Graduation Project Report
« Rapport du Projet De Fin D’Études Spécialité Mécanique ControlAutomatique »

<u>3D food cooking printer</u>

Under the supervision of: Dr. Mohamed Hedaya

Presented by: Amr ELSEBAI
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Jury

Frederic HEIM	***Responsible of master at ENSISA***
Dominique ADOLPHE	***Vice President, UFE***
Osama BADR	***Head, Mechanical Engineering Department, UFE***
Rania Al ANWAR	***Lecturer, Mechanical Engineering Department, UFE***

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Abstract:

The demand for 3D food printing (3DFP) increasing among the consumers due to the technologically driven modern world likely to transform food production by enhancing culinary ingenuity with digital capabilities. However, global 3D food printing is currently at the nascent stage but an important technology can be adopted worldwide with the booming global market demand for customized food.

3D food cooking printer is a machine designed to print food and targeted to cook it in the same time.

In this project, the researcher will design, implement and control a 3d food cooking printer and place a prototype. Also, the final product will be tested.

Project’s goals will be achieved by:

1. Make a conceptual description.

2. Design control system.

3. Make a load analysis on an initial design.

4. Choosing proper material.

5. Choosing proper components.

6. 3D design.

7. Programming the system.

8. Finally, testing the final product.

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The research is developed in seven chapters:

Chapter 1: This chapter will introduce the meaning and the functionality of a 3d printer of food, introducing the background of the project, history of the invention, a literature review to know what the previous researchers achieved and the objective of the research.

Chapter 2: This chapter will discuss the ways of working chosen after literature and comparison, which is the theoretical approach.

Chapter 3: This chapter will show and discuss the design of the injection mechanism and the load analysis to choose the best appropriate material, also the cooking methods
Which is the experimental approach.

Chapter 4: This chapter will show and explain the experiments done with their results to extract the equation needed for cooking, also the calculations done to choose the more suitable specs of motor.

Chapter 5: This chapter will present the programming language.

Chapter 6: This chapter will show the prototype.

Chapter 7: This chapter will summarize all the ideas behind the building and controlling a 3d food cooking printer and the Recommendations.

1 Chapter1 Introduction

1.1 Background:

There is an increasing market need for customized food products, most of which are currently designed and made by specially trained artisans. The cost for such a limited number of pieces is relatively high. Therefore, Scientists believed that it is necessary to invent a machine that is less expensive, faster in performance and has the capacity to assembling atoms of matter to create any object that could possibly exist in the universe for example prepare nutritious meals for every personalized need. It was thus obvious that if humanity had access to a machine that could create anything, it would chiefly be used to make food as shown in (Figure 1).

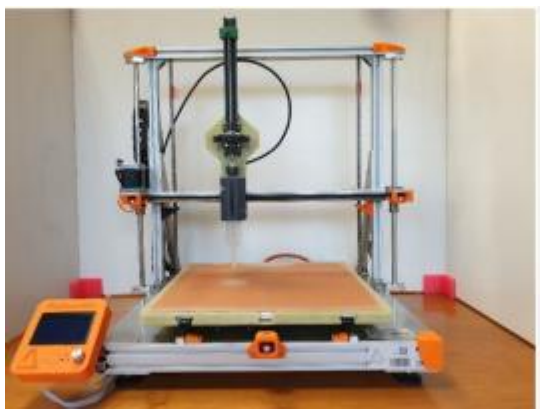


Figure 1: 3d food printing

1.2 History:

3D printing is a revolutionary technique, which has brought rapid advancement in prototyping, conceptual designs, performing feasibility analysis, and performed on prototypes (**Portanguen et al., 2019)**. The board-spectrum applications of 3D printing ranges from different sectors like automobile, prototyping machine design, biomechanics, pharmaceutical, artwork, fashion technology, architecture, and food processing. Combining 3DP and digital gastronomy techniques can digitally visualize food manipulation, therefore creating a new space for novel food fabrication at affordable price. As a result, a customized food design in a form of digital 3D model will be directly transformed to a finished product in a layered structure.

3D food printing (3DFP) is a latest technique to produce highly customized and personalized three-dimensional shape of food products as shown in (Figure 2). The demand for 3D food printing (3DFP) increasing among the consumers due to the technologically driven modern world likely to transform food production by enhancing culinary ingenuity with digital capabilities. However, global 3D food printing is currently at the nascent stage but an important technology can be adopted worldwide with the booming global market demand for customized food **(Jayaprakash et al., 2020; Ramachandraiah 2021)**. Three-dimensional (3D) food printing, also known as Food Layered Manufacture (**Wegrzyn et al., 2012**), can be one of potential alternatives to bridge this gap. It aims to produce 3D custom-designed food objects in a layer-by-layer manner, without object-specific tooling, molding, or human intervention. Thus, this technology can increase production efficiency and reduce manufacturing cost for customized food products fabrication.

Figure 2: old mold for printing food

1.3 Literature review:

There is 3 types of 3d printing presented in literature.

The 3 types of 3d printing:

First one is the 3d printing of food
Second one is the 3d printing of ceramics
And finally the 3d printing of dentistry.

They are all related with the same methods of printing.

- **Brief on 3d printing of ceramics:**

In general, ceramic components are created into shapes that are required using traditional technologies such as injection molding, die pressing, tape casting, and gel casting starting from a mixture of powder with or without binders and other additives. These ceramic forming methods have drawbacks such as lengthy processing times and high costs Figure 3.

As molding is typically required in these processes, it is impossible to construct structures with extremely complicated geometries and interconnected holes.

Due to their exceptional hardness and fragility, ceramic components are notoriously difficult to machine. In addition to the intense wear that the cutting tools are subject to, ceramic parts may also develop flaws like cracking, and it can be challenging to maintain accurate dimensions and acceptable surface quality.

A group of cutting-edge manufacturing techniques known as 3D printing are used to create real items from 3D CAD models in a discrete, line-by-line, layer-by-layer, or additive way.

3d printing of ceramics is one of the most important and helpful in order to fabricate complex shapes of ceramics because it was a challenge without 3d printing.

It is challenging to create highly complicated and exact structures using conventional fabrication techniques like casting and machining. However, 3D printing is a new manufacturing philosophy that makes this possible **(Chin et al., 2019)**

The use of 3D printing in the production of ceramic components as shown in Figure 4 opens up a whole new range of solutions for the issues and difficulties stated above.

Figure 3: 3d printing ceramics

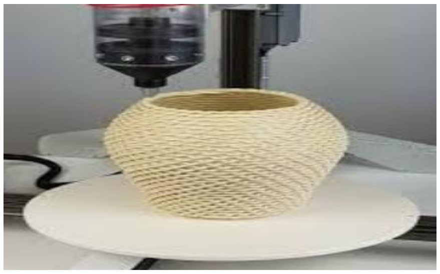


Figure 4:3d printing of ceramics

- **Brief on 3d printing of dentistry:**

Engineering processes can benefit from 3D printing, a lot of people utilize 3D printing. When it comes to dentistry complete dentures and implant teeth are more accessible due to their quick fabrication, high level of precision, and ability to be personalized.

The use of 3D printing in dentistry can also help to streamline the difficult workflow involved in creating dental appliances as shown in (Figure 5) and offer patients more individualized, more affordable treatments.

For instance, the restoration was often made by milling until 3D printing technology became widely used. Currently, 3D-printed restorations have demonstrated a number of benefits. According to several research, 3D printing restorations have much smaller edge and internal gap values than milling restorations (**Dawood et al., 2015**).

The CAD data can be quickly accepted by 3D printing technology. Additionally, it can quickly produce fresh samples, complex shape goods, molds, and models in addition to single and small-batch parts. Numerous benefits include excellent material utilization, significant cost gains, and the ability to produce specific size items as needed. It still has a number of drawbacks, though, including expensive processing and material costs and time-consuming post processing.

Figure 5: 3d printing dentistry

- **Finally the main subject 3d printing of food:**

3D food printing technology is a digitalized technology to produce 3D structure of food construct using pre-designed shape which is modeled using a software or image acquisition hardware, i.e., through a 3D scanner **(Lee et al., 2019a)**. This technology is also called additive manufacturing or rapid prototyping or food layered manufacture (FLM) that can fabricate customized food products **(Ngo et al., 2018).** The developed 3D food product is formed by several layers placed one above the other without any human intervention (Figure 6) **(Xu et al., 2020)**. Several technical challenges exist in relation to the production of 3DFP product. Many researchers are worked on the formulation which is the most complex aspect of producing 3D food construct. Another challenge is to ensure higher production and reduce manufacturing costs for mass customization in food fabrication **(Magaya 2017)**. To overcome such challenges, the different formulation technique was introduced to the development of 3D printing materials in the market to provide different food products with different shapes, colors, and favors at low cost **(Lee et al., 2019 b)**. Since the last 10 years, 3D food printing is growing and different food printing techniques have been developed: cold or hot-melt extrusion, selective laser sintering, inkjet printing and fused deposition modeling (Gholamipour-Shirazi, Kamlow, Norton, & Mills, 2020).

Figure 6: 3d printing food

1.4 Objective:

A number of articles and papers pertaining to food printing have been published over the past few years. Most of them are focused on fabricated novel food items. Recently, some researchers started investigating fundamental-level issues in food printing, such as converting ingredients into tasty products for healthy and environmental reasons. However, such information is scattered in various publications with different technical focuses. **The objective of this work is to** gather, analyze, categorize, and summarize information to create a machine which be able to print and cook food in the same time.

2 Chapter 2 Theoretical approach:

All the methods have the same objective to print but with different manner and end with the same way which is the post processing.

So what we can develop is to cancel or delete the final step which is the post processing.

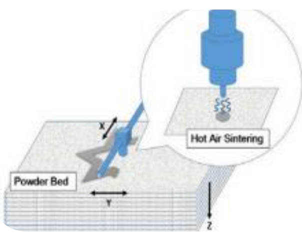
Adding a new method, a new idea which is printing and cooking in the same time.

Methods of 3d printing:

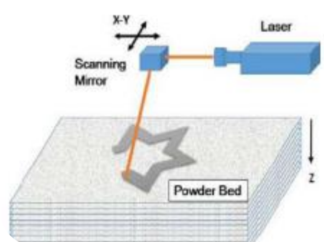
- Selective Sintering technology :

To create complicated shapes, powders can be selectively sintered. A sintering source (hot air or laser) (Figure 7) will move along the X and Y axes after a layer of fresh powder has been applied to fuse the powder particles so they may bind together and form a solid layer.

The fused surface is repeatedly covered with a fresh layer of material particles in this manner until a 3D item is complete.



a) selective hot air sintering



b) selective laser sintering

Figure 7: Selective Sintering

• Hot melt extrusion :

FDM, or hot-melt extrusion, as shown in Figure 8 is another name for this process.
Earliest explanation can be found in Crump's work (Crump et al., 1991).A moveable FDM head is used to extrude melted semi-solid material, which is then deposited onto a substrate. The substance is heated just slightly beyond its melting point, causing it to virtually instantly solidify after extrusion and bond to the preceding layers.

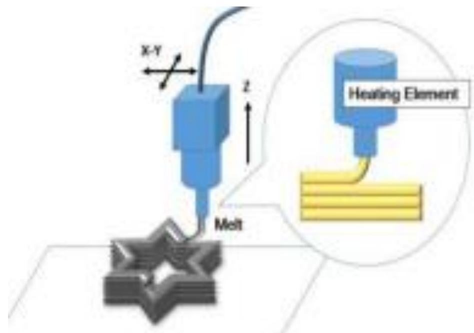


Figure 8: Hot melt extrusion FDM

• Binder jetting :

Each powder layer is equally spread across the fabrication platform in the typical binder jetting method, and liquid binder sprays to bind two successive powder layers (Figure 9).

In order to reduce the disruption produced by the dispensing of the binder, the powder material is typically stabilized using water mist.

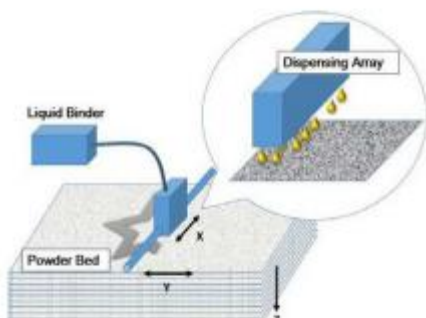


Figure 9: Powder Bed Binder Jetting

- Inkjet printing :

Inkjet food printing uses a syringe-type printer to discharge stream or droplets in a drop-on-demand manner. Layer structures are used to generate 3D edible food products like cookies, cakes, and pastries. This includes pre-patterning food at various processing stages.

The inkjet printing is the most suitable way that it can be used to print the food and cook it in the same time (Figure 10).
Why it’s suitable, because the inkjet printing is the only method that didn’t have a way to sinter

(with laser or hot air) or cooking the dough or the ingredients like the other methods.
Also because all of the other ways will be more difficult and unsuitable with the way of cooking.

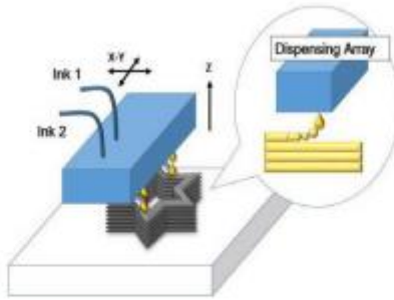


Figure 10: inkjet printing

This is an inspired photo to start the design of the injection mechanism of the dough (Figure 11).

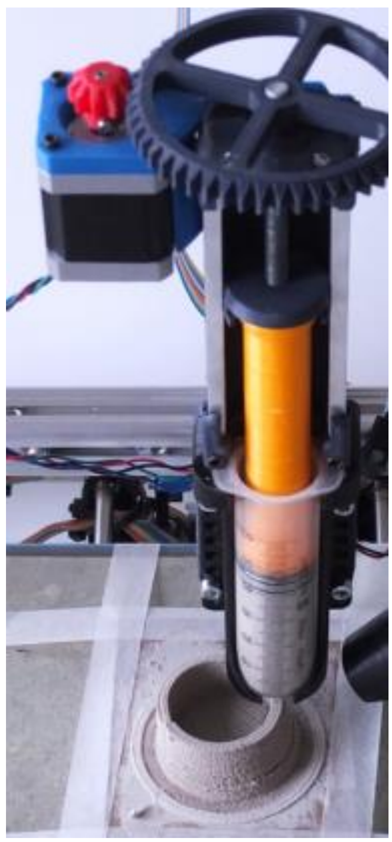


Figure 11: inspired design

Technology for 3D Food Printing Using Extrusion:

In this newly developed method, materials that are soft or slurry-like are placed in an airless syringe or cylinder and forced to extrude through the nozzle tip on the printer bed. Initially, this method was employed for modifying the food structures and was known as fused deposition modelling (FDM).

Three more mechanisms are used in extrusion-based 3D printing:

- Screw-based extrusion.
- Syringe-based extrusion.
- Air pressure-based extrusion.

I. Screw-based extrusion:

The appropriate ingredients are mixed individually and fed into the cartridge in the screw-based extrusion process.
Materials are then transported with the aid of a screw tube and passed through the nozzle tip as shown in Figure 12.
Due to insufficient bonding between the layers of the 3D structure, gel-like materials with high mechanical strength and high viscosity are not ideal for 3D printing technology.

As a result, the printed material has compression, distortion, and lower resolution.

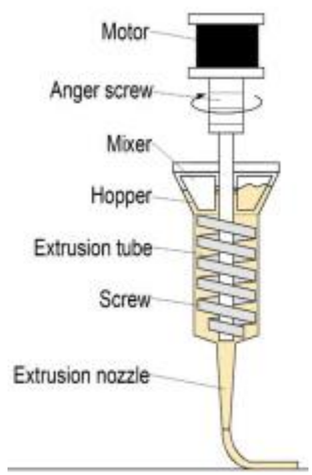


Figure 12: Screw-based extrusion

II. Syringe-based extrusion:

Printable materials are deposited in a syringe tube with one plunger inside during syringe-based extrusion as shown in Figure 13.
The plunger is connected to the stepper motor, which aids in producing a linear motion for the plunger.
The printable material is prompted to pass through the nozzle tip by a step motor.

Furthermore, this kind of printer is appropriate for printing on semi-solid materials like chocolate and dough.

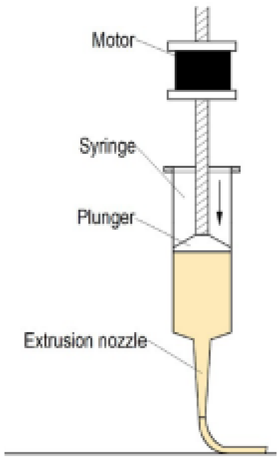


Figure 13: Syringe-based extrusion

III. Air pressure-based extrusion:

In the air pressure-based extrusion procedure (Figure 14), printed materials are kept inside the cartridge tube while air pressure is created by a compressor.
Compressed air is used to forcefully push the printed materials through the nozzle tip onto the printer bed.

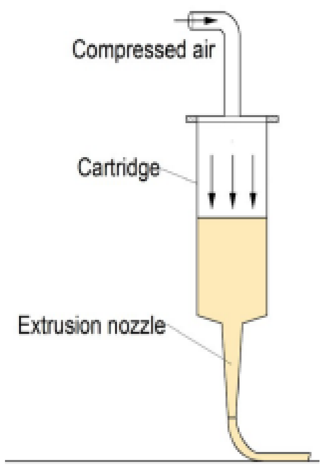


Figure 14: Air pressure-based extrusion

The more appropriate mechanism is the syringe based extrusion.
Why the syringe based extrusion, because the screw based extrusion with gel-like materials with high mechanical strength and high viscosity are not ideal for 3D printing technology, so it will be the same for the dough because it has a high viscosity.
Also for the air pressure based extrusion it will not be suitable because the pushing force of the compressed air can be weak for the dough.

Finally the printer with a syringe based extrusion is appropriate for printing on semi-solid materials like chocolate and dough.

3 Chapter 3: Experimental approach

This chapter will discuss the steps involved in creating the design of the injection mechanism: System used in this project. First,create an initial design with close dimensions to make a load study easier, second conduct a load study to help to select the best components, third make a final design that matches the selected components and calculated loads.

3.1 Design:

The design have to be designed on solid works, then printed and finally assembled on the 3d printer other part.
The design of the injection mechanism was based firstly on the dimension of the syringe (Figure 15) that will be used, the syringe will be bought from the market but the piston will not be used, it will be designed and printed like the other part of the injection mechanism as mentioned because the piston have other critical uses as to fix the power screw inside the piston using the nut of the power screw attached on the top (it will be shown and clearly explained in the Components of the injection mechanism piston part).

Figure 15: syringe design

Components of the injection mechanism:

The injection mechanism is constituted from 8 parts, each part will be explained and exposed with a photo.

First part: holder

Why it's named holder as shown in (Figure 16), because this part attach the main body to the 3d printer on the X axis.

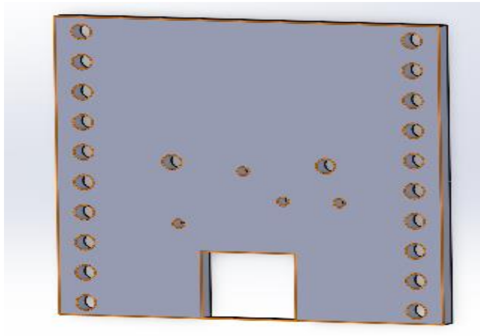


Figure 16: Holder

Second part: the main body

The main body is the part which the syringe and the rest of the injection mechanism will be fixed on (Figure 17).

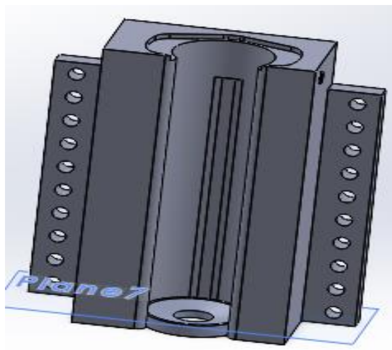


Figure 17: Main body

Third part: the PVC tube

This tube is no designed it's bought and adjusted to the needed dimensions and form, it's used to maintain the piston in his movement (up and down) and to help to fix the motor on the top, the inner diameter of this tube is 32mm and the head of the piston outer diameter is 31.5mm (Figure 18).

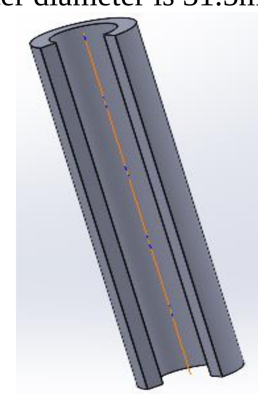


Figure 18: PVC tube

Fourth part: the flange

The flange is a part used to fix the tube on the top of the main body.
The inner diameter of the flange is the same of the outer diameter of the tube which is 50mm (Figure 19).

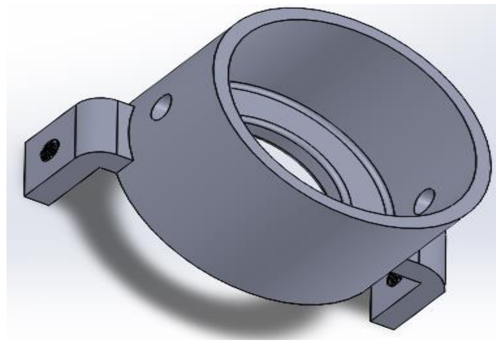


Figure 19: flange

Fifth part: the piston

Fig. 20.a: piston top Fig. 20.b: bottom piston Fig. 20.c: real piston and seal

The first photo is designed to hold the nut of the power screw because the power screw will be inside the piston.
The second photo, the bottom of the piston is designed like the real piston to hold the black part which is the seal (Figure 20 a, b and c).

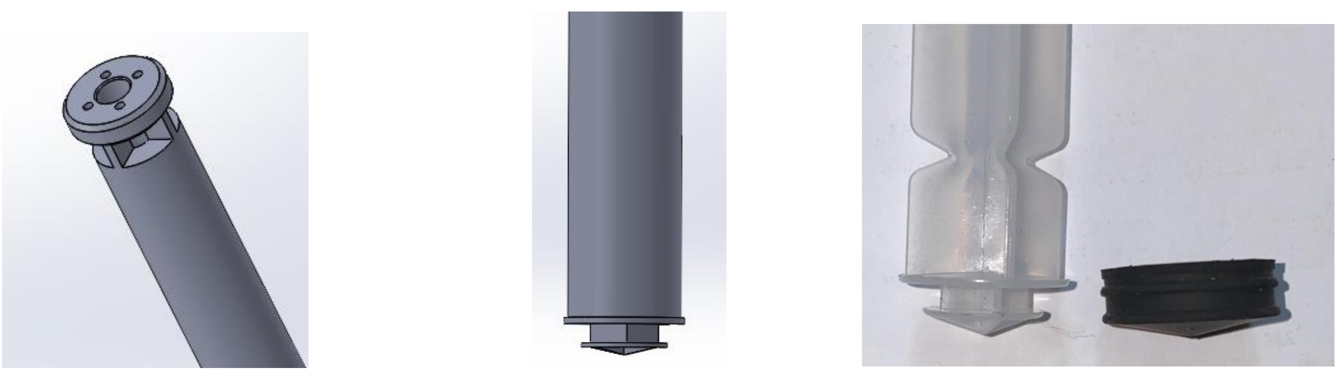


Figure 20: Piston

Sixth part: the motor holder

The motor holder is part with a bottom side to be attached on the tube and the top side is the holder of the motor as shown in (Figure 21).

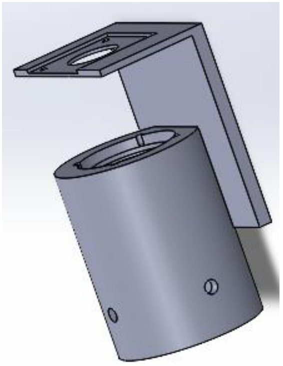


Figure 21: Motor Holder

Seventh parts: the power screw, the nut, the coupler:

The nut will be fixed on the top of the piston to ensure that the piston will go up and down without turn. The power screw (Figure 22) will be fixed on the coupler which will be fixed on the motor to turn.

Figure 22: power screw, nut and coupler

Finally: the motor

The motor chosen is a Nema 17, the most common and affordable in the market.
Of course based on calculations in the chapter of calculations (Figure 23).

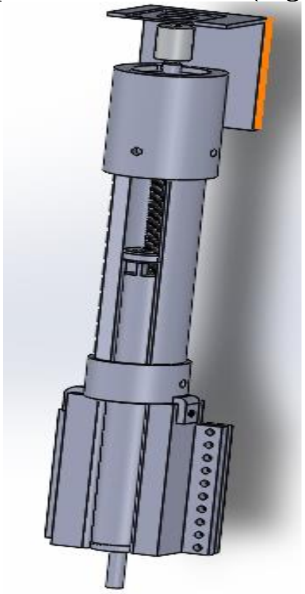


Figure 23: Injection mechanism assembled photo

3.2 Cooking methods:

There is two methods to choose one between them and two ways to utilize for cooking.
First way of cooking:

- **First method:** Cooking by using micro wave:

How the micro wave cook the dough:

The microwave (Figure 24) work by using electromagnetic radiation (micro wave radiation).
Type of radiation: microwave radiation.
Frequency: 2.450 Megahertz (MHz).
Magnetron is the device that generates the microwaves (Figure 25).

Briefly the microwave contain a magnetron which generate radiation which is the microwave radiation.
Normally to make the radiation move around the food we have to put 2 metals to make the radiation bounce between them (the 2 metals).

After the radiation is created the food have the move under those radiation to be absorbed.
When the microwaves are absorbed it cause the molecule to vibrate and generate heat (what cooks the food).

In the microwaves there is a table which turn to rotate the food to ensure that the food is cooked.

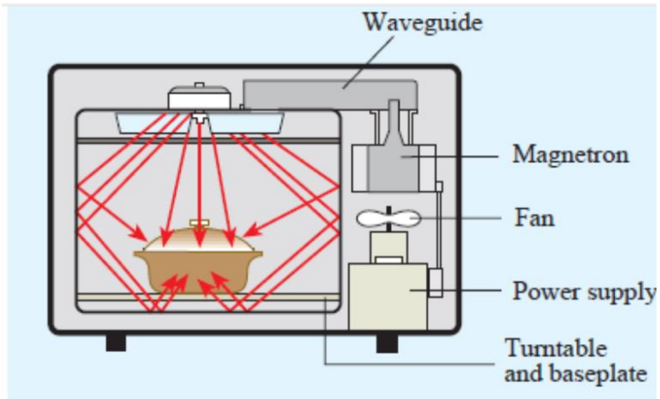


Figure 24: microwave with movement of radiation

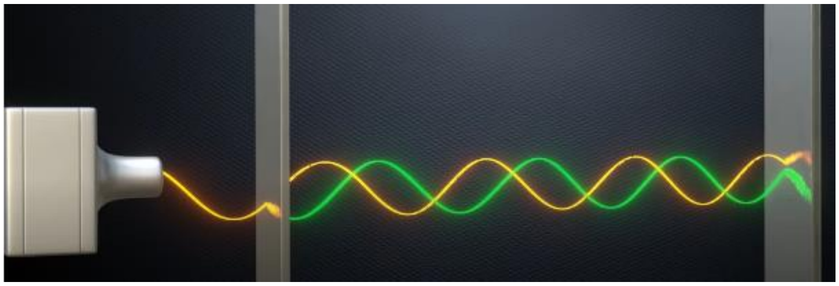


Figure 25: magnetron with movement of radiation

The way that it can be added on the 3d printer:

Fig. 26.a: magnetron with u metal assembled Fig. 26.b: magnetron Fig. 26.c: magnetron on hand

Fig. 26.a: small part of metal attached to the magnetron to generate radiation, designed and constructed to be small to pass on top of the lines of dough to cook the dough using the microwave radiation.

Fig. 26.b: magnetron

Fig. 26.c: magnetron on hand to see how big it is.

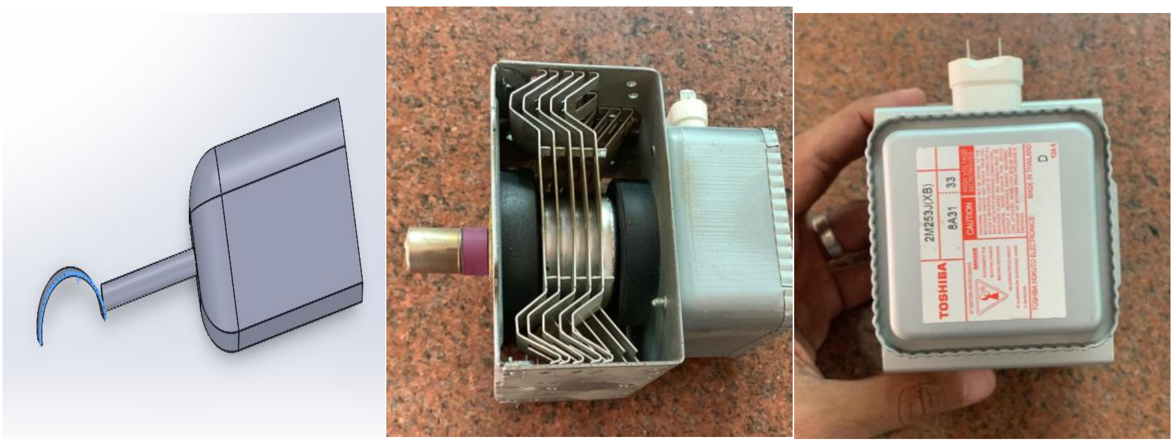


Figure 26: Magnetron

This is the shape of how it can be added and the magnetron have to be fixed on this shape and this is the main problem that we met that it will be so huge.
After designed this shape on solid works and constructed it from metal, the shape was planned to be fixed next to the syringe to move with the syringe on the top of each part of the dough printed and this is what compensate the turning table, also it will move **with the magnetron fixed on it,** to cook the dough on the same time of printing.

After searching for the magnetron, it will be difficult to add the magnetron fixed on the u shape
Because of its huge dimensions it will not be suitable for our small prototype.
As a concept it can be used on huge factories to cook on the same time of printing.

- **Second method:** Cooking by using the heated gun:

How the heated gun will cook the dough:
A lot of experiences was done to see if the heated gun was suitable to be used as a cooking way to cook the dough in the same time of printing.
The points that it has to be exanimated about the heated gun to be suitable with the dough:

- Power of the heated gun
- Degree of temperature
- How much Liter per second of heated air

After many researches of all the heated gun in the market comparing them together to have the best one with varieties in the temperature and the flow to have a lot of options to guarantee the cooking of the dough.
In the most famous market of heated gun in Egypt sharea al gomhoreya at Ramsis, the best heated gun (Figure 27) was bought.

Figure 27: heat gun

Power: 2000 watt
Degree of temperature: there is 9 degree (stages) of temperature.
#comment about the power tool specification:
It was written that there is 3 stages only but there is 9 stages.
In the power tool specification:

- At stage 1 temperature was 50 degree C
- At stage 2 temperature was from 50 to 600 degree C
- At stage 3 temperature was from 50 to 600 degree C

.
How much liter per second of heated air: there is 3 (stages) of air flow.

- At stage 1: 350 l/min
- At stage 2: 350 l/min
- At stage 3: 500 l/min

So the result was not enough and clear for the degree of temperature at each stage.
Using the temperature measure sensor (Avometer), at each stage of the 9 was measured the temperature.
Each stage from the 9 was measured one time on stage 2 of air flow (350 l/min) and the second time on stage 3 of air flow (500 l/min).
The results are in the section of results.

Tableau 1: power tool specification (heat gun)

Hot air gun		**CT19007**
Power tool code	[220-230 V ~50/60 Hz]	-
Rated power at voltage (stage 1 / 2 / 3)	220-230 V [W]	150 / 150-1900 / 250-2000
Amperage at voltage	220-230 V [A]	8.6
Temperature at voltage (stage 1 / 2 / 3)	220-230 V [°C]	50 / 50-600 / 50-600
Air flow (stage 1 / 2 / 3)	[l/min]	350 / 350 / 500
Weight	[kg] ; [lb]	0,8 ; 1.76
Safety class		回/II
Sound pressure	[dB(A)]	85
Acoustic power	[dB(A)]	104
Weighted vibration	[m/s^2]	8,2

The heat gun will not be used directly on the surface of the dough because it will also be so heavy like the magnetron.
So the way that it will be used by attach it on the top of the frame of the 3d printer using the holder of the filament of a normal 3d printer.
Like this:

After attaching the heat gun on the top of the frame using the holder as shown in (Figure 28 a and b) of the filament, a tube or jet which support high temperature will be used as an extension, it will be added from the head of the heat gun to the head of the syringe (nozzle) to be next to the nozzle and move in the same time and same way to cook the food in the same time of printing (Figure 29).

Figure 28: Holder

Fig. 28.a: holder

Fig. 28.b: heat gun attached on the holder

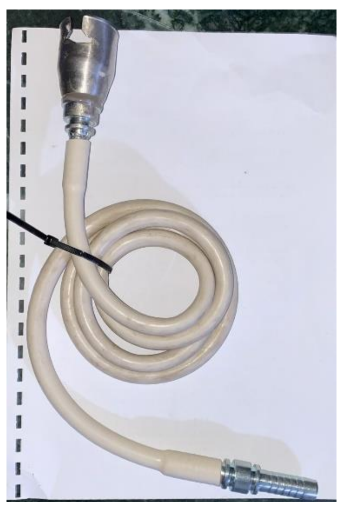


Figure 29: Tube extension

The top head is the one which will be attached to the heat gun head, the head at the bottom will be fixed next to the nozzle of the syringe.

Second way of cooking:

The second way of cooking is the heated bed (Figure 30) of the 3d printer.
It will be used as an added way to help in the cooking of the dough.
The max temperature of the heated bed is 110°c
It can’t be maintained on 110°c because it will burn the dough or over cook at the bottom.

So the temperature will vary depending on experiment and the best matching between the Heated bed and the dough.

So finally the aim of the heated bed is just to help in cooking, just assisting not the main way of cooking.

Figure 30: Heated bed

The heat gun and the heated bed will be used to cook the dough in the same time of printing. All the power tool specifications are available and suitable because it can vary depending on the exact temperature needed to cook the dough.
The exact temperature needed to cook the dough have to be calculated cause there is no reference to know how much of hot air need the dough to be cooked per cm or mm.
There is various in temperature and air flow so it will be helpful to adjust it with the perfect needs of the dough.

3.2 Material:

In order to prevent any deformation during movement, the material utilized must be of a high degree of stiffness.
After searching for materials that can be used in printing, it was found that there are two materialsused:

- PLA (polylactic acid)

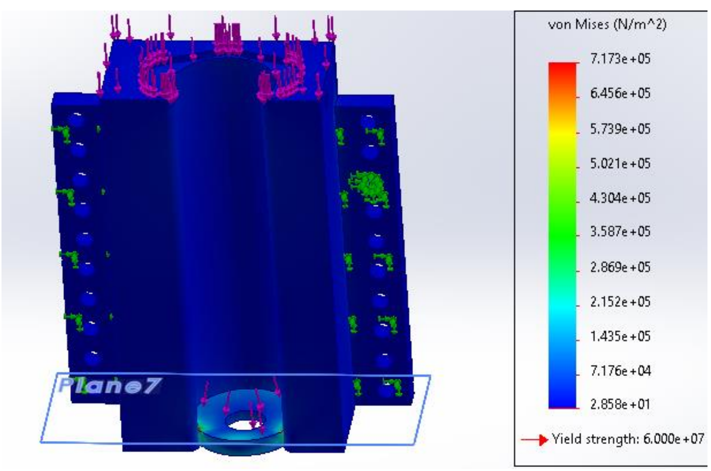
-ABS (acrylonitrile butadiene styrene)

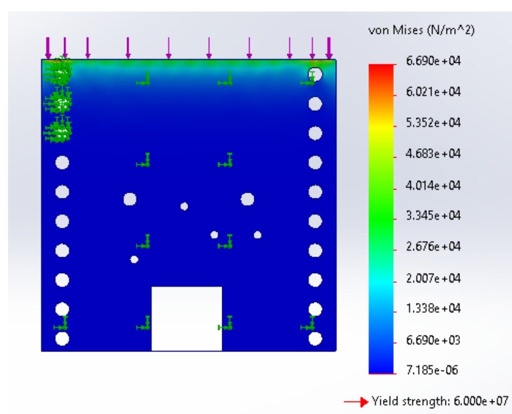
Tableau 2: Difference between ABS and PLA

properties	ABS	PLA
yield stress	50 MPA	60 MPA
Elongation	3.5 – 50%	6%
Flexural Modulus	2.1 – 7.6 GPA	4 GPA
Density	1.0 – 1.4 g/cm3	1.3 g/cm3
Performance	- Higher impact resistance. -Higher flexibility. -Higher temperature resistance (Tg).	-Higher strength. -Higher rigidity. -Stronger layer bond.

As shown in table the difference properties between the two materials, thematerial (PLA) is selected for 3D printing.

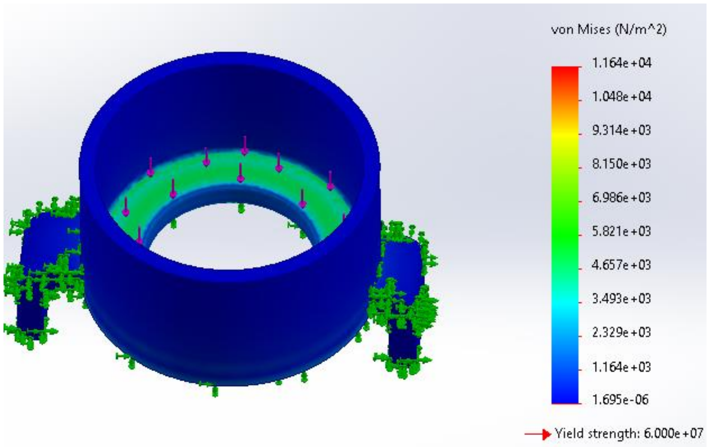
3.3 Load analysis:

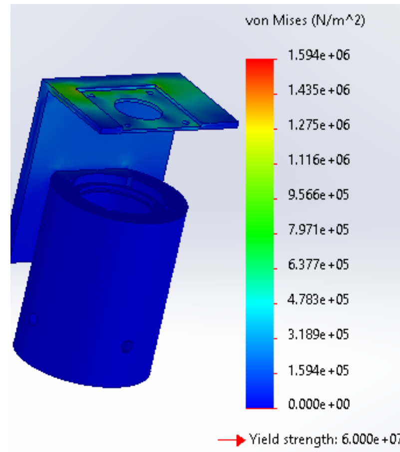




(b) Holder 1

(a) Main body





(d) Motor

holder 1

(c) Flange

Figure 31: stress analysis

The figures (31 a, b, c and d) shown above show the stress analysis of each part of the injection mechanism, the force applied in them are:

- Main body: 21 N which is the weight of the other part which will be fixed at the top of the main body as shown in figure 23, also the weight of the motor is added and the force needed to push the dough.
- Holder : same weight but the weight of main body is also added so it will be 21+0.88=21.88N
- Flange: 21N same weight of the main body.
- Motor holder: 3N only the weight of the motor

The maximum stress is on the main body which is $7.173 \times 10^5 \, {}^{\mathrm{N}}/{}_{\mathrm{m}^2} = 717300 \, {}^{\mathrm{N}}/{}_{\mathrm{m}^2} = 717300 \times 10^{-5} = 0.7173$ MPa so it's too low in comparison with the yield strength which is 60 MPa.
So it's an acceptable value (Figure 32).

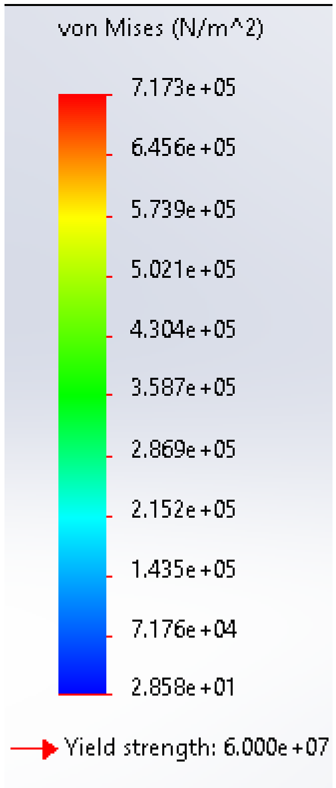


Figure 32: stress analysis result

4 Chapter 4 results:

Results of the experiment and calculations which is done to choose the most suitable material and product to be used, also to choose the ways of working.

4.1 Motor of the extruder:

Calculation for the force needed to push the piston of the motor:

An experiment was done to calculate the force needed.
The dough was putted in the syringe with the same recipe to see how much kg has to be putted on the piston then multiply by 9.8 to have the force.
A huge cup of water of 1150g was putted on the piston, the piston started to move with this weight which is 1150g.
So force $F = (1150 \times 10^{-3}) \times 9.8 = 1.15 \times 9.8 = 11.27$ N
To calculate the torque there is a formula:

$$F \times P = T \times \theta \times \eta$$

Equation 1: mechanical power equation

$F \rightarrow$ Force
$P \rightarrow$ Pitch of the power screw
$T \rightarrow$ Torque
$\theta \rightarrow$ angle of rotation
$\eta \rightarrow$ efficience

Force = 11.27 N
Pitch = 2mm$\times 10^{-3} = 0.002$m
Torque =??
Angle = 2π = 360
Efficience = 0.6

$$T = \frac{F \times P}{\theta \times \eta}$$

$$T = \frac{11.27 \times 0.002}{2\pi \times 0.6} = 0.006 \text{ Nm}$$

Motor specification:

Stepper Motors:
Stepper motors (Figure 33) are categorized by standard sizing indicating their faceplate diameter Stepper motors are by far the most used driving motor in the 3D printing world. These brushless AC motors spin in increments (steps), having precise control of their rotation even without position sensors for feedback.
Since these are not highly complex mechanisms, they are relatively inexpensive.
I chose Stepper motors Nema 17 according to my calculations.
Size: 42mm X 42mm

Step angle: 1.8 degrees per step (200 step per revolution)
Torque: from 0.18 to 0.54 Nm
Current rating: from 0.5 to 2.0 amps per phase
Voltage: from 2.8 to 4.2 volts per phase
Resistance: from 1.5 to 5.0 ohms per phase
Inductance: from 2.0 to 8.0 mH per phase

Figure 33: Stepper motor Nema 17

4.2 Motor to move X, Y and Z axis:

Calculation for the force needed to move in the x, y and z axis:

Choosing the right motor for the X, Y, and Z-axis in a 3D printer depends on several factors, including the weight of the printer components, the speed and acceleration required, and the resolution of the motor.

1. Determine the weight of the components that the motor will be moving:
- The X-axis weighs approximately 560g
- The Y-axis weighs approximately 250g
- The Z-axis weighs approximately 1.5kg

2. Calculate the torque required to move the weight:

Torque = (weight * distance) / 2

Equation 2: Torque

- For the X-axis: torque = (weight * distance) / 2. Assuming the X-axis has a travel distance of 345mm, the torque required would be (0.560kg * 0.345m) / 2 = 0.0966 Nm.
- For the Y-axis: torque = (weight * distance) / 2. Assuming the Y-axis has a travel distance of 350mm, the torque required would be (0.25kg * 0.35m) / 2 = 0.04375 Nm.
- For the Z-axis: torque = weight * gravity. Assuming a gravity of 9.81m/s^2, the torque required would be 1.5kg * 9.81m/s^2 = 14.715 Nm.

3. Determine the speed and acceleration required:
- The maximum speed of the printer is approximately 200mm/s for the X and Y axes and 16mm/s for the Z-axis.

- The maximum acceleration is approximately 500mm/s^2 for the X and Y axes and 100mm/s^2 for the Z-axis.
4. Calculate the resolution of the motor:
- The resolution of the motor will depend on the microstepping settings used in the motor driver and the pitch of the lead screw or belt. For example, if the motor driver is set to 1/16 microstepping and the lead screw has a pitch of 2mm, the resolution would be 3200 steps per revolution (1 revolution = 2mm * 16 microsteps per step * 200 steps per revolution).

4.3 Experiment of measuring the degree of each stage of the heat gun:

The aim of the experiment is to measure the temperature at each stage, one time at stage 2 and the second time at stage 3 of air flow with respecting the distance from the head of heating to the head of measuring using the Avometer.
The distance was from 2 to 3 cm.

- At stage 2 of air flow: 350 l/min

  Distance 2/3 cm

Table 3: Avometer reads at stage 2

Temperature 1	47°c
Temperature 2	55°c
Temperature 3	66°c
Temperature 4	91.5°c
Temperature 5	140 °c
Temperature 6	175°c
Temperature 7	207°c
Temperature 8	241°c
Temperature 9	265°c

- At stage 3 of air flow: 500 l/min

  Distance 2/3 cm

Table 4: Avometer reads at stage 3

Temperature 1	54°c
Temperature 2	61.5°c
Temperature 3	68°c
Temperature 4	122°c
Temperature 5	171 °c
Temperature 6	208°c
Temperature 7	245°c
Temperature 8	278°c
Temperature 9	306°c

Now the exact temperature of each stage is known.

4.4 Experiment of cooking the dough:

The aim of this experiment is to know the curing process needed for the dough which will be extruded from the syringe not the curing process of a normal cake and the exact flow rate (extrusion rate) which is related with the curing process.

- **Curing process:**

Conditions of curing process.
Temperature.
Time per volume.
Percentage of air.

- **Flow rate:**

When the time per volume will be calculated it will be easy to know the flow rate.

Create a relation between the volume and the time of cooking which is the flow rate.

$$Q = \frac{V}{T}$$

Equation 3: flow rate equation

Q: The flow rate
V: volume of the dough extruded from the syringe
T: time of cooking the dough extruded

Conditions of curing process:

- Type of cake
- Size of cake
- Temperature

Temperature:

It depend also on the volume and of course the type of cake which is specifically the type of dough.
Normally most of the cake are cooked from 175°c to 190°c around 180°c.

The temperature will be determinate exactly from the experiments.

Time per volume:

There is no reference for an exact equation to determine the time per volume so it will be found from the experiments.

Percentage of air:

Cake leavened with baking powder or baking soda contain more air than cake leavened with yeast.

Experiment 1:

It was a small experiment to know the exact time of a point (Figure 34) of 4.5mm of diameter which is the head of the extruder of the syringe and a height of average 1mm.
Another shape which is a line of 40mm and width 1mm and height 0.5mm with another type of syringe.
All of this measure are average.
The types of extrusion (point, line) was exposed to a source of heating which is a lighter, exposed to a distance of 5mm because when this distance is increased like to 10mm there was no effect and the 5mm was burning the surface of the dough and the line.
So it was not working.

Figure 34: point and line printing test

Experiment 2 :

in the second experiment the objective was to calculate the time of cooking on different volume to create an equation and that will be with using matlab.

Recepie of the dough:

Table 5: Recepie

Material	Quantity
Egg	120g (2 eggs)
Suggar	100 g
Oil	100ml
Milk	100ml
Baking powder	10g
Flour	200g

After mixing all together, 4 different shapes with different radius was used to cook the dough of the cake.
The radius was 6cm, 5.5cm, 4cm and 2.5cm.
The 4cm shape was constructed was not available, it was constructed with a paper of butter and aluminum foil and piercing on it to have different dimensions but it was used with the dimensions of 4cm only.

So after using those 4 pots with different radius, the dough was putted into the pot with also different height (Figure 35).
For the height, 4 standard height was used (0.5cm, 1cm, 1.5cm, 2cm) applied on each different radius pot.

Fig. 35.a, b, c: the pot of 4cm radius design

Figure 35: the pot of 4cm radius design

For example:
Pot with radius 6mm is cooked one time with a the dough on height 0.5cm another time on height 1cm, 1.5cm and finally 2cm (Figure 36).
Same for the other pots.

And finally to be compared with each other to obtain a formula for the time of cooking per volume.

Figure 36: pot radius = 4cm

Firstly the pot is weighed before putting the dough to subtract it from the final weight after cooking to have the net weight, then weighed containing the dough before cooking and finally weighed containing the dough after cooking (Figure 37).
This for having the result of the dough before and after cooking of all the pots cause even if it's the same type of pot but it had different weight so each put has to be weighed.
Finally, the oven was prepared at 180°c and each pot putted in the oven is calculated by time of entrance and when it's out (Figure 38).

Figure 37: pot r: 6 & 5.5mm

Figure 38: pot r: 2.5mm

Result of the experiment:

Table 6: result of experiment 2

experiment	Height	Radius	Mass Before	Mass After	Time of cooking	Volume	Area
1	0.5	6	56	48	17.4	56.548	245.044
2	1	6	114	104	21.4	113.097	263.893
3	1.5	6	157	148	21.56	169.646	282.743
4	2	6	208	200	16	226.194	301.592
5	0.5	5.5	57	55	20.4	47.516	207.345
6	1	5.5	96	87	14.54	95.033	224.623
7	1.5	5.5	146	138	15.28	142.549	241.902
8	0.5	4	36	33	11.37	25.132	113.097
9	1	4	51	48	14.15	50.265	125.663
10	1.5	4	84	80	18.2	75.398	138.230
11	1	2.5	21	20	11.3	19.634	54.977
12	1.5	2.5	31	29	12.61	29.452	62.831
13	2	2.5	37	35	13.08	39.269	70.685

Now we can put the result on matlab (Figure 39) to create a fitting curve with the time, area and volume.
After creating the fitting curve the best fitting cure is chose to create the equation.

Result of MATLAB fitting curve:

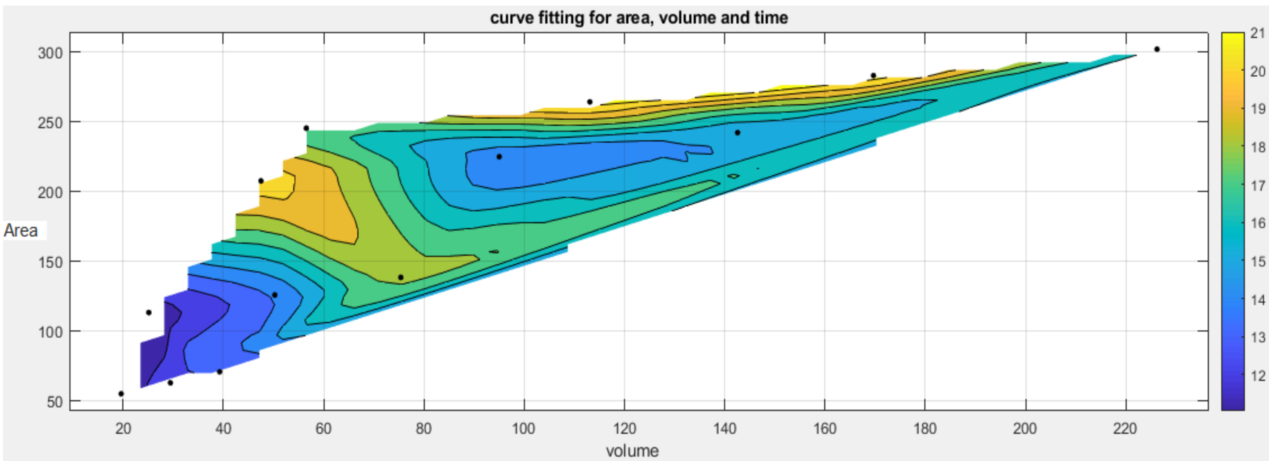


Figure 39: curve fitting for area, Volume and time

Experiment 3:

Final experiment, was referenced by Dr.Yehia in faculty of agriculture.
After discovering that the 2 last experiences was not accurate or didn't go as planned.
So finally after consulting Dr.Yehia the equation will be calculated with another way.

From the exact recipe of the dough, the total mass and the percentage of water has to be calculated to calculate the moisture content.
After knowing the moisture content which is the quantity of water in the dough, the percentage is putted on a diagram (moisture content per time) to know how much time will be taken to arrive to the suitable percentage of water on the dough to be cooked.

Graph 1: moisture content /time graph

Figure 40: show the result of moisture content that the dough have to arrive after cooking which is 20%.
The 35% is the moisture content of the dough calculated below in the calculations in equation 4.

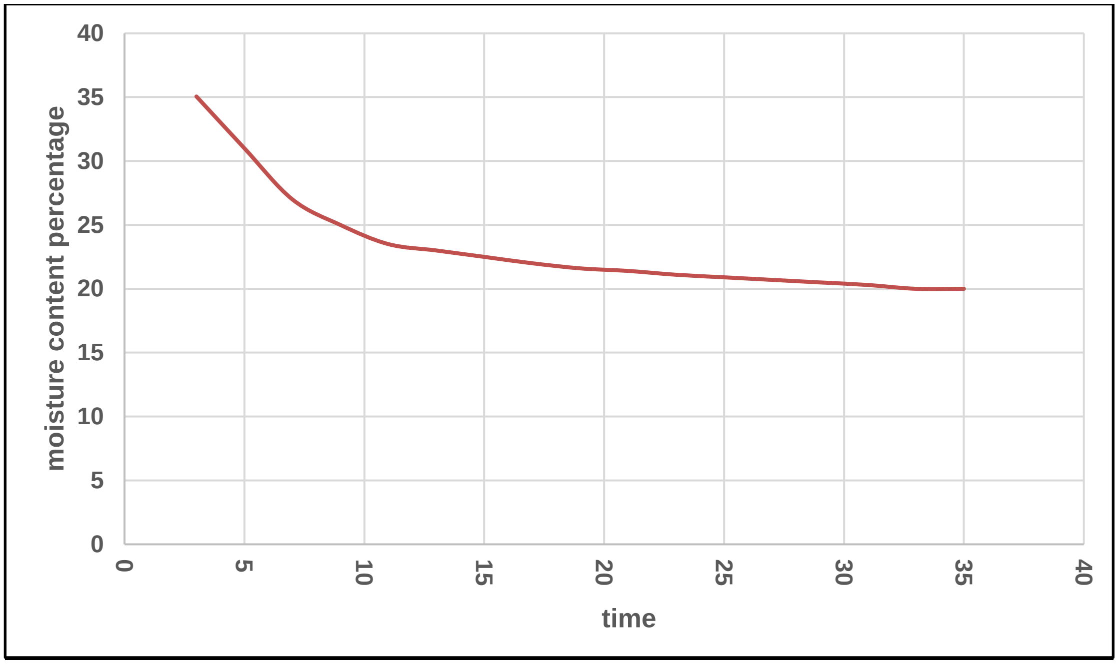


Figure 40: Graph 1: moisture content /time graph

The dough is weighed and then putted in a pot with known weight empty, then weighed finally in the pot.
The pot is putted in the oven and the gas is calculated from the beginning by taken a photo of the counter of gas and a stop watch is open to count the time.
Every 2 minutes the pot is taken out to be weighed until the last one has the same weight of the one before.
The quantity of gas is measured by comparing the first photo of the counter of gas to the last one to see the difference and then count the quantity of gas used.

Table 7: recepie quantity with percentage of H_2 O and density

Material	Quantity	Percentage of H_2O	Value of the percentage of the weight	density
Egg	63g	75%	47.25	1.03 g/cm^3
Sugar	50g	0%	0	1.5 g/cm^3
Oil	40g	0%	0	0.93 g/cm^3
Milk	40g	87%	34.8	1.034 g/cm^3
Baking powder	4g	0%	0	0.75 g/cm^3
Flour	90g	14%	12.6	0.65 g/cm^3

$$\text{total } H_2O = 47.25 + 34.8 + 12.6 = 94.65$$
$$\text{total Mass} = 63 + 50 + 40 + 40 + 4 + 90 = 287g$$

$$\text{weight of the pot} = 211\text{g}$$
$$\text{after mixing weight} = 270\text{g}$$

$$\text{moisture content} = \frac{\text{total } H_2O}{\text{total Mass}}$$

Equation 4: moisture content

$$\text{moisture content} = \frac{94.65}{270}$$
$$\text{moisture content} = 0.3505 \times 100$$

$$\text{moisture content} = 35.055$$

Table 8: result of experiment 3

Weight	Time	Readings
M1= 481g = 270g	T1= 3 mins	Reading 1=2392.076m^3
M2= 481g = 270g	T2= 5 mins	
M3= 480g = 269g	T3= 7 mins	
M4= 479g = 268g	T4= 9 mins	
M5= 479g = 268g	T5= 11 mins	
M6= 478g = 267g	T6= 13 mins	
M7= 477g = 266g	T7= 15 mins	
M8= 477g = 266g	T8= 17 mins	
M9= 475g = 264g	T9= 19 mins	
M10= 475g = 264g	T10= 21 mins	
M11= 474g = 263g	T11 = 23 mins	Reading 11=2392.175m^3
M12= 472g = 261g	T12= 25 mins	
M13= 471g = 260g	T13= 27 mins	
M14= 469g = 258g	T14= 29 mins	
M15= 468g = 257g	T15= 31 mins	
M16= 465g = 254g	T16= 33 mins	
M17= 465g = 254g	T17= 35 mins	Reading 17=2392.235m^3

Gas rate= reading 1-reading 17= 2392.076 – 2392.235= 0.159 m^3 used to cook the dough

$1\text{m}^3 \rightarrow 6000 \times 4.18$ kJ
So $0.159 \times 6000 \times 4.18 = 3987.72$ kJ
Density of the cake $\rho = 1200\ \text{kg/m}^3 = 1.2\ \text{g/cm}^3$

$$V_{total} = \frac{M_{total}}{\rho_{total}}$$

Equation 5: volume equation

$V_{total} = \frac{M_{total}}{\rho_{total}} = \frac{270}{1.2} = 225\ \text{cm}^3$
Energy per 1 $\text{cm}^3 = \frac{\text{Energy}}{1\text{cm}^3} = \frac{3987.72\ \text{kJ}}{225\ \text{cm}^3} = 17.723\ \text{kJ/cm}^3$
Equation 6: energy per 1 cm3

Energy of 1 kg hot air $= 1\ \mathrm{kg} \times \mathrm{cp_{air}} \times \Delta t$
Equation 7: Energy of 1 kg hot air

$$\Delta t = t_2 - t_1 = 180℃ - 25℃$$

t_1 Temperature of the room
t_2 Temperature of the oven

Energy of 1 kg hot air $= 1 \times 0.24 \times (180 - 25)$
Energy of 1 kg hot air $= 1 \times 0.24 \times 155 = 38.75\ \mathrm{kJ}$

Quantity of hot air needed to cook per cm^3

Quantity of hot air per volume $= \frac{38.75\ \mathrm{kJ}}{17.723\ \frac{\mathrm{kJ}}{\mathrm{cm^3}}} = 2.186\ \frac{\mathrm{cm^3}}{\mathrm{kg}}$

So now it's known that each 2.186 cm^3 of dough needs 1 kg of hot air.

As mentioned before there is 3 stage of air flow, if the second stage will be used so the air flow will be 350 l/min.
To be more accurate let's assume that it will be 300 l/min of air flow.

$300\ {}^{\mathrm{l}}/_{\mathrm{min}} \rightarrow 0.3\ \mathrm{kg/min}$

So this is the flow rate result needed to cook a dough in the 3d printer:

$$0.3 \times 2.186 = \mathbf{0.6558}\ {}^{\mathbf{cm^3}}/_{\mathbf{min}}$$

To be more efficient let's approximate the value, assume that the flow rate will be:

$$\mathbf{1}\ {}^{\mathbf{cm^3}}/_{\mathbf{min}}$$

This how the velocity will be calculated:

$$V = v \times A$$

Equation 8: volume flow rate

V = volume
v = velocity
A = area

To calculate the velocity the inner diameter of the nozzle of the syringe has to be measured.

$$D_i\mathrm{nozzle} = 4.3\ \mathrm{mm}$$

$$v = \frac{V}{A} = \frac{1}{\frac{\pi}{4} \times (4.3)^2} = 0.0688\ \mathrm{cm/min}$$

$$v = 0.688\ \mathrm{mm/min}$$

$$v \approx 0.7\text{mm/min}$$

Now the velocity required to move the nozzle in the directions X, Y and Z (depending on the printing shape) is known.

$$v = N \times P$$

Equation 9: Linear velocity

$N = \text{number of rev}$
$P = \text{pitch of the power screw}$

Pitch of the power screw = 2mm

$0.7 = N \times 2$
$N = \frac{0.7}{2} = 0.35\ \text{rev/min}$

The rev of the motor of the extruder needed to push the dough.

5 Chapter 5: control

5-1: programming language 1:

Arduino language which is C is the programming language used to control the motor of the piston for the following reasons:

1. The micro controller is Arduino.

2. The parts that Arduino uses are simple to attach.

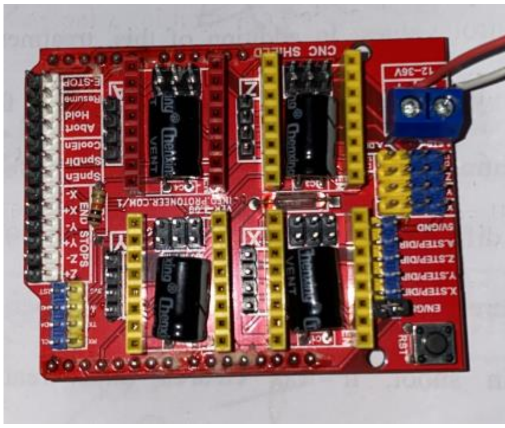
3. The Arduino language which is C language is written into the stepper motor controller, allowing it to easily move the piston up and down to push the dough out smoothly.

Connections:

Connect an Arduino (Figure 41) to a Nema 17 stepper motor need a stepper motor driver and to connect this driver to the Arduino its need a CNC shield.

- CNC (Figure 42) shield have to be connected to the Arduino by inserting the CNC shield onto the Arduino board, ensuring that the pins are properly aligned and securely attached.
- Insert the stepper motor (Figure 43) driver into the slot on the CNC shield.
- Connect the four wires from the Nema 17 to the appropriate terminals on the CNC shield board.

Figure 41: Arduino



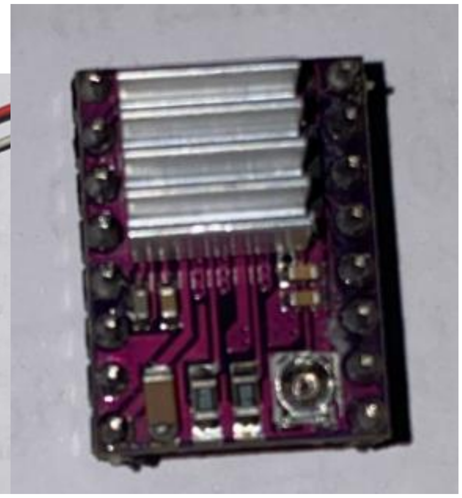


Figure 42: CNC shield

Figure 43: stepper motor Driver

5-2: programing language 2:

4.1.1 Motherboard use a microcontroller Atmel Atmega 1284P as shown in (Figure 44) which use C as a programming language used to control the motor of x, y and z axis, allowing them to move in their direction to print the desired shape with the dough (Figure 45).
Also used to control the heated bed to increase or decrease the degree of temperature.

Figure 44: Atmel Atmega 1284P

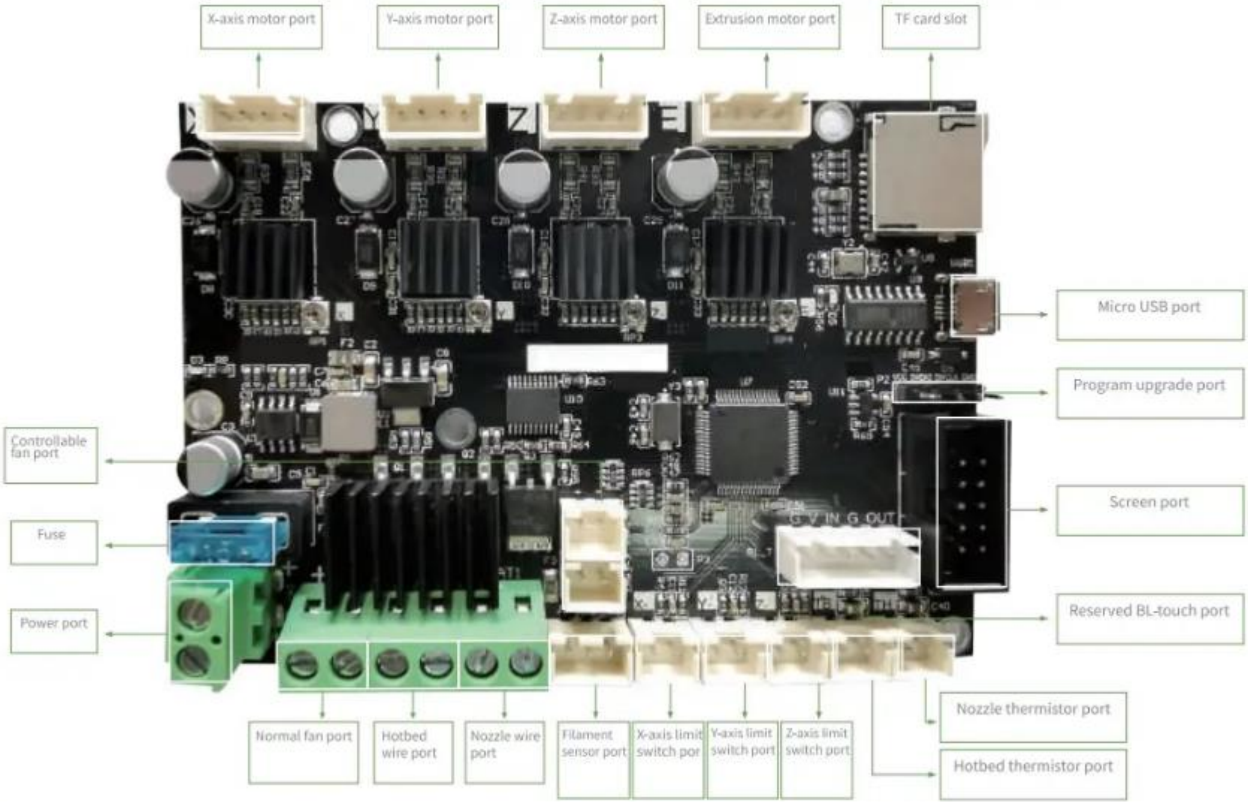


Figure 45: Mother board 4.1.1

6 Chapter 6: Prototype

Prototype:

A prototype has been built, it has been tested and evaluated. The results have shown that it is able to print in the same time of cooking which is the target as shown in (Figure 46).

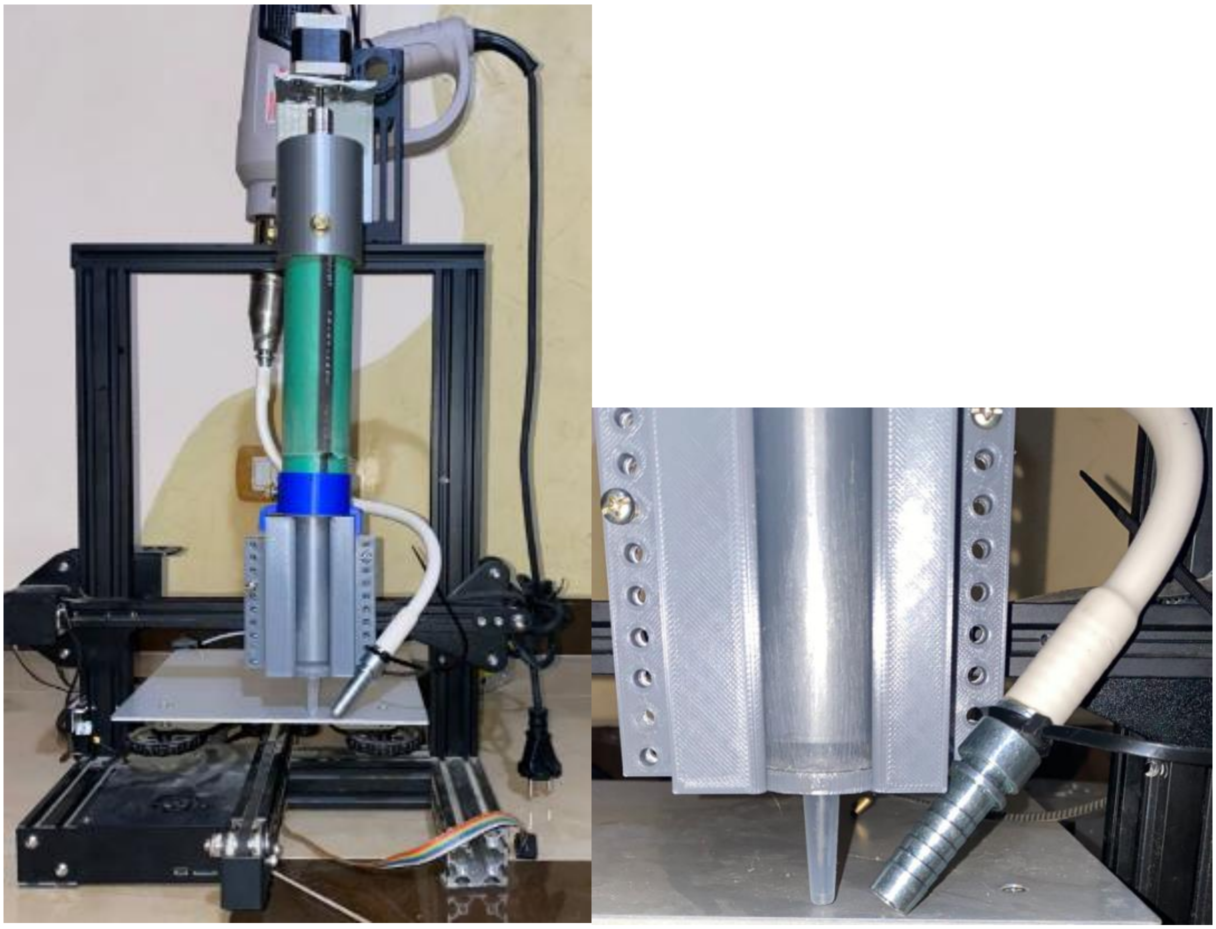


Figure 46: final prototype

7 Chapter 7: Conclusion and Recommendations

7.1 Conclusion:

In the end the task and goals were accomplished within the ten-week timeframe.

In conclusion, the development of a 3D printer that is capable of printing food and cooking it at the same time with temperature and speed detected is an exciting and challenging project that has the potential to revolutionize the food industry. This project has the potential to bring a new level of customization and convenience to food preparation, allowing users to create unique and personalized cakes on demand. However, it also presents a number of technical challenges, including the need to manage multiple printing and cooking processes simultaneously, as well as the need to ensure the safety and quality of the food being printed. With careful planning and development, however, this project has the potential to create a truly unique and innovative product that could change the way we think about food preparation and cooking.

A 3D food printing technology is a promising innovation that has the potential to revolutionize the way we prepare and consume food. This technology uses digital designs to create three-dimensional objects made from edible materials and cook it in the same time, allowing for highly customized and precise food preparation. The 3D food cooking printer combines the capabilities of a 3D printer and a cooking device, enabling users to print and cook food simultaneously. The printer uses a variety of edible ingredients and can create intricate shapes and textures, allowing for endless possibilities in food design. The technology also has the potential to improve food sustainability by reducing food waste and enabling the creation of personalized meals tailored to individual dietary needs. While still in its early stages of development, the 3D food cooking printer holds promise for the future of food preparation and consumption.

7.2 Recommendation:

Building a 3D food printer can be a challenging and complex procedure that calls for knowledge of both mechanical engineering and computer programming. Following are some suggestions for creating a 3D food printer:

1. Select the appropriate 3D printing method: There are various 3D printing methods, including FDM (Fused Deposition Modelling), SLA (Stereolithography), and SLS (Selective Laser Sintering). The option depends on the kind of food you want to print and the printing speed you need. Each technique has advantages and disadvantages.

2. Choose the proper resources: Both the printing and cooking materials you choose must be palatable and secure for consumption. Chocolate, bread, cheese, and mashed potatoes are a few typical materials utilised in 3D food printing. To make sure the food items maintain their shape while printing, you might also need to add thickeners or binders.

3. Create the printer hardware: The extruder, the print bed, the nozzle, and the motors that move the nozzle and the print bed are all parts of the printer hardware. Either create the hardware from scratch or adapt an existing 3D printer to your specifications.

4. Create the software: The 3D food printer's software is its brain, directing how the print bed and nozzle move. It will be necessary to create software that can read 3D models and convert them into printer-friendly instructions. Software that can modify the recipe and cooking conditions according to the kind of food you are printing might also be necessary.

5. Test and improve: After constructing the 3D food printer, you must give it a thorough testing to make sure it functions as planned. If you want to increase the printing quality or speed, you might need to make changes to the hardware or software.

In addition to building the 3D printer, you will also need to develop recipes and cooking techniques that are suitable for 3D printing. This may involve experimenting with different ingredients and cooking methods to achieve the desired texture and flavor.

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9 Appendix:

Programming language 1:

```
// Stepper Motor X
  const int stepPin = 2; //X.STEP
  const int dirPin = 5; // X.DIR

 void setup() {
 // Sets the two pins as Outputs
 pinMode(stepPin,OUTPUT);
 pinMode(dirPin,OUTPUT);
 }
 void loop() {
 digitalWrite(dirPin,HIGH); // Enables the motor to move in a particular direction
 // Makes 200 pulses for making one full cycle rotation
 for(int x = 0; x < 200; x++) {
 digitalWrite(stepPin,HIGH);
 delayMicroseconds(500);
 digitalWrite(stepPin,LOW);
 delayMicroseconds(500);
 }
 delay(1000); // One second delay

 digitalWrite(dirPin,LOW); //Changes the rotations direction
 // Makes 400 pulses for making two full cycle rotation
 for(int x = 0; x < 400; x++) {
 digitalWrite(stepPin,HIGH);
 delayMicroseconds(500);
 digitalWrite(stepPin,LOW);
 delayMicroseconds(500);
 }
 delay(1000);
 }
```

Explanation:

```
 const int stepPin = 2; //X.STEP
const int dirPin = 5; // X.DIR
```

These lines define the step and direction pins used for controlling the stepper motor.

```
void setup() {
  pinMode(stepPin, OUTPUT);
  pinMode(dirPin, OUTPUT);
}
```

This is the setup function that initializes the `stepPin` and `dirPin` as outputs.

Programming language 2:

Code used to move the X, Y, and Z motors and heat the bed:

```
#include <AccelStepper.h>

#include <U8glib.h>

// Define the pins for the X, Y, and Z
stepper motors

#define X_STEP_PIN 54

#define X_DIR_PIN 55

#define Y_STEP_PIN 60

#define Y_DIR_PIN 61

#define Z_STEP_PIN 46

#define Z_DIR_PIN 48

// Define the pin for the bed heater

#define BED_HEATER_PIN 4

// Define the maximum speed and
acceleration for the motors

#define MAX_SPEED 3000

#define MAX_ACCEL 1000

// Define the steps per revolution for
each motor

#define X_STEPS_PER_REV 200

#define Y_STEPS_PER_REV 200

#define Z_STEPS_PER_REV 400

// Create an instance of the
```

```
AccelStepper library for each motor
AccelStepper
X_AXIS(AccelStepper::DRIVER,
X_STEP_PIN, X_DIR_PIN);
AccelStepper
Y_AXIS(AccelStepper::DRIVER,
Y_STEP_PIN, Y_DIR_PIN);
AccelStepper
Z_AXIS(AccelStepper::DRIVER,
Z_STEP_PIN, Z_DIR_PIN);
void setup() {
  // Set the maximum speed and
acceleration for each motor
X_AXIS.setMaxSpeed(MAX_SPEED
);
X_AXIS.setAcceleration(MAX_ACC
EL);
Y_AXIS.setMaxSpeed(MAX_SPEED);
Y_AXIS.setAcceleration(MAX_ACC
EL);
Z_AXIS.setMaxSpeed(MAX_SPEED
);
Z_AXIS.setAcceleration(MAX_ACC
EL);
  // Set the steps per revolution for
each motor
X_AXIS.setStepsPerRevolution(X_ST
EPS_PER_REV);
```

```
Y_AXIS.setStepsPerRevolution(Y_ST
EPS_PER_REV);
Z_AXIS.setStepsPerRevolution(Z_ST
EPS_PER_REV);
  // Set the pin for the bed heater as an
output
  pinMode(BED_HEATER_PIN,
OUTPUT);
}
void loop() {
  // Move the X, Y, and Z motors to
their starting positions
  X_AXIS.moveTo(0);
  Y_AXIS.moveTo(0);
  Z_AXIS.moveTo(0);
  // Wait for the motors to reach their
starting positions
  while (X_AXIS.distanceToGo() != 0
|| Y_AXIS.distanceToGo() != 0 ||
Z_AXIS.distanceToGo() != 0) {
    X_AXIS.run();
    Y_AXIS.run();
    Z_AXIS.run();
  }
  // Turn on the bed heater
digitalWrite(BED_HEATER_PIN,
HIGH);
  delay(10000); // Wait for the bed to
```

```
heat up
  // Move the X, Y, and Z motors to a
new position
  X_AXIS.moveTo(1000);
  Y_AXIS.moveTo(1000);
  Z_AXIS.moveTo(100);
  // Wait for the motors to reach the
new position
  while (X_AXIS.distanceToGo() != 0
|| Y_AXIS.distanceToGo() != 0 ||
Z_AXIS.distanceToGo() != 0) {
    X_AXIS.run();
    Y_AXIS.run();
    Z_AXIS.run();
  }
  // Turn off the bed heater
digitalWrite(BED_HEATER_PIN,
LOW);
}
```

Explanation:

```
#define X_STEP_PIN 54
#define X_DIR_PIN 55
#define Y_STEP_PIN 60
#define Y_DIR_PIN 61
```

```
  #define Z_STEP_PIN 46

  #define Z_DIR_PIN 48
```

These lines specify the X, Y, and Z stepper motor pins.

```
  #define BED_HEATER_PIN 4
```

This line defines the pin used for the bed heater.

```
#define MAX_SPEED 3000
#define MAX_ACCEL 1000
```

These lines define the maximum speed and acceleration for the motors.

```
#define X_STEPS_PER_REV 200
#define Y_STEPS_PER_REV 200
#define Z_STEPS_PER_REV 400
```

These lines define the steps per revolution for each motor.

```
AccelStepper X_AXIS(AccelStepper::DRIVER, X_STEP_PIN, X_DIR_PIN);
AccelStepper Y_AXIS(AccelStepper::DRIVER, Y_STEP_PIN, Y_DIR_PIN);
AccelStepper Z_AXIS(AccelStepper::DRIVER, Z_STEP_PIN, Z_DIR_PIN);
```

These lines create instances of the AccelStepper library for each motor, using the pins defined earlier.

```
void setup() {
  X_AXIS.setMaxSpeed(MAX_SPEED);
  X_AXIS.setAcceleration(MAX_ACCEL);
  Y_AXIS.setMaxSpeed(MAX_SPEED);
  Y_AXIS.setAcceleration(MAX_ACCEL);
  Z_AXIS.setMaxSpeed(MAX_SPEED);
  Z_AXIS.setAcceleration(MAX_ACCEL);

  X_AXIS.setStepsPerRevolution(X_STEPS_PER_REV);
  Y_AXIS.setStepsPerRevolution(Y_STEPS_PER_REV);
  Z_AXIS.setStepsPerRevolution(Z_STEPS_PER_REV);

  pinMode(BED_HEATER_PIN, OUTPUT);
}
```

The motors and heating element are initialised by this setup function. Each motor's maximum speed and acceleration are set using the'setMaxSpeed()' and'setAcceleration()' operations, and each motor's steps per revolution is set using the'setStepsPerRevolution()' function. The pin for the bed heater is set as an output using the 'pinMode()' function