Ansys Workbench, once the metrology and reverse engineering methodology was applied. The measurements obtained by metrology were taken as references, and in comparison with the optical comparator the correct measurements of the nozzle were verified, by referencing each of the nozzle geometries in a physical manner as detailed below.
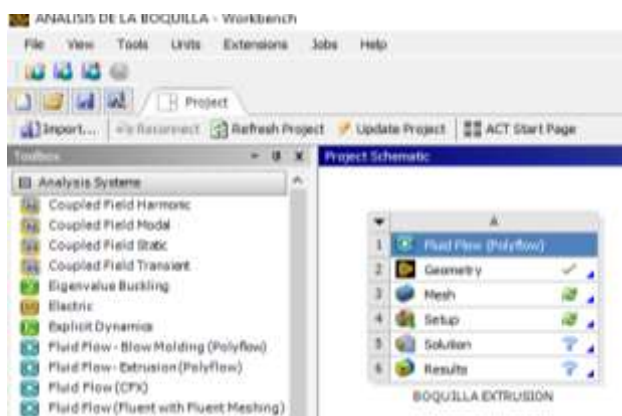
Figure 37 Interaction with Ansys Workbench-Fluid Flow
Own Authorship
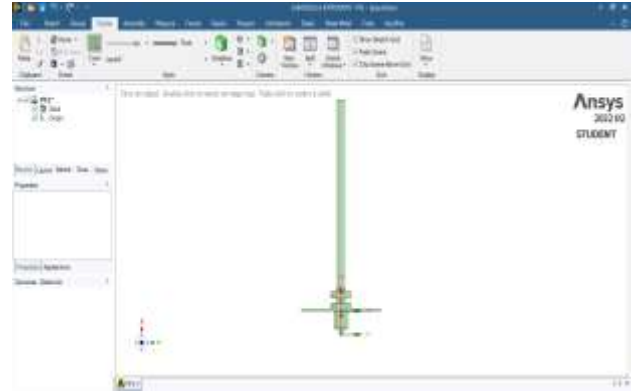
Figure 37 Ansys Workbench-SpaceClaim nozzle modeling
Own Authorship

Each of the angles were taken to verify the geometries of the nozzle and perform an analysis of each edge to apply the most appropriate material and perform a specific meshing, and finally perform an analysis by the Finite Element Method, this analysis will be to obtain the best results for a physical manufacture of the nozzle in the future.
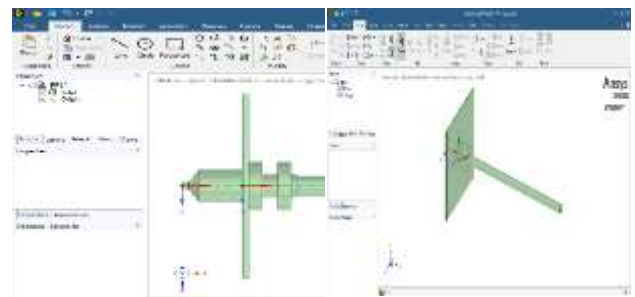
Figure 38 Trimetric and Top view of the nozzle
Own Authorship

Results

According to the results obtained, the 3% margin of error compared to conventional metrology with the use of optical technologies, a comparison was made and it was concluded that the use of this type of technology allows identifying more adequate geometries and with lower margins of error.

With the design in Ansys workbench, Spaceclim's CAD design library, it can be verified that with the 3D modeling 112746 nodes were obtained, 1 cm in size for each element, resulting in 57461 elements.
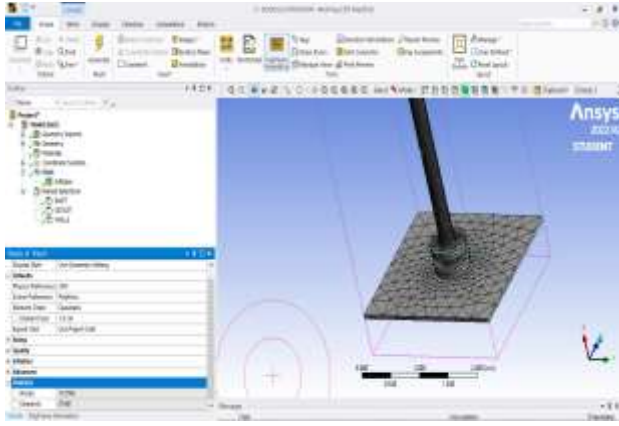
CORTEZ-SOLIS, Reynaldo, ARENAS-ISLAS, David, BETANZOS-CASTILLO, Francisco and FUENTES-CASTAÑEDA, Pilar. Design of a nozzle for Stratasys uPrint SE Plus 3D printer. Journal Industrial Engineering. 2023

Figure 39 Nodes and Meshing Elements
Own Authorship

Subsequently, the meshing in each nozzle space was verified to identify possible collisions or geometries that present a margin of error, for each of the steps.
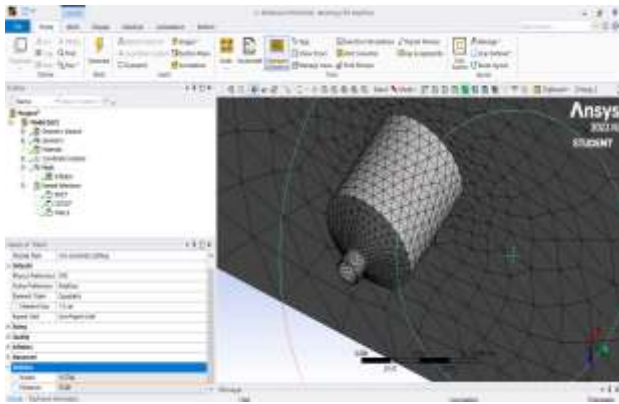

Figure 40 Verification of geometries and mesh elements
Own Authorship

Annexes

For the CAE section, the boundary conditions to be assigned to the element (nozzle) were taken as a reference, generating as fluid inputs. Equations (15), (16) and (17) referring to Newtonian and non-Newtonian fluids were used to determine the viscosity in the simulation, verifying the behavior of the material and the behavior of the nozzle.

The following parameters were taken into account in order to perform the simulation of fluid behavior, fluid velocity, displacement and to obtain a viscosity parameter.

Parameters with ABS impression material:

Density = 1030 kg/m³
Viscosity = 1.24 e-0.5
Nozzle Material: Aluminum

Mathematical Modeling:

Fluid flow

$$\tau = \eta\left(\frac{dv}{dy}\right) \qquad (15)$$

where:
τ=Shear stress.
η=Viscosity coefficient (Pa.s).
$\left(\frac{dv}{dy}\right)$ =Velocity or shear rate

Newtonian Fluids

$$\mu = \frac{\sigma}{\gamma} \qquad (16)$$

Non-Newtonian Fluids

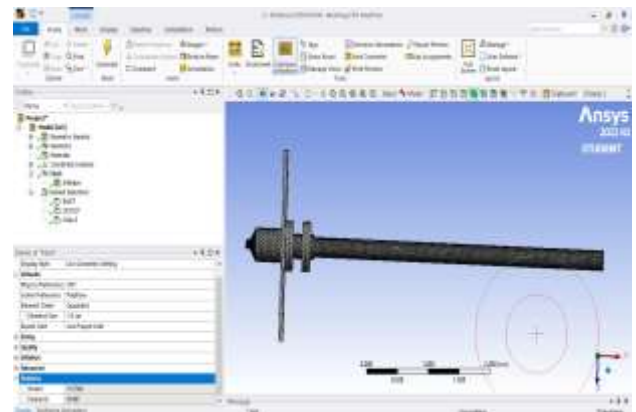$$\eta = \frac{\sigma(\Upsilon)}{\Upsilon} \qquad (17)$$

Figure 41 Assignment of input and output boundary conditions
Own Authorship

Once the inputs and outputs were identified with the behavioral parameters of the ABS material with a viscosity of 1.24 e-0.5 kg/(m s) and a flow density of 1030 kg/m³.

Subsequently it was moved for a results analysis to another Ansys Workbench library called Fluent to perform the material behavior through the Aluminum nozzle design as a results approach more with reality.

Figure 42 Analysis with inlet boundary conditions, oultet in Fluent
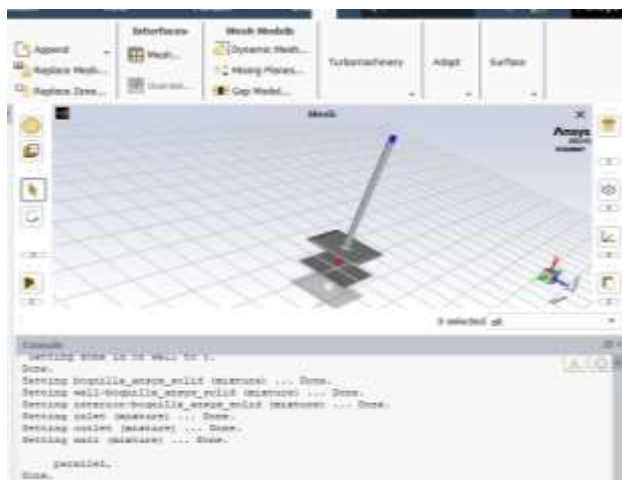*Own Authorship*

Figure 43 Verification of results and meshing in Fluent
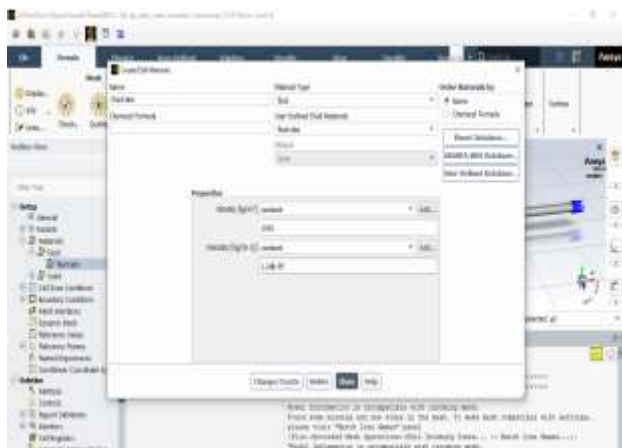*Author's own work*

Figure 44 Configuration of viscosity and density parameters
Own Authorship

Once the material parameters were configured in the Fluent software, a temperature of 300° C was determined for the extrusion material of the nozzle for the ABS material.

Obtaining the following results of viscosity and behavior of the material, as a non-Newtonian material.

With a velocity of 10.91 m/s as maximum level, in a plane of 1.653 e-02.
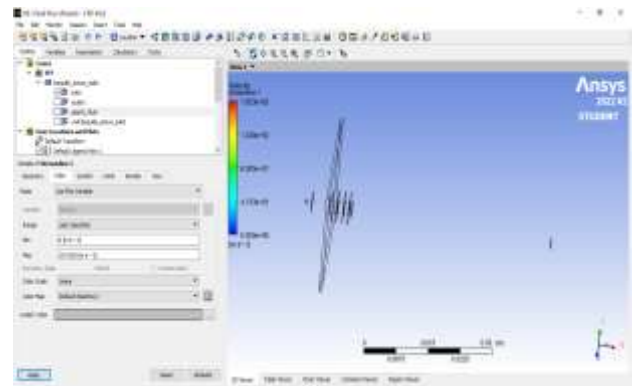
Figure 45 Velocity behavior
Own Authorship

As a result of a pressure of 3.201e+08 Pa maximum and a minimum of -3.592 e+07.
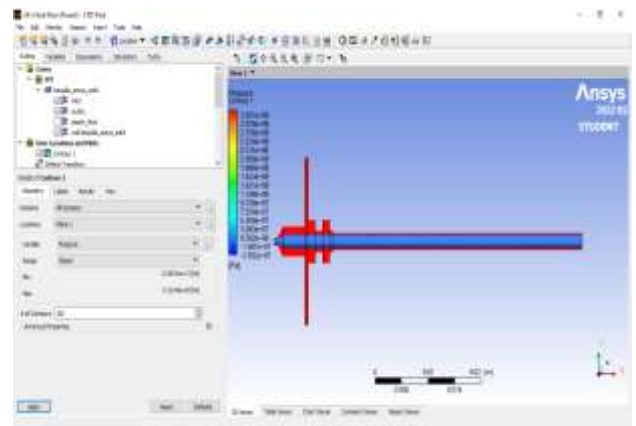

Figure 46 Material pressure analysis
Own Authorship

In the analysis it was determined how a parameter more turbulence in the nozzle of 8.262 e+02 maximum and 1.033 e+02 minimum, which could be observed that aluminum in this first analysis transfers heat more adequately throughout the nozzle in value of (m² s²).
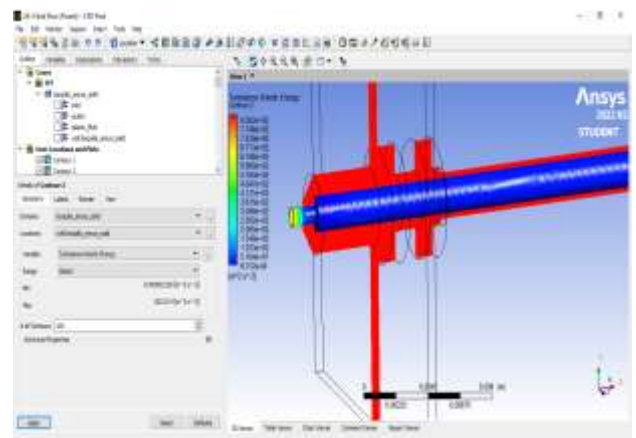

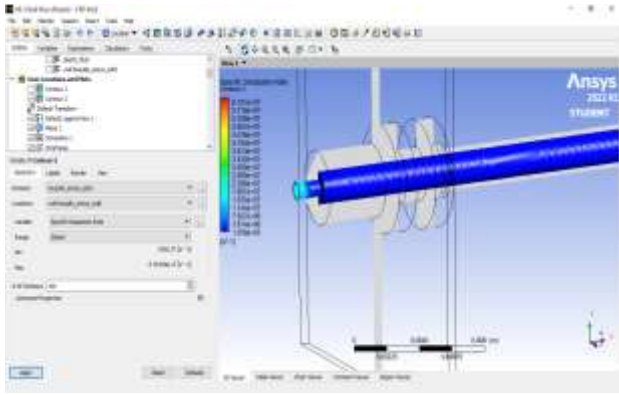**Figure 47** Maximum and minimum turbulence
Own Authorship

Figure 48 Dissipation rate
Own Authorship

Acknowledgement

Conclusions

The objective and main point of this project was the modeling and design of a 3D printer nozzle of the Stratasys brand, and as breakdown points application of the different metrology techniques and the use of optics technologies for obtaining the geometry of the nozzle.

It is determined that the application of reverse engineering in the use of reverse engineering technique and modeling analysis was performed, therefore, it was identified that the accuracy of obtaining geometries is more accurate with the use of optical comparator due to its shadow projection for small parts, and compared to the use of measuring instrument can obtain a geometry, but with a deviation or a margin of error of 3% between the two techniques.

The main objective is concluded because the Tecnológico does not have these spare parts and the acquisition of these nozzles have a discontinuity in the market by the manufacturer, with the design and modeling of this nozzle can be sent to manufacture new nozzles with the standard plans in the field of mechanical drawing.

With the Finite Element Analysis, it can be observed that the nozzle is viable to be manufactured and constructed in a physical way, and that it will be possible to reduce the waste of material according to the manufacturing selected by the institution, carrying out the pertinent modifications of the project.

Recommendations

As recommendations to perform more future simulations with more materials, as first analysis was performed with aluminum material for the nozzle, but it is proposed to perform analysis with brass to verify the flow behavior of ABS material and compare both materials to verify which is the most suitable.

As well as the analysis with other libraries and different meshing with different steps between each element of each of the 3D models of the nozzle, taking as reference other types of nozzles.

References

Ahmad, Z. (2006). *Principles of corrosion engineering and corrosion control.* Amsterdam: IChem; Elsevier.

Alex Mauricio Tipán-Suárez, C. M.-C.-M.-S. (202). Diseño Mecatrónico para la fabricación de una impresora 3D. *6*(3).

Costa, J. A. (2018). Tecnología para el prototipado rapido: Impresoras 3D. *3*(1).

GARCÍA, E. P. (2006, junio). *CIMAV repositorio.* CIMAV Repositorio: http://cimav.repositorioinstitucional.mx/jspui/handle/1004/606

Hernández, A. Y. (2021). *METODOLOGÍA DE DISEÑO MODULAR PARA LA REDUCCIÓN DE PARTES Y ANÁLISIS ESTRUCTURAL EN UNA CAJA DE BATERÍAS DE USO AUTOMOTRIZ.* Nuevo León Monterrey: UANL. http://eprints.uanl.mx/21613/1/1080314528.pdf

IMPRESORAS3D.COM. (2021, Julio 26). *Impresoras3D.Com EVERYTHING TO CREATE.* https://www.impresoras3d.com/guia-de-boquillas-para-impresoras-3d/

Iturriaga de la Fuente, G. (1999). *México Patente nº 2268902.*

Jersson Xavier León Medina, E. T. (2013). Diseño de un prototipo de impresora 3D que aplica la Técnica de Prototipado Rapido Mdelado Por Deposición Fundida. Colombia: Universidad Pedagógica y Tecnológica de Colombia.

KEYENCE. (2023, julio 20). *Conceptos Básicos de la Medición Dimensional y los Intrumentos de Medición (Fundamentos de Medición).* https://www.keyence.com.mx/ss/products/measure-sys/measurement-selection/type/projector.jsp

Leal Alanís, S. A. (2011, junio). *eprints.uanl.mx.* http://eprints.uanl.mx/2495/1/1080049438.pdf.

Ledo, I. E. (2011). Caracterización del Latón. *Metalurgica, 30*(1), 57-54.

Lozano, J. J. (2006). VANADIO: CONTAMINACIÓN, METABOLISMO Y GENOTOXICIDAD. *Internacional Contaminación Ambiental, 22*(4), 173-189.

Mayer, M. (n.d.). *3D Solved.* The 3D Printing Search Engine!: https://3dsolved.com/es/todo-sobre-boquillas-de-impresion-3d/

Mazzola, I. L. (2021). Ventajas, desventajas y perspectiva estudiantil de la tecnología del CAD/CAM en el proceso enseñanza-aprendizaje de la educación dental. *Revista Cubana de Investigaciones Biomédicas.*, 1-13.

O.C. Zienkiewicz, R. T. (2000). *The Finite Element Method.* Barcelona España: McGraw Hill. https://doi.org/ISBN-0750650494

Ortega, A. J. (n.d.). *Fabricación Digital: Introducción al modelado e impresión 3D.* España: Secretaria General Tecnica, Subdirección General de Documentaciones y Publicaciones.

Sheila, W., Bisson, C., y Duffy, A. P. (2012). Applying a behavioural and operational diagnostic typology of competitive intelligence practice: empirical evidence from the SME sector in Turkey. *Journal of Strategic Marketing, 20*(1), 19-33. https://doi.org/http://dx.doi.org/10.1080/0965254X.2011.628450

SIEMENS. (2023, 06 22). *Diseño Asistido por Ordenador (CAD).* Diseño Asistido por Ordenador (CAD): https://www.plm.automation.siemens.com/global/es/our-story/glossary/computer-aided-design-cad/12507

Song, Y., Rampley, C. P., & Chen, X. (2019). Application of bacterial whole-cell biosensors in health. In Y. Song, C. P. Rampley, & X. Chen, *Handbook of Cell Biosensors* (pp. 1-17). Springer Nature Switzerland AG.

Talens Oliag, P. (n.d.). Caracterización del comportamiento reológico de un alimento fluido plástico. . *Universidad Politecnica de Valencia*, 1.

V.Hutton, D. (2004). *Fundamental of Finite Element Analysis.* USA: McGraw-Hill. https://doi.org/0-07-239536-2

Woodbury, K. A. (2003). Inverse Engineering Handbook. *CRC PRESS, 1st Edition*, 480. https://doi.org/https://doi.org/10.1201/9781420041613

Zambrano-Herrera, W. (2020). REOLOGÍA DE POLÍMEROS. *Agrollania, 19*, 48. https://doi.org/ISSN: 2665-0053