MECT411 Capstone Team Project

Eastern Mediterranean University

Faculty of Engineering

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Designing and Manufacturing 3D Printer

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ABSTRACT

Due to the problems caused by the complex parts production by traditional machining such as lack of quality and the need of plenty time for production process, the industry has turned to produce parts by 3D printer. The main purpose of this report is to investigate and explain the concepts of a 3D printer that increase the quality of production and reduce the time needed for the manufacturing process. First, the report discusses the increasing demands on production and manufacturing, and the 3D machines as a solution to compensate these demands. Some of 3D machines types and the characteristics of each one will be listed. Then it focuses on 3D printer types and how do they function. It shows also the applied fundamental concepts of Arduino, stepper motor and cartridge heater. After that it illustrates in details how to design and manufacture 3D printer from all aspects whether mechanical or electrical and even software, and clarify how to link between mechanical and electrical parts to work together. Finally at the end of the report a shown diagrams and calculations are explained. In addition, the manufacturing process of the mechanical components and the connecting of the electrical circuit will be illustrated. Finally, the assembly of the whole prototype, testing it and discussing its results will be clarified.

Keywords: 3D printer, 3D machines, manufacturing products, Arduino, stepper motor, cartridge heater, mechanical and electrical combination.

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CHAPTER 1

INTRODUCTION

Since the Industrial Revolution has begun, the whole world became interested in industry and its development. Many countries have allocated large budget for scientists and engineers to develop industry in all respects and merge them with the latest technology to facilitate the manufacturing process because of many reasons. Quality is the most important of these reasons, because it contributes to reduce the life of production and accelerate its failure and breaking it with corrosion factors such as rust. Also the time needed produce an object has been a major reason because the manufacture of a simple piece needs a lot of time and passes through several stages for its formation. On the other hand, when a large quantity of pieces is needed to be manufactured , the number of workers will be increased or a lot of processing time will be consumed. Engineers have discovered many improved designs and have added new devices from time to time. 3D machines, for example, were founded to increase productivity with less time and the highest efficiency and quality. It is capable of producing complex pieces during several minutes only.

3D printer project 2; its purpose is to have the highest efficiency and lowest time for the production process. The report will firstly explain in details how to design and manufacture a 3D printer. Secondly, it will clarify components operation, how it work and how to install them. Lastly, connecting the mechanical and electrical components together will be explained and programming the Arduino to reach the main purpose of the project.

This project will be a good reference for mechanical, mechatronic and electrical departments because it will show the combination between the mechanical and electrical work during the machine operation.

The whole report will summarize the 3D printer construction, classification of 3D printers, filament, cartridge heater, stepper motor and Arduino. And it will let the reader to be familiar with these words in his/her carrier as a mechanical / mechatronic / electrical engineer.

1.1 Why 3D machines?

Manufacturing products is the main base for almost everything is used in everyday life by using an enormous variety of methods. Each one depends on several factors including time value, cost, quality, accuracy and complexity.

Few decades ago, people used to create their products manually and by using simple traditional tools that were used to produce inaccurate low quality objects, which was consuming human's energy, time and cost.

Thus, nowadays technology is taking the lead in everything that surrounds us including manufacturing process. Therefore, new kinds of machines were invented in order to reduce the lack of high performance, increase productivity and efficiency in the industrial field, and also to cope with people's dramatically increasing demands. These machines are called 3D machines.

3D machines are from the most essential machines that are used recently to build 3D objects due to many reasons. To begin with, their simplicity and complexity at the same time; complexity in designing the machines in order to manufacture very high quality products, and simplicity in the method of building different types of objects from different materials. Moreover, speed and less time are required for designing and prototyping any object mainly because of using digital devices during the process. In addition, these types of machines do not need expensive equipment for the product construction, so it can be considered them economically efficient. Nevertheless, the most important reason is that there is no excessive human involvement during building the object which is considered to be a massive development in the history of manufacturing.

1.2 Types of 3D Machines

In this part of the first chapter types of 3D-machines are going to be talked about with brief information about each one. The most famous and common used types in factory are CNC machines and 3D printers.

1.2.1 - CNC Machines

CNC is an acronym for the first letters of "Computer Numerical Control". It’s a multi-function mechanical machine that have tool box as (cutter, driller, miller) which can be controlled manually or automatically by using a computer, nowadays most of them use a computer to control it. CNC can build shapes in 3 axis (X, Y, Z), or more depending on the application. This machine typically have a controller to give order to the electrical and mechanical parts, some commands are given as a program language to the machine by codes called (G-CODE) which is simple to be written by hand and generate it by training. Before the G-CODE is applied, the code should be considered as correct, otherwise the machine will be damaged if correct values aren't given to make tests. There are some programs on the computers that can understand the codes which are applied, and it will draw a sample of the shape that is wanted, in this case it will be sure about the design and at the same time it won't damage the CNC machine which is very expensive. After sending the codes to the machine, it will start to make the design. The computer changes the design by using Computer Aided Design software (CAD), into numerical prototype. The numerical can be considered to be the coordinates for the graph and they control with movement of the tool box.

Types of CNC:

1–Milling machine.

2– Lathes.

3- Plasma cutters.

4- Electric discharge machining.

5- Water jet cutters.

1.2.2 - 3D Printers

The world of industry also call it as" additive manufacturing (AM)"it's a type of 3D machines which has the ability to build 3D shapes by scanning a product by using a 3D- scanner then transfer it by computer as dots and connect these dots by lines which totally will create a complete geometry and change it as program language, or directly give the commands from specific computer language or design program, so the design will be objected before it's built in real.

3D-printers basically depend on melted materials to build the shapes, so different filament gives different applications. Plastic filament is a common type or by using powder bed with inkjet printer head. One type of 3D printers squirts out a stream of heated, semi-liquid plastic that will become dry as the printer's head moves around of the shape to create the outline of each layer within the object.

3D-printers became very important in life because it's used in many functions like building any model shapes that are want. Moreover, in medicine it's used to make effective pills that make the price of medicine cheaper because the production expense will decrease. Another example is a machine that can build real houses automatically without any human control with great speed and high accuracy.

1.3 Objective of the Project

- **Designing**

  The project needs a full design for all the pieces and assemble them to form our 3D printer, and designing the external shape of it. In addition, conducting some tests on the design is also needed to make sure that the printer will work without any problems.

- **Manufacturing**

  The external shape of the 3D printer will be manufactured by different machines which exist in the workshop.

- **Installing the 3D printer**

  A full 3D printer will be installed by using Arduino, stepper motors and cartridge heater (all will be mentioned and explained in details in the report) and the operation of these components will be combined together through a programmed Arduino.

- **Programming**

  The Arduino will be programmed, tested and diagnosed to change the operation settings of the stepper motors to get the highest efficiency, quality and minimum time. In addition, to connect the 3D printer with simulation software before starting production.

1.4 Organization of the Report

In chapter I 3D machines concept is briefly introduced and various types of these machines (CNC machine, 3D printer) are mentioned and discussed too.

In chapter II a literature review will be introduced showing the history, previous works done and the development of the 3D printer technologies. Also how to make a 3D printer and its functions will be discussed. A brief review about types of 3D printers will be also listed. Finally, the type of 3D printer that was chosen and the reason of choosing it will be mentioned.

In Chapter III, the designing and manufacturing of the prototype will discussed in details with the components, materials and manufacturing plan. Modeling and analyzing results will be added to compare with types of 3D printer.

In chapter IV manufacturing, assembling and testing processes will be illustrated.

In chapter V experimental results will be obtained and final results will be discussed.

Last chapter is about future works and conclusion.

This report will include appendices (Logbooks, Gant chart, Technical drawings, Engineering standards and Manufacturing photos).

CHAPTER 2

Literature review

In this chapter old publication and researches will be surveyed, purpose of 3D printers will be discussed and finally five types will be illustrated.

2.1 History of 3D Printer

The beginning of additive manufacture usage was in rapid prototyping (RP) since 1980s until 1990s. Prototypes allow the manufacturers and the designers to test their object even before they start to produce and finish it. As a result, that makes the engineers to be able to produce their products much faster than it was. By using RP, the designer starts to use a program in the computer to design the objects, which is called Computer Aided Design (CAD) software. The processor of the machine follows the product by building it layer by layer which is known as 3-D printing.

The earliest foundation of 3-D printing technologies happened at Massachusetts Institute of Technology (MIT) and at a company called 3D Systems. In 1990's, MIT started to publish it as 3-D printer, which is officially known as 3D P. In 2011, MIT gives the right for six companies to develop the machine process in the manufacture. Therefore, 3D systems start to have types of 3-D printing and develop new methods and open many branches since 1986, the foundation year.

After that, factories began to use this technology to produce products and it became widely spread. In 1992, Bill Clinton worked in 3D Systems (Charles Hull's company) who found first Stereolithography apparatus (SLA) and Selective Laser Sintering (SLS)[1]. Stereolithography apparatus depends on building the product layer by layer, while Selective Laser Sintering depends on sprout laser at a powder instead of liquid. The 3D system still on the top of 3-D printing field, other companies started to come over with new technology such as Z Corporation, Stratasys continue on AM technologies. In 2005, the first revolutionary of 3D-printer was the programming that becomes an open-source. Dr. Adrian Bowyer's RepRap Project launched an open-source initiative to produce a 3D printer that could print most of his own pieces. In 2008, Darwin released a self-reproduce printer that's able to do that. After a period of time, people started writing their programs everywhere based on their various ideas, and share them around the entire internet which makes it look like a game for technology lovers [2].

The technology has been improved a lot in many ways, such as the required time to print the figure, the details of the product, and how much clean is the finishing when it's completed. The material and equipment is getting cheaper and offer many types as plastic and ceramic and the processes is going faster. Nowadays, the size of printing varies from small electronic device to building homes or big real cars. The system of 3-D still new in the field of manufacture and still needs more develop. However, this technology is better than the common process which is called Computer Numerical Controlled (CNC) machine. CNC process is the opposite of AM because CNC machines remove the Iron filings of the object while the AM build it by one line on the top of the other.

Figure 2.1 shows the growth in 3D printer products in the last 10 years.

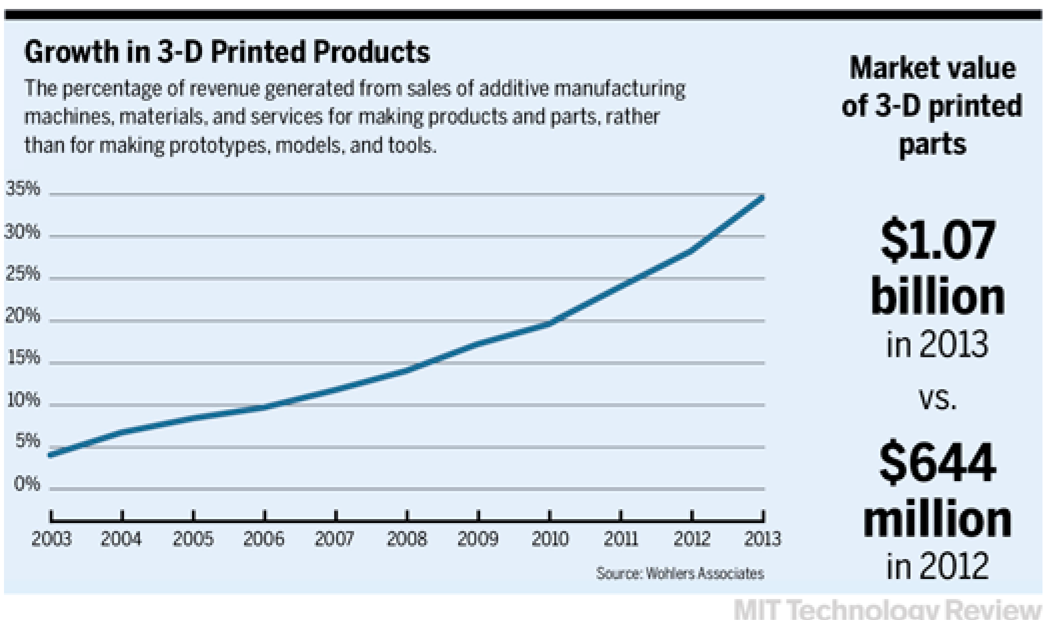

Figure 2.1 Growth in 3D printer products [3]

2.2 Purpose of 3D Printer

3D printing or as they are called additive manufacturing is a process of producing 3D solid objects from a digital file. The manufacturing of a 3D printed product is accomplished by using additive processes. First of all, a 3D CAD sketch is introduced to the 3D printing software, it will be sent to the microcontroller. The microcontroller then sends the proper commands to move the extruder along the axes. Furthermore, the microcontroller also controls the extrusion process. In the end, the extruder puts layer over layer to create the final 3D printed object. Figure 2.2 shows the block diagram of this process.

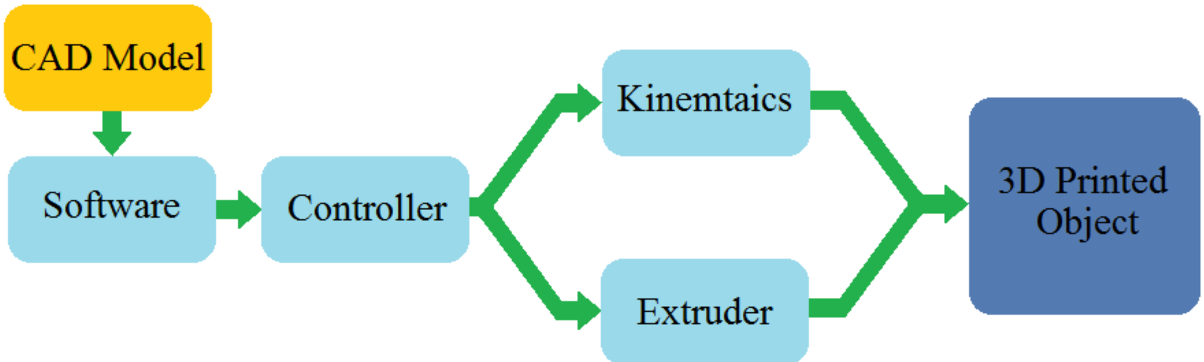

Figure 2.2 The block diagram of 3D printing process

3D printers have many methodologies in the printing process and each methodology is printing specific types of materials.

2.3 Types of 3D Printers

3D printers are classified into several categories based on the technology used in printing and all those types are additive. The main difference is in the way of building layers to create the final object. Some species use melting the material to produce layers. The most technological methods used in this type of printing are fused deposition modeling (FDM) and selective laser sintering (SLS). On the other hand, stereolithography (SLA) is one of the most common technological methods which is curing a photo-reactive resin with a power source like UV laser one layer at a time.

2.3.1 Extrusion

This type is the most species used and the most prevalent. It is using a process called FDM, which is an acronym for the first letters of Fused Deposition Modeling. This process is derived from several systems like automatic gasket deposition, automatic polymeric foil hot air welding system and hot-melt gluing. It was disclosed in 1980 after the development by S. Scott Crump and it was the first commercial appearance in 1990 by Stratasys. FDM are producing the parts by extruding small materials which have sclerosis property that is quick to be formed of layers successfully. Metal wire and thermoplastic filament are examples for the materials used and has the required properties.

FDM used diverse polymers among them, high density polyethylene (HDPE), acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polycarbonate (PC), polyphenylsulfone (PPSU), high impact polystyrene (HIPS) and PC / ABS. These polymers are made from virgin resins in the form of filaments.

In the extrusion process, the plastic rod is fed to the extruder through a motor and gears. The plastic moves between the two gears and enters the extruder's nozzle. Then the plastic is melted by a heater that is fixed around the nozzle. The melted plastic will exit the nozzle through a small opening of a diameter of 2-6 mm. Also a fan that is attached to the extruder will cool down the plastic on the printing plate. The speed of flow and movement of the head of extrusion are adjusted by stepper motors or servo motors. Extrusion process in this type of 3D printers is passed through cold end and hot end. Figure 2.3 shows the process of 3D printing by extrusion method.

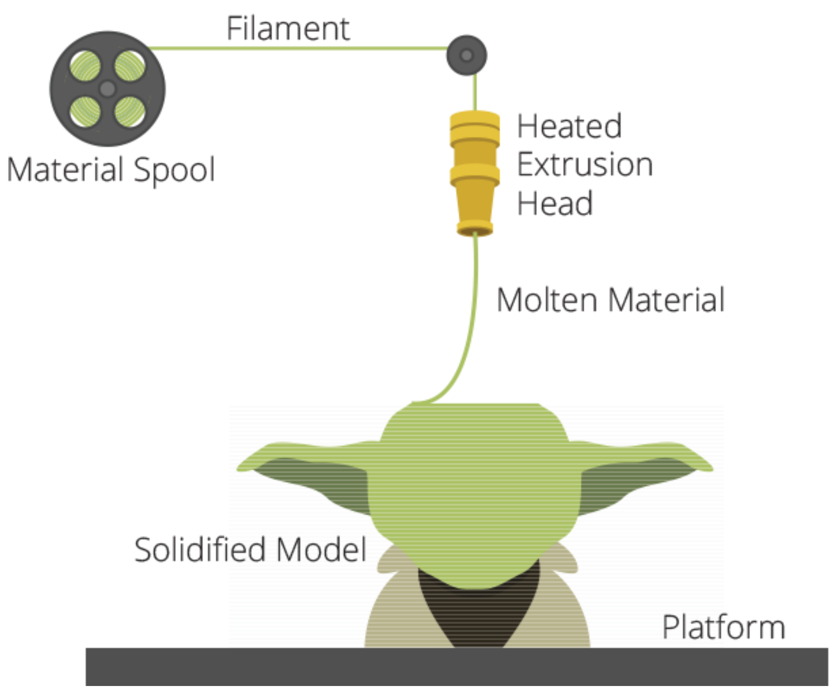

Figure 2.3 3D printing by extrusion method [4]

Each type has advantages and disadvantages but the most prominent of disadvantages of this type of 3D printers is the inability to manufacture structures for several reasons, including that it will not be supported during the building process. In addition, the support which is designing within the structure will be breaking during the finishing process because of the thin of support. On the other hand, among the most prominent of its advantages is it used for the manufacture of large-size industrial objects also it used in a lot of different desktop models.

2.3.2 Light Polymerized

In 1986, stereolithography (SLA) was invented by Chuck Hull who is the founder of the largest and most successful 3D printers company called 3D Systems. SLA based on the use of photopolymerization to manufacture solid objects from liquid materials. This process reached from several studies, such as photosculpture which was found by François Willème in 1860 and photopolymerization which have been uncovered by Mitsubishi's Matsubara in 1974. In 1987, the first SLA machine was sold and it is still the main element of 3D printing since that date. Figure 2.4 shows the process of 3D printing by SLA technique.

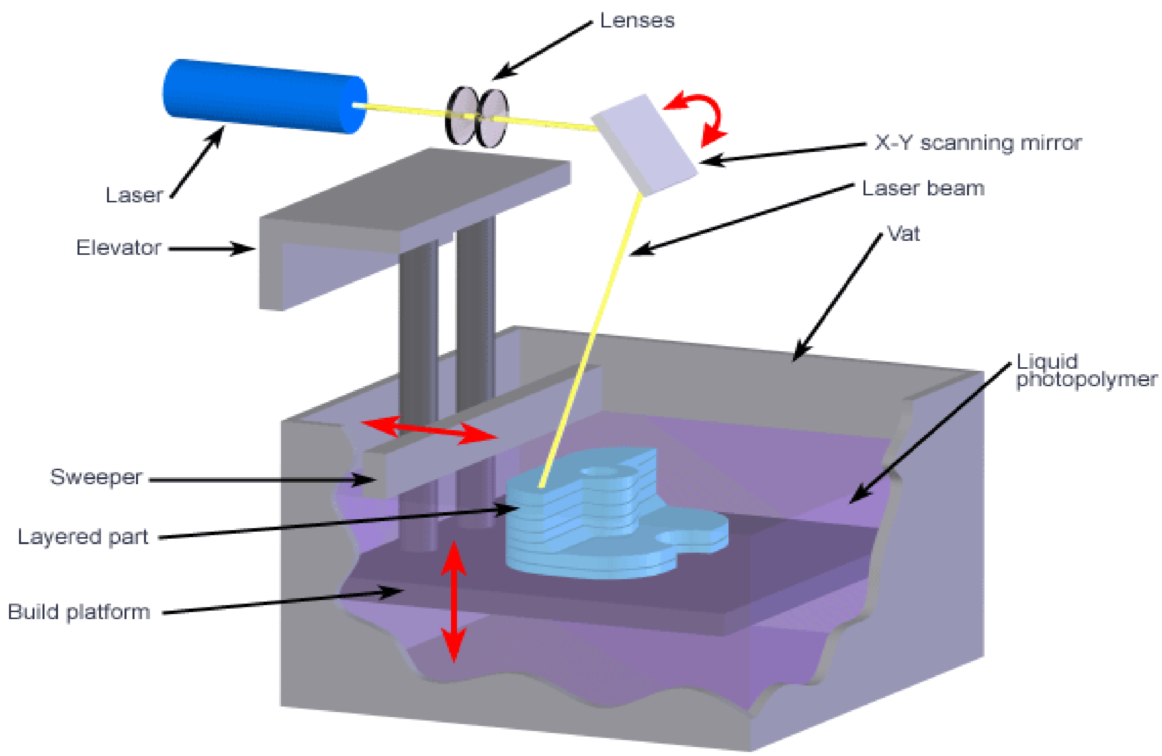

Figure 2.4 3D printing by SLA technique [5]

Photosculpture method is based on taking a group of pictures for the body from different angles so that they are equal in dimension. After that, projecting each photograph on the screen is done. The modeling clay is tracking the outline which got it from the photograph. In photo-polymerization, lighting controls the liquid polymer which includes chromophores, this controlling must be under safelight conditions. As a result, a hardening of the liquid polymer is resulted. Otherwise, added molecules are used to interact with the solution to begin polymerization process with the knowledge that these molecules have the photosensitive.

In polymerization, StereoLithography Apparatus (SLA) is the beginning of everything and it is considered the basis of 3D printing. The laser beam which is used for SLA is like that is using in SLS machine but it differs in one point, it will not melt the powder because it has not a powerful property. In addition, it uses a special plastic so that means it remains liquid until it is exposed to light like ultraviolet light. The chemical property will change the covalent bonds which are resulting from polymerization monomers because it is exposed to light. In the beginning, it builds a plate then starts to move down with simple spaces to shine the light to the polymer liquid again. It repeats this process until the object is fully manufactured. Finally, the liquid polymer is dried after all that. This process has been completed with manufacturing solid model.

The advantage of this type is the ability to manufacture a very small object and has a very fine features using 3D micro-fabrication technique which are used in multiphoton photopolymerisation. This method uses a beam of light and focuses it to follow 3D object which is surrounded by a block of gel. In addition, this approach has the ability to manufacture features sizes less than 100 nm with ease and without any problems. Also, it has the ability to manufacture complex structures and interlocking objects.

There is another approach based on the use of synthetic resins. This technique is used to produce objects consisting of several materials with different rates. In systems research is launching beam of light from the bottom, and this allows for the spread of the resin in a thin and uniform layers. As a result of this method it can underestimate the manufacturing time dramatically. Objet Connex is an example that uses this approach and is commercially available.

2.3.3 Powder Bed

It is a famous manufacturing process. In 1993, this technology was earlier developed at the Massachusetts Institute of Technology (MTV). After that Z Corporation obtained an exclusive license Powder bed and inkjet 3D printing in 1995, known by several names like 3D printing (3DP), binder jetting and drop-on-powder is a type of rapid prototyping and additive manufacturing which are known as layered manufacturing technology to produce objects from digital data which it describes. In addition, this technology of manufacturing includes Selective Laser Melting and Selective Laser Sintering.

The idea of this process based on layered manufacturing technology. The product depends on many thin cross sections finishing with 3D model. So the head of the machine moves during a bed of powder metal, by spread an especial liquid binding material. A thin layer is spread on complete section of the layer and start again on top of it until the product is complete. Unbound powder is attaching layer by manually or automatically operation to remove the extra parts and this process is called "de-powdering" and the removed parts can be used again for another product. Figure 2.5 shows the process of 3D printing by powder bed method.

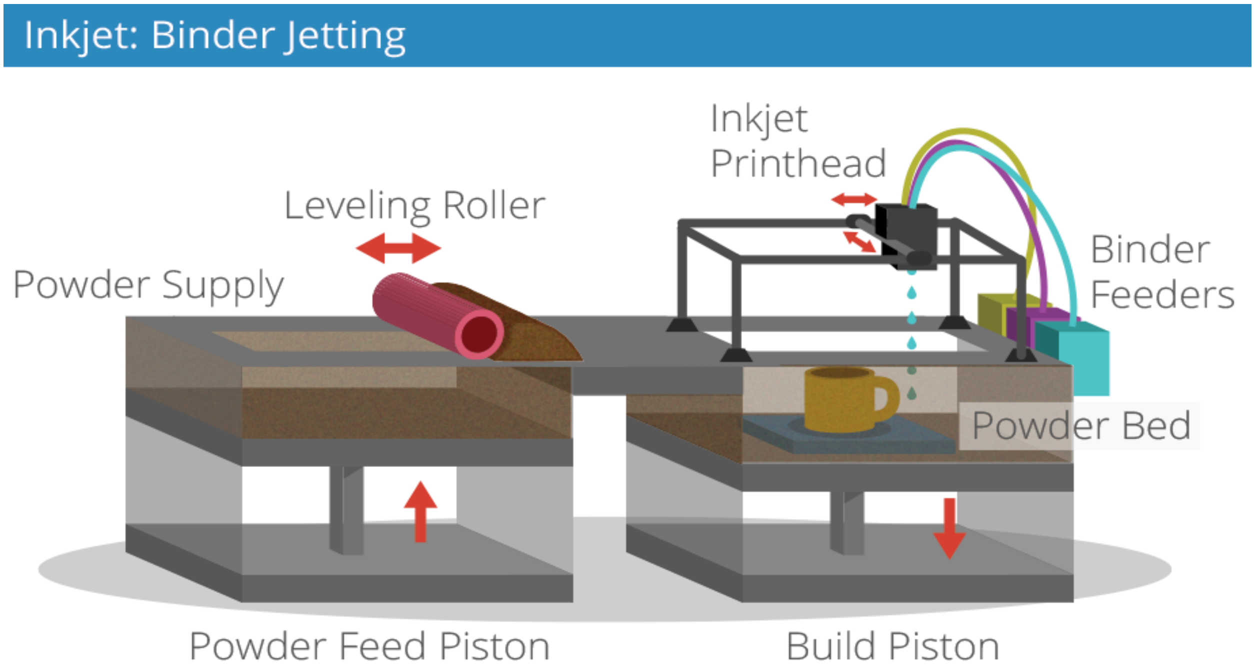

Figure 2.5 3D printing by powder bed method [4]

2.3.4 Laminated

Laminated object manufacturing (LOM) is considered as a fast process. It comes to produce the product faster than the bed-powder and it is developed by Helisys Inc. It could use many materials in the same process. The adhesive- plastic, paper successively fixed together and cut to final shape by laser or sharp material.

The object can be re-shaped after it's printed by machines as drilling or milling, the material feedstock defines the process and usually this process is used to re-range the thickness.

Laminated object manufacturing is composed of eight sections which are foil supply, heated roller, laser beam, scanning prism, laser unit, layers, moving platform and wastes. It consists of several sequential operations and complementary to each other. The process is prolonged application as follows. Firstly, sheet is adhered to a substrate with a heated roller. Secondly, laser traces desired dimensions of pattern. Thirdly, laser cross hatches non-part area to facilitate waste removal. Next, dais with completed layer moves down out of the way. After that, the material is rolled into position. Then, the platform goes down to a new position to hold next layer. Finally, the process is repeated again [6].

Each process has advantages and disadvantages, but the most important advantages of this type is the cheap price due to readily available raw material and the possibility of producing large parts because no chemical reaction is necessary. On the other hand, dimensional accuracy is inconsiderable less than selective laser sintering and stereolithography but no milling step is necessary.

2.3.5 Wire

Build near-net-shape parts are considered as type of an additive manufacturing process which is Electron Beam Freeform Fabrication (EBF^3). This process needs raw materials less than other processes. In addition, it is different from that trademark with finish machining. The working principle of EBF^3 is building a metallic object directly from CAD, then the object is divided to numerically sliced into layer. After that, it can be used to post-process program to write a G-CODE to define the layer path and parameter for the EBF^3 equipment. This type uses focused beam of the electron in a vacuum environment. As a result it is creating a molten pool on a substrate of metal. This beam is directed on the surface of the substrate while the molten pool is fed by metal wire. The deposit solidifies rapidly after the electron beam crosses it; the part will be strengthened enough to support itself. The process will repeat until it makes our needs shape. The size is limited and the extra wire could be used it again "feedstock".

2.4 The Chosen Type of 3D Printers

This project is a consumer class 3D printer with plastic extruder. The majority of the consumer class 3D printers has the same mechanisms for plastic extruding but differs in the 3-axis movement mechanism.

This type of 3D printers is chosen for several reasons. This first reason is that the technology used in this type is very flexible and have the ability to deal with small overhangs through the support of the lower layers. Also the printing by this technology is a quick way for the modeling because of the manufacturing process is longer fast. That makes the rapid industrialization relatively inexpensive alternative compared with different manufacturing methods. In addition, products manufactured through this kind of 3D printers have thermal resistance properties. All of the above lead us to choose this type of 3D printers because it is the most economical whether for the cost or the time required for manufacturing as well as the agility, high speed, flexibility and accuracy of the manufacturing process.

This type of 3D printers are used for aviation applications and medical tissue engineering applications.

This project aims to make a full design of a 3D printer including the software and the hardware design. The Printer must be user friendly and easy to operate by a non-specialist by using common CAD software such as SolidWorks. The aim is also for the cost of the project to be less than similar printers in the market.

CHAPTER 3

DESIGN AND MANUFACTURING

In this chapter the components of the project will be listed, suitable material will be selected according to the parameters of each part of the project, the related equations and calculations will be carried, and finally cost analysis of the project will be presented.

3.1 Prototype Components

Every system consists of several components, choosing the suitable component is crucial in any system and it should be chosen carefully in order to assure the proper operation of the system. The prototype of 3D printer consists of several components. The design itself is simple and easy to be manufactured and analyzed. This project is made of different components that include mechanical, electrical and controller. Some components are interfaced digitally for example drivers of the stepper motors and the LCD controller. Other components need analog interfacing like fans, thermistor and the extruder heater. In this section, the system's components will be discussed in details.

3.1.1 Arduino Mega 2560

Arduino is a little smart mind, which is called microcontroller or microprocessor, these controllers have different inputs and outputs, and are able to control the machines in an efficient way. PIC microcontrollers, Arduino, and programmable logic controls (PLC's) are some types of controllers, which are able to control any system with high efficiency and fast processing. Here, the Arduino will be introduce controllers; introduction to Arduino, types of Arduino, and interfacing with Arduino.

Atmega processor is a tool for making computers that can sense and control more of the physical world than your PC. It is an open source physical computing platform based on a simple microcontroller board and expansion environment for writing any program for the board. The Arduino Mega uses the Atmega chip as the controller, so basically they are the same thing except that the Arduino Mega has a complete board while the Atmega is only a chip that needs to be connected to breadboard or any other board. Arduino Mega can be used to increase interactive objects, taking inputs from a variety of motors, sensors, controlling devices, a variety of lights, and other physical outputs. Arduino projects can be worked alone or communicate with a running software on your computer e.g. Flash.

Arduino has programming language which is an implementation of wiring. It is a similar physical computing platform because it depends on the processing environment of multimedia programming.

There are many models of Arduino with different sizes, colors, and form factors, such as Arduino Mega2560, Arduino Uno, Arduino Mini, and Arduino Nano. The best choice for our project is Arduino Mega2560, because it has 256 KB of memory which is 8 times more than the Uno also it has 54 input and output pins, 16 of them are analog pins. Figure 3.1 is showing Arduino Mega2560 that is used in the project [7].

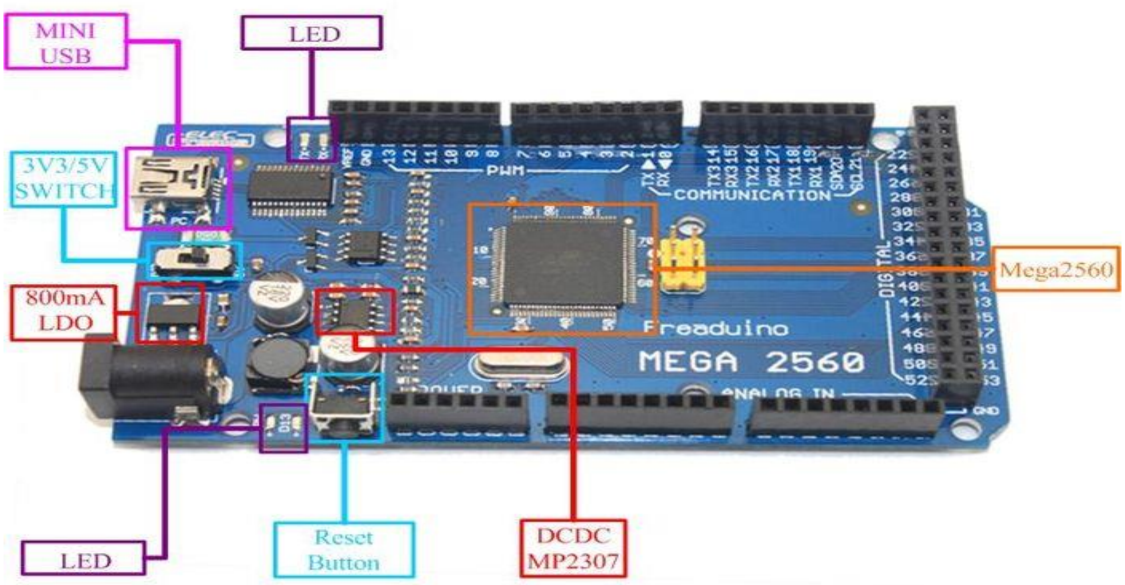

Figure 3.1 Arduino Mega2560

3.1.2 Stepper Motor

A basic function in a 3D printer is the movement of the three axes(X, Y and Z) for manufacturing the product. In order to have the rotating and linear movements of those axes, motors are needed to convert the electrical input into a mechanical movement for creating the object to be built. These movements must be very precise, controllable and operate at different speeds.

There are many different kinds of motors that provide linear and rotation movement but our motors must be suitable to the printer's requirements, such as running on a low power rating because there isn’t much resistive torque needed. The motors should also be easily controlled and move with synchronization between them by a simple digital circuit. In addition, they must move to exact and accurate locations step by step with minimum error.

But first, some types of DC motors will be mentioned as long as they have characteristics of precision, easy controllability and discrete in order to know the difference among them and take the best one that fits the printer’s needs.

Types of motors:

Brushed DC motor:

A brushed DC motor is the ordinary motor that is used in most of the applications. Its main parts are an armature which acts as an electromagnet with two poles, a rotor which is the permanent magnet, a commutator and the brushes that are connected to the commutator. When the windings are charged, the rotor starts rotating causing the commutator to reverse the direction of the current twice every turn, then changing the polarity to the permanent magnet, so the armature keeps rotating. This DC motor has pros such as low cost, simplicity and can be available in different sizes. It also has cons like short life due to the brushes, it produces noise, and it’s difficult to control it precisely and can be useless in robots as they produce the slightest torque.

Brushless DC motor:

A brushless DC motor is similar to the brushed one but it doesn't contain brushes. The prime feature of the brushless motor is that it consists of a rotor as a permanent magnet and a stator as an electromagnet. To follow the change in current orientation and measure the magnets position, these motors use Hall Effect sensors. On one hand brushless motors are efficient in high velocity applications, can produce more power and don't produce noise. On the other hand, they are expensive because of their sophisticated design and need controllers in order to control their speed.

Linear motor:

A linear motor has a structure that is almost similar to a brushless DC motor. It is a motor that works in a linear movement instead of rotation, so it doesn't produce any torque. Therefore, it's impossible to use it in application that has rotation movement.

Servo motor:

A servo motor is a combination of a DC motor, gears, control circuit and a position sensor. It uses servomechanism in its performance that means using an encoder for position and motion feedback to control the speed and final position. The position of servo motors in a classical DC motor, can't be controlled more precisely than in a servo motor. PWM (Pulse-Width-Modulation) is used for the control signal of servo motors. However, the position is determined by the duration of the positive pulse, rather than speed of the servo shaft. A neutral pulse value depends on the servo (most of the time will be about 1.5ms) keeps the servo shaft in the center position. If that pulse value is increased, the servo will turn clockwise, and a shorter pulse will turn the shaft anticlockwise. The servo control pulse is repeated every 20 milliseconds, to send commands to the servo to know where to go, even if that means remaining in the same position. Although servo motors are very accurate, quite small for simple applications and have a high torque, they are unsuitable for the 3D printer, because it's difficult to use it in continuous rotation as long as they move to certain angles [8].

Stepper motors:

A stepper motor is a brushless, synchronous motor with a special characteristic which is simple positioning control, and moving in discrete steps by dividing a full rotation into a number of steps. They have several coils that are organized in groups called "phases", by energizing each phase the rotor will rotate step by step with a specific angle as it's shown in Figure 3.2; this rotation angle is proportional to the input pulse of the motor. Therefore, for controlling the speed and the position of the steps, a computer is evolved, which is a unique feature for using a stepper motor to gain a very precise motion in its applications. In addition, microstepping is a unique technology in the stepper motor which is control the current in the motor winding to a degree that divides the number of positions between its poles, so that it lets the motor to move smoothly and accurately. The stepper motor has three main types: variable-reluctance, permanent-magnet, and hybrid [8].

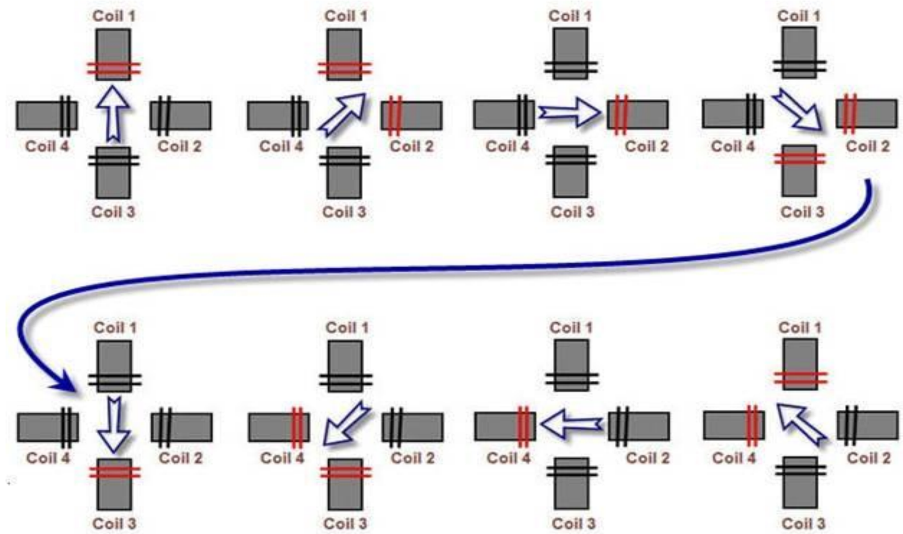

Figure 3.2 The rotation of a stepper motor

From the previous study of DC motors, it is concluded that the most convenient motor for printing 3D objects is the stepper motor because of these reasons:

- Stepper motors can contain a "home" switch or other element for keeping the motion at high range of stability.
- Excellent position accuracy is obtained.
- If the windings are energized, the motor has full torque when it's not moving.
- No errors are accumulated from one step to the next.
- Very good responding to start-stop-reverse commands.
- Long life because of the brushes absence.
- Its response to the input pulses provides an open-loop control, helping the motor to work easier and inexpensive to control.

- A large range of rotational velocities can be controlled as the velocity is proportional to the frequency of the input pulses [9].

3.1.3 Stepper Driver

As long as the Arduino can't provide enough power to permit the motors to work directly, a chip that is connected to it is used called stepper driver, which acts as a bus between the motor and the Arduino for controlling the motion of the stepper motor. The most fundamental function of the stepper driver is helping the motor to move in microsteps by providing fractional steps. This helps smooth out the movement of the stepper motor and not vibrating during the process. Stepper drivers usually work by chopping up a supply voltage using an embedded PWM chip. These chips need minor support circuitry.

The stepper driver is generally connected to three main wire interface:

- STEP pin where the controller pulses it to move the motor one step.
- DIR pin which is set to choose whether a step is a clockwise step or counterclockwise step.
- GND pin [10].

The driver in Figure 3.3 is used in the project which is A4988 DMOS Microstepping Driver.

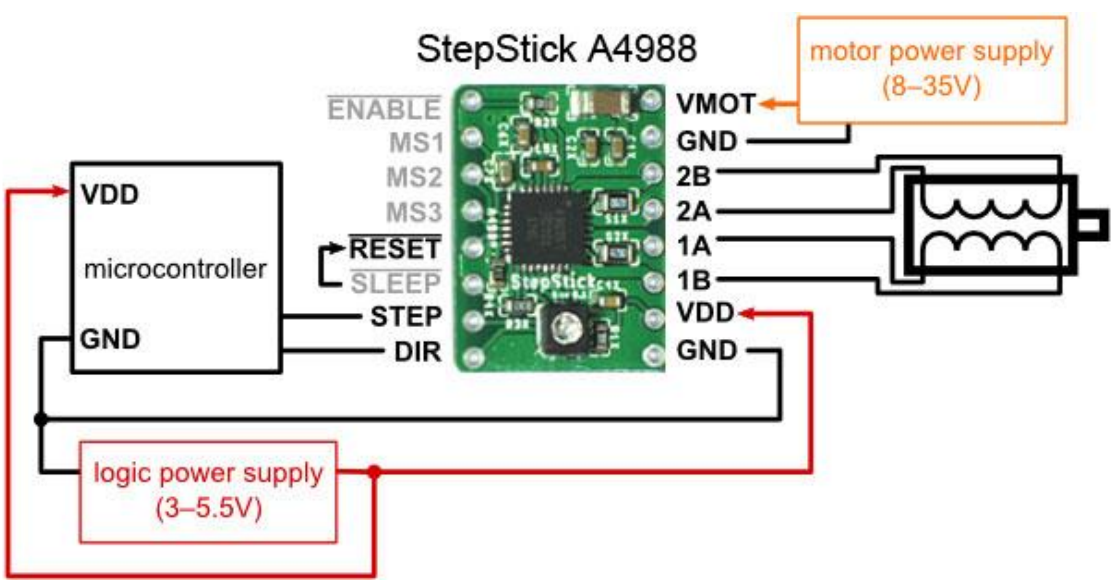

Figure 3.3 A4988 DMOS Microstepping Driver [11]

Figure 3.4 illustrates that functional block diagram of A4988 DMOS Microstepping Driver.

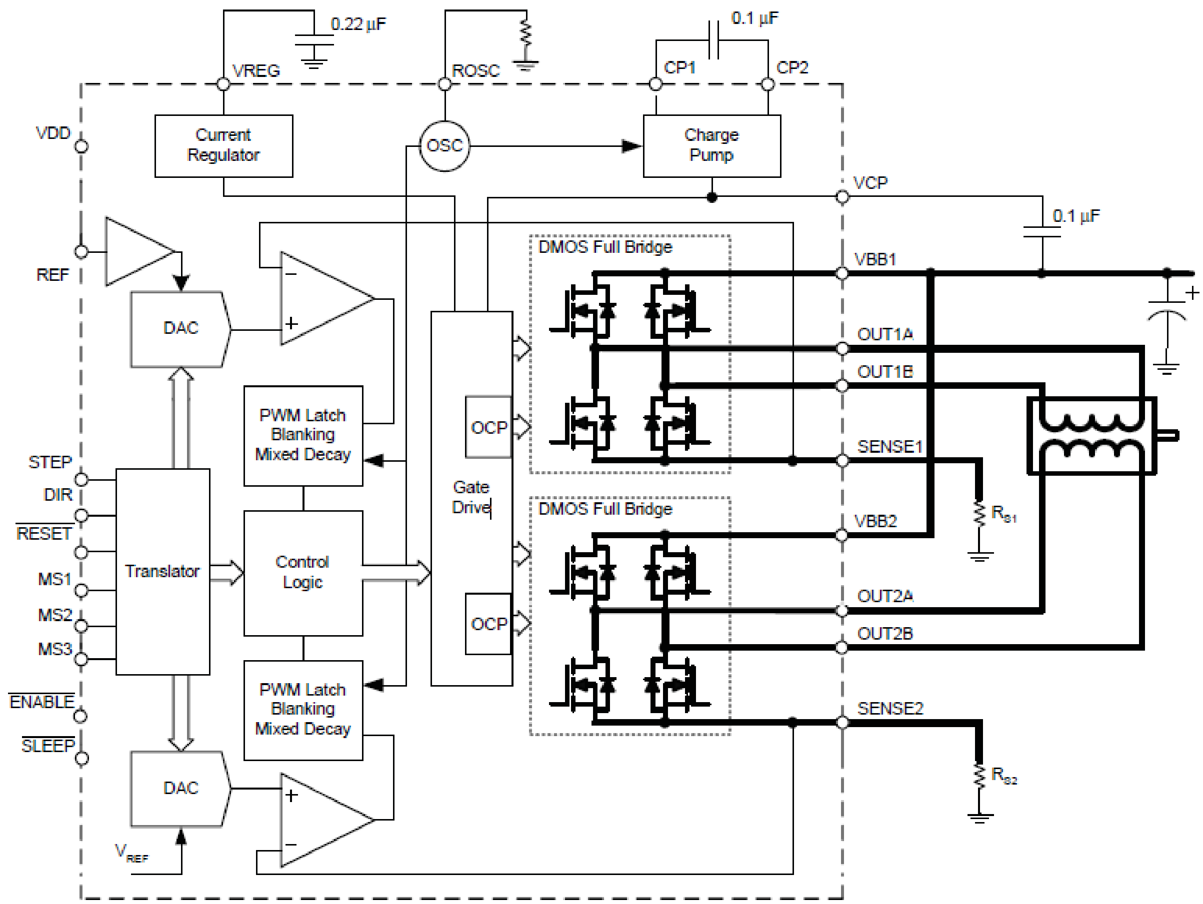

Figure 3.4 Functional block diagram of A4988 DMOS Microstepping Driver [12]

A4988 DMOS Microstepping Driver:

This is a driver designed to operate bipolar stepper motors in full-, half, quarter-, eighth-, and sixteenth-step modes as shown in Figure 3.5. Its output drive capacity is up to 35V and ±2 A.

It has a built in translator. The translator is used to make the implementation of micro stepping easier when a complex microprocessor is not available. It does not need phase sequence tables, high frequency control lines, or complex interfaces to a program [13].

While the stepping operation is in process, the chopping control in the A4988 automatically selects the current decay modes which are two types: one is slow or the other is mixed. The device is set at the beginning to a fast decay for a proportion of the fixed off-time, and then it moves into a slow decay for the remaining of the off-time in the mixed decay mode. Mixed decay current control results in reduced audible motor noise, high step accuracy, and less power dissipation [14].

A circuitry that has internal synchronous rectification control makes the power dissipation during PWM operation to be better. Internal circuit protection contains: under voltage lockout (UVLO), crossover-current protection and thermal shutdown with hysteresis. Special power-on sequencing is not required [9].

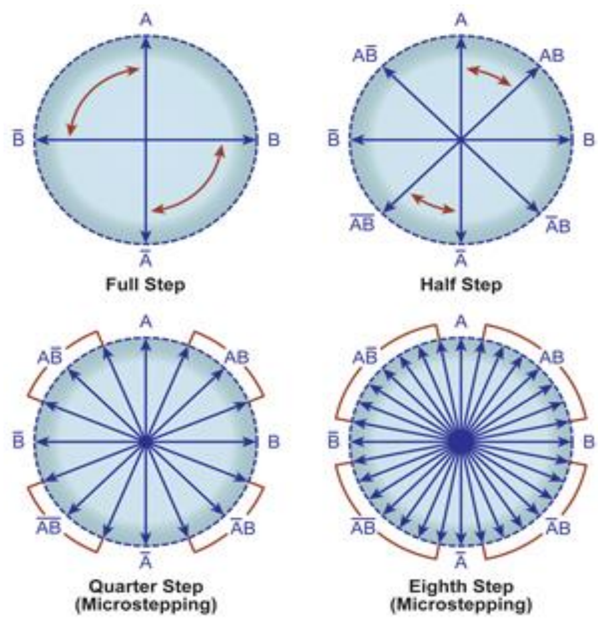

Figure 3.5 Microstepping in the stepper motor

3.1.4 Extruder

The extruder is the main part of the whole procedure; it’s a moving head that helps creating the object from the plastic filament layer by –layer.

The hot end of the extruder consists of several parts which are:

3.1.4.1 Cartridge Heater

A cartridge heater is a joule heating element (electrical resistance) that is used in the plastic heating process; it’s highly compacted and basically depends on the surface watt density which can reach up to 50 W/cm². But in this 3D printer will not reach to that level.

In Figure 3.6, it's seen that it consists of an outer metal enclosure called a sheath containing resistive wiring while electrical insulation separate between this wiring and the sheath.

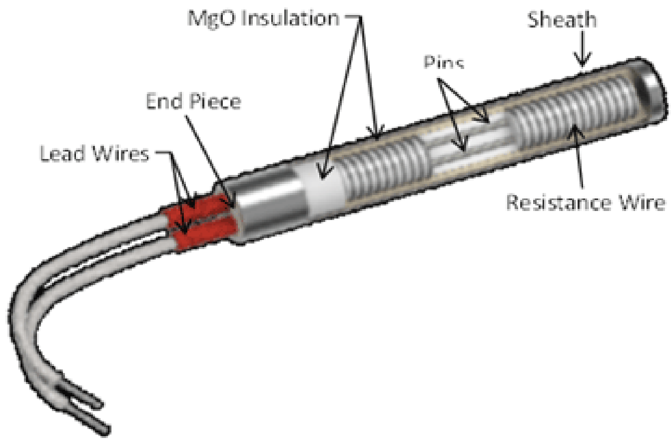

Figure 3.6 Cartridge heater

3.1.4.2 NTC Thermistors

For permitting the cartridge heater to work properly, a sensor is needed for the temperature control as it's an important factor that should be put between the heater and the working surface of the part.

One of the most popular sensor types for cartridge heater applications are thermocouple, Resistance Temperature Detectors (RTD) and thermistors.

A Thermistor is made of semiconductor material that is like a type of resistor used to measure temperature changes, because the temperature change leads to the change of resistance. It works in the range of (-40 ~ 150) °C with accuracy = ±0.35. It has two different types, Positive thermal coefficient (PTC) an increase in resistance occurs with an increase in temperature, whereas the negative ones (NTC) works inversely.

But for a 3D printer the most suitable one is NTC thermistors because of the following reasons:

- It's used in these kinds of machines, unlike the PTC which is used in other applications such as fuses.
- It is usually more accurate than a thermocouple, and the thermocouples can

handle higher temperatures and give small voltages.

- It typically measures limited temperature range, while RTDs are useful over larger temperature ranges,
- It responds very rapidly to changes in temperature.
- Small in size compared to thermocouples.

The relationship between its resistance and the temperature is nonlinear. Furthermore, the resistance changes negatively and sharply with any positive change in temperature. Figure 3.7 can explain the characteristics of RTD, thermocouple and thermistors. The sizes are chosen based on engineering standard (see Appendix-D-Table D.10).

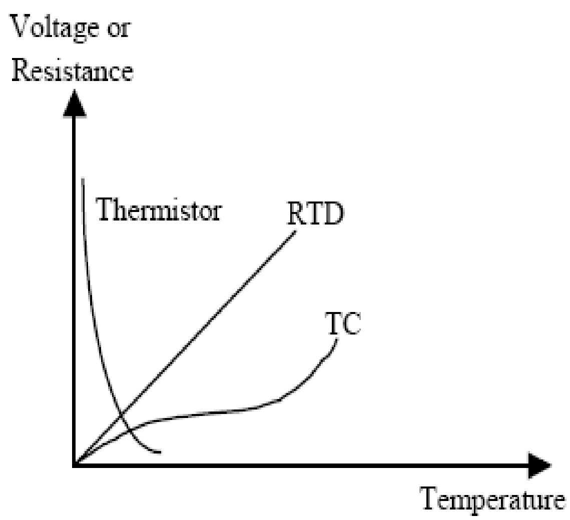

Figure 3.7 Characteristics of the Three Temperature sensors

3.1.4.3 Nozzle

After melting the plastic filament via the cartridge heater, the molten plastic will exit from a small pipe called nozzle that is used to direct or modify the flow of the molten plastic over the table in a prescribed geometry, and deposits a thin string of plastic.

It also has varying cross sectional areas and whenever the nozzle is smaller, it gives smaller details and sharper corners. The sizes are chosen based on engineering standard (see Appendix-D-Table D.11).

3.1.5 PTFE Tubing

PTFE (polytetrafluoroethylene) tube is a tube that is used for the plastic string to enter through it before melting it and after it. It has very excellent properties such as:

- Non-stick properties.
- Temperature resistance is possible that up to 260º C.
- Aging resistance.
- Low permeability.
- Superior chemical resistivity and low coefficient of friction.
- Mechanical resistance under severe conditions.

3.1.6 End Stops

For controlling the motion of the parts in the 3D printer an end stop switch as it's seen in figure is used, which is a switch controlled by the motion of a machine part or existence of an object.

While building the object, the stepper motors shouldn’t move continuously, they have to stop at certain points to draw the exact figure accurately. Because of this, the limit switch is used as an interlock, which is an electromechanical device that consists of an actuator connected to a set of contacts mechanically. When an object comes to the end of its motion, the device operates the contacts to break the electrical circuit, then the motor stops moving.

In this printer, four limit switches are used on the x, y, and z axes.

A sample of limit switch shown in Figure 3.8.

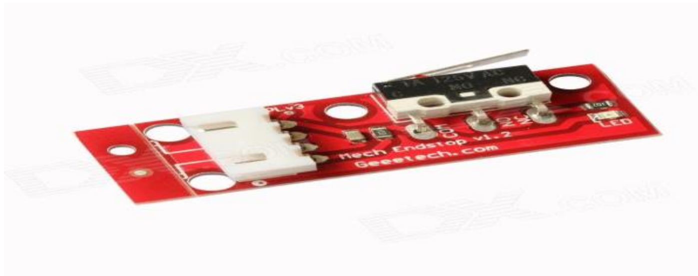

Figure 3.8 Limit switch (end stop) for 3D printer

3.1.7 RAMPS 1.4

It's an electronic device used with Arduino mega as a shield type it's used for many functions related to motor so it has maximum of five stepper drivers to handle five stepper motors. In our project, it is used for three reasons. Firstly, it handles more than one stepper motor for different axis. Secondly, it has three MOSFET’S which used for fan and heater. Finally, the cost is low if it's compared with ready circuit. Ass shown in the following Figure 3.9.

Figure 3.9 RAMPS 1.4

3.1.8 Graphical LCD

It's used as the feedback of the process and give us the information like (error, temperature, etc...) as it's shown in Figure 3.10.

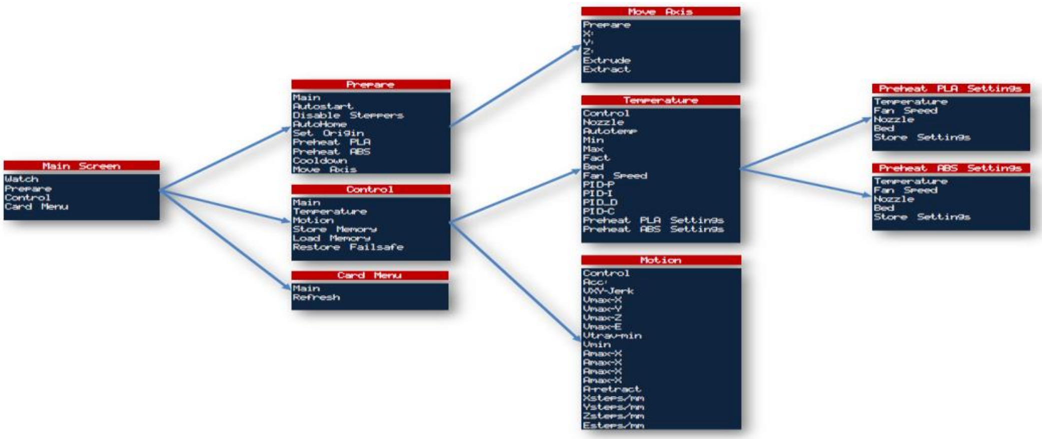

Figure 3.10 LCD Screen Menu Tree [15]

3.1.9 Fan

It's used for cooling for many reasons. Firstly, 3D printer produce high temperature during the process because of that is needed to use system that can cool down the controller to prevent from damage. Secondly, heating is occurred by the uneven cooling between outer of a printed part and inner sections. The outside material will cool down and shrink faster than the inside material if it's compared between them. This will cause the outside material to bend unlike the hot material which won’t.

3.1.10 Bearing

To decrease the friction and make the motor move faster and better bearings will be used. There are many kinds of bearings but linear bearings and ball bearings will be used for the project and they were selected depending on the desired requirements.

3.1.10.1 Linear Bearing

It is designed to make movement frictionless in one direction.

3.1.10.2 Ball Bearing

Generally they use the bearing to reduce the friction between two parts connected, so it allows the rotation and linear motion to work properly. In our project it's used between the shaft and the object which holds the shaft inside it. The following Figure 3.11 shows the design of 608 bearing.

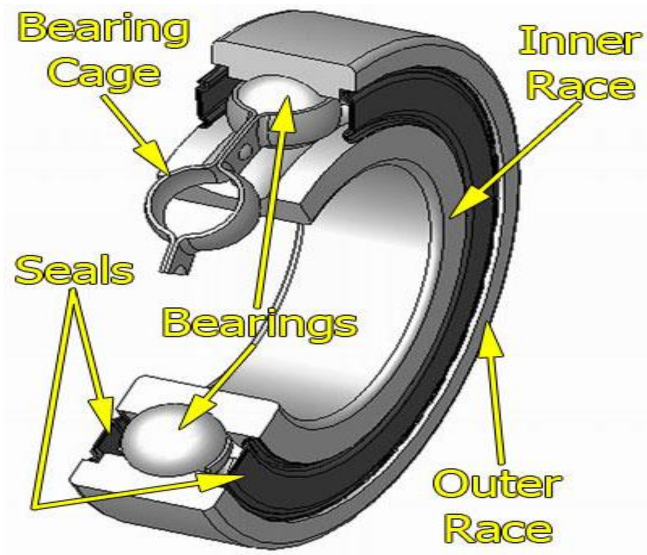

Figure 3.11 608 Bearings

3.1.11 Rods

It's a mechanism to connect the parts or to be as a transmission where the rods are usually made from steel or aluminum and there are two common types. Linear Rods, Threaded Rods.

3.1.11.1 Linear Rods

It is a steel metal and looks like a shaft shape; it's used to hold the extruder and makes move it easily to the three axes X, Y, Z. Steel is used because it's strong enough to carry the printed parts and the table, it's also available everywhere. The sizes will be chosen based on engineering standard (see Appendix-D-Table D.9).

3.1.11.2 Threaded Rods

It is a long shaft used in 3D printer to hold the plate where it's threaded all and usually they use it in tension.

In this Figure 3.12 thread rod is shown. The sizes will be chosen based on DIN 975-1986 (see Appendix-D-Table D.4).

Figure 3.12 Thread rods

3.1.12 Pneumatic Quick Release Fittings

Generally it's used to connect two parts as fluid easily. It could be used as assembly part and if the tool is changed as shown in Figure 3.13, i.e. It's used to connect PTFE tubing in the project so it's used to protect the plastic filament when it's inside it.

Figure 3.13 Pneumatic Quick Disconnect

3.1.13 Timing Pulley

Timing belts transmit torque and motion from a driving to a driven pulley. The main purpose of the timing belts in the 3D printer is to convert the motion of the motor from rotary to linear of the sliders synchronously and with very high precision. During operation, when the belt is under load, a difference of tensions of the belt on the entering and leaving sides of the pulley is developed. This is called effective tension Te, and it represents the force transmitted between the driver pulley and the belt. At the driver pulley effective tension is generated. The generated tension is the actual working force that overcomes the load and overall resistance to the belt motion [16]. The sizes will be chosen based on ISO (see Appendix-D-Table D.6).

3.1.14 Timing Belt

First of all, should be specified pitch p of timing belt as shown in the Figure 3.14 below; belt pitch is known as the distance between the centerlines of two close teeth and is measured at the belt pitch line. On another hand, pulley pitch is measured on the pitch circle, it is known as the arc length between the centerlines of two contiguous pulley grooves. Pitch circle corresponds with the pitch line of the belt while the belt is rolled around the pulley. The one which is used in our project is GT2 Timing Belt.GT2 Belt have a special profile with rounded teeth which reduces slippage, it is very suitable for precision applications such that 3D printers and CNC machines [16]. The sizes will be chosen based on DIN/ ISO 10823 (see Appendix-D-Table D.8).

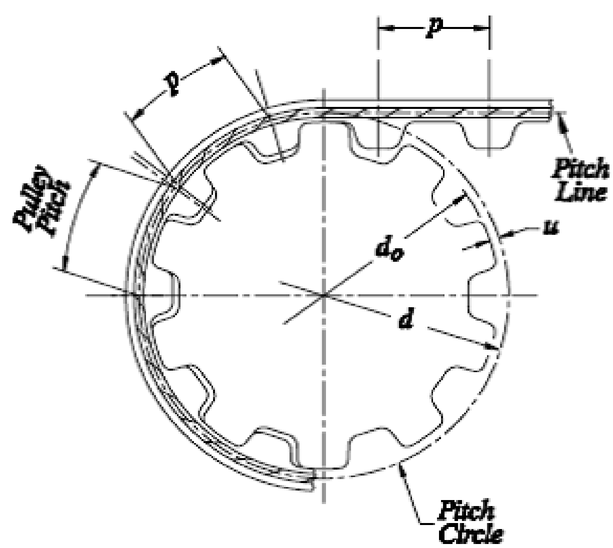

Figure 3.14 Timing belt pitch and pulley pitch [17]

3.1.15 Braided Cable Sleeving

Use this component by covering the cables to protect them from scratch which leads to cutting it. It will be exposed to heat after adjusting it to become not removable, that would give the cable long life and more protection. The sizes will be chosen based on engineering standard (see Appendix-D-Table D.7).

3.1.16 Nuts

A steel part inner threaded and it's usually used with thread rod to give the rod more strength and stack it together as in the Figure 3.15 below. The sizes will be chosen based on ASMEANSI B18.2.4.6M-2010 and DIN 439-1-1987 (see Appendix-D-Table D.2 and Table D.3).

Figure 3.15 Nuts

3.1.17 Bolts

Bolt is a sequence threaded used to join two parts by having the same diameter and have inner threaded. It can be seen almost in every machine or mechanical designs. Steel bolt is used because it has long life it also doesn’t become dusty and can be found easily in Cyprus. The sizes will be chosen based on engineering standard (see Appendix-D-Table D.1).

3.1.18 Set Screws

It uses generally Power screw that will be used to lift the load of the printing table in addition to protect the parts to resist the torque that will apply on it, generally it's used in gears. The sizes will be chosen based on ISO 7434-1983 (see Appendix-D-Table D.5).

3.1.19 Aluminum for Extruder and Brackets

An aluminum part used for (90 degree) intersection to make the farm of 3D printer becomes cubic shape.

3.2 Materials Selection

Different materials are used in manufacturing the prototype, each part is made from different materials than others. The material should be selected to fit the specifications and the properties of each part of the prototype.

3.2.1 Filament

There are different types of plastic that can be used for 3D printer. Each type of material is used for specific applications based on material properties. Our project is based on the most common types of plastics which are PLA and ABS. They are both thermoplastics that are moldable and soft when heated. They can also be reprocessed and used once more.

There are three main criteria that the material used for printing must contain, first, extrusion into plastic filament, second, extrusion and trace-binding through the process of 3D printing, so in the end it's used in the application.

ABS is strong, flexible, and high temperature resistant. This makes it preferable for professional applications. It is petroleum based, so when it's heated it has an undesirable smell. To print using ABS a heated bed is required because it will warp when cooled.

PLA is a biodegradable plastic, with a wide range of colors and translucencies. It is plant based that will give a sweet smell when heated unlike the ABS type. When the head of the extruder is properly cooled, PLA has lower layer heights, sharper printed corners, and bigger maximum printing speeds. PLA also does not need a cooler bed. Because of the previous properties PLA is preferred for home printers and hobbyists.

3.2.2 Plywood

It's a type of thin wood glued to each other to have the same thickness and shape and usually it has 90 degree angel for boundary .It has many applications because it has high flexibility, strength and low thickness. There are many types of Plywood deepens on the application for example: Softwood plywood, Hardwood plywood, Tropical plywood, Aircraft plywood, Decorative plywood (overlaid plywood), Flexible plywood and Marine plywood. In our project Tropical Plywood will be used because it's strong enough and cheap comparing with other types finally, it has high quality and density.

3.2.3 Aluminum

Aluminum is one of the most important materials that trademark companies use it for component structure. It can resist corrosion, can be recycled and has low density which makes the product stronger and at the same time gives good looking, for example, it's used in most of the smart phones nowadays. It will be used in our project because it has low weight which doesn't make the printer work with high pressure on it; it also gives us strong frame transmission.

3.3 Calculations

This section is about prototype studying and calculations by using the relative equations, starting from studying motor selection, cartridge heater, thermistor, electrical circuit, belt and power screw calculations, shafts and guiding rods and finally PID controller for the extruder's heater.

3.3.1 Motor Selection

The stepper motors that are selected need some calculations that will allow them to work properly.

The motor will be selected according to the needs of the Z-axis, which is most critical. The selection of this motor will be used for the rest of the motors (X, Y-axis and feeder motor). The rise torque to move a load up the thread is defined by the following Eqn. 1 and Figure 3.16 clarifies its parameters:

$$T_r = \frac{F \times D_p}{2}\left[\frac{L + \pi \times f \times D_p}{\pi \times D_p - f.L}\right] \qquad (1)$$

Where:

F is the Load to move [N].

Dp is the Pitch Diameter [m].

L is the lead [m/rev].

f is the friction coefficient.

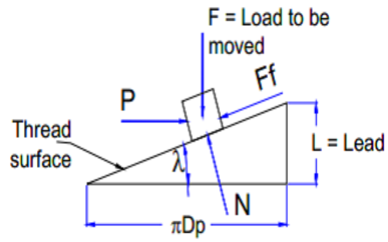

Figure 3.16 Free body diagram

The force carried on the motor calculated through using Eqn. 2:

$$F = \left(m_{material} + m_{plate}\right) \times g \qquad (2)$$

The lowering torque is found from the Eqn. 3:

$$T_l = \frac{F \times D_p}{2}\left[\frac{\pi \times f \times D_p - L}{\pi \times D_p + f.L}\right] \qquad (3)$$

The electrical specifications for the motor are also needed. There are 2 critical parameters:

- Amps per phase - This is the maximum current that the motor windings can handle without overheating.
- Resistance per phase - This is the resistance of each phase. A Voltage rating is often stated [18].

That leads for using Ohm's law Eqn. 4:

$$V = R \times I \qquad (4)$$

In addition, the motor draws the highest current when the motor stops

3.3.2 Cartridge heater:

In the cartridge heater there is "Watt density" parameter that refers to the heat flow rate of the cartridge heater. To calculate it, this Eqn. 5 is used:

$$\text{Watt Density} = \frac{W}{\pi \times D \times HL} \qquad (5)$$

Where:

W= wattage (w)

D= diameter (mm)

HL = Heated Length (mm)

Watt Density W/mm.

3.3.3 Thermistor

The thermistor resistance-temperature relationship can be approximated by Eqn. 6,

$$R = R_{ref} \times e^{\beta(\frac{1}{T}-\frac{1}{T_{ref}})} \qquad (6)$$

Where:

T is temperature (in kelvin)

T_{ref} is the reference temperature, usually at room temp (25 °C-298.15 K).

R is the resistance of the thermistor (ohm).

R_{ref} is the resistance at T_{ref} [19].

β is a calibration constant that depends on the thermistor material, usually it's between 3,000-5,000 K.

The melting temperature of the PLA/PHA plastic filament should be set between $180-220$C°.

3.3.4 Belt Calculations

Finding the length of the belt:

Here an example will be given, as shown below in Figure 3.17 that displays the procedure

1- taking the both of the small and the large pulley and adding them

10+2=12

2- taking the half of pi=3.16 because the half distance from the diameter is known and multiply them

12*1.6=19.2

3-taking the distance as twice because one way from P10-P2, P2-P10

So 24+24=48

4-Finally adding the total distance (48) to the (19.2)

And the result is 67.2$\cong$ $67 inch$

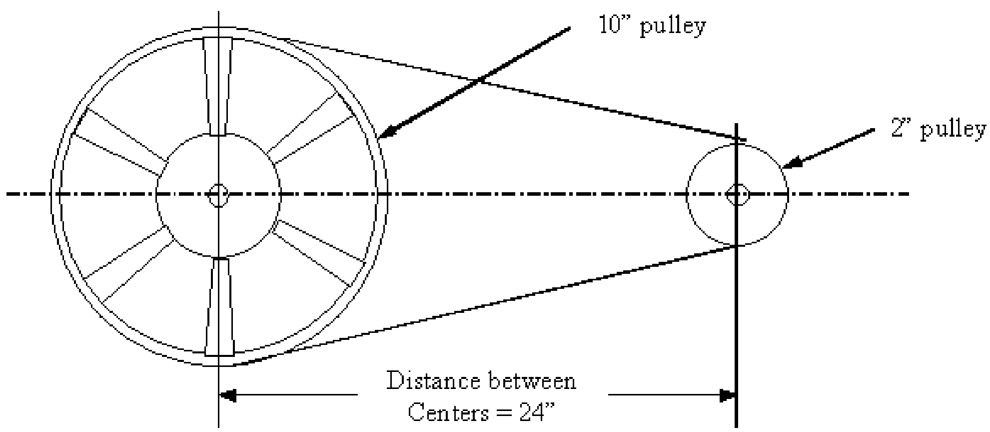

Figure 3.17 Finding the length of the belt [20]

Analyze the force on the belt:

Maximum speed of sliders V = 180 mm/s = 0.18 m/s which will be used in Eqn. 7

$$\omega = \frac{V * 60}{r_{pulley}} \qquad (7)$$

From the T vs ω graph shown in Figure 3.18 can be reached for Eqn. 8:

$$F = \frac{T}{r} \qquad (8)$$

Eqn. 9 to calculate force on the belt (FB):

$$FB = \frac{F}{2} \quad (9)$$

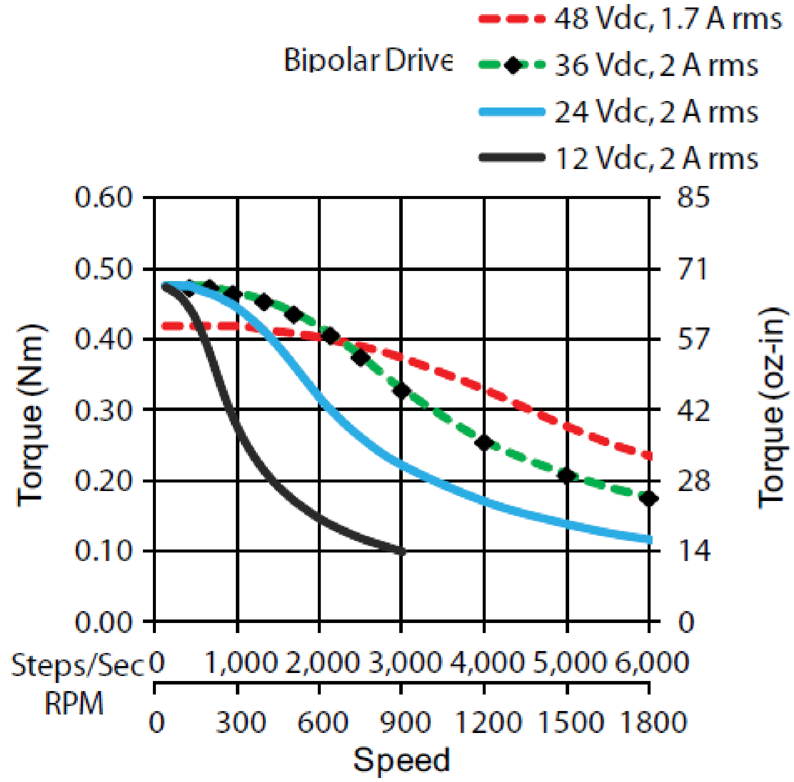

Figure 3.18 Torque speed characteristic of the stepper motor used

A presentation of belt force analysis is seen in Figure 3.19.

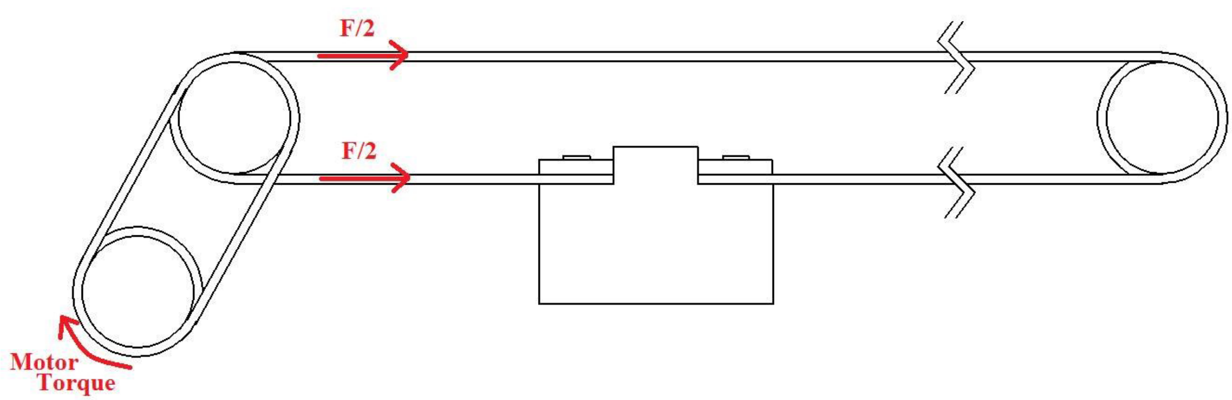

Figure 3.19 Belt force analysis

GT2 Belt is 2mm tooth pitch and 6mm wide. Moreover, there are pulleys designed to be used with GT2 6mm wide belts and with the same pitch. From the datasheet [21], the Working tension of this belt is 89 N. So, the GT2 Timing Belt is good for the application. Details are clarified in Figure 3.20.

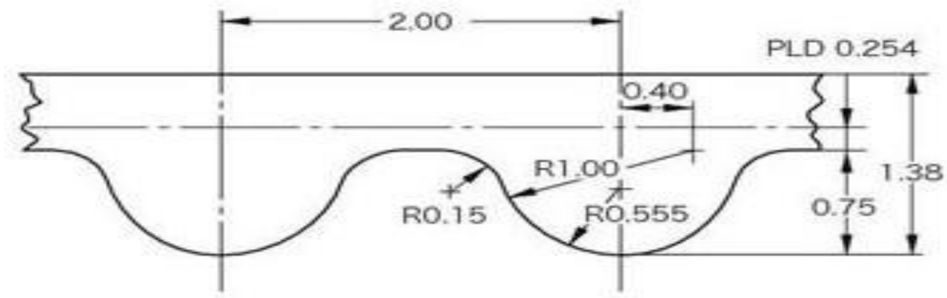

Figure 3.20 GT2 timing belt technical details

3.3.5 Power Screw Calculations

The most available power screw is $T8\ Stainless\ Steel\ power$, with M4x5mm it is commonly used in 3D printers and very suitable for precise applications. For power screw design, it should be specified how much torque will be applied to the nut of the screw to overcome the friction forces and the force caused by the table and the weight of the printed parts. Also, specifying the power screw pitch diameter D_P , and the lead of the screw L, lead is defined as the axial distance that the screw would move in one revolution.

Power screw calculations:

Eqn. 10:Screw calculation

$$D_P \quad = \mathrm{D} - \frac{L}{2} \qquad (10)$$

Where: Dp is the pitch diameter.

D:is the major diameter.

L:the axial distance that the screw would move in one revolution

The pitch angle can be calculated according to Eqn. 11:

$$\lambda = tan^{-1}\left(\frac{L}{\pi\ D_P}\right) \qquad (11)$$

Where: λ is the pitch angle.

The maximum mass that the power screw will carry is the mass of the table and the mass the printed parts, were calculating according to the Eqn.12.

$$F = mass\ \times\ 9.81 \qquad (12)$$

In power screws, the first engaged thread carries 0.38 of the load, the second 0.25, the third 0.18, and the seventh is free of load. So the maximum force carried is equal to 0.38F. With the number of teeth nt set to 1 having the largest level of stresses in the thread-nut combination.

The bending stress on the root of the thread is calculated by Eqn. 13:

$$\sigma_b = \frac{6 \times F}{\pi \times d_r \times n_t\ \times L} \qquad (13)$$

Where:

σ_b is the binding stress.

d_r is the inside diameter.

n_t is the number of teeth.

L:the axial distance that the screw would move in one revolution

In order to find transvers shear at the center of the thread Eqn. 14 is needed to be used:

$$\tau = \frac{3 \times F}{\pi \times dr \times nt \times L} \qquad (14)$$

The stainless steel tensile strength is 505 MPa, which means the power screw can bear the calculated stresses with a very high factor of safety.

3.3.6 Shafts and Guiding Rods

Rotating shafts will be used to transmit motion and carry the mechanism's weight. Moreover, sliders will be attached to the shafts so they operate as guiding rods. For these reasons, stainless steel rods are chosen to overcome friction between moving parts. With the least diameter in market is equal to 8mm, bending stress calculations will be based on that diameter as expressed in Eqn.15.

$$\sigma = \frac{Mc}{I} \qquad (15)$$

Eqn. 16:

$$M = F \times D \qquad (16)$$

Where:

D is the half of the shaft's length.

F is the summation of the weights subjected on the shaft.

F=weight of the extruder + weight of sliders + weight of inside shafts

The bending strength of the stainless steel is about 505 MPa [22].

3.3.7 PID Controller for The Extruder's Heater

The PID controller is a proportional, integrator, differentiator controller that helps the device to give a desired output with minimum errors, so it calculates an error value as the difference between a measured process variable and a desired set point. In Figure 3.21 as seen, the block diagram of the PID controller along with plant. It is an important component in the extruder heating process which gives an accurate temperature of the plastic filament.

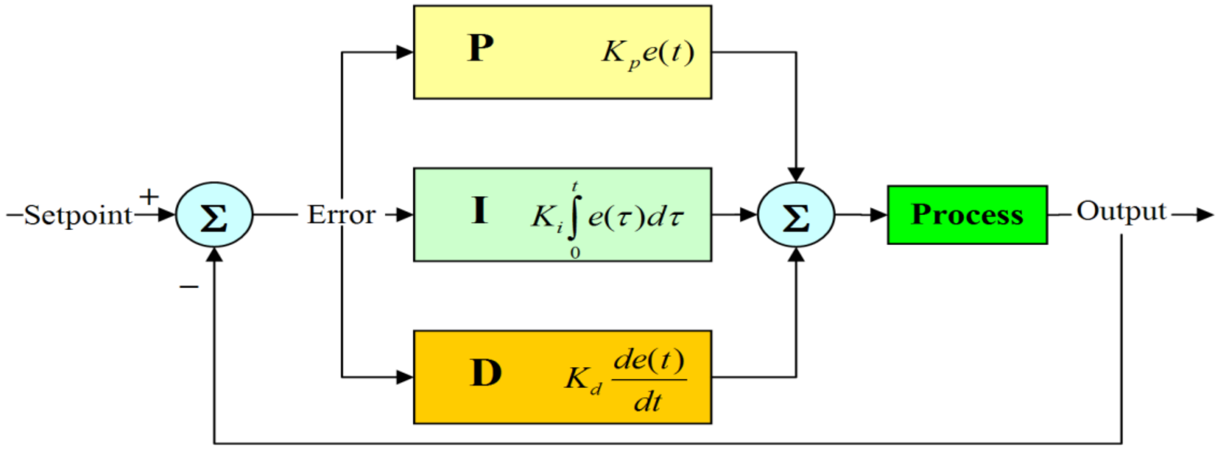

Figure 3.21 Block diagram of the PID controller [23]

The PID equation is determined by Eqn. 17:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de}{dt} \tag{17}$$

Where:

e: error

t: present time

τ: Variable of integration; it takes values from time 0 to the present t.

A PID controller operates on the error in a feedback system and does the following:

- It calculates a gain proportional to the error- Kp.
- It calculates a gain proportional to the integral of the error- Ki.
- It calculates a gain proportional to the derivative of the error- Kd.
- Then the three terms - the P, I and D terms, are added to have a control signal that is applied to the system being controlled [24].

3.4 Electrical circuit

The best way to power the 3D printer is using ATX power supply unit or a PC power supply unit to convert the 220VAC current to DC one with voltage of 12V and current of 10-20 A depending on the component wanted to electrically be fed. For example:

- Electronics such as Arduino, stepper motors, extruder…etc.
  The power should be computed by using Eqn. 18

$$P = V \times I \tag{18}$$

Complete circuit of the 3D printer is show on the Figure 3.22.

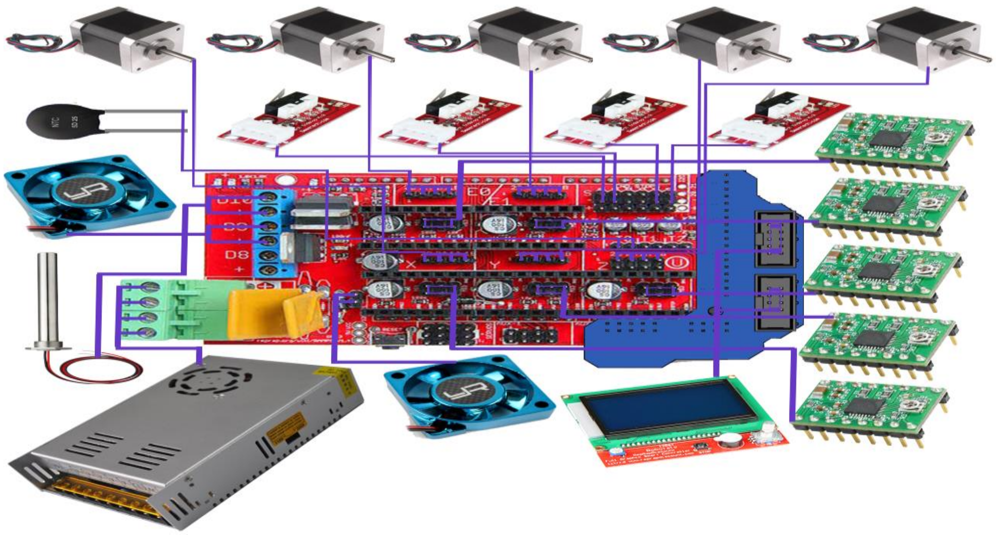

Figure 3.22 3D circuit of 3D printer

The circuit below in Figure 3.23 is the electrical circuit of the 3D printer drawn by Visio 2010:

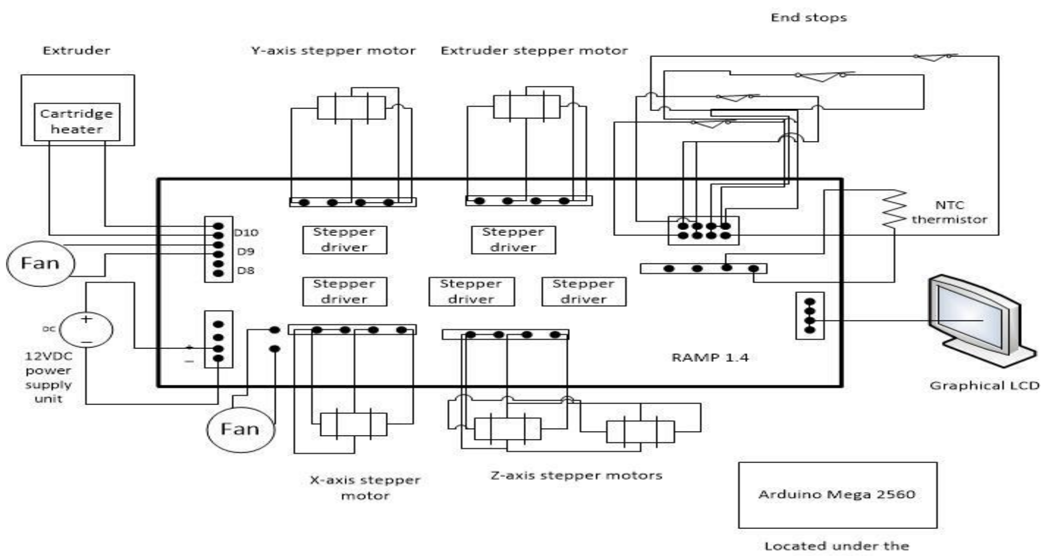

Figure 3.23 Schematic electrical circuit of 3D printer

3.5 Theoretical Results

The calculations results of the previous equations will be introduced in this part.

- ✓ **Cartridge heater:**

By using Eqn. 5:

W= wattage= 1000 watt

$D_{cartridge}$= diameter (mm) =19.05 mm

HL = Heated Length (mm) = 241.3mm

Watt Density W/mm.

$$Watt\ density = \frac{1000}{\pi \times 19.05 \times 241.3} = 0.0692\ W/mm$$

- ✓ **NTC thermistor:**

By using Eqn. 6:

$$\mathrm{R} = \mathrm{R_{ref}} \times \mathrm{e}^{\beta(\frac{1}{T} - \frac{1}{T_{ref}})}$$

Where:

T is temperature (in kelvin) = 220C = 493.15 K

T_{ref} is the reference temperature = 298.15 K

R_{ref} is the resistance at Tref = 100Kohm

β is a calibration constant = 4085 K

$$R = 100000 \times e^{4085\,(\frac{1}{493.15} - \frac{1}{298.15})} = 443.75\ ohm$$

- ✓ **Estimating the power consumption of the electrical parts:**

By using Eqn. 18 and V= 12V

- Four Stepper motors, 1.2A each: 12*1.2*4= 30 W
- Cartridge heater: 40 W
- Two Fans: 0.08*12*2=1.92 W
- LCD display: 5 W
- Remained electronics such as drivers, end stops…etc: 100mA*12= 5W

Total consumption is about 77W and 6.5 A,

Therefore, a PC power supply unit is suggested to be used in the project with 160W and 16A, more power is better than less because the RAMPS 4.1 board only draw needed power and current which are needed for the printer to be operated.

- ✓ **Stepper motors:**

1. Calculation s per unit:

   - Steps per inch.

The steps per inch should be computed by using Eqn. 19 and Eqn. 20

$$Leadscrew\left(\frac{Revolution}{Inch}\right)*\left(\frac{1}{Microstep}\right)*Motor\left(\frac{Step}{Revolution}\right)=Step/Inch$$

(19)

$$1\frac{turns}{inch}*\frac{1}{\frac{1}{16microstep}}*200\ step\ per\ revolution=3200micro\ steps\ per\ inch$$

$$3200microstep/in\times 1/2.54\frac{in}{cm}=1259.84microstep/cm$$

- Steps per revolution.

Most stepper motors, including the ones are used, move 1.8 degrees per step, steps per revolution is needed to be calculated in our project by using Eqn. 21 so stepper motor can be moved to the correct coordinate.

$$\frac{\frac{360\ Degree}{1\ Revolution}}{\frac{Degree}{Step}}=\frac{Step}{Revolution}$$

(21)

$$\frac{\mathbf{360}\boldsymbol{degree}}{\mathbf{1}\boldsymbol{Revolution}}\div\mathbf{1.8}\frac{\boldsymbol{degree}}{\boldsymbol{step}}=\mathbf{200}\ \boldsymbol{Step/Revolution}$$

2. For the torque calculations:

The rise torque to move a load up the thread is defined by Eqn. 1:

$$T_r = \frac{F \times D_p}{2}\left[\frac{L + \pi \times f \times D_p}{\pi \times D_p - f.L}\right]$$

$$T_r = \frac{19.62 \times 0.01045}{2}\left[\frac{0.0031 + \pi \times 0.15 \times 0.01045}{\pi \times 0.01045 - 0.15 \times 0.0031}\right]$$

$$T_r = 0.02541730843\ \mathrm{N.m}$$

3. The force carried on the motor is calculated through using Eqn. 2:

$$F = (m_{material} + m_{plate}) \times g$$

$$F = 2\mathrm{kg} \times 9.81\frac{m}{s^2} = 19.62\mathrm{N}$$

4.The lowering torque is found from Eqn. 3:

- ✓ finding:
- ✓ D_P = 10.45 mm.
- ✓ f= 0.15 for led angle λ =5.394265743°.
- ✓ L= 3.10 mm/rev

$$T_l = \frac{F \times D_p}{2}\left[\frac{\pi \times f \times D_p - L}{\pi \times D_p + f.L}\right]$$

- ✓ $T_r = \frac{19.62 \times 0.01045}{2}\left[\frac{\pi \times 0.15 \times 0.01045 - 0.0031}{\pi \times 0.01045 + 0.15 \times 0.0031}\right] = 0.005617486808\ \mathrm{N.m}$
- ✓ **Force on the belt:**
- ✓ Maximum speed of sliders V = 314.16 mm/s = 0.31416 m/s which will be used in Eqn. 7

$$\omega = \frac{V * 60}{r_{pulley}}$$

$$\omega \ = \frac{0.31416 \ * 60}{5 \ * \ 10^{-3}} = 3739.2 \ 1/\text{min}$$

$$\omega \ = \frac{1}{3739.2} * 0.000291 = 7.78241335 * 10^{-8} \ \text{rad}$$

From the T vs ω graph shown in Figure 3.18 can be reached for Eqn. 8:

$\omega = 7.78241335 * 10^{-8}$ rad , Torque (T) = 0.45N.m

$$\text{F} \ = \frac{\text{T}}{\text{r}}$$

$$\text{F} = \frac{0.45}{5 \ * \ 10^{-3}} = 90 \ \text{N}$$

Eqn. 9 is used to calculate force on the belt (FB):

Force on the belt (FB):

$$\text{FB} = \frac{\text{F}}{2} = 45 \ \text{N}$$

Power screw calculations:

Eqn. 10.To calculate the power on screw

$$D_P = \text{D} - \frac{\text{L}}{2}$$

$$D_P = 12 - \frac{3.10}{2} = 10.45$$

Where: D_p is the pitch diameter.

D is the major diameter.

The pitch angle can be calculated according to Eqn. 11:

$$\lambda = \tan^{-1}(\frac{\text{L}}{\pi \text{Dp}})$$

$$\lambda = \tan^{-1}\left(\frac{3.10}{\pi \times 10.45}\right) = 5.394265743°$$

Where: λ is the pitch angle

The maximum mass that the power screw will carry is the mass of the table and the mass the printed parts, which are both equal to 2.5 kg. Where calculating according to the Eqn.12.

$$F = \text{mass} \times 9.81$$

$$F = 2 \times 9.81 = 19.62 \text{ N}$$

In power screws, the first engaged thread carries 0.38 of the load, the second 0.25, the third 0.18, and the seventh is free of load. So the maximum force carried is equal to 0.38F. With the number of teeth set to 1 having the largest level of stresses in the thread-nut combination.

The bending stress on the root of the thread is calculated by Eqn. 13:

$$\sigma_b = \frac{6 \times F}{\pi \times dr \times nt \times L}$$

Where: σ_b is the binding stress.

d_r is the inside diameter.

L is the lead of the screw.

$$\sigma_b = \frac{6 \times 19.62}{\pi \times 0.009853 \times 1 \times 0.00310} = 1.226789935 \text{ MPa}$$

In order to find transvers shear at the center of the thread Eqn. 14 will be needed to be use:

$$\tau = \frac{3\times F}{\pi\times dr\times nt\times L}$$

$$\tau = \frac{3\times\ 19.62}{\pi\times 0.009853\times 1\times 0.00310} = 0.6133949673\ \text{MPa}$$

The stainless steel tensile strength is 505 MPa, which means the power screw can bear the calculated stresses with a very high factor of safety.

- ✓ **Shafts and Guiding Rods**

By using Eqn. 16:

$$M = F\times D$$

Where: D_{rod} is the half of the shaft's length.

F is the summation of the weights subjected on the shaft.

F=weight of the extruder + weight of sliders + weight of inside shafts =2.4 N

With the least diameter in market is equal to 8mm, bending stress calculations will be based on that diameter as expressed in Eqn.15

$$\sigma = \frac{32(2.4\times 0.45)}{\pi(0.0083)} = 1.325396345\ KPa$$

The bending strength of the stainless steel is about 505 MPa, so shafts with 8mm diameter will be more than enough.

3.6 Designing by SolidWorks

The full assembly SOLIDWORKS sketch of the designed 3D printer is shown in the Figure 3.24 below.

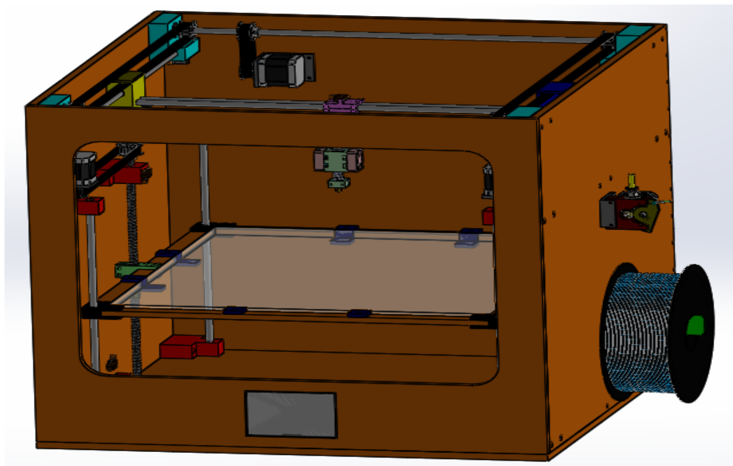

Figure 3.24 Final mechanical design of 3D printer

Bed size = 415 mm × 478 mm × 13mm

Full size = 555 mm × 584 mm × 510 mm

The views of the SolidWorks drawing are shown in the following Figure 3.25 with real dimensions, in addition to the exploded view.

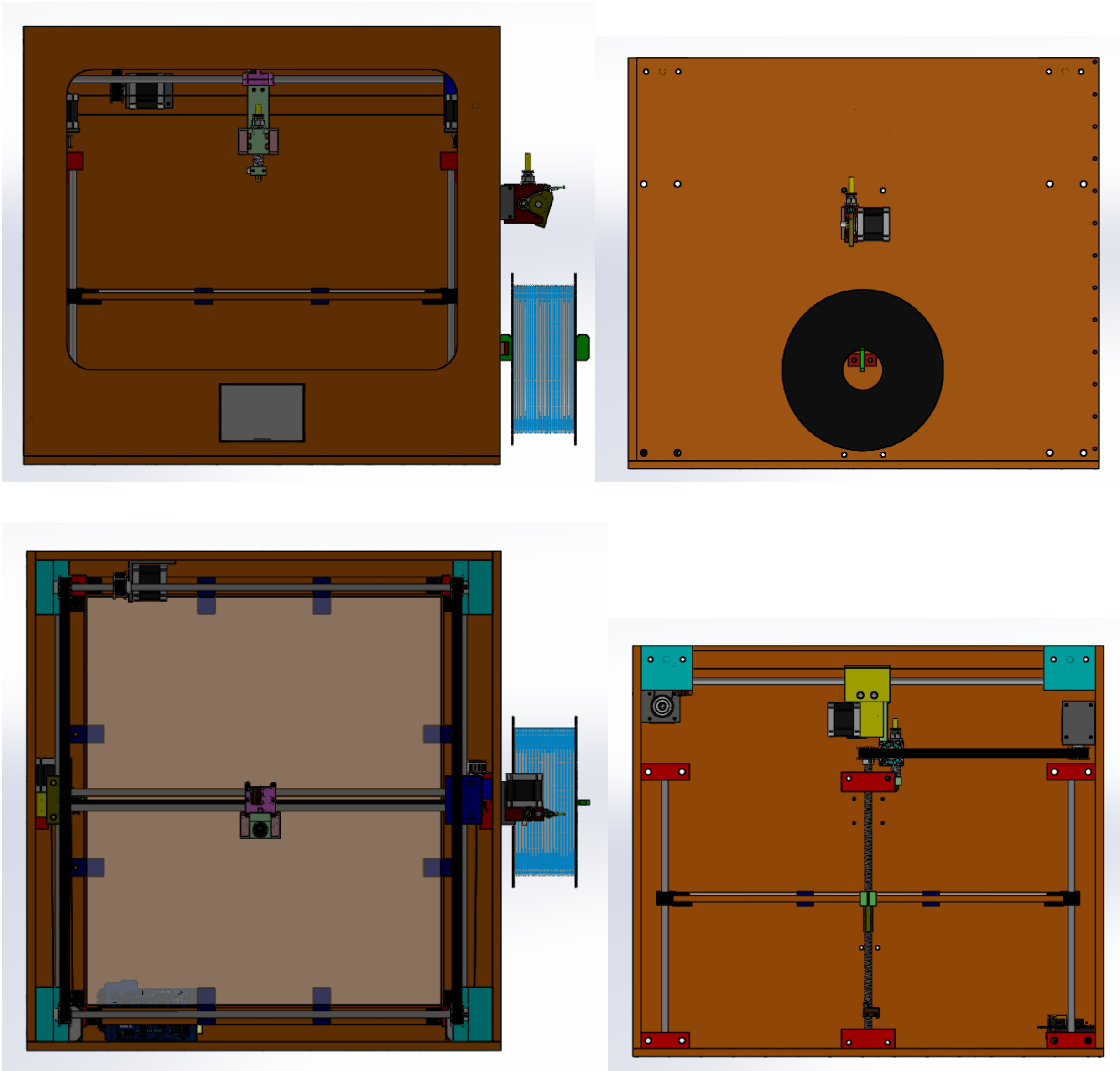

Figure 3.25 Views of the SolidWorks drawing

3.7 Interfacing

Interfacing is the point of interaction between the software and hardware, a microcontroller can be interfaced with other devices, such as sensors, motors, switches, keypads, displays, memory and even other microcontrollers. In our 3D printer, there are some components that are interfaced digitally like the LCD controller and drivers of the stepper motors. Other components need analog interfacing like fans, thermistor and the extruder heater.

3.8 Programing

In order for the Arduino to function with the RAMPS 4.1, a specific kind of firmware will be used to control each part in the printer which is called Marlin Firmware. It's a group of libraries that contain programmable command for leading all the electrical components of the printer such as, motors movements, filament temperature, PID values ….etc. Figure 3-26 and Figure 3-27 below shows a copy of the firmware:

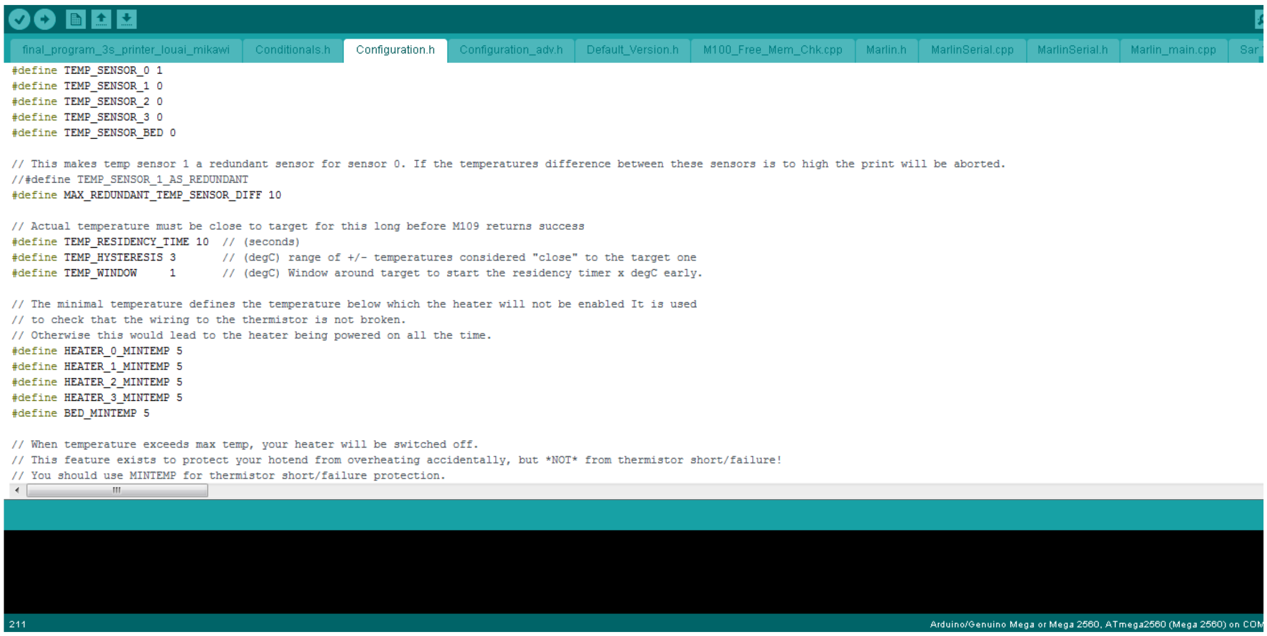

Figure 3-26 Some commands of Marlin firmware

Figure 3-27 Another part of Marlin firmware

3.9 Slicing process

Computer transforms the 3D sketch (e.g. Solid Works sketch) to a code that the microcontroller understands which is known as the G-code or G-programming language-code is a language in which people tell computerized machine tools how to make something. The how is defined by instructions on where to move, how fast to move, and through what path to move, this method is used for CNC machines and 3D printers. The following Figure 3.28 concludes the slicing process.

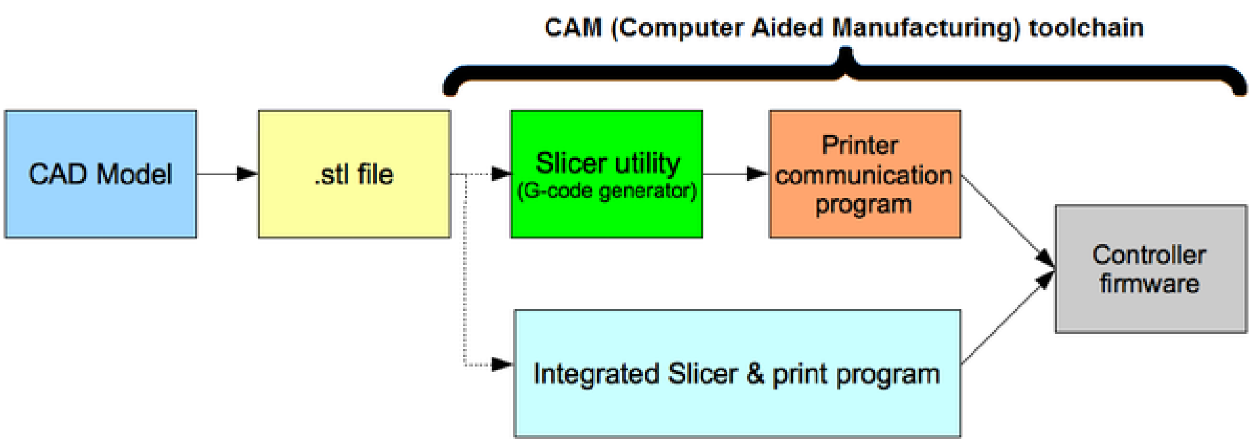

Figure 3.28 Slicing process

3.10 Software

3D printers extrude plastic like ABS or PLA from filament. The filament is pulled into the extruder and heated in its nozzle (hot end) and finally deposited. The extruder (also called print-head) will move while extruding, or move (jump) without extruding. A slicer program allows to calibrate printer settings for various types of "areas to print", like:

- Extrusion speed (rotations / minute).
- Head speed temperature.
- Fan on/off.

The program allows defining:

- Wall thickness filling patterns.
- Extrusion speed, head speed and temperature per type of area.

Deposited filament for a layer or a section of a layer depends on extrusion speed, head movement speed, and temperature. In addition, factors like movement patterns, plastic brand, fan on/off …etc. Also have an influence on the design [25]. Some examples on slicer and control software:

Skeinforge, SFACT slicer, Slic3r, Repetier-Host, and Netfabb are some examples on slicers. In our project Repetier-Host will be used which is easy to use and is suitable for our needs.

3.11 Manufacturing

In 3D-Printer project many machines will be used as (Milling, Turning, Drilling, CNC, Shipping, and Cutting) to produce parts to be ready for assembly.

Milling machine use to make the surfaces smooth and the thickness can be reduced of parts where it has high accuracy and fast work. This machine will be used for substrates and extruder also in feeder because these parts should be accurate dimension. The reason behind that is the substrates will give the strength to the bed of 3D-printer and for extruder it's needed to have specific thickness so the cooling system can cool the filament easily, and for the feeder should be not have huge space so that will make the filament easily pass during the feeder also it will not have space to leave the filament without tension.

Drilling machine is almost used in all the parts by making holes to join the parts by using screw, another application of that it's used to join the rod inside the supporter after fit it with bearing.

Turning machine will be used to all parts which have cylindrical shapes as rod to reduce the diameter of rod in addition to chamfer the edges so it will be easier to insert it in the supporter or substrates.

CNC machine, will be used for high accuracy and for some material as wood as some parts for frame of bed in the 3D printer and the holder of the extruder because it needs high accuracy to produce.

Cutting machine will be used to make the frame of the 3-printer like having places with specific dimension as LCD location.

3.12 Assembling

The assembly process will be accomplished by joining all the parts of the system together. Mechanical machines will be used to join all the parts together. To begin with, the wooden box of the 3D-Printer will be cut and shaped into different sizes of rectangular shapes and a window for the front and drill it in the corners where wooden supporters will be held by screws. After that, the 3 axes will be put and connected by the supports, screws and pulleys so they can move easily. The motors will be held by using belts and pulleys to let them move tightly. Then, the extruder will be drilled to insert the heater and the thermistor in it and fix it by the plastic supports on the Y axis, the same process will be done for the feeder. Moreover, the plastic filament will be fixed on the outside wall of the wooden box. For the steel plate, it's going to be set horizontally by using 8 Z shaped aluminum supporter and springs to adjust the balance of it. Finally, for the electronic components, the RAMPS board will be set on the Arduino and 5 stepper motors, heater, the thermistor, 2 fans, 4 stepper drivers, LCD screen, 5 end stops and 12V DC power supply will be connected to the RAMPS .

3.13 Cost Analysis and Suppliers List

In this section required materials, components, their quantities, prices and suppliers list will be introduced.

The following Table 1 shows the previous requirements:

Table 1 Cost Analysis and Suppliers List

Item	**Quantity**	**Price per unit (TL)**	**total cost (TL)**	**Supplier**
Stepper motors	5	45	225	Robotizmo, Istanbul, Turkey
Arduino Mega 2560	1	45	45	Robotizmo, Istanbul, Turkey
Belt pulley	14	9	126	Robotizmo, Istanbul, Turkey
Linear Bearings	20	16	320	Robotizmo, Istanbul, Turkey
Threaded rods	2	30	60	Famagusta industrial area, Cyprus
608 Bearings	10	7.5	75	Robotizmo, Istanbul, Turkey
Linear rods	10	6.5	65	Robotizmo, Istanbul, Turkey
Nuts	2	3	6	Famagusta industrial area, Cyprus
Belt	14 m	9	126	Robotizmo, Istanbul, Turkey

NTC thermistors	10	6.5	65	Robotizmo, Istanbul, Turkey
RAMPS 1.4	1	35	35	Robotizmo, Istanbul, Turkey
Stepper drivers	5	10	50	Robotizmo, Istanbul, Turkey
End stops	5	6.5	32.5	Robotizmo, Istanbul, Turkey
Graphical LCD	1	65	65	Robotizmo, Istanbul, Turkey
Nozzle	1	5	5	Robotizmo, Istanbul, Turkey
Pneumatic Fittings	2	4	8	Famagusta industrial area, Cyprus
Fan	2	7.5	15	Robotizmo, Istanbul, Turkey
Cartridge heater	1	7.5	7.5	Robotizmo, Istanbul, Turkey
8mm*50cm shafts	10	11	110	Robotizmo, Istanbul, Turkey
PTFE tubing 2*4	2m	10	20	Robotizmo, Istanbul, Turkey
PTFE tubing 3*5	4m	23	92	Robotizmo, Istanbul, Turkey

Jumping wires	25	1.5	38	Robotizmo, Istanbul, Turkey
Bolts	20	1	20	Famagusta industrial area, Cyprus
Electrical wires	21m	1	21	Electrical shop, Cyprus
Set screws	5	1	5	Famagusta industrial area, Cyprus
3D Printer filament	1 KG	65	65	Robotizmo, Istanbul, Turkey
Plastic supporters	10	20	200	Rhino3d, Istanbul, Turkey
Feeder	1	50	50	Rhino3d, Istanbul, Turkey
Wood	16	-	150	University Carpenter, Famagusta, Cyprus
Total cost			2102 Tl	

Table 2 below illustrates other payments that were paid in order to get the previous components.

Table 2 Miscellaneous Costs

Miscellaneous Costs	Price (TL)
Transportation	30
Delivery	90
Total cost	120

CHAPTER 4

MANUFACTURING AND ASSEMBLY

This chapter will explain how the manufacturing process was conducted; also details of assembly step by step and testing of final project will be reported.

4.1 Manufacturing

To manufacture the prototype, components were manufactured in the workshop using conventional (Cutting, drilling, welding, grinding, joining) and modern manufacturing techniques (3D Printer).

4.1.1 Wooden Box

The wooden box protects the mechanical and electrical parts of the printer inside it. The following steps were taken in order to manufacture it:

1. Measuring the dimensions of the wooden slices as the following: (see Figure 4.1)
    - (554.99x500x10 mm) 1 piece (see APPENDIX C DRAWING NO 1-31)
    - (500x584x10 mm) 1 piece (see APPENDIX C DRAWING NO 2-31)
    - (500x574x10 mm) 2 pieces (see APPENDIX C DRAWING NO 3-31)
    - (500x534.99x10 mm) 1 piece (see APPENDIX C DRAWING NO 5-31)

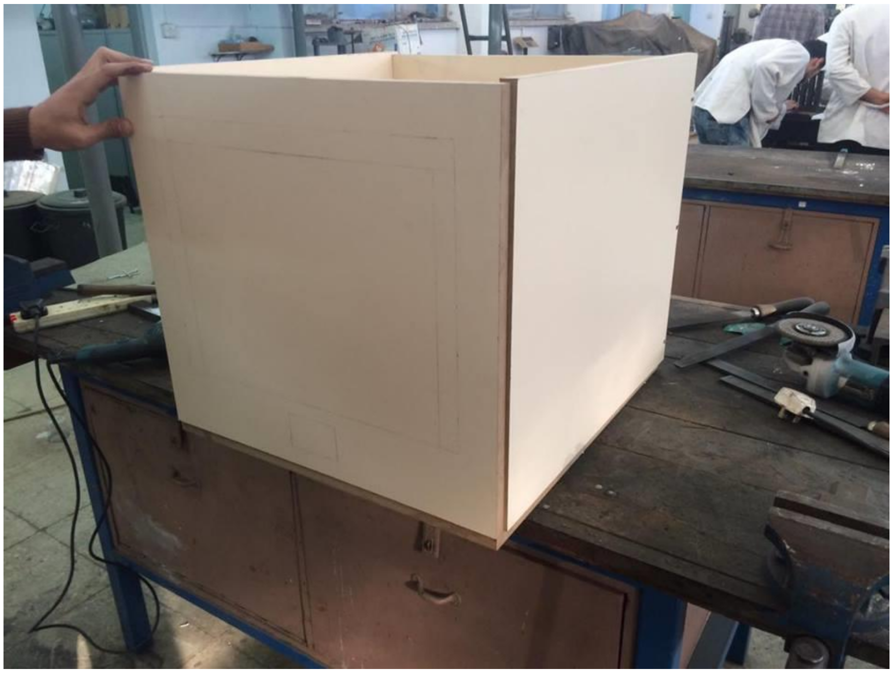

Figure 4.1 Box wooden

2. Cutting the wooden pieces by a wood combination machine as in Figure 4.2

Figure 4. 2 Cutting the wooden slices

.

4.1.2 Plastic Supporters

The plastic supporters are used to set the moving components or that will carry weight. They were manufactured in our department's workshop by the CNC machine but the raw material was not suitable for the machine. Therefore; 3D printing was the best solution for making them because it can use convenient kind of plastic that could give the wanted parts more accurate dimensions.

The plastic pieces were manufactured by a 3D printer as in Figure outside the workshop (see APPENDIX C DRAWING NO 6-31, NO 7-31, NO 11-31, NO 17-31, NO 18-31, NO 19-31, NO 23-31, NO 25-31, NO 24-31, NO 26-31, NO 30-31). But there were some problems with them, like some holes were tight, for widening them by an adjustable fixing machine.

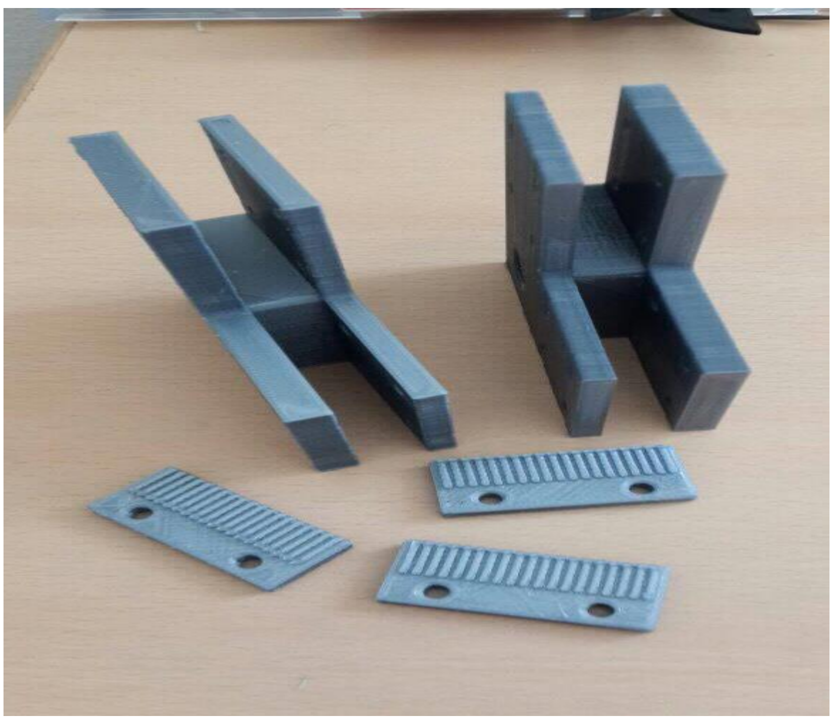

Figure 4. 3 Two types of plastic supporters

4.1.3 Wooden Supporters

The wooden supporters are used to fix several components that don't bear much pressure as long as they are weaker than plastic. It choose L shape as connect between shafts for Z axis and it has been made the teeth plastic to connect the belt for X,Y axes .

(See APPENDIX C DRAWING NO 14-31, NO 12-31, NO 20-31, NO 22-31, NO 27-31, NO 28-31, NO 29-31)

They were manufactured by using the milling machine to adjust the height and width of each block as they were designed before.

Then the drilling machine was used to create the holes on the wood to set the shafts and for the bearing .

4.1.4 Managing the Belts

For controlling the shafts movements synchronously between two points in the X, Y, Z axis, specific lengths of the belt should be cut for connecting two points and make them tight enough to lead the motors to move in precise steps.

There were two methods to make close loops of the belt pieces:

1. By designing small plastic slices (See APPENDIX C DRAWING NO 26-31), which have teeth to catch the belt better in order to increase the fraction between the belt and the shaft for the Y and X axes as shown in Figure 4.7

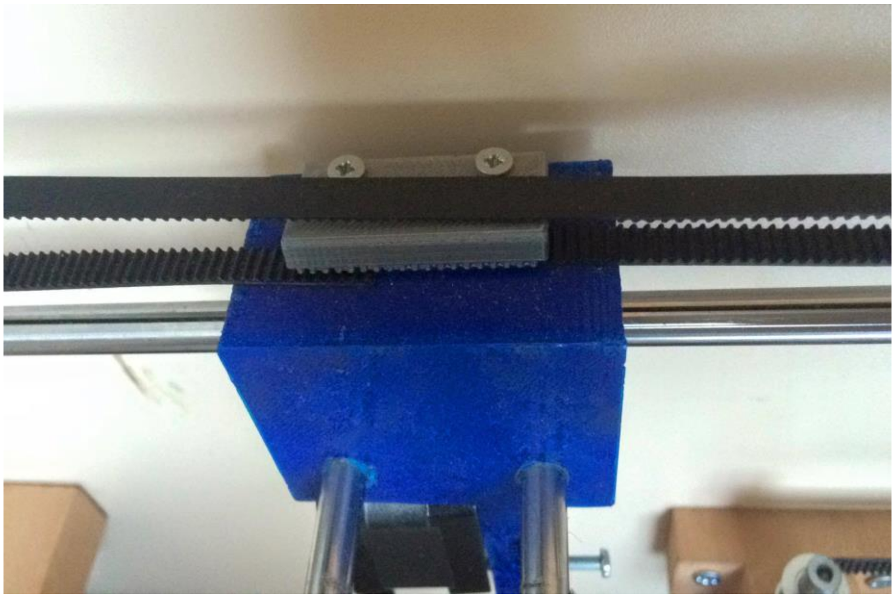

Figure 4. 4 Catching the belt by a plastic slice

2. By using glue and cooling spray for Z axis .

4.1.5 Extruder

The following steps were taken into consideration to manufacture the extruder:

1. Using the milling machine to produce the shape and fins for cooling as shown in Figure 4.9

Figure 4. 5 Shaping the extruder

2. Making holes by the drilling machine as shown in Figure 4.10 to enter the thread rod inside for permitting the filament to move easily inside it and another holes for setting fans.

Figure 4. 6 Drilling the extruder

3. Another piece of aluminum was cut with the same diameter of the thread rod and another two holes were produced for the cartridge heater and the thermistor and one in the bottom for the nozzle.

   Figure 4.7 shows the last design of the extruder (See APPENDIX C DRAWING NO 16-31).

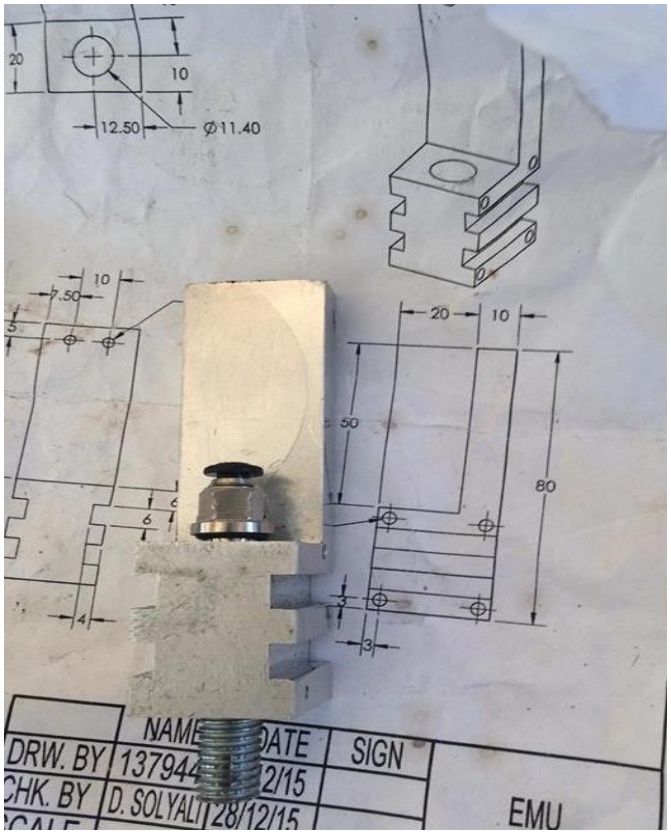

Figure 4. 7 The last design of the extruder

4.1.6 Steel plate.

After the decision of using a glass plate to print the object on it, a steel plate was replaced because it's more stronger than the glass where it can be adjusted easily, also it resist the high tempter that the extruder produce. And the second reason its more economical ,as it has been took from the work shop for free.

To make it convenient, a cutter machine was used to cut the length. Then four holes were punched for the screws, and for more accuracy it has put springs inside the screw which gives much more stability, also 8 parts were made as Z shape to support our plate and make sure it doesn't vibrate while its printing.

See Figure 4.8 below

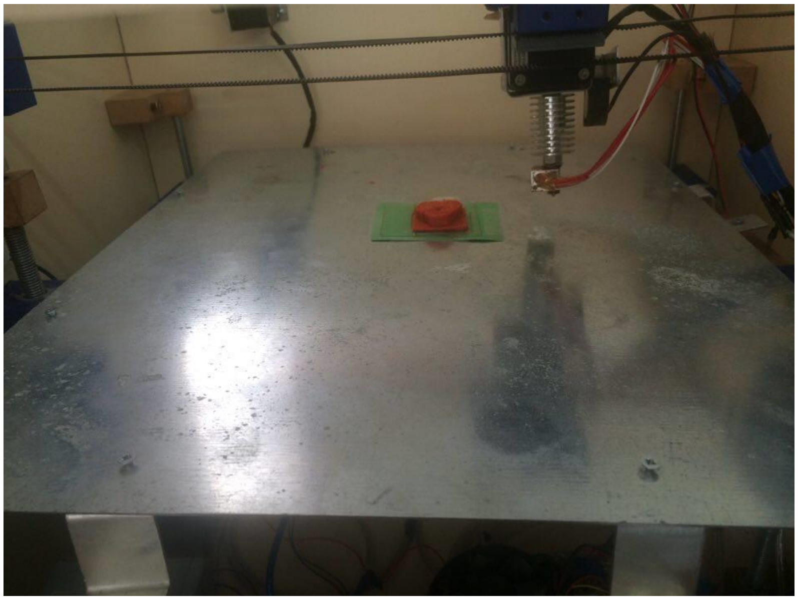

Figure 4. 8 The Steel plate

4.1.7 Shafts

A turning machine was used to set the length and change the diameter of the shafts as shown in Figure 4.9:

Figure 4. 9 Adjusting the shafts' lengths and diameters

4.2 Assembly

The assembly process was accomplished by joining all the parts of the system together as shown in Figure 4.9

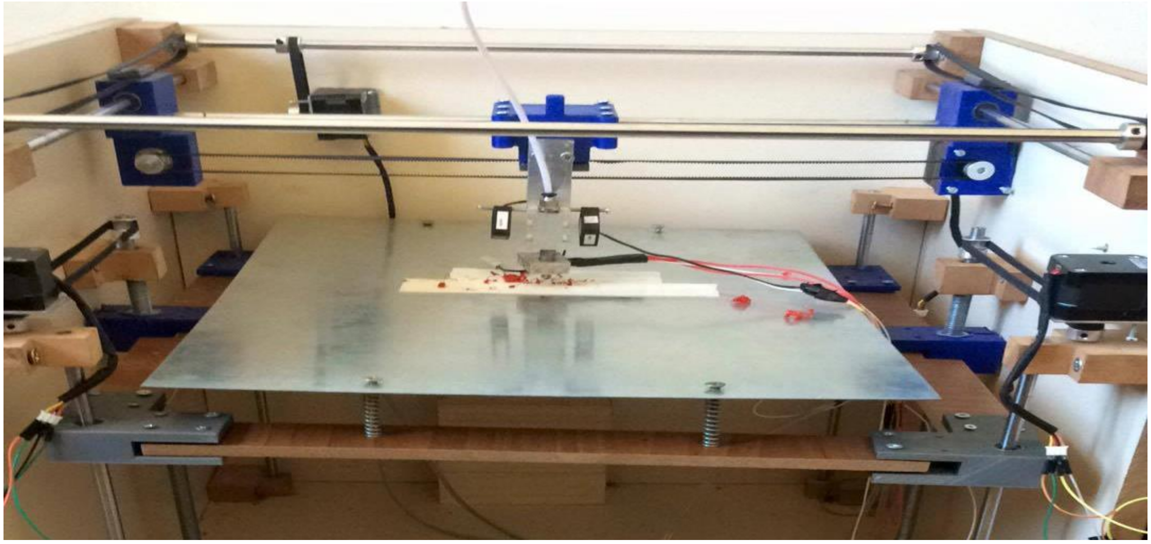

Figure 4. 9 Prototype after assembling

First of all, the five pieces of wood were combined together with screws to build the wooden box as in Figure 4.10

Figure 4. 10 The last prototype of the wooden box

Then, the bearings were put inside the wooden and plastic supporters to set the X, Y and Z shafts as shown in Figure 4.11

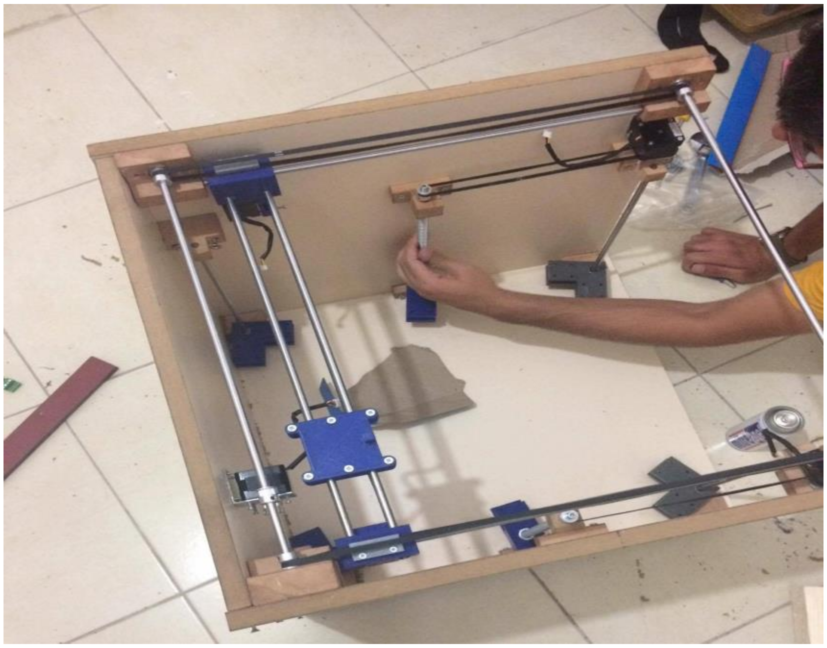

Figure 4. 11 Setting the components on the wooden base

Finally, the electrical circuit was connected as shown in Figure 4.18 (See Figure 3.23 in chapter 3).

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Testing of Final Project

After manufacturing process is done, and all components were assembled together, the Marlin firmware was uploaded to the Arduino, and a simple shape was designed and also uploaded to the Repetier software to be printed as shown in Figure 5.1

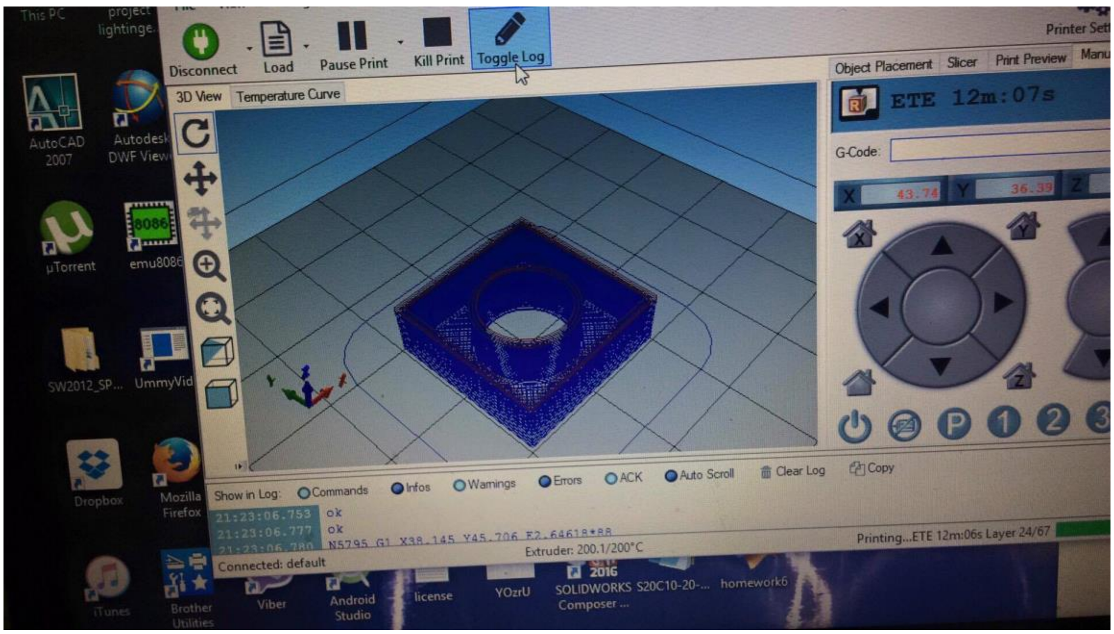

Figure 5. 1 Repetier software

Then, the plastic filament was filled inside the PTFE tube to lead it to the extruder. After that, the cartridge heater was programmed in order to increase its temperature to 210 C as shown in Figure 5.2

Figure 5. 2 Setting the heater's temperature

Finally, the printer started to move and print the object layer by layer as shown in Figure 5.3

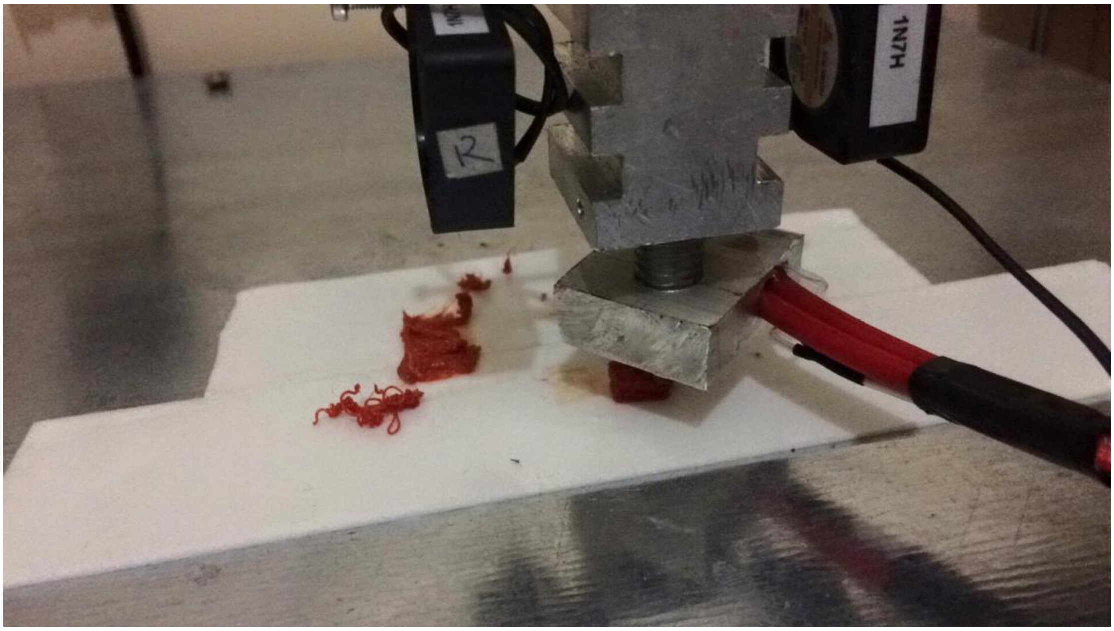

Figure 5. 3 Printing an object

After the printing process was finished, the last prototype of the final printed object is seen in Figure 5.4

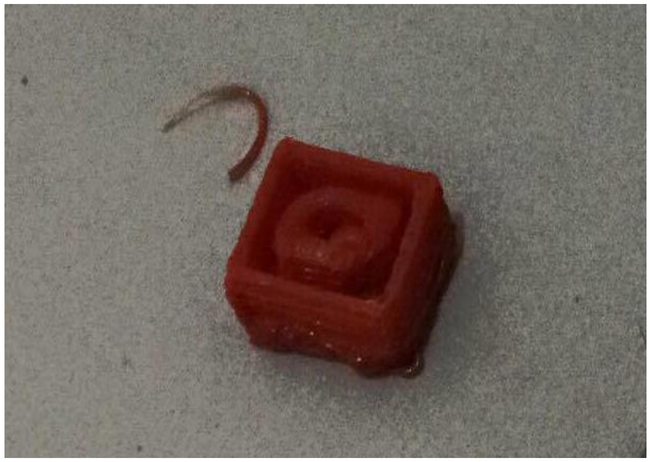

Figure 5. 4 The last prototype of the final printed object

5.2 Discussion of Results

After testing the project, all the results were satisfied into a certain point. But the efficiency of the printed objects could be enhanced by increasing the accuracy of the manufacturing process of the components, several factors were found that caused these unwanted results. Firstly, the extruder was not made in good quality and modern machines; that led to be cleaned every time it's used which is not supposed to be like that. Secondly, the extruder was shaking due to the belt weakness and the performance of the stepper motors. In addition, the power supply wasn't supplying enough power for moving the motors with suitable speeds and for heating the heater properly. Nevertheless, the plastic was solidifying inside the nozzle. Finally, the steel plate wasn't light enough for the Z axis to move with the right steps and also because of the friction.

5.3 Technical Difficulties

Many difficulties were faced during the process of manufacturing, assembling and testing. The accuracy of the workshop machines was not good enough to produce the parts in high quality because they were old and the drilling machine has been deflected. Moreover, it was almost hard for the Z axis to move easily because of the high friction and the weight of the plate, so a lubricant material was put to decrease the fraction. In addition, the LCD screen was not compatible with the RAMPS board which led to changing some programming commands to work properly. Finally, the plastic was stick inside the nozzle, so it was fixed by putting a small piece of PTFE tube inside it and changed the place of the feeder motor above the extruder to ease the filament dragging inside it.

CHAPTER 6

FUTURE WORK & CONCLUSION

The future works and developments of the project will be discussed in this chapter as well a final conclusion.

6.1 Future Work

The project is a simple type of a 3D printer with basic features, therefore some developed suggestions are wished to be added in the future. Firstly, the printer will not just print an object from programmed commands, but it'll also capture and scan any real shape and directly print it. Secondly, the efficiency of the printer will be worked on, so it'll print more rapidly an accurately. Thirdly, the extruder would be rebuilt to accept more than 210 ℃ temperature in order to use other plastic filaments with good quality. Finally, a smaller prototype of the printer would be better to deal with. As long as all other similar projects have all the previous features, it's not difficult for them to be added someday.

6.2 Conclusion

This report has explained the construction of an ordinary 3D printer by its all aspects. The report summarized the engineering problem and the objective of the project. Then, a brief history and a comparison between different types of 3D printers were introduced. Later, project mechanical and electronic components were proposed, materials were selected, design related calculations were solved by using suitable formulas, programming process with convenient software and cost analysis with detailed list of suppliers were illustrated. Moreover, manufacturing steps were explained in details, assembling process has been clarified, testing was conducted and experimental results were reported. Finally, these experimental results were plugged into related equations and calculations were made. As a conclusion, 3D printer is an excellent alternative for creating products as if it compare with CNC machine ,The CNC would take more time and it couldn't do the shape as 3D because it's cutting not building as 3D from filament instead of regular machines that are used nowadays. Although its efficiency and accuracy is low, it can become more sophisticated and improved by extending it with advanced settings and manufacturing technologies in the upcoming years.

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APPENDICES

APPENDIX A - LOGBOOK

Logbook: Massa Alsafadi 149110

DATES	DETAILS
14/10/2015	Firstly, I joined my project team that consists of 3 students including me. I discussed the project topic with my advisor who is different from theirs Dr. Prof. Mustafa Kemal Uyguroglu and explained briefly about the electrical part of the project.
20/10/2015	I started searching for topics related to the 3D printer needs and gathering information from different sources.
22/10/2015	First meeting with the team members was held to discuss the 3D printer function and components.
25/10/2015	Report format and needed topics were known.
27/10/2015	A group meeting was held to distribute our duties.
29/10/2015	I met my advisor and asked him about the electrical function of the 3D printer.
9/11/2015	Exact electrical components were chosen.
16/11/2015	My members and I started define the calculations.
20/11/2015	I began to write the "Introduction" and "Why 3D printer?" parts in the first chapter.
30/11/2015	I started to write my duties in the second chapter.
7/12/2015	A group meeting was held to manage the third chapter topics.
10/12/2015	I started writing stepper motor, stepper driver, extruder and end Stops sections and their calculations in the third chapter.
17/12/2015	I visited my advisor and he gave me some tips and notes about my

	writing.
20/12/2015	I drew the electrical circuit of the 3D printer and searched for engineering standards.
23/12/2015	A meeting was held for repairing and organizing the report.
25/12/2015	I revised my advisor for checking my parts.
26/12/2015	I added my logbook and the references.
28/12/2015	I submitted the report to my advisor.
1/2/2016	A group meeting was held to select our materials and components.
26/2/2016	My group mates and I had meeting to share our search results.
3/3/2016	We decided which suppliers to visit and started in Famagusta industrial areas.
9/3/2016	My group and I found a supplier in Istanbul and ordered the components.
22/3/2016	We found a Turkish supplier to print some components.
31/3/2016	We started to combine and try the electrical circuit.
3/3/2016	A group meeting was held to discuss some problems.
1/4/2016	I had a meeting with my adviser to share information.
21/4/2016	I started to edit the old report.
24/4/2016	I searched on the web for the programming part.
2/5/2016	We tested the electrical components and made sure that they're fine.
6/5/2016	My group and I assembled the electrical and mechanical parts
12/5/2016	We worked on wiring the electrical circuit.

20/5/2016	I searched for some solutions for the extruder's problems.
25/5/2016	I brought fans for cooling the heated circuit
29/5/2016	I completed writing the report.
30/5/2016	We showed our final work to our advisor.

Logbook: Louai Mikawi 127340

DATES	DETAILS
14/10/2015	Firstly, I joined my project team that consists of 3 students including me. I discussed the project topic with my advisor Dr. Davut Solyalı
20/10/2015	I started searching for topics related to the 3D printer needs and gathering information from different sources.
22/10/2015	First meeting with the team members was held to discuss the 3D printer function and components.
25/10/2015	Report format and needed topics were known.
27/10/2015	A group meeting was held to distribute our duties.
29/10/2015	I talked with my supervisor about the idea that we have
9/11/2015	Exact mechanical components were chosen.
16/11/2015	My members and I started define the calculations.
20/11/2015	I began to write the "Types of 3D machine" and "History of 3D-Printer" parts in the first chapter.
30/11/2015	I started to write my duties in the second chapter.
7/12/2015	A group meeting was held to manage the third chapter topics.
10/12/2015	I started writing mechanical component that we need in details.
17/12/2015	We choose the material that we need and write about it .
19/12/2015	After the design I wrote the assembly.
20/12/2015	I wrote about the calculation for mechanical component, before test it
23/12/2015	A meeting was held for repairing and organizing the report.
25/12/2015	I finished the interface and software.
26/12/2015	I added my logbook and the references.
1/2/2016	A group meeting was held to select our materials and components.
26/2/2016	My group mates and I had meeting to share our search results.
1/3/2016	we started to manufacture the wooden box.
3/3/2016	We decided which suppliers to visit and started in Famagusta

	industrial areas.
9/3/2016	My group and I found a supplier in Istanbul and ordered the components.
22/3/2016	We found a Turkish supplier to print some components.
24/3/2016	We started to combine and try the electrical circuit.
31/3/2016	A group meeting was held to discuss some problems.
1/4/2016	I had a meeting with my adviser to share information
15/4/2016	We bring a block of aluminum for extruder
21/4/2016	We started to manufacture the extruder by using milling machine.
24/4/2016	I worked on the programming part.
30/4/2016	we fixed some problems with the wooden and plastic supports in the workshop.
2/5/2016	I tested the electrical components and made sure that they're fine .
6/5/2016	My group and I assembled the electrical and mechanical parts
10/5/2016	We fixed some problems in the shafts and supporters.
12/5/2016	We worked on wiring the electrical circuit.
15/5/2016	We fixed some problems with the Z axis shafts.
20/5/2016	I test the in extruder temperature of extruder and control to stabilize it
25/5/2016	I fixed some problems makes the accuracy of printing not better.
30/5/2016	We showed our final work to our advisor.

Logbook: Mustafa Altabshi 137944

DATES	DETAILS
14/10/2015	Firstly, I chose our capstone project with my team members. Afterword, we had a meeting with our adviser where we have discussed our project, and learned about that technology.
19/10/2015	Project Proposal Request to Dr. Davut Solyali and **Assist. Prof. Dr. Neriman Özada (Vice Chair).**
22/10/2015	Group meeting was held. I started working on Gantt chart.
25/10/2015	Conversing about the objective and scope of our project, learning more information’s on 3D printer technology.
27/10/2015	Group meeting was held and duties were distributed where I took the responsibility to design our 3D printer.
29/10/2015	My team members and I suggested several designs and ideas with our advisor.
31/10/2015	I started looking for 3D printer various types.
2/11/2015	I have talked with some friends, who are expert in 3D printer, which would give us a good start and avoid mistakes.
6/11/2015	I started drawings design 3D printer using SolidWorks software.
9/11/2015	We met our advisor and asked for his help in choosing the electrical and mechanical components.
16/11/2015	I and my team members started with calculations.
20/11/2015	I started writing my part of introduction chapter.
30/11/2015	I started writing the types of 3D printer for literature review chapter.
7/12/2015	My team members and I visited our advisor for extra information and explanation. Preliminary design was suggested.
10/12/2015	I started selecting the materials for our project.
17/12/2015	I sent my final works to my other team members and we worked on organization of the report.

20/12/2015	I drew 3D circuit of electrical components of the 3D printer.
23/12/2015	We made a review for whole report to insure that everything is perfect.
26/12/2015	I prepared my logbook.
28/12/2015	We have submitted the final report to the supervisor Assit.Prof. Neriman Ozada.
1/2/2016	A group meeting was held to select our materials and components
26/2/2016	My group mates and I had meeting to share our search results
1/3/2016	we started to manufacture the wooden box.
3/3/2016	We decided which suppliers to visit and started in Famagusta industrial areas.
9/3/2016	My group and I found a supplier in Istanbul and ordered the components.
22/3/2016	We found a Turkish supplier to print some components.
24/3/2016	I started to bring all component that we need after study the future work
31/3/2016	A group meeting was held to discuss some problems.
1/4/2016	I had a meeting with my adviser to share information
15/4/2016	We bring a block of aluminum for extruder
21/4/2016	We started to manufacture the extruder by using milling machine.
25/4/2016	I worked on thread rod by using turning machine .
30/4/2016	we fixed some problems with the wooden and plastic supports in the workshop.

2/5/2016	I make some research and calculation for belt and torque
6/5/2016	My group and I assembled the electrical and mechanical parts
10/5/2016	We fixed some problems in the shafts and supporters.
12/5/2016	We worked on wiring the electrical circuit.
30/5/2016	We showed our final work to our advisor.

APPENDIX B - GANTT CHART

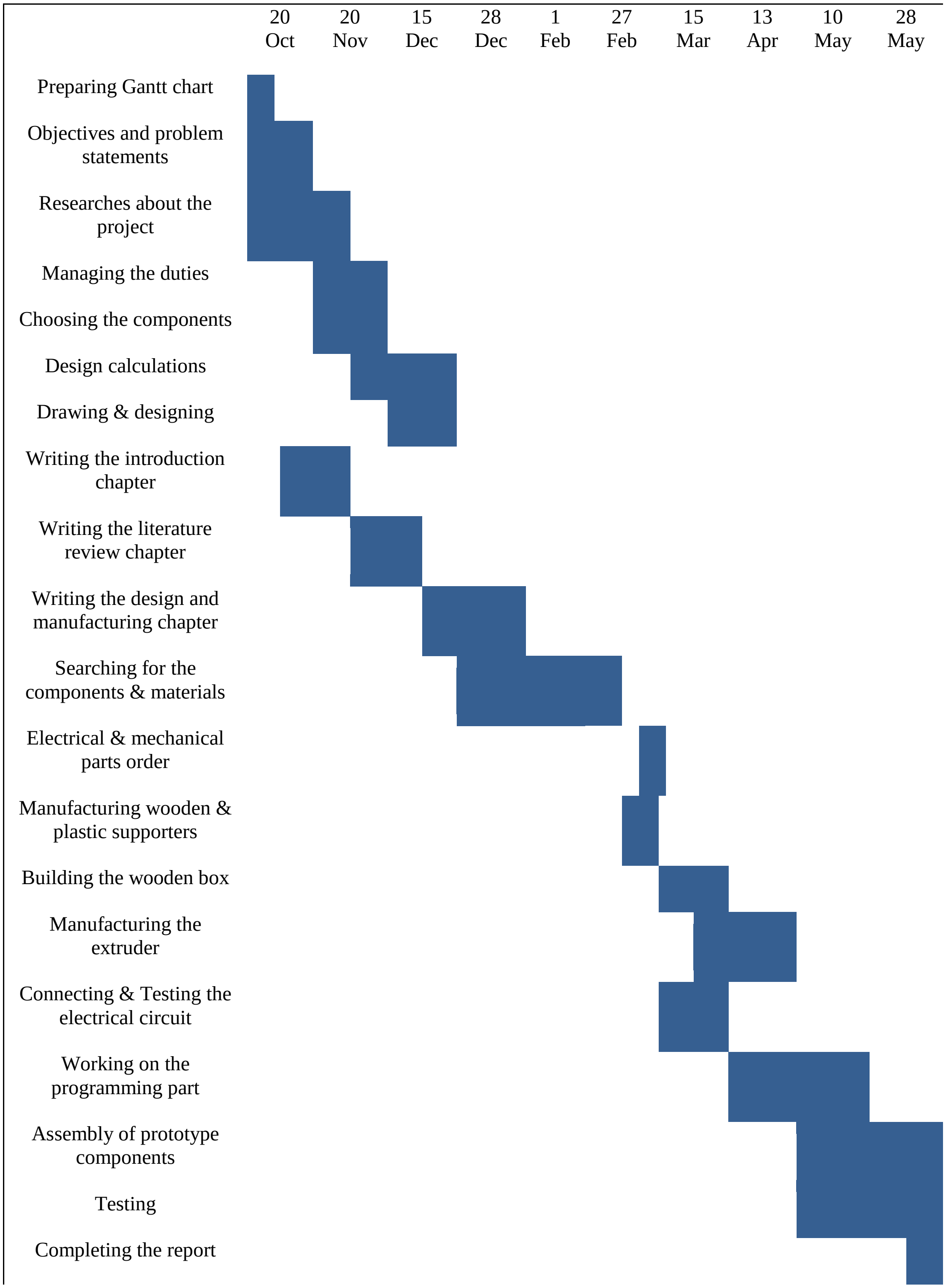
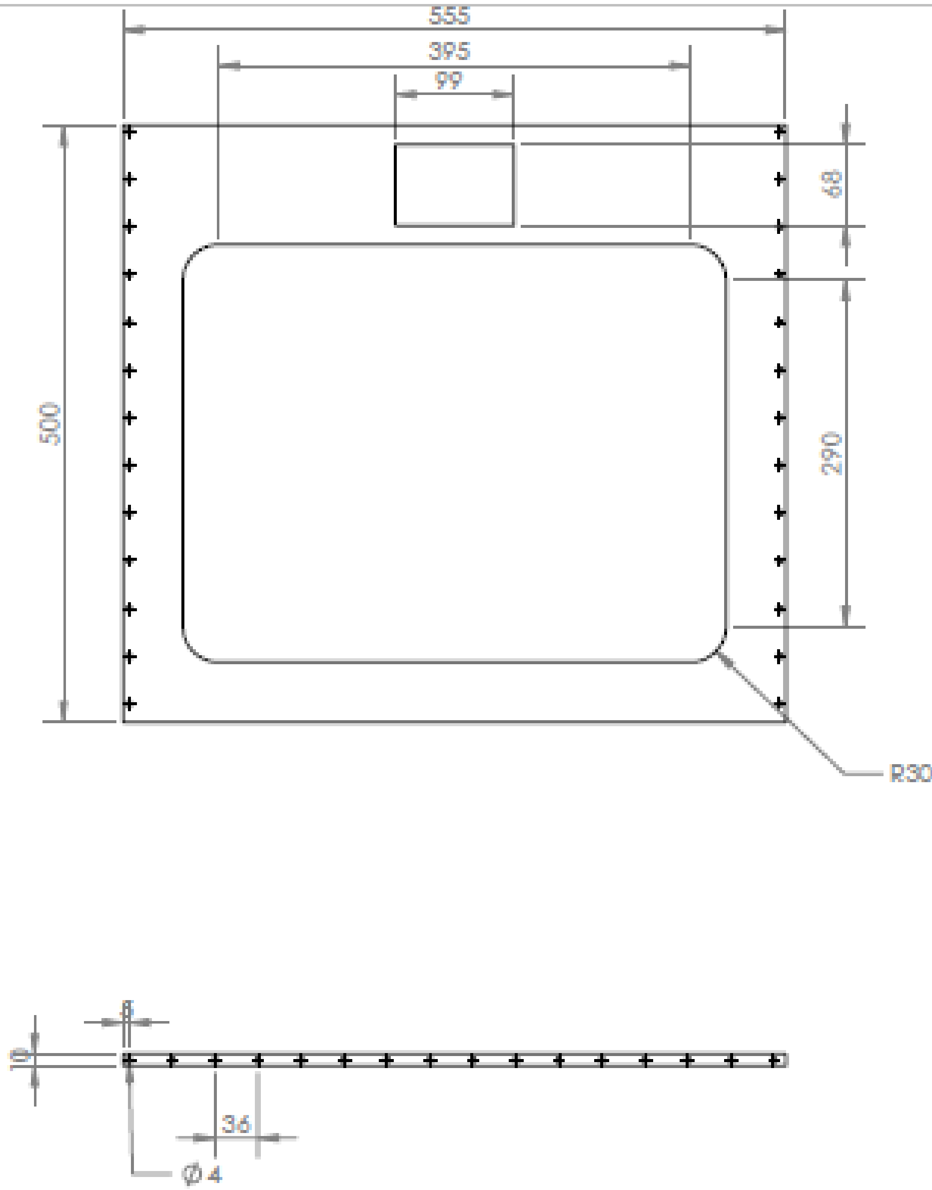


Figure B1. Gantt Chart

APPENDIX C - DRAWINGS



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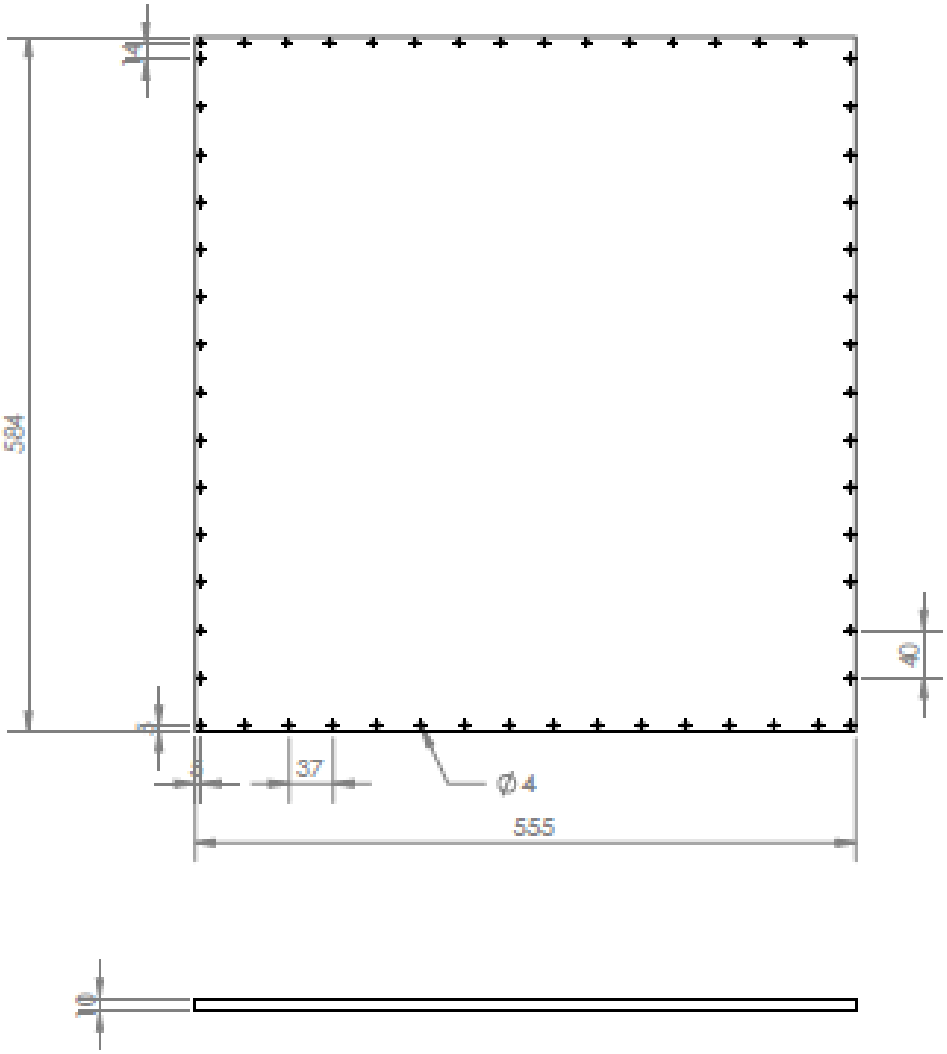

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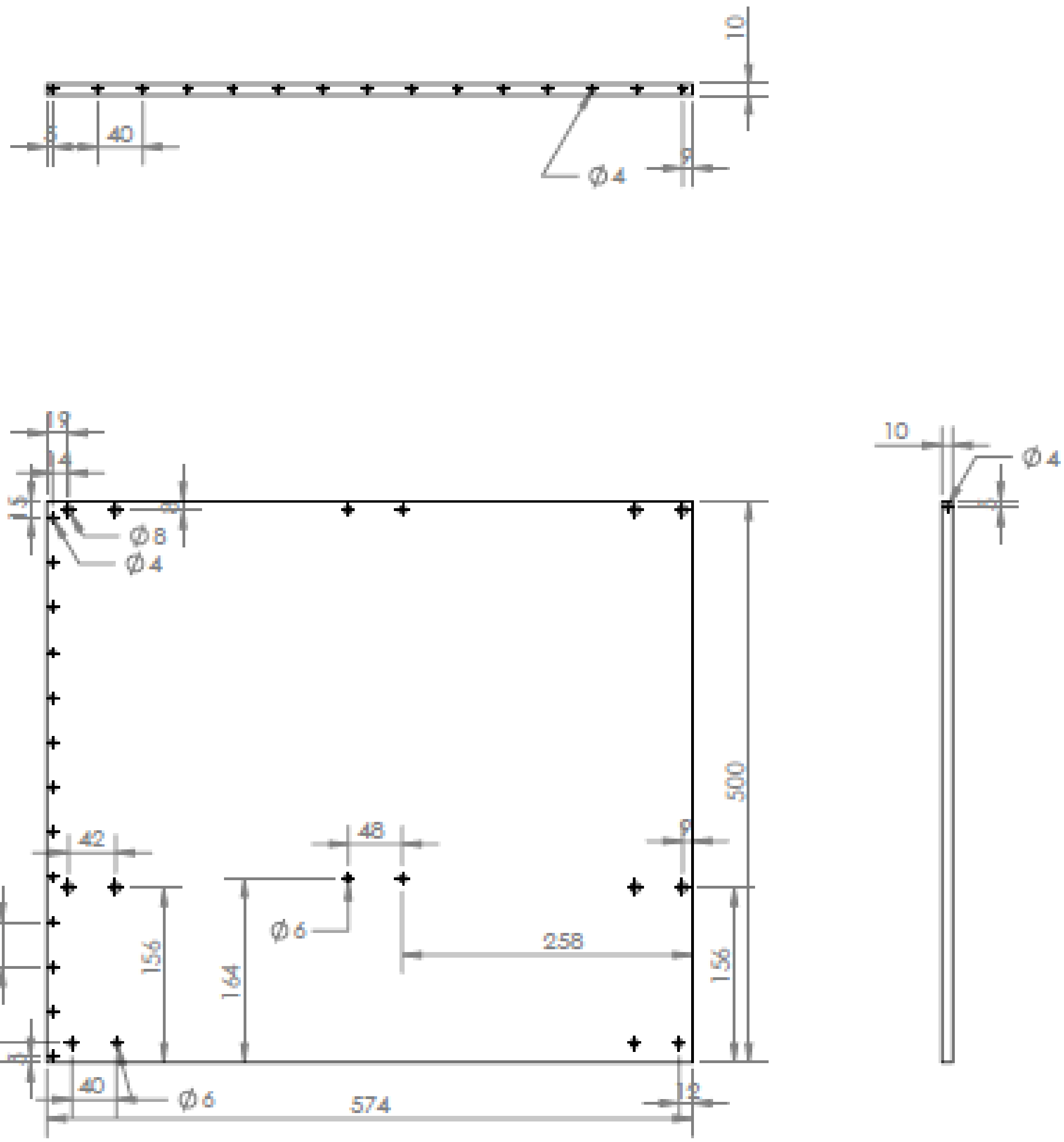

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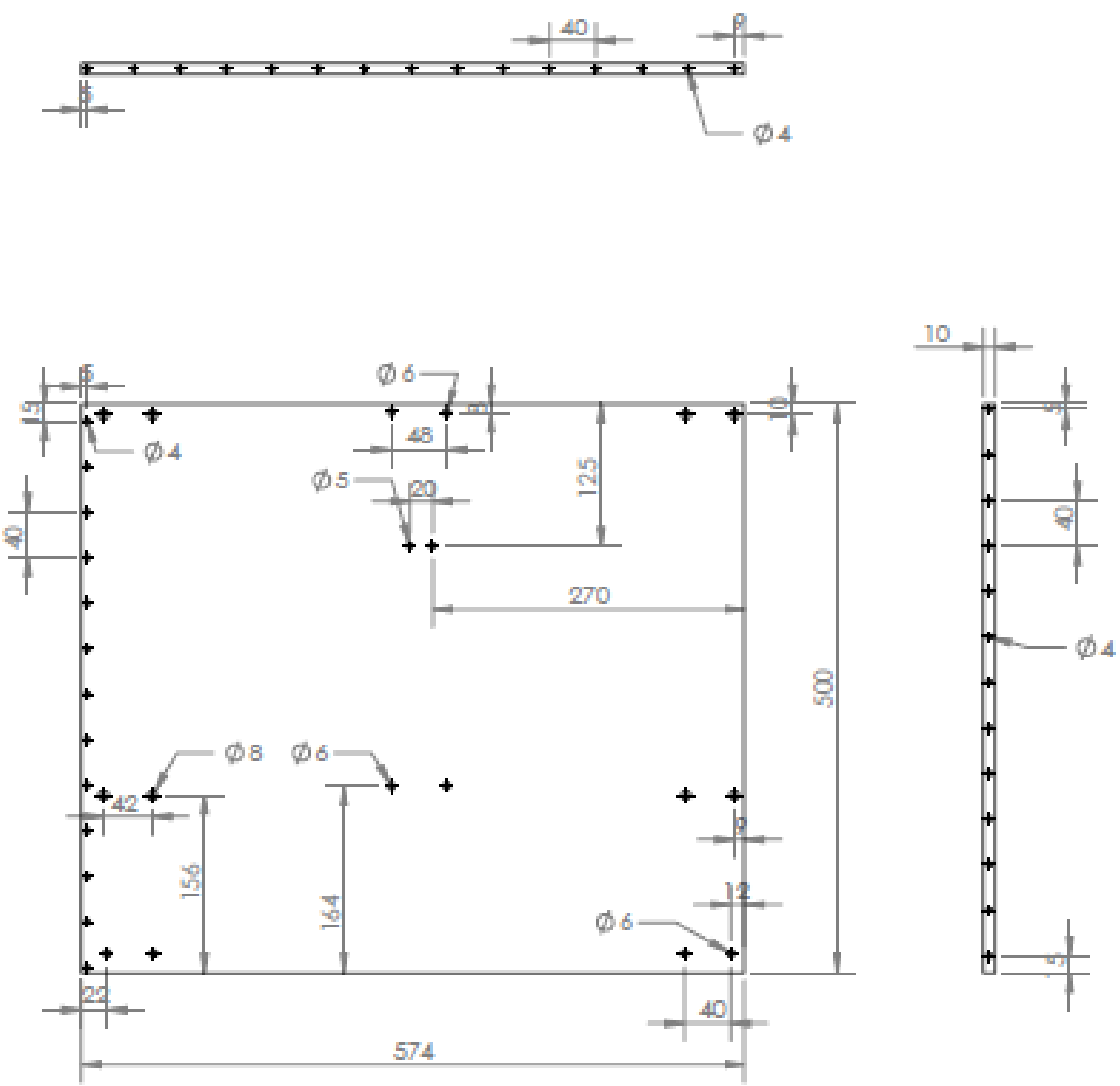

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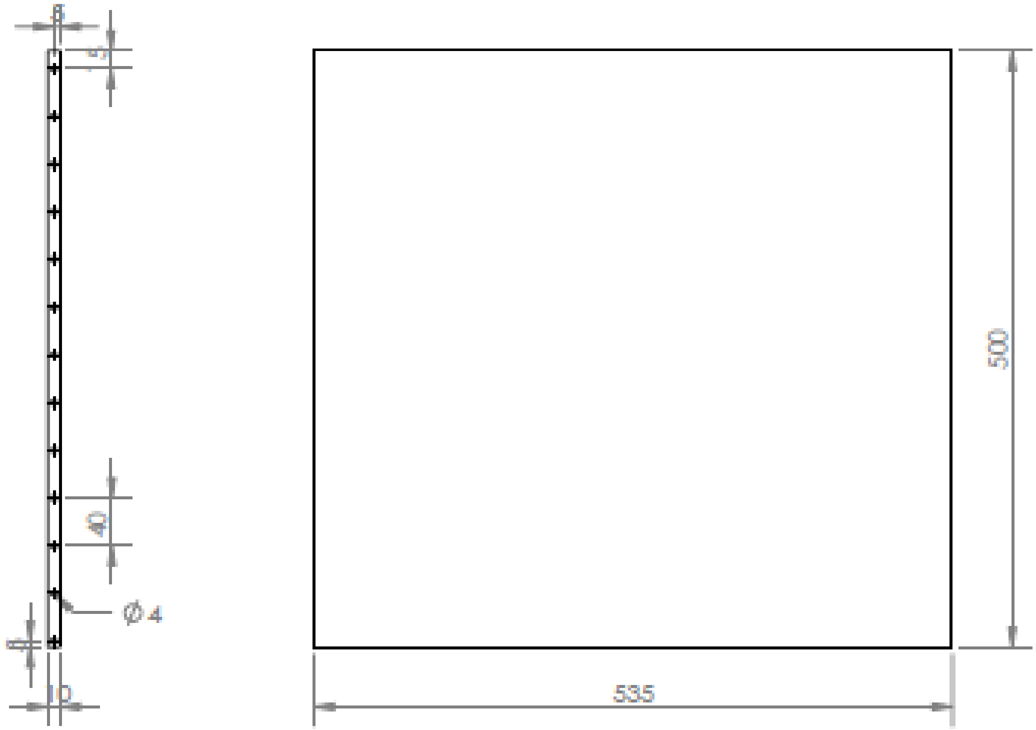

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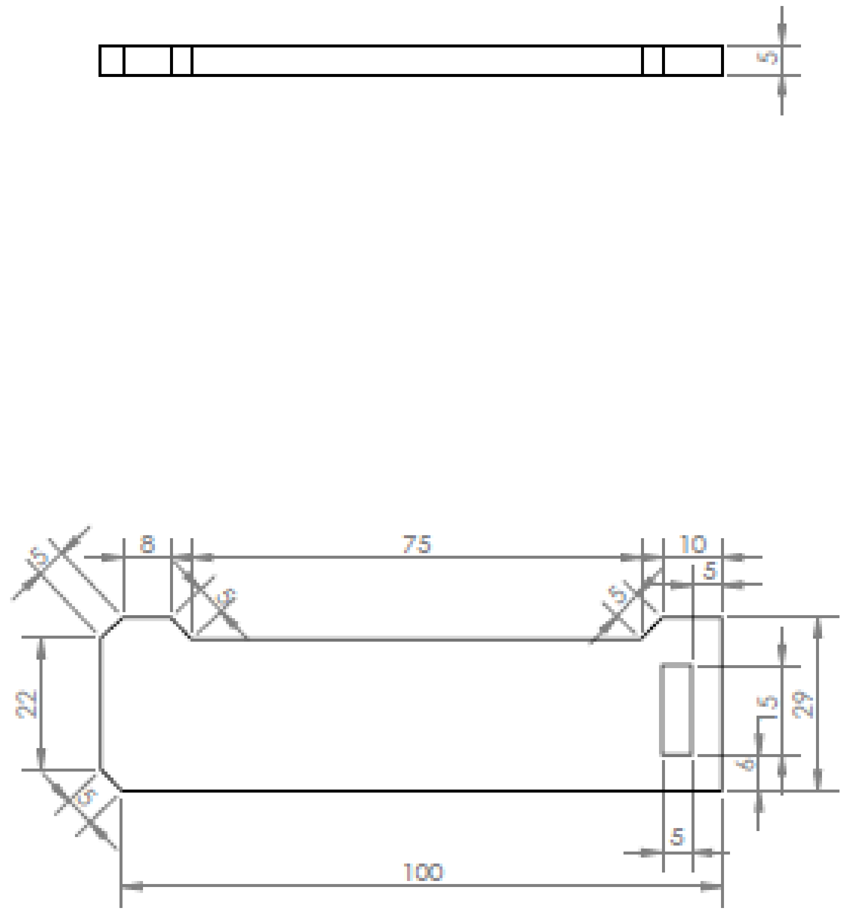

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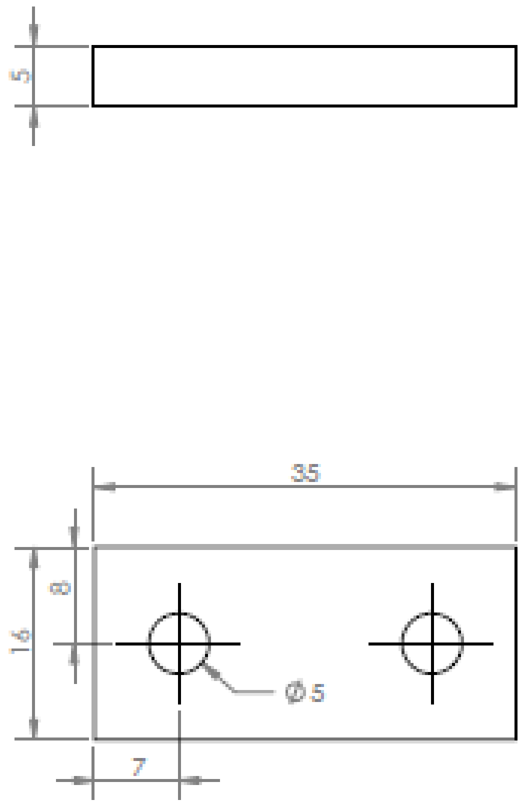

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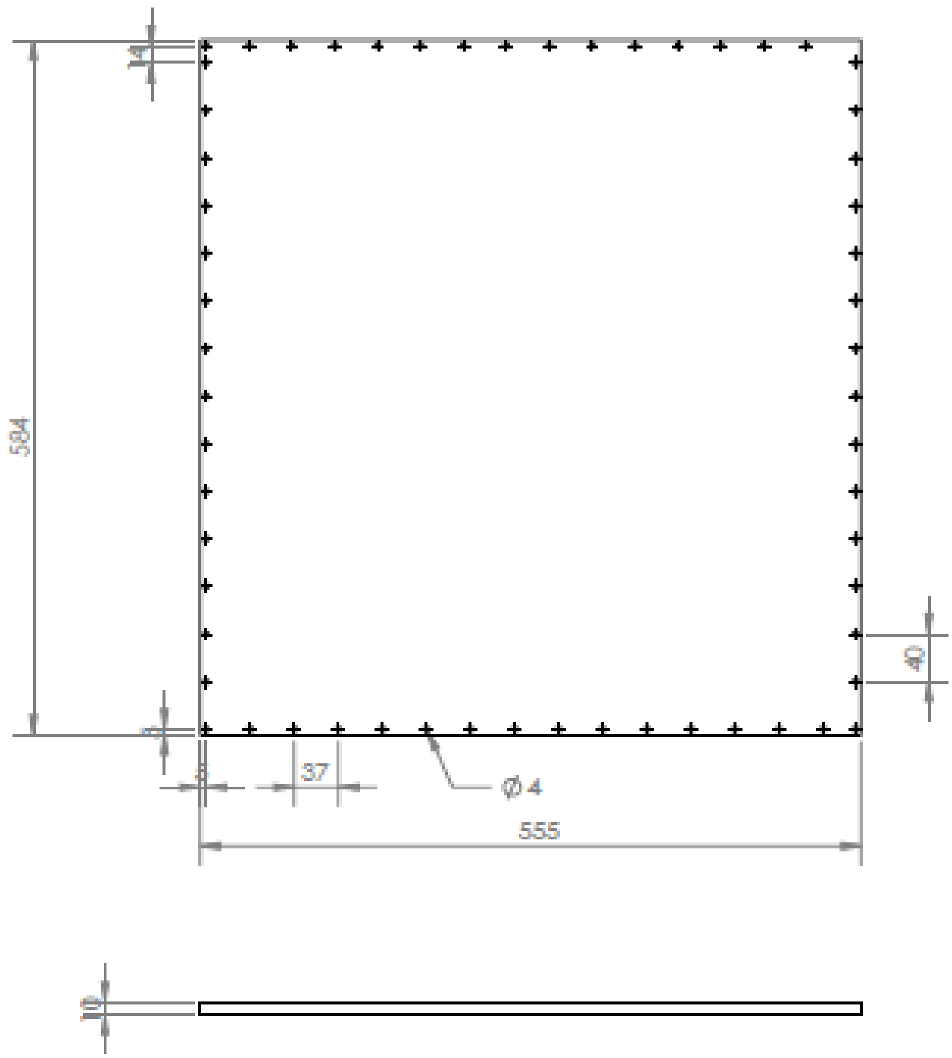

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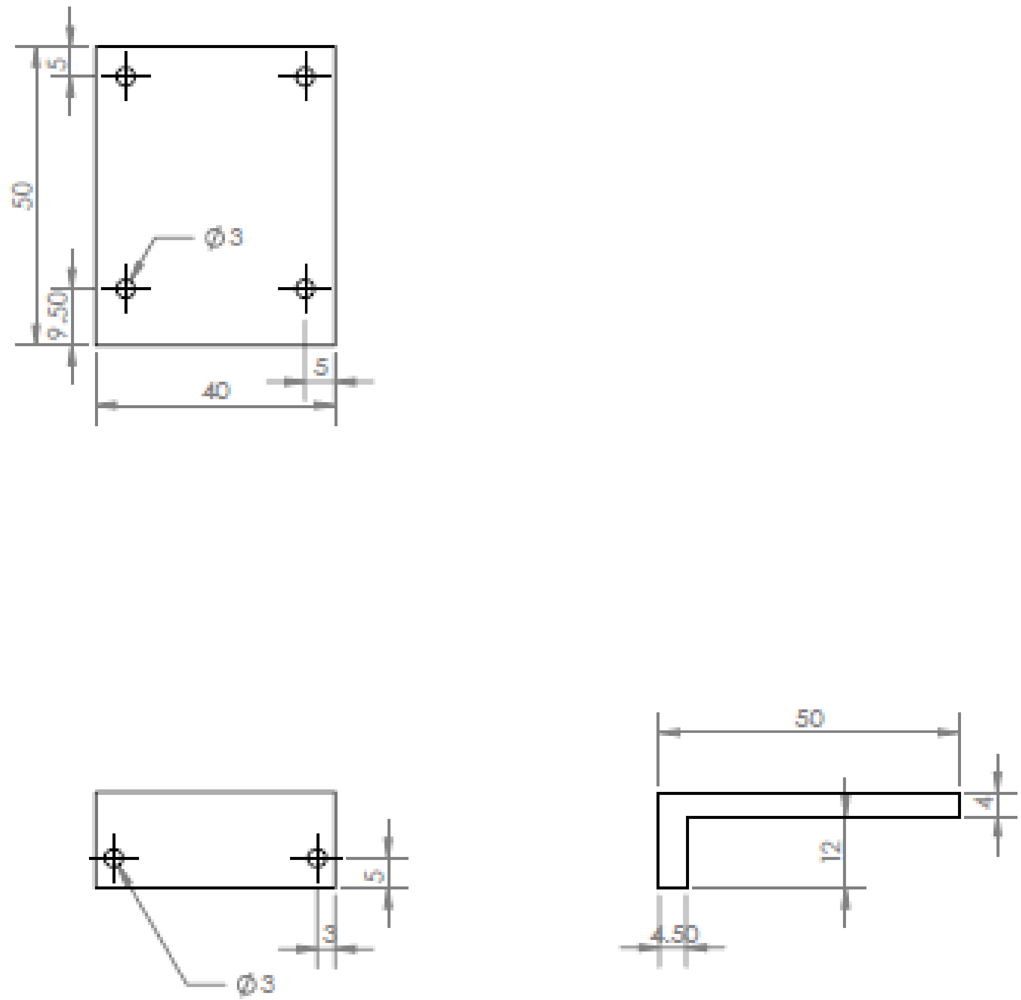

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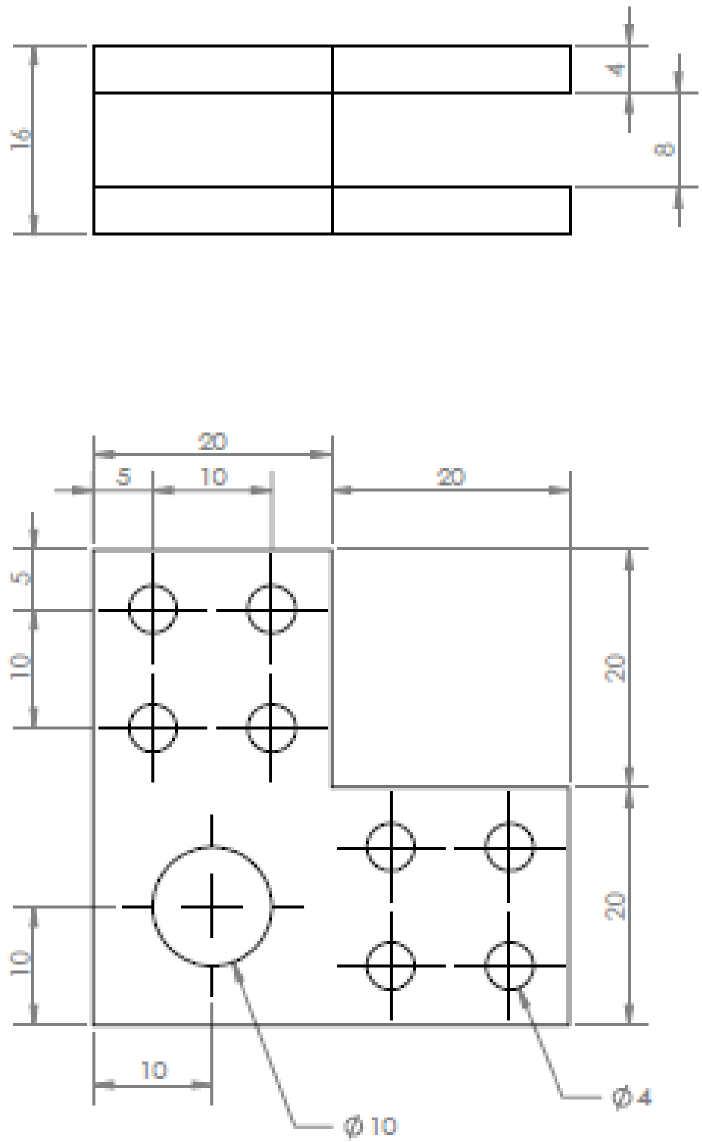

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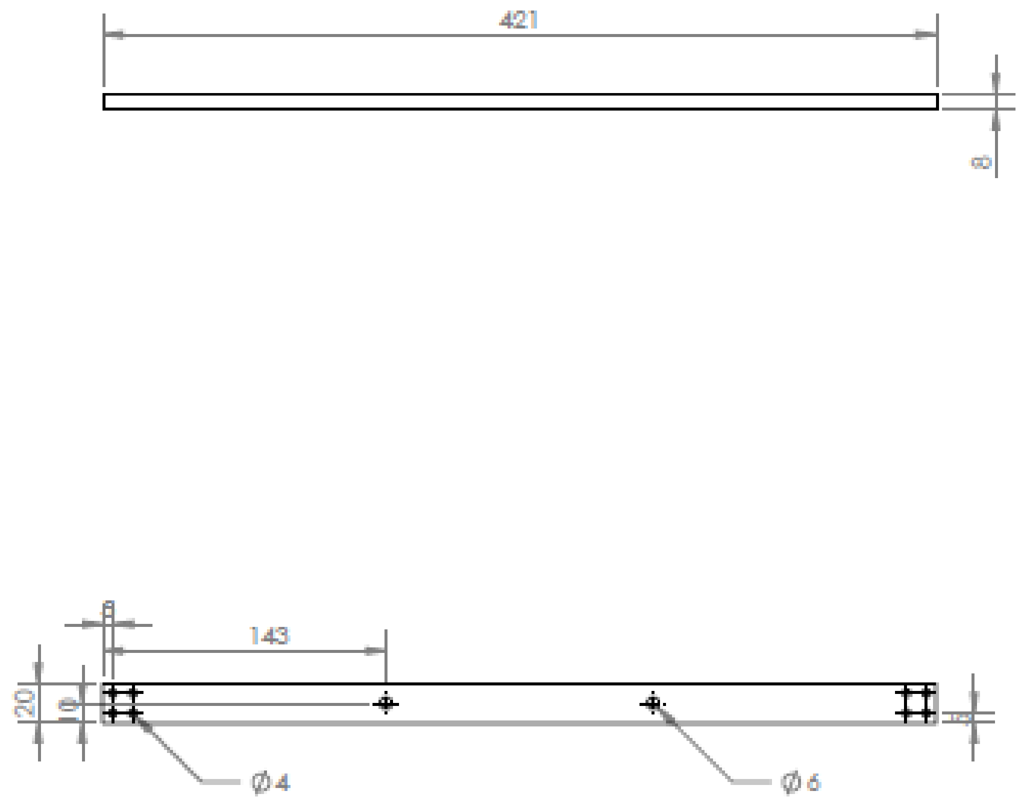

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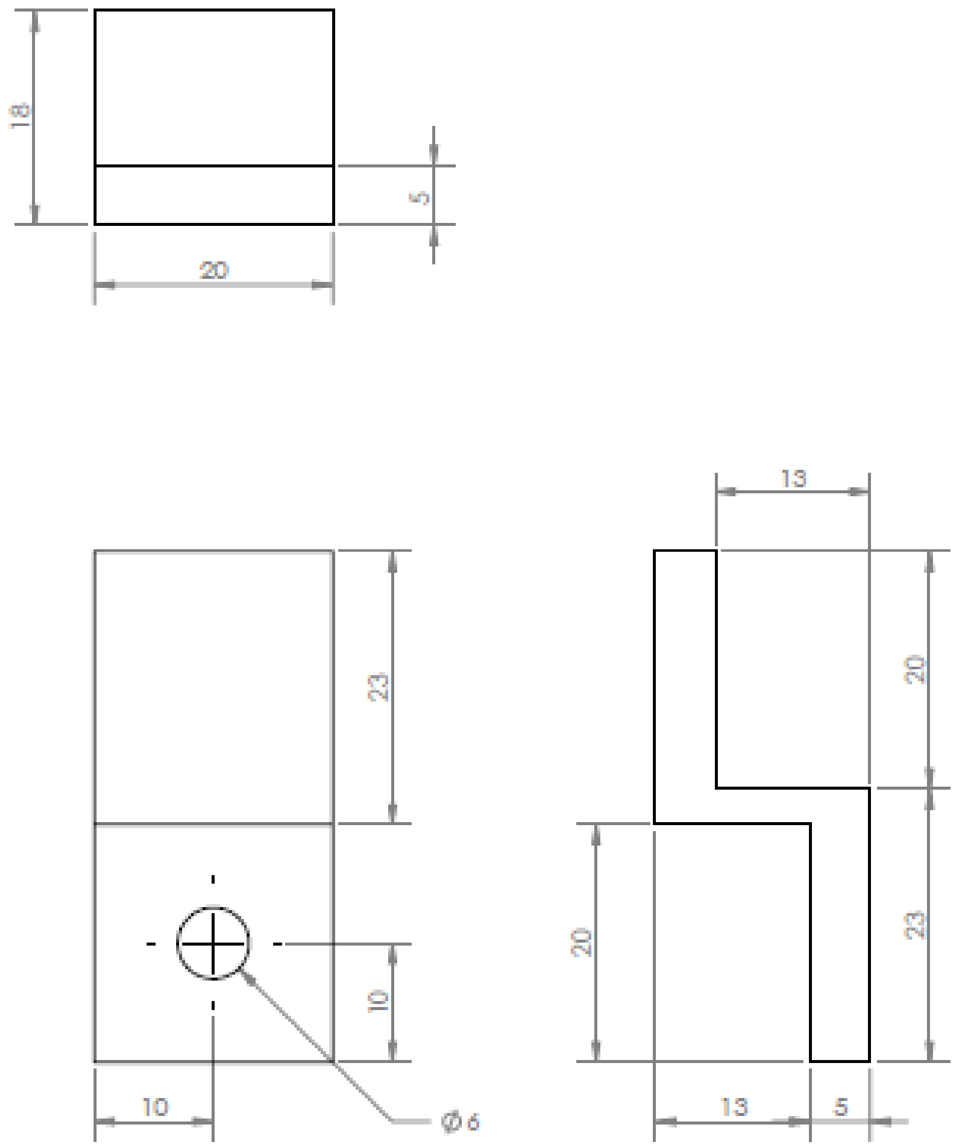

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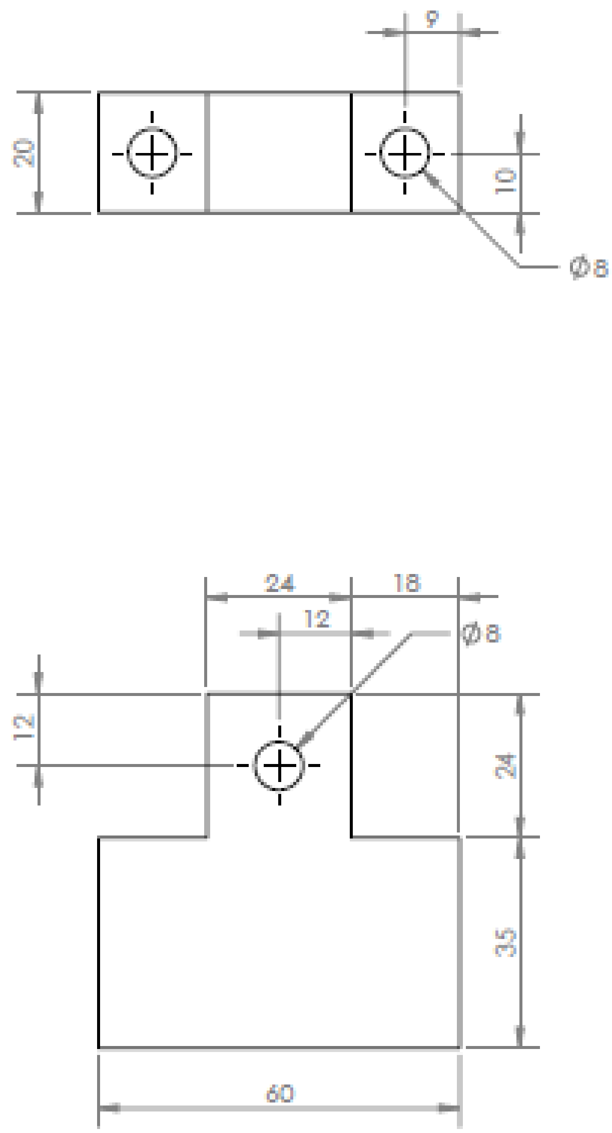

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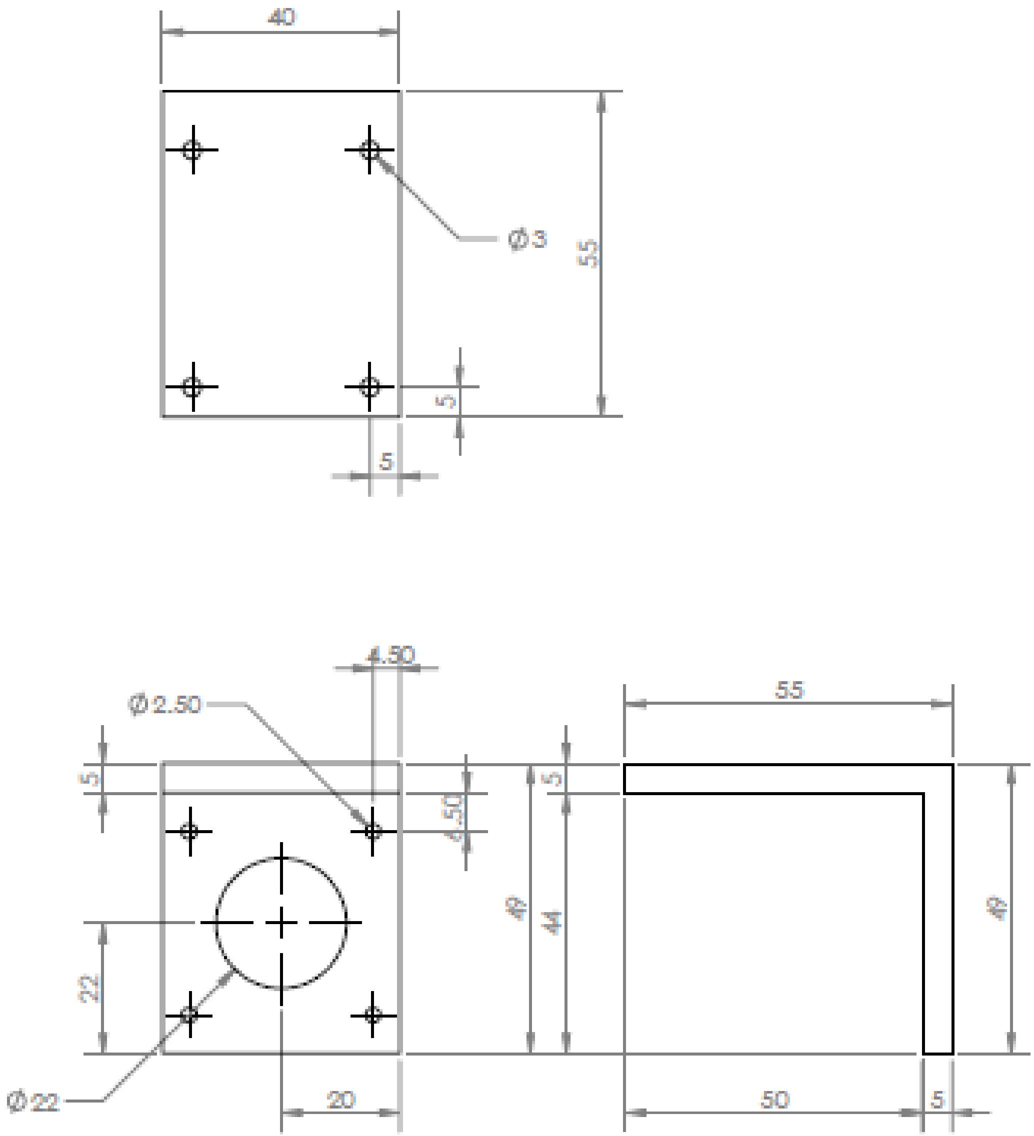

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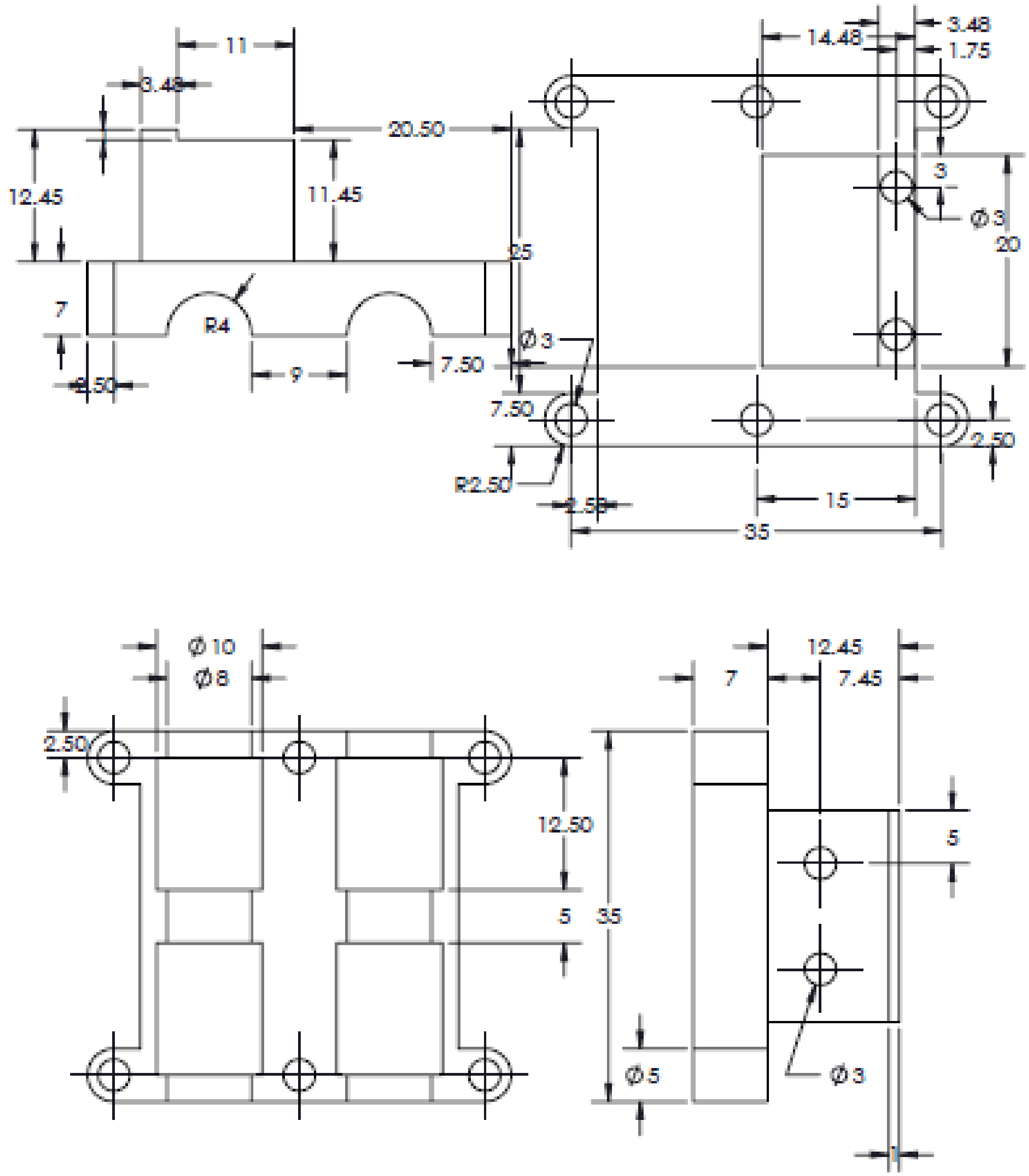

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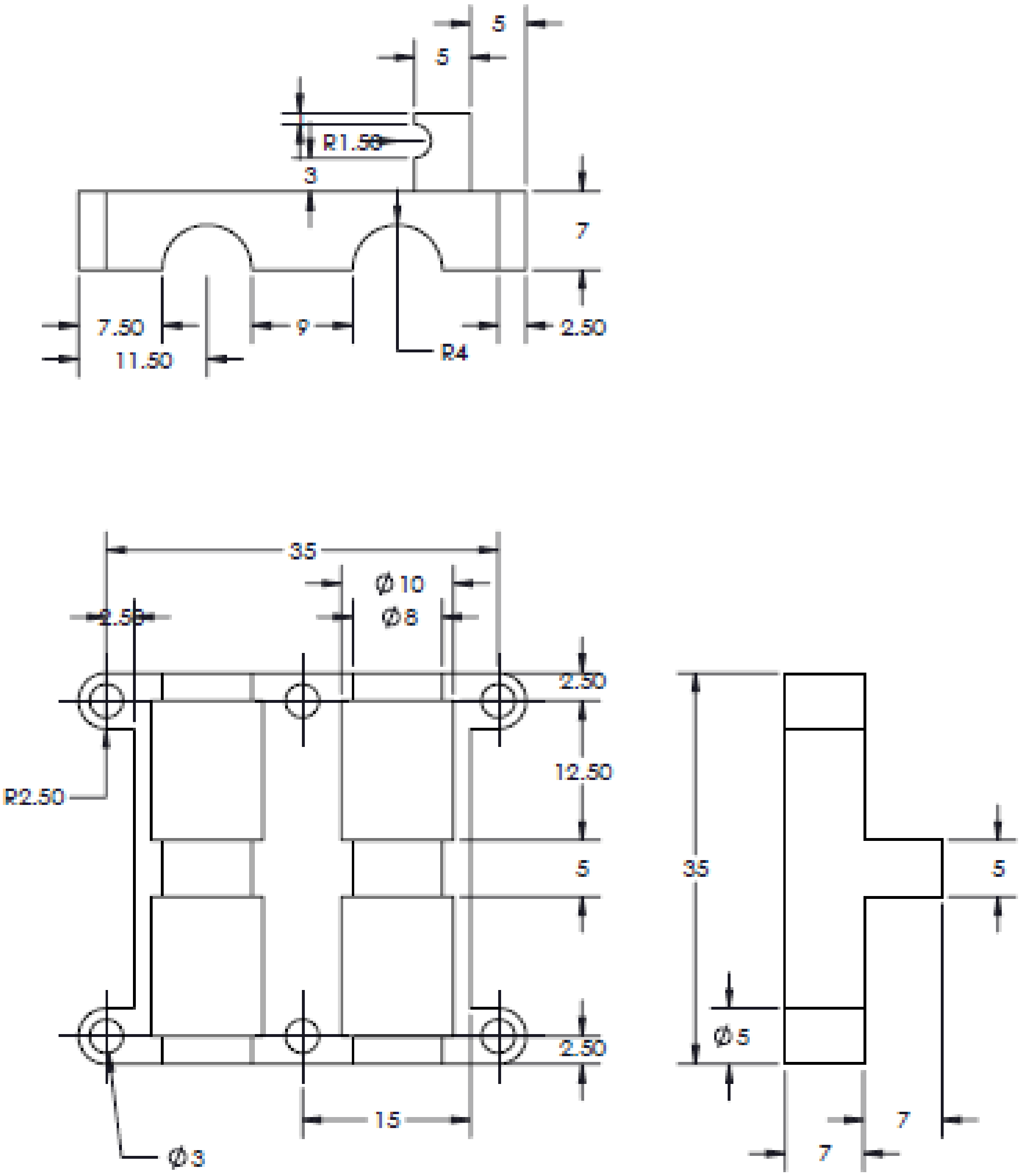

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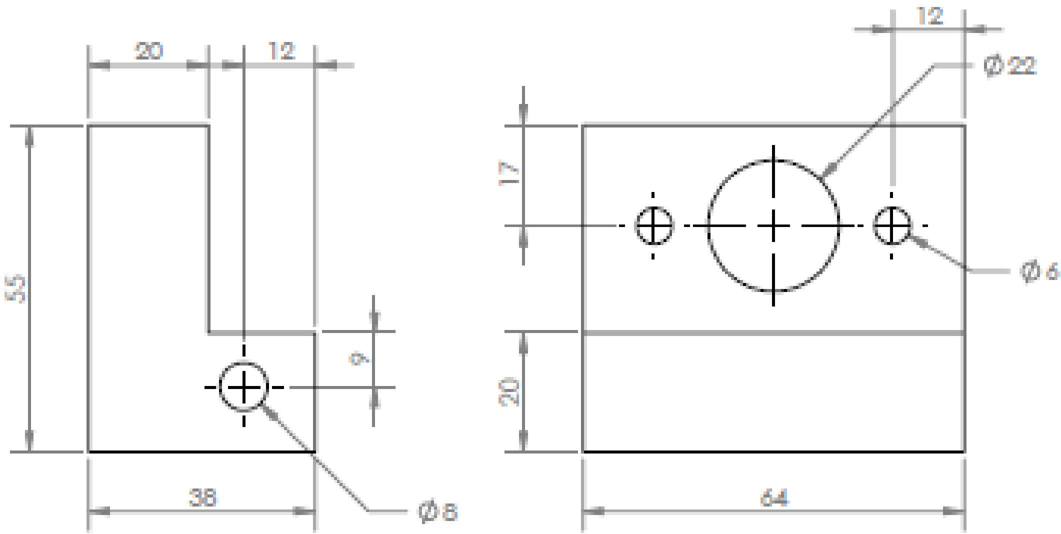

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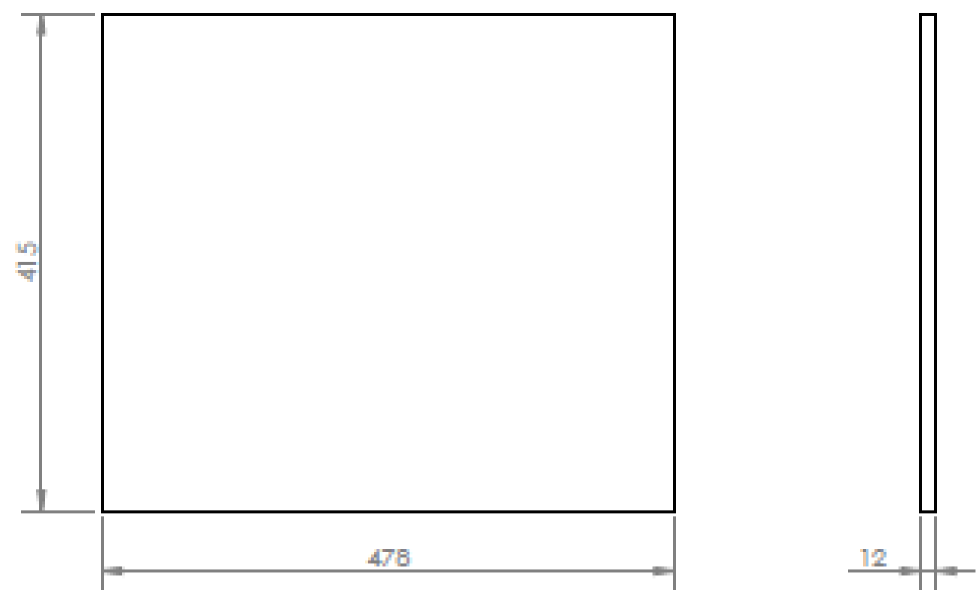

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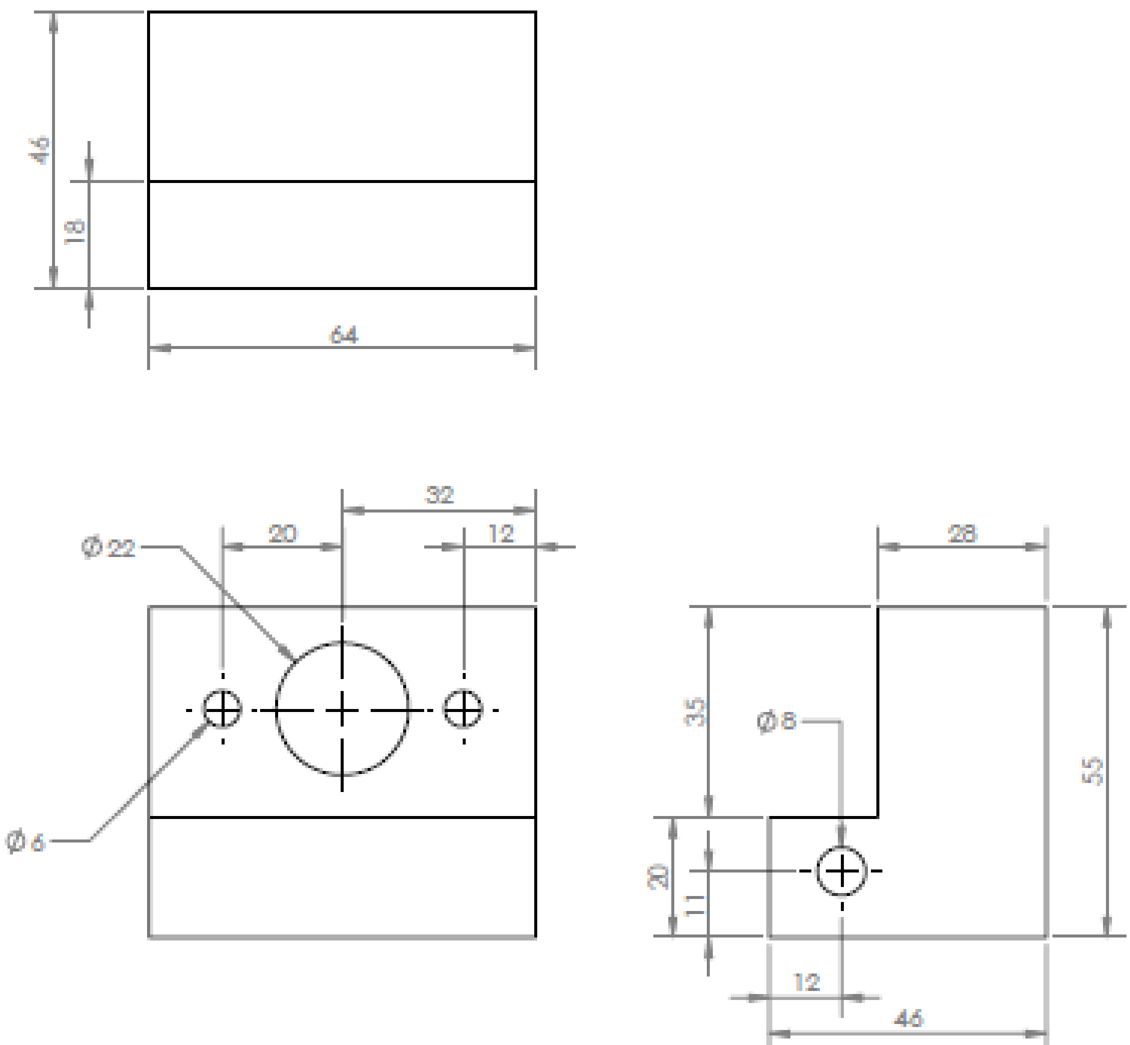

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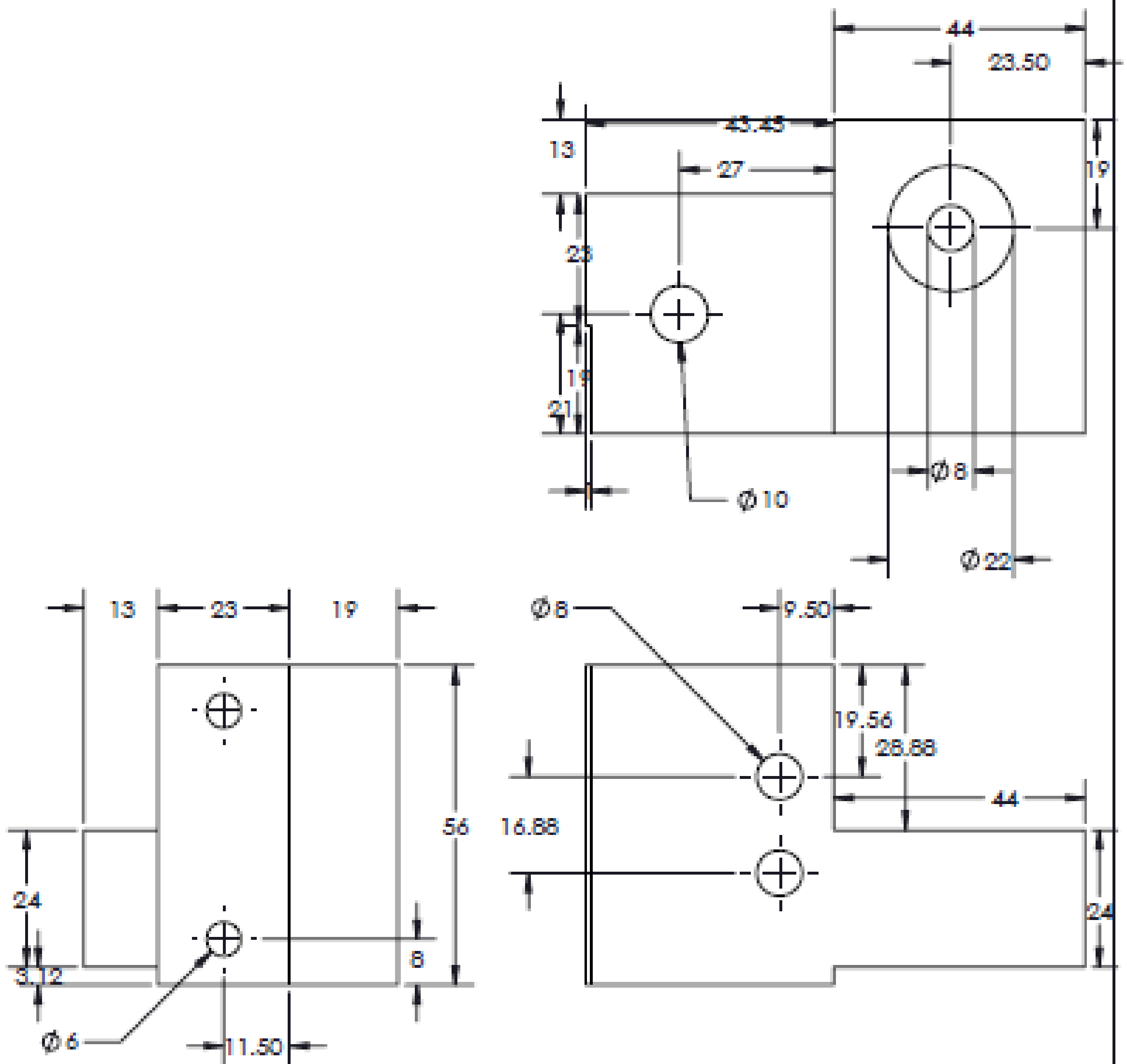

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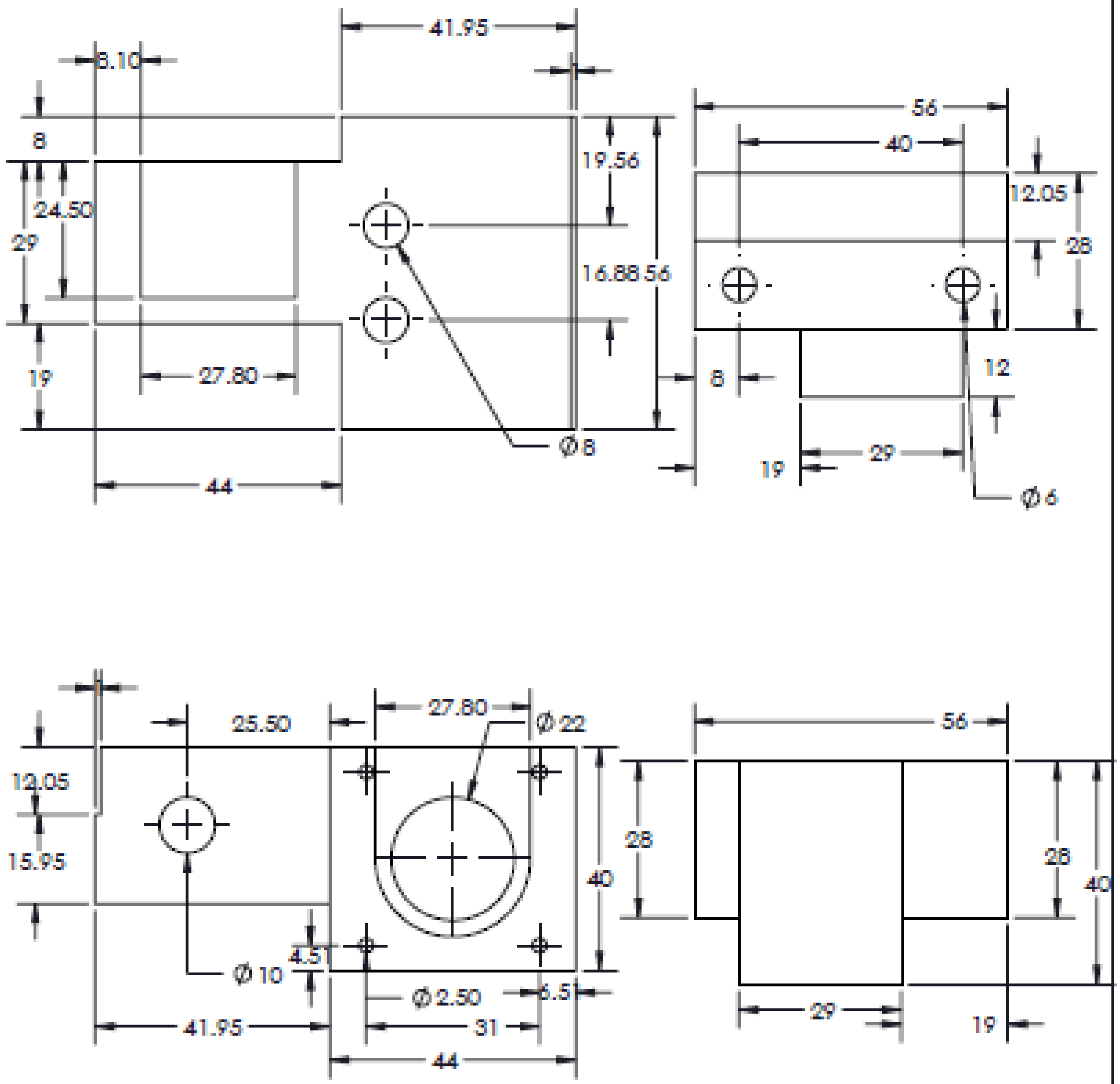

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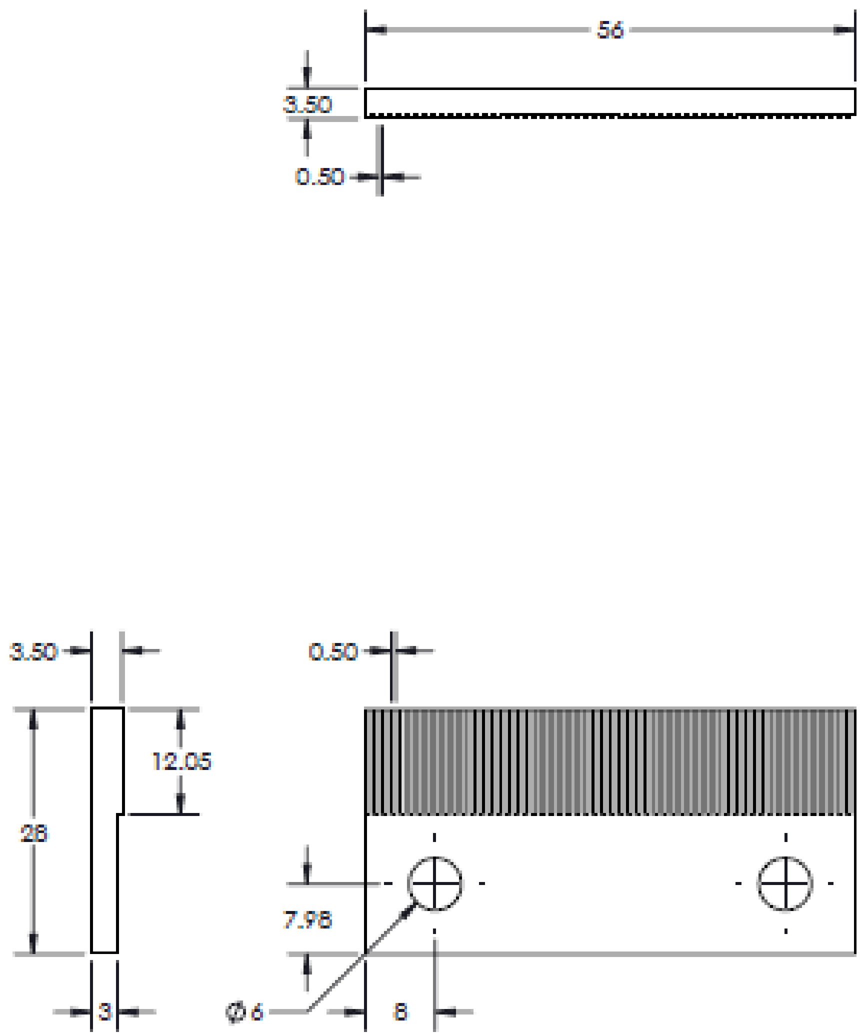

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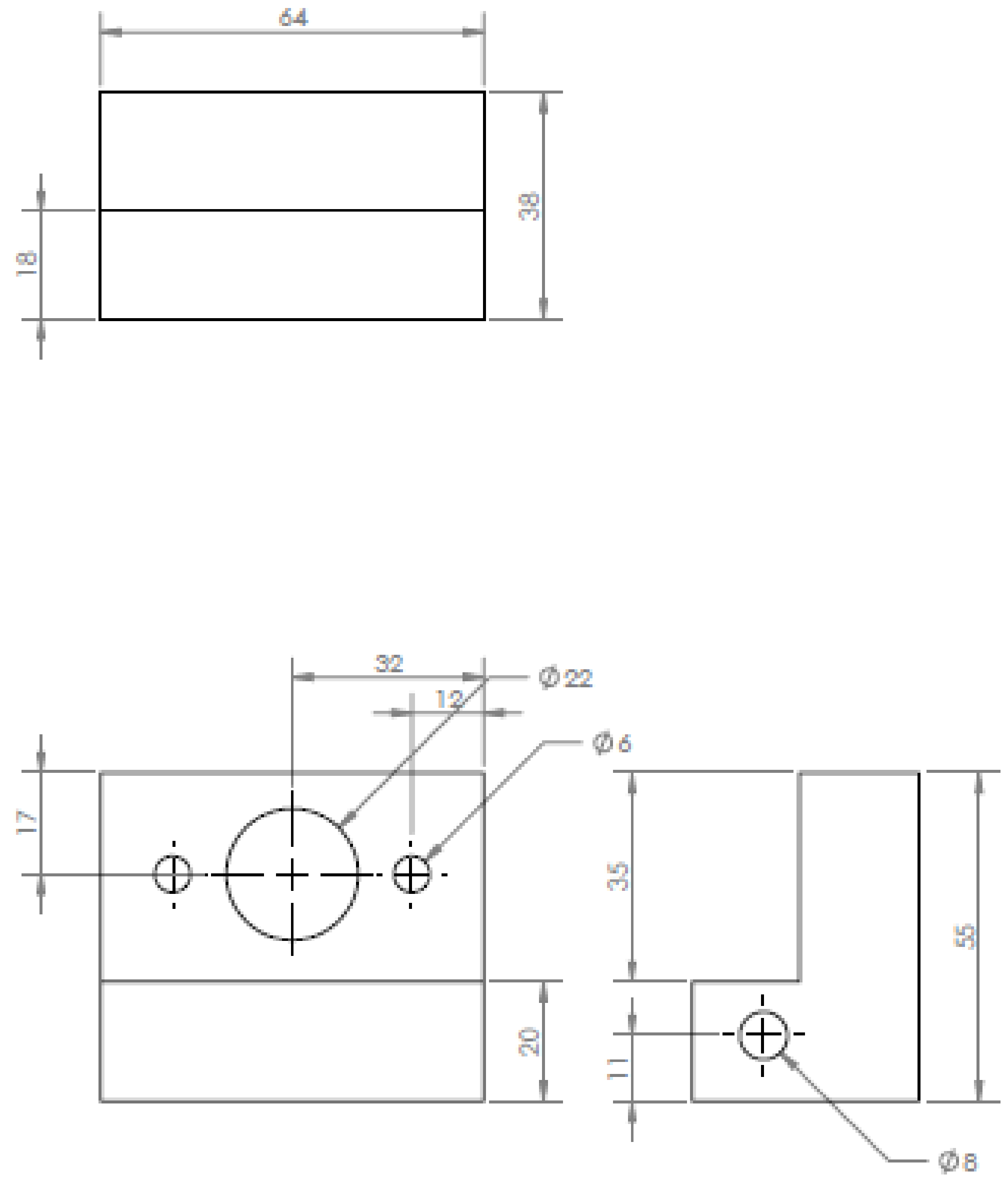

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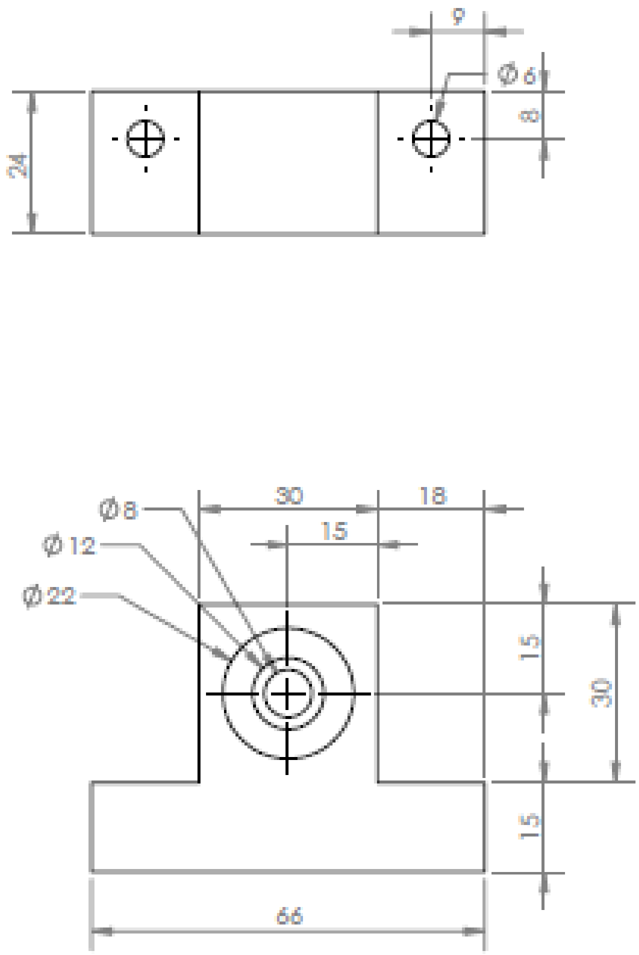

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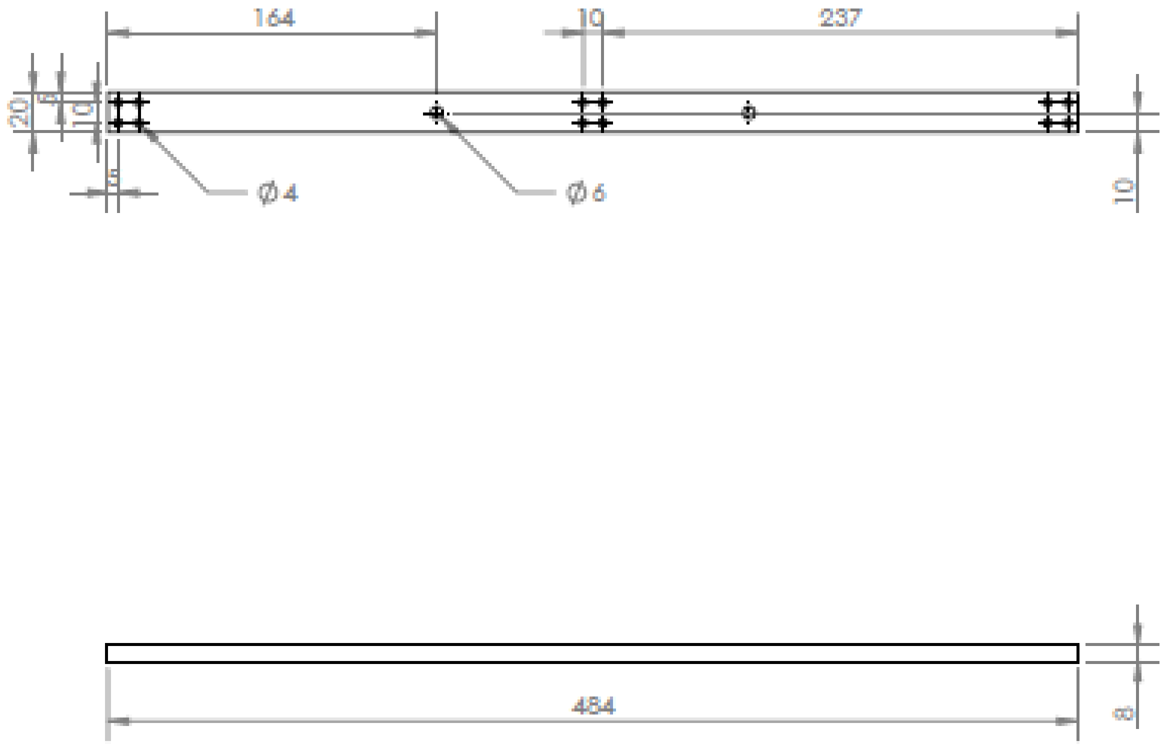
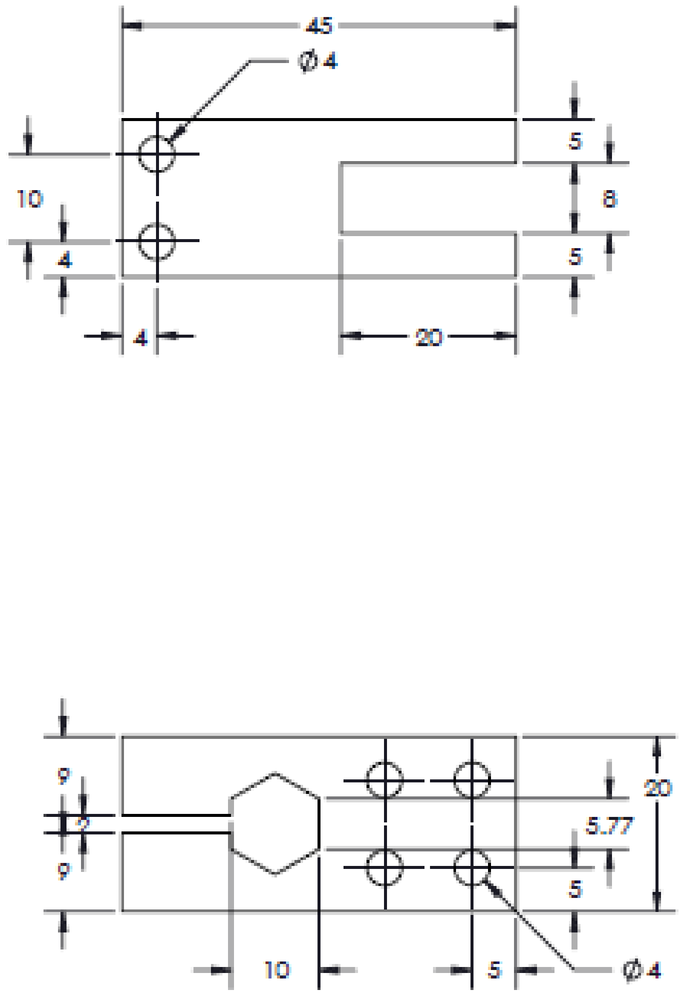
SCALE 1:1	SUPPORTER 5			DRW.NO 1-23



	NAME	DATE	SIGN	EMU
DRW.BY	137944	15.12.15		
CHK.BY	D.SOLYALI	28.12.15		
SCALE 1:3	PLATE FRAME 2			DRW.NO 1-24



	NAME	DATE	SIGN	EMU
DRW. BY	137944	15/12/15		
CHK. BY	D. SOLYALI	28/12/15		
SCALE 3:2	NUT HOLDER			DRW.NO 1-25

APPENDIX D - ENGINEERING STANDARDS

✓ Electrical Engineering Standards

Several electrical engineering standards that are used in this project will be introduced in this section:

Standards from IEEE (The Institute of Electrical and Electronics Engineers):

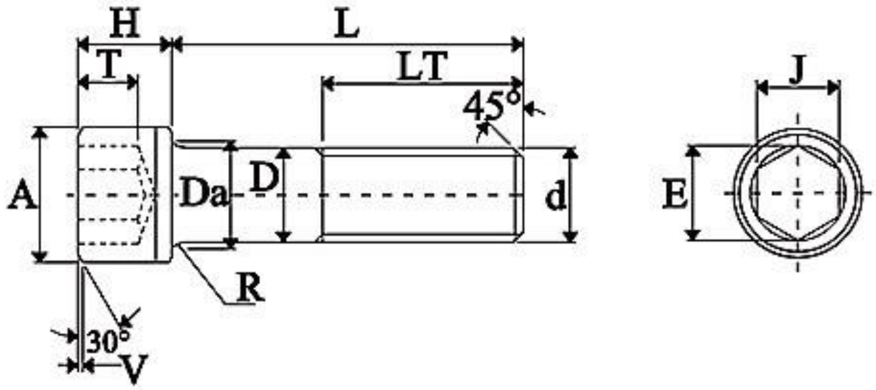
- IEEE 1255-2000 – IEEE guide for evaluation of torque pulsations during starting of synchronous motors.
- IEEE P3030 - intended as the first draft standard to define an architectural framework for consumer 3D printing based upon interoperability and portability of 3D printing solutions, but it's still under test nowadays.
- IEEE 1142-1995 guide for the design, testing, and application of moisture-impervious, solid dielectric, 5–35 kV power cable using metal-plastic laminates [26].

Standards from IEC (The International Electrotechnical Commission):

- IEC 60539-2:2003 is applicable to surface mount directly heated negative temperature coefficient thermistors, typically made from transition metal oxide materials with semiconducting properties. https://webstore.iec.ch/publication/2481
- IEC 60063:2015 provides series of preferred values for the resistance of resistors and for the capacitance of capacitors.
- IEC 60073 Basic Safety principles for man-machine interface, marking and identification - coding principles for indicators and actuators [27].

✓ Mechanical Engineering Standards

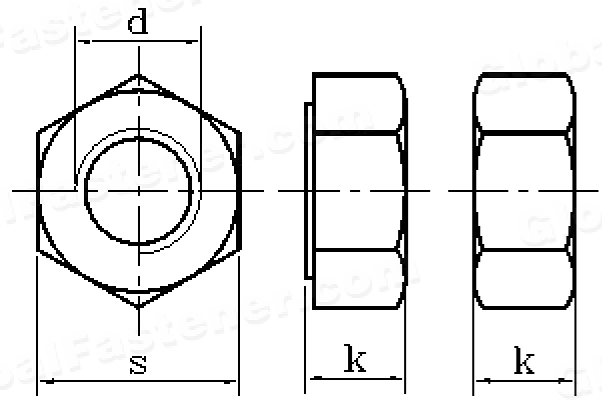
Table D.1: Bolt specifications



Unit : mm

Thread Size(d)	Thread Pitch	D		A		H		V	J		E	T	R	Da
		Nominal Size Max.	Min.	Nominal Size Max.	Min.	Nominal Size Max.	Tolerance Min.	Approx	Nominal Size	Tolerance	Approx	Min.	Min.	Max.
M3	0.5	3	2.86	5.5	5.32	3	2.86	0.3	2.5	+0.080 +0.020	2.87	1.3	0.10	3.6
M4	0.7	4	3.82	7.0	6.78	4	3.82	0.4	3.0	+0.080 +0.020	3.44	2.0	0.20	4.7
M5	0.8	5	4.82	8.5	8.28	5	4.82	0.5	4.0	+0.095 +0.020	4.58	2.5	0.20	5.7
M6	1.0	6	5.82	10.0	9.78	6	5.70	0.6	5.0	+0.140 +0.020	5.72	3.0	0.25	6.8
M8	1.25	8	7.78	13.0	12.73	8	7.64	0.8	6.0	+0.140 +0.020	6.86	4.0	0.40	9.2
M10	1.5	10	9.78	16.0	15.73	10	9.64	1.0	8.0	+0.175 +0.025	9.15	5.0	0.40	11.2
M12	1.75	12	11.73	18.0	17.73	12	11.57	1.2	10.0	+0.175 +0.025	11.43	6.0	0.60	13.7
M14	2.0	14	13.73	21.0	20.67	14	13.57	1.4	12.0	+0.212 +0.032	13.72	7.0	0.60	15.7
M16	2.0	16	15.73	24.0	23.67	16	15.57	1.6	14.0	+0.212 +0.032	16.00	8.0	0.60	17.7
M18	2.5	18	17.73	27.0	26.67	18	17.57	1.8	14.0	+0.212 +0.032	16.00	9.0	0.60	20.2
M20	2.5	20	19.67	30.0	29.67	20	19.48	2.0	17.0	+0.230 +0.050	19.44	10.0	0.80	22.4
M22	2.5	22	21.67	33.0	32.61	22	21.48	2.2	17.0	+0.230 +0.050	19.44	11.0	0.80	24.4
M24	3.0	24	23.67	36.0	35.61	24	23.48	2.4	19.0	+0.275 +0.065	21.73	12.0	0.80	26.4

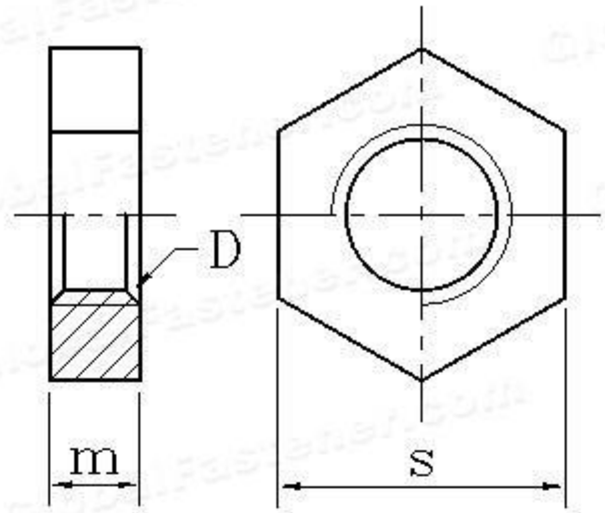
Table D.2: Nuts specifications according to ASMEANSI B18.2.4.6M-2010



Unit: mm

d	P	s		k	
		max	min	max	min
M12	1.75	21.00	20.16	12.3	11.9
M14	2	24.00	23.16	14.3	13.6
M16	2	27.00	26.16	17.1	16.4
M20	2.5	34.00	33.00	20.7	19.4
M22	2.5	36.00	35.00	23.6	22.3
M24	3	41.00	40.00	24.2	22.9
M27	3	46.00	45.00	27.6	26.3
M30	3.5	50.00	49.00	30.7	29.1
M36	4	60.00	58.80	36.6	35.0
M42	4.5	70.00	67.90	42.0	40.4
M48	5	80.00	77.60	48.0	46.4
M56	5.5	90.00	87.20	56.0	54.1
M64	6	100.00	96.80	64.0	62.1
M72	6	110.00	106.40	72.0	70.1
M80	6	120.00	116.00	80.0	78.1
M90	6	135.00	130.50	90.0	87.8
M100	6	150.00	145.00	100.0	97.8

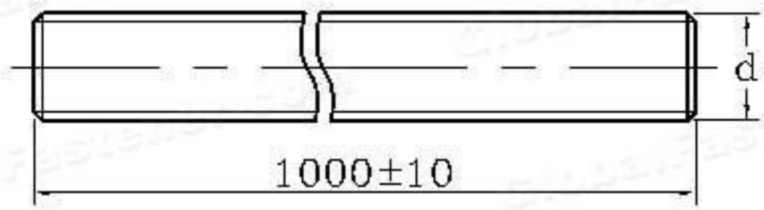
Table D.3: Nuts specifications according to DIN 439-1-1987



Unit: mm

D	P	m		s		Weight (7.85kg/dm³) kg/1000 pieces
		max	min	max	min	
M1.6	0.35	1	0.6	3.2	2.9	0.06
M2	0.4	1.2	0.8	4	3.7	0.11
M2.5	0.45	1.6	1.2	5	4.7	0.22
M3	0.5	1.8	1.4	5.5	5.2	0.29
M3.5	0.6	2	1.6	6	5.7	0.37
M4	0.7	2.2	1.8	7	6.64	0.57
M5	0.8	2.7	2.3	8	7.64	0.83
M6	1	3.2	2.72	10	9.64	1.6
M8	1/1.25	4	3.52	13	12.57	3.2
M10	1/1.5	5	4.52	17	16.57	7.2

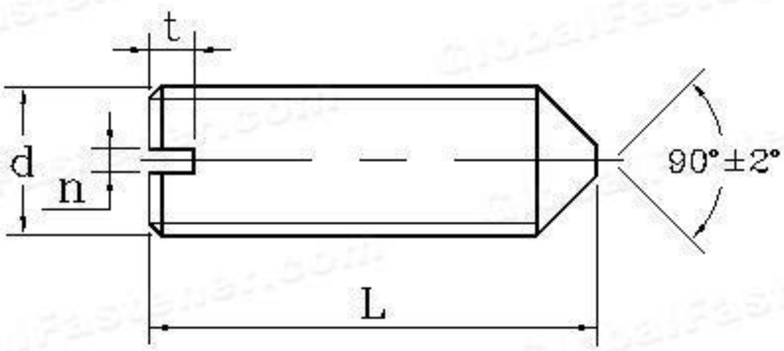
Table D.4: Threaded rod specifications according to DIN 975-1986



Unit: mm

d	P	Weight (7.85kg/dm³) kg/1000 pieces	d	P	Weight (7.85kg/dm³) kg/1000 pieces
M2	0.4	18.7	M20	1.5/2.5	2080
M2.5	0.45	30	M22	1.5/2.5	2540
M3	0.5	44	M24	2/3	3000
M3.5	0.6	60	M27	2/3	3850
M4	0.7	78	M30	2/3.5	4750
M5	0.8	124	M33	2/3.5	5900
M6	1	177	M36	3/4	6900
M8	1/1.25	319	M39	3/4	8200
M10	1/1.25/1.5	500	M42	3/4.5	9400
M12	1.25/1.5/1.75	725	M45	3/4.5	11000
M14	1.5/2	970	M48	3/5	12400
M16	1.5/2	1330	M52	3/5	14700
M18	1.5/2.5	1650			

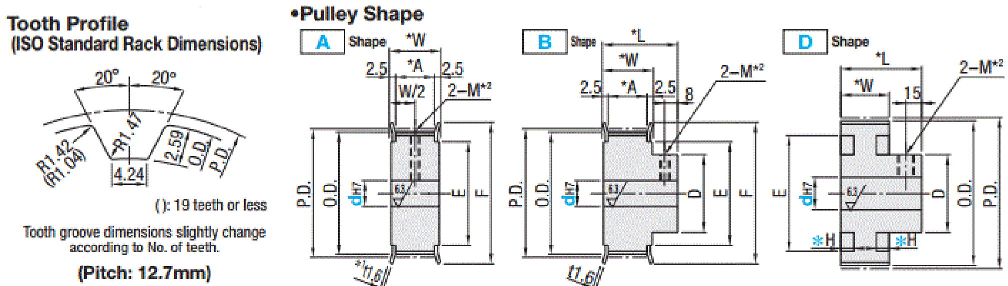
Table D.5: Set screw specifications according to ISO 7434-1983



Unit:mm

d		M1.2	M1.6	M2	M2.5	M3	M3.5	M4	M5	M6	M8	M10	M12
P		0.25	0.35	0.4	0.45	0.5	0.6	0.7	0.8	1	1.25	1.5	1.75
n	Nom	0.2	0.25	0.25	0.4	0.4	0.5	0.6	0.8	1	1.2	1.6	2
	max	0.4	0.45	0.45	0.6	0.6	0.7	0.8	1	1.2	1.51	1.91	2.31
	min	0.26	0.31	0.31	0.46	0.46	0.56	0.66	0.86	1.06	1.26	1.66	2.06
k	max	0.52	0.74	0.84	0.95	1.05	1.21	1.42	1.63	2	2.5	3	3.6
	min	0.4	0.56	0.64	0.72	0.8	0.96	1.12	1.28	1.6	2	2.4	2.8

Table D.6: Belt pulley specifications according to ISO



*1 t=2.0 for 40~50 toothed pulleys (Cut Flange).
*2 Shaft Bore Specifications H (Round Hole), V,F (Stepped Hole) and Y (Both Sides Stepped Hole), do not have tapped holes.

Tapped Hole Dimensions (Shaft Bore: P / N / C)

dr Shaft Bore Inner Dia.	M (Coarse)	Accessory Set Screw
12	M4	M4x3
13~17	M5	M5x4
18~30	M6	M6x5
31~46	M8	M8x6
47~65	M10	M10x8

Part Number: Type	Teeth	Type Nominal Width	Pulley Shape	Shaft Bore Specifications	H dH7 A Shape	H dH7 B-D Shape	P dH7 A Shape	P dH7 B-D Shape	N/C dH7 A Shape	N/C dH7 B-D Shape	HU dH7 A Shape	HU dH7 B-D Shape	PU dH7 A Shape	PU dH7 B-D Shape	NU dH7 A Shape	NU dH7 B-D Shape	V/F dH7 A Shape	V/F dH7 B Shape	V/F ZH7 A Shape	V/F ZH7 B Shape	V/F J (0.1mm Increment) A Shape·B Shape	Y d A Shape	Y Q(H7)/R(H7) A Shape	Y S/T A Shape	P.D.	O.D.	D	F	E
(7075 Aluminum Alloy) ATPA ATPB ATPK ATPN	14	H075	A B	H HU P PU N NU C V F Y	12-37	12-35	12-30	12-29	12-29	12-25	F-M	F-M	F-K	F-K	F-K	F-J	12-35	12-33	14-37	14-35	(For A Shape) 3.0≤J≤W-3.0 (For B Shape) 3.0≤J≤L-3.0	12-35	14-37	3~28 S+T≤W-3	56.60	55.22	39	61	45
	15				12-42	12-41	12-34	12-33	12-30	12-29	F-P	F-N	F-L	F-L	F-K	F-K	12-40	12-39	14-42	14-41		12-40	14-42		60.64	59.27	45	67	50
	16				12-48	12-44	12-40	12-36	12-35	12-30	F-R	F-P	F-N	F-M	F-M	F-K	12-46	12-42	14-48	14-44		12-46	14-48		64.68	63.31	48	70	56
	17				12-52	12-44	12-44	12-36	12-40	12-30	F-S	F-P	F-P	F-M	F-N	F-K	12-50	12-42	14-52	14-44		12-50	14-52		68.72	67.35		80	60
	18				12-52	12-46	12-44	12-38	12-43	12-35	F-S	F-Q	F-P	F-M	F-P	F-M	12-50	12-44	14-52	14-46		12-50	14-52		72.77	71.39	50		
	19				14-59	14-46	14-49	12-38	14-47	14-35	G-S	G-Q	G-R	F-M	G-Q	G-M	14-57	14-44	16-59	16-46		14-57	16-59		76.81	75.44		87	67
	20	H100			14-59	14-54	14-50	14-46	14-50	14-38	G-S	G-S	G-S	G-Q	G-S	G-M	14-57	14-52	16-59	16-54		14-57	16-59		80.85	79.48	58	87	67
	21				14-67	14-54	14-57	14-46	14-50	14-38	G-S	G-S	G-S	G-Q	G-S	G-M	14-65	14-52	16-67	16-54		14-65	16-67		84.89	83.52		95	75
	22				14-67	14-54	14-57	14-46	14-50	14-38	G-S	G-S	G-S	G-Q	G-S	G-M	14-65	14-52	16-67	16-54		14-65	16-67		88.94	87.56			
(1045 Carbon Steel) ATPT ATP ATPP	24				16-76	16-54	16-65	16-46	16-50	16-38	H-S	H-S	H-S	H-Q	H-S	H-M	16-74	16-52	18-76	18-54		16-74	18-76		97.01	95.65		104	84
	25				16-80	16-59	16-65	16-49	16-50	16-41	H-S	H-S	H-S	H-R	H-S	H-N	16-80	16-57	18-82	18-59		16-75	18-82		101.06	99.69	63	111	90
	26				20-80	20-59	20-65	20-49	20-50	20-41	J-S	J-S	J-S	J-R	J-R	J-N	20-80	20-57	22-82	22-59		20-75	22-82		105.11	103.73			
	28				20-80	20-59	20-65	20-49	20-50	20-41	J-S	J-S	J-S	J-R	J-R	J-N	20-80	20-57	22-94	22-59		20-75	22-94		113.19	111.82		123	102
	30	H150			20-80	20-59	20-65	20-49	20-50	20-41	J-S	J-S	J-S	J-R	J-R	J-N	20-80	20-57	22-95	22-59		20-75	22-95		121.28	119.90		127	105
	32				20-80	20-59	20-65	20-49	20-50	20-43	J-S	J-S	J-S	J-R	J-R	J-P	20-80	20-57	22-95	22-59		20-75	22-95		129.36	127.99		135	115
	34				20-80	20-67	20-65	20-57	20-50	20-49	J-S	J-S	J-S	J-R	J-R	J-R	20-80	20-65	22-95	22-67		20-75	22-95		137.45	136.07	71	144	125
	36				20-80	20-67	20-65	20-57	20-50	20-49	J-S	J-S	J-S	J-R	J-R	J-R	20-80	20-65	22-95	22-67		20-75	22-95		145.53	144.16		152	130
(1045 Carbon Steel) ATPT ATP ATPP	38	H200	A D		20-80	20-67	20-65	20-57	20-50	20-49	J-S	J-S	J-S	J-R	J-R	J-R	20-80	-	22-95	-		20-75	22-95		153.62	152.24	88	165	140 (126)
	40				20-80	20-67	20-65	20-57	20-50	20-49	J-S	J-S	J-S	J-R	J-R	J-R	20-80		22-95			20-75	22-95		161.70	160.33		170	150 (135)
	42				20-80	20-67	20-65	20-57	20-50	20-49	J-S	J-S	J-S	J-R	J-R	J-R	20-80		22-95			20-75	22-95		169.79	168.41		180	155 (143)
	44				20-100	20-67	20-65	20-57	20-50	20-49	J-S	J-S	J-S	J-R	J-R	J-R	20-100		22-125			20-100	22-125		177.87	176.50		190	170 (152)
	48	H300 *1			20-100	20-67	20-65	20-57	20-50	20-49	J-S	J-S	J-S	J-R	J-R	J-R	20-100		22-125			20-100	22-125		194.04	192.67		205	180 (168)
	50				20-100	20-67	20-65	20-57	20-50	20-49	J-S	J-S	J-S	J-R	J-R	J-R	20-100		22-125			20-100	22-125		202.13	200.76		210	185 (175)
	60		D		-	25-67	-	25-57	-	25-49	-	J-S	-	J-R	-	J-R	-	-	-	-		-	-		242.55	241.18	88	-	216
	72					25-67		25-57		25-49	-	J-S	-	J-R	-	J-R									291.06	289.69			265

For inch hole dimensions detail information refer to next page.
Z-d≥2 for Shaft Bore Specification V.
Q(R)-d≥2 for shaft bore specification Y.
Available number of teeth with nominal width H075 and H200 is up to 36.
*E dimension in ( ) are for D Shape with 38~48 teeth.
Shaft Bore Dia. 13, 14, 17, 21~50 are not available for Shaft Bore specification C.
*1) Available up to 36 Teeth for H300.

Table D.7: Braided cable sleeving specifications

Standard Braided Copper Cables

	Cross Sectional Area								
New England Part Number	Equivalent Size	Circular Mil Area	SQ MM	AWG of Wire	Number of Wires	Construction	Nominal Width	Nominal Thickness*	LBS/ 1000 FT
NE4136TR	30 AWG	100	0.051	36	4	4/1/1936	0.019 Round		0.333
NE6240TR	30 AWG	113	0.057	40	12	6/2/1936	0.018 Round		0.384
NE12242TR	29 AWG	150	0.076	42	24	12/2/1942	0.023 Round		0.499
NE6136TR	29 AWG	150	0.076	36	6	6/1/1936	0.022 Round		0.499
NE8240TR	29 AWG	154	0.078	40	16	8/2/1940	0.018 Round		0.512
NE8136TR	27 AWG	200	0.101	36	8	8/1/1936	0.021 Round		0.666
NE12240TR	27 AWG	231	0.117	40	24	12/2/1940	0.025 Round		0.768
NE12136TR	26 AWG	300	0.152	36	12	12/1/1936	0.028 Round		0.999
NE16240TR	26 AWG	308	0.156	40	32	16-2-40	0.026 Round		1.024
NE8134TR	25 AWG	318	0.161	34	8	8/1/1934	0.030 Round		1.060
NE16136TR	24 AWG	400	0.200	36	16	16-1-36	0.029 Round		1.330
NE16340TR	24 AWG	461	0.230	40	48	16-3-40	0.035 Round		1.400
NE24136TR	23 AWG	600	0.300	36	24	24-1-36	0.047	0.020	2.000
NE12236TR	23 AWG	600	0.300	36	24	12/2/1936	0.047	0.025	2.000
NE8336TRT	23 AWG	600	0.300	36	24	8/3/1936	0.038 Round		2.000
NE66-40T	22 AWG	634	0.320	40	66	14-4-40 & 2-5-40	0.041 Round		1.920
NE16134TR	22 AWG	635	0.320	34	16	16-1-34	0.038 Round		2.110
NE16236T	21 AWG	800	0.410	36	32	16-2-36	0.063	0.025	2.420
NE16640T	21 AWG	923	0.470	40	96	16-6-40	0.063	0.031	3.070
NE12940TR	20 AWG	1038	0.530	40	108	12/9/1940	0.065 Round		3.460
NE16336T	20 AWG	1200	0.610	36	48	16-3-36	0.094	0.020	4.000
NE24236T	20 AWG	1200	0.610	36	48	24-2-36	0.094	0.025	4.000
NE16436T	18 AWG	1600	0.810	36	64	16-4-36	0.094	0.025	5.320
NE24336T	18 AWG	1800	0.910	36	72	24-3-36	0.109	0.025	5.450
NE16536T	18 AWG	2000	1.010	36	80	16-5-36	0.125	0.025	6.660
NE124244TR	17 AWG	2016	1.020	44	504	12-42-44	0.068 Round		6.290
NE24436T	17 AWG	2400	1.220	36	96	24-4-36	0.156	0.031	7.990
NE24536T	16 AWG	3000	1.520	36	120	24-5-36	0.188	0.020	9.990
NE24736T	14 AWG	4200	2.130	36	168	24-7-36	0.219	0.031	13.980
NE241036T	13 AWG	6000	3.040	36	240	24-10-36	0.250	0.040	19.980
NE48636T	12 AWG	7200	3.650	36	288	48-6-36	0.375	0.030	23.970
NE241336T	12 AWG	7800	3.950	36	312	24-13-36	0.281	0.047	25.970
NE48836T	11 AWG	9600	4.860	36	384	48-8-36	0.500	0.030	31.960
NE241636T	11 AWG	9600	4.860	36	384	24-16-36	0.375	0.063	31.960
NE24430T	11 AWG	9600	4.860	30	96	24-4-30	0.313	0.050	31.960
NE24530T	10 AWG	12000	6.080	30	120	24-5-30	0.375	0.050	39.960
NE481136T	9 AWG	13200	6.690	36	528	48-11-36	0.625	0.040	43.950
NE24730T	8 AWG	16800	8.510	30	168	24-7-30	0.438	0.063	55.940
NE481536T	8 AWG	18000	9.120	36	720	48-15-36	0.630	0.040	61.150
NE832-36T-1	7 AWG	20800	10.500	36	832	(32-17-36)&(16-18-36)	1.000	0.045	69.260
NE481936T	7 AWG	22800	11.600	36	912	48-19-36	0.813	0.050	75.900
NE244036T	7 AWG	24000	12.200	36	960	24-40-36	0.530	0.094	75.160
NE241030T	7 AWG	24000	12.200	30	240	24-10-30	0.500	0.094	81.510
NE482236T	6 AWG	26400	13.400	36	1056	48-22-36	0.880	0.040	87.900
NE241530T	5 AWG	36000	18.200	30	360	24-15-30	0.630	0.094	127.800
NE488640T	5 AWG	39670	20.100	40	4128	48-86-40	0.810	0.125	134.700
NE246736T	4 AWG	40200	20.400	36	1608	24-67-36	0.750	0.094	142.700
NE484036T	4 AWG	48000	24.300	36	1920	48-40-36	1.000	0.094	163.000
NE242030T	4 AWG	48000	24.300	30	480	24-20-30	0.750	0.125	170.400
NE242730T	3 AWG	64800	32.800	30	648	24-27-30	0.940	0.125	230.100
NE486036T	2 AWG	72000	36.500	36	2880	48-60-36	1.250	0.094	255.600
NE243230T	2 AWG	76800	38.900	30	768	24-32-30	1.000	0.125	248.000
NE488436T	1 AWG	100800	51.100	36	4032	48-84-36	1.630	0.125	357.900
NE244430T	1/0 AWG	105600	53.500	30	1056	24-44-30	1.250	0.125	374.900
NE2242730T	1/0 AWG	129600	65.700	30	1296	2(24-27-30)	1.130	0.250	460.200
NE2243230T	2/0 AWG	153600	77.800	30	1536	2(24-32-30)	1.250	0.250	545.500
NE2243530T	3/0 AWG	168000	85.100	30	1680	2(24-35-30)	1.250	0.250	596.500
NE3243230T	4/0 AWG	230400	116.700	30	2304	3(24-32-30)	1.250	0.375	818.100
NE4243230T	300 MCM	307200	155.700	30	3072	4(24-32-30)	1.375	0.500	1091.000

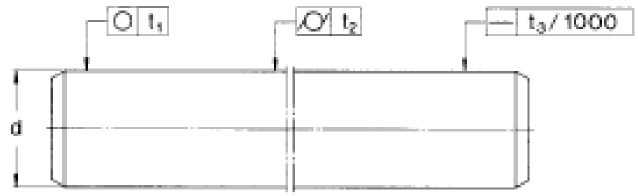
*All measurements are in inches unless otherwise stated.

Material is manufactured to width specification; thickness dimensions are given as reference only and may vary slightly due to the manufacturing process inherent with braiding. Please contact our design team for your specific requirements.

Table D.8: Belt specifications according to DIN/ ISO 10823

	POLY CHAIN® GT2 14MGT-2520-37	**CHAIN DIN 8178 16B - 2**
Length belt / chain - mm	2520	2540
Pitch - mm	14	25.4
Ratio	2.64	2.63
No of grooves - driveR pulley	34	19
No of grooves - driveN pulley	90	50
Outside diameter driveR pulley - mm	151.52	153.32
Outside diameter driveN pulley - mm	401.07	404.52
Weight driveR pulley - kg	3.8	8.3
Weight driveN pulley - kg	17.2	27.6
Width belt / chain - mm	**37**	**74**
Centre distance - mm	816.45	822.13
Speed - Rpm	700	700
Design power - kW	30	30
Weight belt / chain - kg	0.74	13.72
Total drive weight - kg	**21.74**	**49.62**

Table D.9: Hard coated linear rod specifications



Basic data for the various models for the precision shafts of high-grade steel

Shaft	Accuracy of dimension and form Shafts to tolerance h6					Shafts to tolerance h7				
Nominal diameter	Diameter deviation		Roundness	Circularity	Straightness[1]	Diameter deviation		Roundness	Circularity	Straightness[1]
d	high	low	t_1	t_2	t_3	high	low	t_1	t_2	t_3
mm	µm									
3	0	−6	3	4	150	0	−10	4	6	150
4	0	−8	4	5	150	0	−12	5	8	150
5	0	−8	4	5	150	0	−12	5	8	150
6	0	−8	4	5	150	0	−12	5	8	150
8	0	−9	4	6	120	0	−15	6	9	120
10	0	−9	5	7	120	0	−15	7	10	120
12	0	−11	5	8	100	0	−18	8	11	100
14	0	−11	5	8	100	0	−18	8	11	100
16	0	−11	5	8	100	0	−18	8	11	100
20	0	−13	6	9	100	0	−21	9	13	100
25	0	−13	6	9	100	0	−21	9	13	100
30	0	−13	6	9	100	0	−21	9	13	100
40	0	−16	7	11	100	0	−25	11	16	100
50	0	−16	7	11	100	0	−25	11	16	100
60	0	−19	8	13	100	0	−30	13	19	100
80	0	−19	8	13	100	0	−30	13	19	100

[1] Shafts with straightness 50 mm/1000 mm to order.

Table D.10: Thermistor specifications

TABLE OF STANDARD RTD AND THERMISTOR VALUES

Class	Pt RTD		THERMISTOR									
Type	100 Ohm	1000 Ohm	2.2k	3k	10k Type 2	10k Type 3	10k Dale	10k 3A221	10k "G" US	20k	20k "D"	100k
Accuracy	±0.3°C 0.0385 curve	±0.3°C 0.0385 curve	±0.2°C 0/70°C	±0.2°C 0/70°C	±1.0°C -50/150°C	±0.2°C 0/50°C	±0.2°C -20/70°C	±1.1°C 0/70°C	±0.2°C 0/70°C	Consult Factory	Consult Factory	Consult Factory
Temp. Response*	PTC	PTC	NTC	NTC	NTC	NTC	NTC	NTC	NTC	NTC	NTC	NTC

*PTC: Positive Temperature Coefficient

*NTC: Negative Temperature Coefficient

STANDARD RTD AND THERMISTOR VALUES (Ohms Ω)

°C	°F	100 Ohm	1000 Ohm	2.2k	3k	10k Type 2	10k Type 3	10k Dale	10k 3A221	10k "G" US	20k	20k "D"	100k
-50	-58	80.306	803.06	154,464	205,800	692,700	454,910	672,300	-	441,200	1,267,600	-	-
-40	-40	84.271	842.71	77,081	102,690	344,700	245,089	337,200	333,562	239,700	643,800	803,200	3,366,000
-30	-22	88.222	882.22	40,330	53,730	180,100	137,307	177,200	176,081	135,300	342,000	412,800	1,770,000
-20	-4	92.160	921.60	22,032	29,346	98,320	79,729	97,130	96,807	78,910	189,080	220,600	971,200
-10	14	96.086	960.86	12,519	16,674	55,790	47,843	55,340	55,252	47,540	108,380	122,400	553,400
0	32	100.000	1000.00	7,373	9,822	32,770	29,588	32,660	32,639	29,490	64,160	70,200	326,600
10	50	103.903	1039.03	4,487	5,976	19,930	18,813	19,900	19,901	18,780	39,440	41,600	199,000
20	68	107.794	1077.94	2,814	3,750	12,500	12,272	12,490	12,493	12,260	24,920	25,340	124,900
25	77	109.735	1097.35	2,252	3,000	10,000	10,000	10,000	10,000	10,000	20,000	20,000	100,000
30	86	111.673	1116.73	1,814	2,417	8,055	8,195	8,056	8,055	8,194	16,144	15,884	80,580
40	104	115.541	1155.41	1,199	1,598	5,323	5,593	5,326	5,324	5,592	10,696	10,210	53,260
50	122	119.397	1193.97	811.5	1,081	3,599	3,894	3,602	3,600	3,893	7,234	6,718	36,020
60	140	123.242	1232.42	561.0	747	2,486	2,763	2,489	2,486	2,760	4,992	4,518	24,880
70	158	127.075	1270.75	395.5	527	1,753	1,994	1,753	1,751	1,990	3,512	3,100	17,510
80	176	130.897	1308.97	284.0	378	1,258	1,462	1,258	1,255	1,458	2,516	2,168	12,560
90	194	134.707	1347.07	207.4	-	919	1,088	917	915	1,084	1,833	1,542	9,164
100	212	138.506	1385.06	153.8	-	682	821	679	678	816.8	1,356	1,134	6,792
110	230	142.293	1422.93	115.8	-	513	628	511	509	623.6	1,016	816	5,108
120	248	146.068	1460.68	88.3	-	392	486	389	388	481.8	770	606	3,894
130	266	149.832	1498.32	68.3	-	303	380	301	299	376.4	591	456	3,006

Table D.11: Nozzle specifications

Std. Nozzle (Size)* Number	Equiv. Orifice Diam. (inches)	Nozzle Flow (GPM) at Various Pressures (PSI)													
		250	500	600	700	800	1000	1200	1500	2000	2500	3000	3500	4000	5000
2.0	.034	.50	.71	.77	.80	.89	1.00	1.10	1.20	1.40	1.60	1.70	1.90	2.00	2.23
3.0	.043	.75	1.05	1.19	1.25	1.34	1.50	1.60	1.85	2.10	2.35	2.60	2.85	3.00	3.35
3.5	.048	.87	1.23	1.40	1.47	1.56	1.75	1.90	2.17	2.45	2.73	3.05	3.32	3.50	3.90
4.0	.052	1.00	1.40	1.60	1.70	1.80	2.00	2.20	2.50	2.80	3.10	3.50	3.80	4.00	4.50
4.5	.055	1.10	1.50	1.70	1.90	2.00	2.20	2.40	2.80	3.00	3.60	3.90	4.30	4.50	5.03
5.0	.057	1.30	1.80	1.90	2.10	2.20	2.50	2.80	3.10	3.80	4.00	4.40	4.70	5.00	5.60
5.5	.060	1.40	1.90	2.10	2.30	2.50	2.80	3.00	3.40	3.90	4.40	4.80	5.20	5.50	6.20
6.0	.062	1.50	2.10	2.30	2.50	2.70	3.00	3.20	3.70	4.20	4.80	5.20	5.60	6.00	6.70
6.5	.064	1.70	2.30	2.50	2.70	2.90	3.30	3.60	4.00	4.60	5.20	5.70	6.00	6.50	7.30
7.0	.067	1.80	2.50	2.70	2.90	3.10	3.50	3.80	4.30	5.00	5.60	6.10	6.60	7.00	7.80
7.5	.070	1.90	2.70	2.90	3.20	3.40	3.80	4.10	4.60	5.30	6.00	6.50	7.00	7.50	8.40
8.0	.072	2.00	2.80	3.10	3.40	3.60	4.00	4.40	5.00	5.60	6.20	7.00	7.50	8.00	8.90
8.5	.074	2.20	3.00	3.30	3.60	3.80	4.30	4.60	5.30	6.00	6.70	7.40	8.00	8.50	9.50
9.0	.076	2.30	3.20	3.50	3.80	4.00	4.50	5.00	5.50	6.40	7.10	7.80	8.50	9.00	10.10
9.5	.078	2.40	3.40	3.70	4.00	4.30	4.80	5.20	5.80	6.80	7.60	8.30	9.00	9.50	10.60
10.0	.080	2.50	3.50	3.90	4.20	4.50	5.00	5.40	6.10	7.00	8.00	8.70	9.40	10.00	11.20
12.0	.087	3.00	4.20	4.60	5.00	5.40	6.00	6.40	7.30	8.40	9.50	10.40	11.20	12.00	13.40
15.0	.094	3.80	5.30	5.80	6.40	6.80	7.50	8.20	9.20	10.60	12.00	12.90	14.00	15.00	16.80
20.0	.109	5.00	7.10	7.80	8.40	9.00	10.00	10.80	12.20	14.20	16.00	17.40	18.80	20.00	22.40
30.0	.141	7.50	10.60	11.60	12.80	13.60	15.00	16.40	18.40	21.20	24.00	26.00	28.00	30.00	33.50

*A commonly used standard for nozzle size is the "nozzle number" which is equivalent to the nozzle capacity in GPM at 4000 PSI. Spray angle does not affect nozzle flow.

APPENDIX E - MANUFACTURING PHOTOS

Figure E. 1 Cutting the wooden slices

Figure E- 2 The final design of the wooden box

Figure E- 3 Shaping the extruder

Figure E- 4 Drilling the extruder

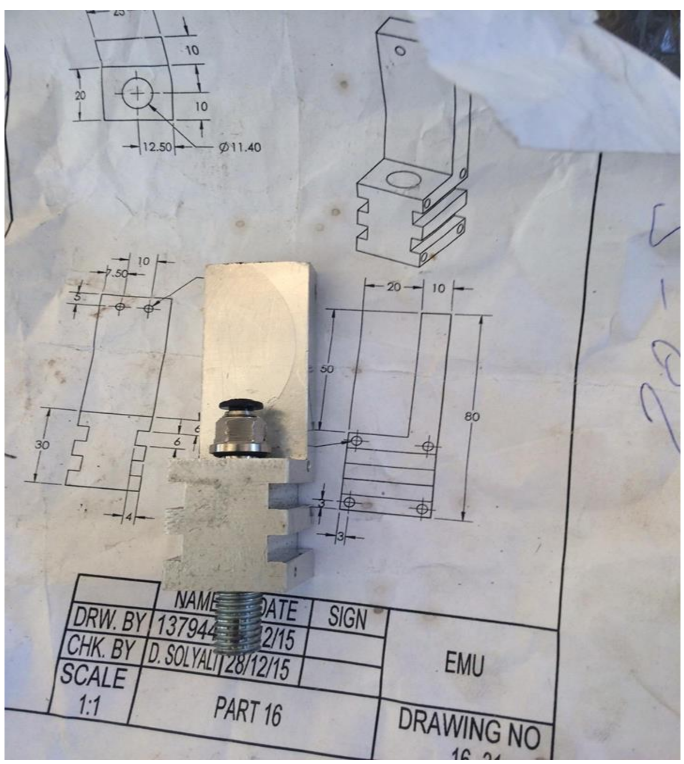


Figure E- 5 The final design of the extruder

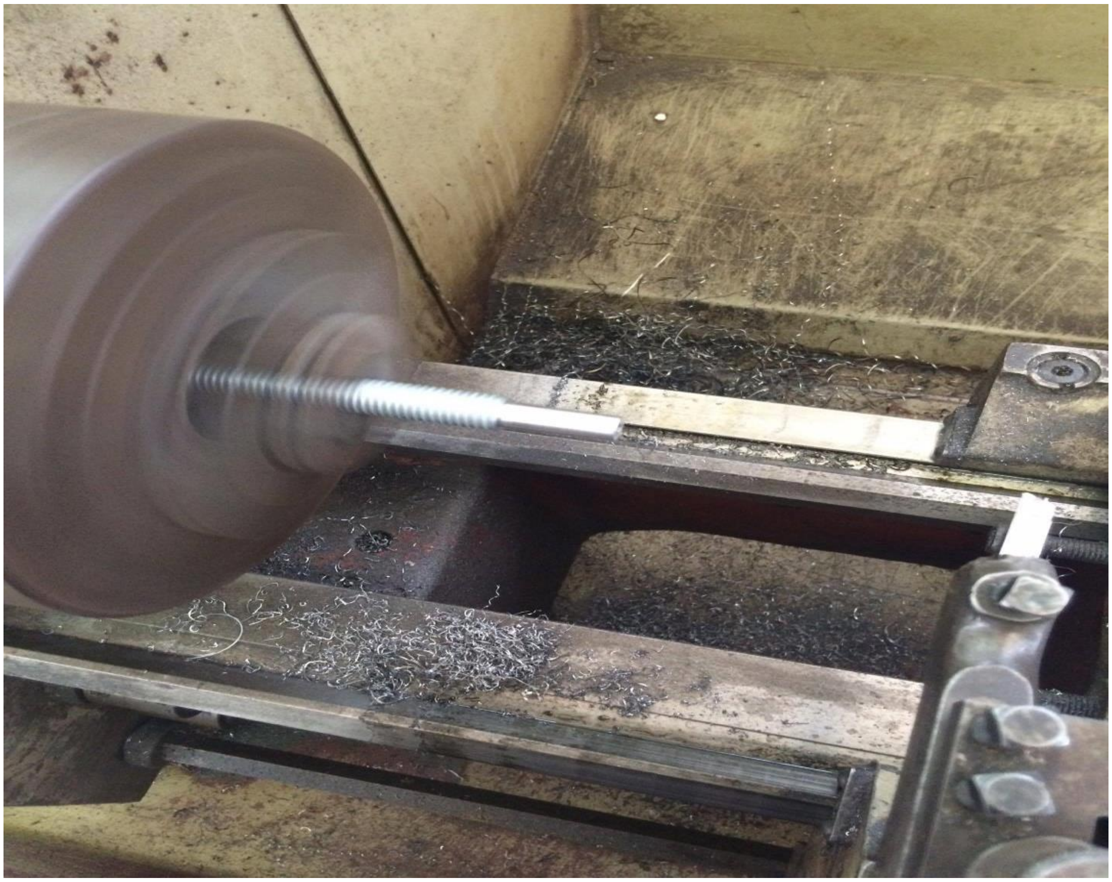


Figure E- 6 Adjusting the shafts' lengths and diameters

Figure E- 7 Testing the electrical circuit

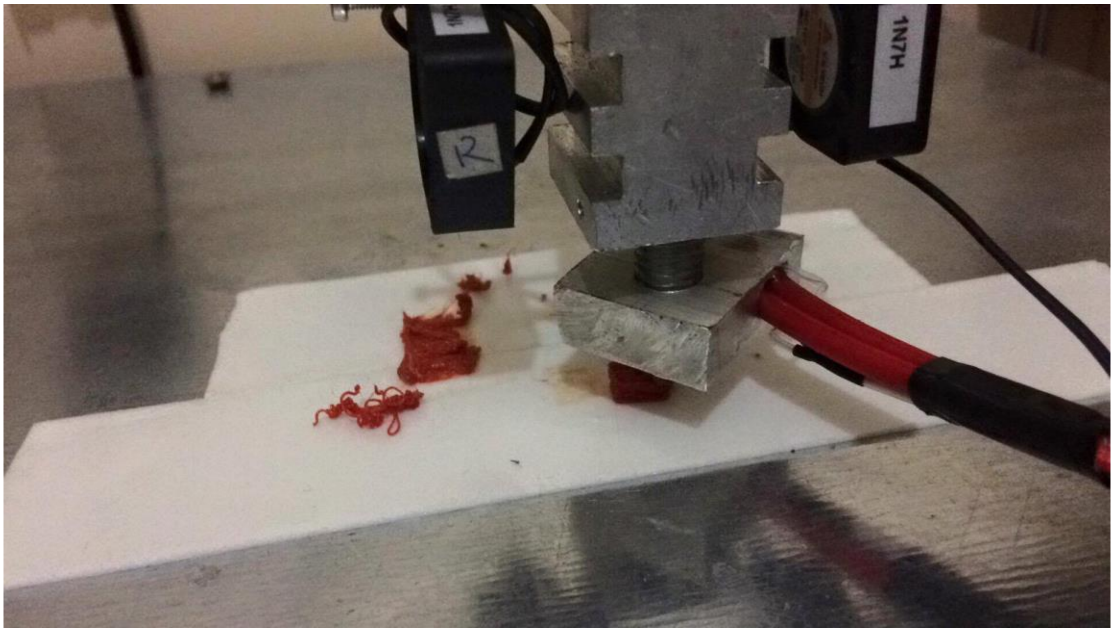


Figure E- 8 Printing an object

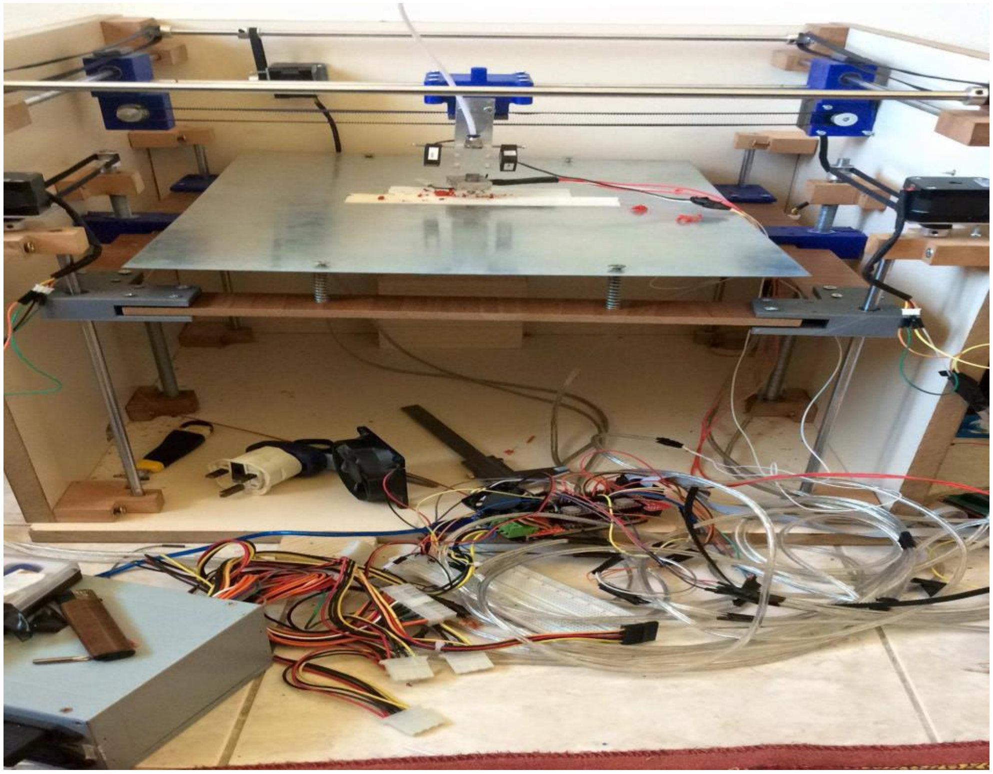


Figure E- 9 Prototype after assembly

APPENDIX F – POSTER & WEBSITE

Figure F- 2 3D Printer Poster