



Eastern Mediterranean University
Department of Mechanical Engineering
Capstone Team Project

Name of Project: *Redesign and Development of Plastic Filament Extrusion Machine.*

Group Number: 12

Group Members:

143230 *HASHEM ALHARTHI* (*Team Leader*)

15700444 *HUSSAIN SHAWISH*

15700833 *TARIG MAKKI*

143115 *ABDULRAHMAN ABOUHANY*

Supervisor: Assist. Prof. Dr. Mohammed Bsher A. ASMAEL

Semester: *Spring 2019*

Submission Date: *17th of June 2019*

Jury members	Signature
Assoc. Prof. Dr. QASIM ZEESHAN	
Assist. Prof. Dr. DAVUT SOLYALI	
Assist. Prof. Dr. MOHAMMED BSHER A. ASMAEL	

ABSTRACT

This report is about redesign and development of plastic extrusion machine that will be capable of producing continuous plastic filament with a diameter of 3 (mm). Extrusion is a polymer conversion operation in which a solid thermoplastic material is melted, forced through an extrusion die of the desired cross-section, and cooled in a water bath.

In order to produce a good quality of the plastic filament product, the temperature in each zone of the extruder barrel must be properly set and precisely controlled. The temperature of the plastic extrusion system has a wide range of variation subject to various disturbances. The system is generally nonlinear and so, controlling the temperature is a challenging process, as it has multiple stages and the system is coupled with each other.

The aim of this report is to illustrate the design process of the plastic extrusion machine, including, the design of the driving, controlling, and cooling systems. Also, this report illustrates the design progress through stages from the formulation of the problem statement to prototype testing.

The project scope includes all aspect of design and fabrication to create a plastic extrusion machine that is easy to use, safe, and low cost to facilitate its usability in producing continuous plastic filaments which are used in 3D printing technology. From here the significance of the project becomes since it contributes to the success and development of mankind.

The project objectives are design for cost, safety, assembly, high performance, and the environment.

The project constraints are redesign limitations, economic, availability, manufacturability, sustainability, and ethical.

TABLE OF CONTENTS

ABSTRACT	i
LIST OF FIGURES	vii
LIST OF TABLES	x
LIST OF SYMBOLS and ABBREVIATIONS	xii
CHAPTER 1 - INTRODUCTION	1
1.1. Detailed definition of the project.....	1
1.2. Significance of the project	2
1.3. Detailed project objectives	3
1.3.1 Design for cost.....	3
1.3.2 Design for safety	3
1.3.3 Design for assembly	3
1.3.4 Design for performance	4
1.3.5 Design for the environment	4
1.4. Detailed project constraints	4
1.5. Report Organization	5
CHAPTER 2 - LITERATURE REVIEW	6
2.1. Background information.....	6
2.1.1 History of plastic forming	6
2.1.2 Polymers.....	6

2.2. Concurrent solutions.....	9
2.3. Comparisons of the concurrent solutions	11
2.4. Engineering standards of the concurrent solutions.....	13
CHAPTER 3 -DESIGN and ANALYSIS	14
3.1. Selected design	14
3.1.1 Extruder barrel.....	14
3.1.2 Extruder screw.....	16
3.1.3 Drive system.....	18
3.1.4 Control system.....	20
3.1.5 Cooling system	25
3.1.6 Band heaters	26
3.1.7 Extrusion die.....	28
3.1.8 Hopper	29
3.1.9 Table.....	30
3.2 Engineering standards.....	31
3.3. Design calculations.....	32
3.3.1 Polymer melt flow rate in the extruder.....	32
3.3.2 Extrusion capacity	37
3.3.3 Gearbox output analysis	38
3.3.4 Energy contribution by band heaters	38
3.4 Cost analysis	40

CHAPTER 4 – MANUFACTURING PLAN	43
4.1 Manufacturing process selection	43
4.1.1 Extruder barrel.....	43
4.1.2 Extruder screw.....	44
4.1.3 Control system.....	44
4.1.4 Drive system motor	44
4.1.5 Cooling system	45
4.1.6 Band heaters	45
4.1.7 Extrusion die.....	45
4.1.8 Hopper	46
4.1.9 Table.....	46
4.2 Detailed manufacturing process	47
4.2.1 Extruder barrel.....	47
4.2.2 Extruder screw.....	47
4.2.3 Control system.....	48
4.2.4 Drive system motor	48
4.2.5 Cooling system	50
4.2.6 Band heaters	51
4.2.7 Extrusion die.....	51
4.2.8 Hopper	51
4.2.9 Table.....	52
CHAPTER 5 - PRODUCT TESTING PLAN.....	54

5.1 Verification plan of the objectives of the project	54
5.2 Verification plan of the applied engineering standards	55
CHAPTER 6 - RESULTS and DISCUSSIONS	57
6.1. The results.....	57
6.1.1 Polymer melt flow rate	57
6.1.2 Drive system.....	58
6.1.3 Band heaters	60
6.2. The engineering standards	60
6.3. The constraints.....	61
CHAPTER 7 - CONCLUSIONS and FUTURE WORKS.....	62
7.1. The conclusions	62
7.2. The future works.....	64
REFERENCES.....	66
APPENDIX A: Electronic Media	68
APPENDIX B: Constraints	69
APPENDIX C: Standards.....	70
APPENDIX D: Logbook.....	71
APPENDIX E: Project Timeline.....	74
APPENDIX F: Product Breakdown Structure	75

APPENDIX G: Wiring diagrams of the control system 77

APPENDIX H: Assembly Instructions 79

APPENDIX I: Operating Instructions 80

APPENDIX J: Engineering drawings 81

LIST OF FIGURES

Figure 1: Components and features of a single-screw extruder (Groover, 2010).....	2
Figure 2: Viscosity as a function of temperature for selected polymers (Groover, 2010)	7
Figure 3: Diagram of an injection molding machine (Groover, 2010)	9
Figure 4: Injection blow molding: (1) parison is injected molded around a blowing rod; (2) injection mold is opened and parison is transferred to a blow mold; (3) soft polymer is inflated to conform to the blow mold; and (4) blow mold is opened, and blown product is removed (Groover, 2010).....	10
Figure 5: Compression molding for thermosetting plastics: (1) charge is loaded; (2) and (3) charge is compressed and cured; (4) part is ejected and removed (Groover, 2010).....	10
Figure 6: Extruder motor.....	18
Figure 7: Jaw coupling.....	19
Figure 8: TK-13 thermocouple (D = 6 mm, wire length = 3 m) (Tense Electric and Electronic, 2019)....	20
Figure 9: Temperature control unit contactors.....	21
Figure 10: Autonics TCN4M-24 R temperature controller (Autonics Corporation, 2018).....	22
Figure 11: Eaton VFD controller (Eaton Industries GmbH, 2019).....	23
Figure 12: Motor and temperature control units.....	25
Figure 13: Cooling system configuration.....	26
Figure 14: Ceramic band heaters assembly.....	28

Figure 15: Selected extrusion die design.....	28
Figure 16: Selected hopper design.....	29
Figure 17: Plastic extrusion machine table. Note: complete table design configuration and dimensions are illustrated in Appendix J.....	30
Figure 18: Drag and pressure flow in the metering zone of a single screw extruder (Harper, 2000). Note: symbol h here represents screw flight diameter (D).....	32
Figure 19: Details of an extruder screw inside the barrel (Groover, 2010).....	33
Figure 20: Material removal process of the control system stands using a hand drill.....	48
Figure 21: Machining the coupling using the vertical milling machine with the aid of the shaft key cutter.....	49
Figure 22: The screw shaft connection (coupling).....	49
Figure 23: The manufacturing of the cooling tank.....	50
Figure 24: Automated hacksaw.....	50
Figure 25: Spot welding machine.....	52
Figure 26: Cutting using portable abrasive cut-off machine.....	53
Figure 27: Drilling process for table wheels using a drill press machine.....	53
Figure 28: Continuous flow plastic.....	54
Figure 29: Aligning of the motor and screw with an Allen key.....	55

Figure 30: Extrudate profile (sharkskin defect) at low motor speed.....59

Figure 31: Extrudate profile (smooth surface) at sufficient motor speed.....59

LIST OF TABLES

Table 1: Thermoplastics properties (Harper, 2000).....	8
Table 2: Criteria matrix for plastic forming machines selection.....	12
Table 3: Extruder barrel design specifications.....	15
Table 4: Extruder screw design specifications.....	17
Table 5: Selected motor and gearbox design specifications (GAMAK, 2016).....	19
Table 6: Autonics TCN4M-24 R temperature controller data (Autonics Corporation, 2018)....	22
Table 7: Eaton VFD controller data (Eaton Industries GmbH, 2019).....	24
Table 8: Criteria matrix for band heaters selection.....	27
Table 9: Ceramic insulated band heaters design specifications.....	27
Table 10: Selected designs engineering standards.....	31
Table 11: Extruder design and operating parameters.....	36
Table 12: Capital investment.....	42
Table 13: Other expenses.....	42
Table 14: Criteria matrix for extruder barrel manufacturing method selection.....	43
Table 15: Criteria matrix for extruder screw manufacturing method selection.....	44
Table 16: Milling selection matrix.....	45

Table 17: Criteria matrix for hopper welding method selection.....	46
Table 18: Criteria matrix for table welding method selection.....	47
Table 19: Temperature distribution over screw zones for different thermoplastics.....	60
Table 20: Testing engineering standards.....	60

LIST OF SYMBOLS and ABBREVIATIONS

3D	Three dimensional
P	Power
MPa	Mega Pascal
p	Pitch diameter
rpm	Revolutions per minute
DC	Direct current
AC	Alternating current
lb	Pound
Hz	Hertz
V	Voltage
I	Current
A	Ampere
in	inch
Ra	Reduction area
IGBT	Insulated-gate bipolar transistor
g	grams
CAD	Computer-aided design
VFD	Variable frequency drive
PID	Proportional, integral and derivative
TIG	Tungsten inert gas

CHAPTER 1 - INTRODUCTION

1.1. Detailed definition of the project

Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective.

Plastic extrusion machine design process includes elements of the engineering design process. The general layout, type of extruder screw, contributes to determining the type of plastic extrusion machine. There are different types of extruder screws: single-screws, mixing-screws, twin-screws, and vented screws. For this project, type of screw is standard single-extruder screw.

A single-screw extruder as shown in Figure 1 (Groover, 2010) consists of a screw in a barrel. One end of the extruder barrel is attached to the feed throat while the other end is open, and the barrel is surrounded by heating elements. A feeding hopper is located above the feed throat. The screw itself is coupled through a gearbox (reducer), to a drive motor that rotates the screw in the barrel. An extrusion solid-round profile die is connected to the open end of the extruder with a screen pack forming a seal between the extruder and die.

During extrusion, thermoplastic pellets are fed from the hopper, through the feed throat of the extruder, and into the extruder barrel. The pellets fall onto the rotating screw and are packed in the feed section of the screw. The packed pellets are melted as they travel through the compression section of the screw, and the melt is mixed in the metering section. The pressure generated in the extruder forces the molten polymer through the die. The extruder output is called extrudate.

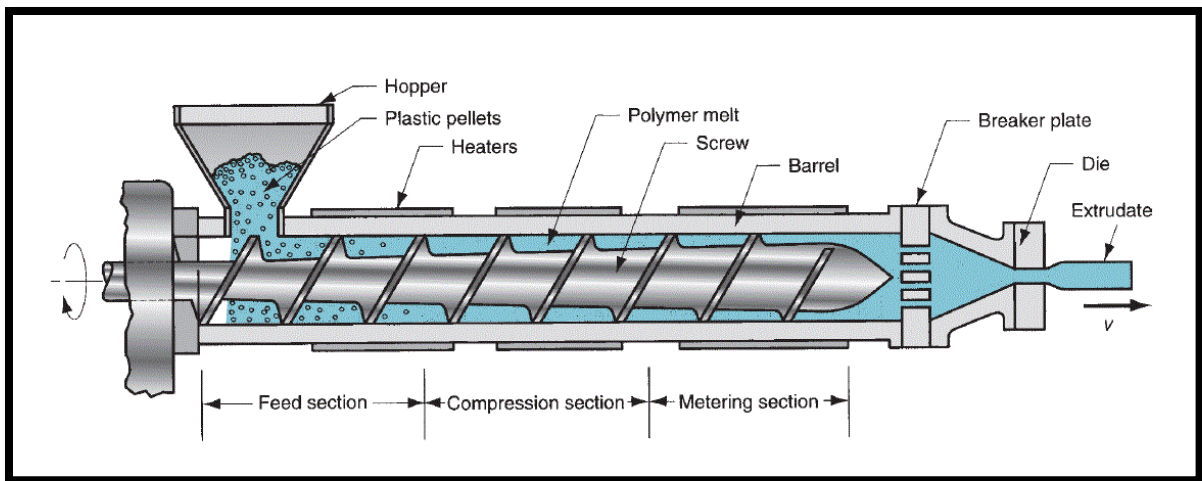


Figure 1: Components and features of a single-screw extruder (Groover, 2010).

1.2. Significance of the project

Plastics are inexpensive, durable materials, and can be manufactured easily to various types of products that can be used in many applications. However, plastic production reached the highest levels over the last decades. Most of the produced plastics are discarded within a short period from the year of manufacturing. This disposal generates several environmental and health problems. Therefore, recycling plastic disposal becomes important. The extrusion process is the simplest process of recycling and reusing the plastic. This is achieved using a plastic extrusion machine.

The products that are produced using a plastic extrusion machine are important in a person's everyday life. Also, plastic extrusion machine products are essential materials that are used in many applications.

The significance of this project becomes from the ability to design and manufacture a plastic extrusion machine that is capable of producing a continuous filament with a diameter of 3 (mm) from various types of discarded thermoplastics such as polypropylene (PP), and high-density polyethylene (HDPE). The usage of this plastic filament will be for 3D printing technology, with the intent to make the 3D printing sustainable and economic.

1.3. Detailed project objectives

The main project objective is to design and manufacture a plastic extrusion machine that is capable of producing continuous plastic filament with a diameter of 3 (mm). The detailed project objectives are illustrated below.

1.3.1 Design for cost

Design for cost is the conscious use of engineering processing technology to reduce the design cost. This is achieved using suitable low-cost materials and manufacturing processes. For example, the selected cooling water bath design was made of plastic, not metals. Also, the manufacturing processes were of low-cost such as simple arc welding processes instead of high-cost welding processes.

1.3.2 Design for safety

The design of the plastic extrusion machine includes safety equipment to ensure the safety of personnel and working place. For example, control units include circuit breakers to protect the electrical devices from damage caused by excess current from an overload or short circuit. Also, the motor control unit includes an emergency stop button to deal with immediate hazardous situations.

1.3.3 Design for assembly

Design for assembly (DFA) is a method that is used to measure the ease with which a product can be assembled. Also, DFA is a tool that assists in the design of products. The following guidelines are followed to achieve DFA objective:

- Minimize the overall component count.
- Minimize the usage of weld joints to ease the maintenance process.
- Avoids unstable positions for the components of the machinery during assembly.
- Design all components for end-to-end symmetry.

1.3.4 Design for performance

The design of the plastic extrusion machine included several features that increase the performance. For example, the installed gearbox permits a 25% increase in torque. As a result, the screw can withstand high resistances and provide greater output. Also, the selected band heaters provide high temperatures in short periods. Which will reduce the time to heat the barrel (that is, reduce costs).

1.3.5 Design for the environment

Design for the environment (DFE) is an environmentally conscious design. The plastic extrusion machine function is to recycle a wide range of polymers. Also, the selected design of the extrusion machine itself included factors that address environmental design issues. For example, design the machine with high separability by making fasteners accessible and easy to release so that the components can come apart easily.

1.4. Detailed project constraints

1. **Redesign limitations:** The redesign and development of the product are limited to drive system, control system, cooling system, and machine table as the extruder barrel and screw are from the previous capstone project.
2. **Economic:** The design should be economical than other similar commercial design.
3. **Availability:** The product should be designed using materials and components available in the local market.
4. **Manufacturability:** The product should be manufactured in the university mechanical engineering department workshop.
5. **Sustainability:** The design should be robust and sustainable.
6. **Ethical:** The design should be original, and the references should be cited in the design report.

1.5. Report Organization

This report consists of seven chapters and eight appendices. First, chapter 1 provides a detailed definition of the project, project significance, objectives, and constraints.

In chapter 2, a brief background about the history of plastic forming is presented. Also, the concurrent solutions of the selected polymer shaping process alongside their engineering standards are illustrated.

In chapter 3, first, a detailed explanation of each selected part/component for the plastic extrusion machine is provided. For example, the geometry of the extruder barrel and screw is illustrated. Also, design specifications of the drive system, control system, cooling system, band heaters, extrusion die, feeding hopper, and table are presented. Furthermore, the design calculations including, polymer melt flow rate, extrusion capacity, gearbox analysis, and energy contribution by band heaters are illustrated. Finally, the cost analysis including capital investment and bill of materials (BOM) are provided.

In chapter 4, the manufacturing plan for each part/component of the project is explained in detail. Also, the manufacturing processes selection criteria matrices are provided. In chapter 5, the product testing plan is illustrated which entails the verification plan of the objectives of the project and the applied engineering standards.

In chapter 6, the testing results and discussions including polymer melt flow rate, drive system, and band heaters are illustrated. Then the results of the applied engineering standards and design constraints are presented. Finally, in chapter 7, a conclusion of the complete design process and the design progress through stages is presented. Also, the possible future works for the project are proposed.

CHAPTER 2 - LITERATURE REVIEW

2.1. Background information

2.1.1 History of plastic forming

Plastic forming machines were rapidly developed until the 1930s. The first single-screw extruder for polymers was produced in 1951 in Japan for extrusion of wire/cable coating from low-density polyethylene. Since then, many kinds of single-screw extruders have been manufactured and used for example, for fiber-spinning of polyamide and polyester and for film-making of poly (vinyl chloride) and polyolefin (Sakai, 2013).

2.1.2 Polymers

A polymer molecule consists of many repeating mers to form very large molecules held together by covalent bonding. Elements in polymers are usually carbon plus one or more other elements such as hydrogen, nitrogen, oxygen, and chlorine. Secondary bonding (van der Waals) holds the molecules together within the aggregate material (intermolecular bonding). Polymers have either a glassy structure or mixture of glassy and crystalline. There are differences among the three polymer types (Groover, 2010):

1. In thermoplastic polymers, the molecules consist of long chains of mers in a linear structure. These materials can be heated and cooled without substantially altering their linear structure.
2. In thermosetting polymers, the molecules transform into a rigid, three-dimensional structure on cooling from a heated plastic condition. If thermosetting polymers are reheated, they degrade chemically rather than soften.
3. Elastomers have large molecules with coiled structures. The uncoiling and recoiling of the molecules when subjected to stress cycles motivate the aggregate material to exhibit its characteristic elastic behavior.

Polymer melt viscosity varies from 10^2 - 10^6 (Pa-s). The average value for thermoplastics is 10^2 (Pa-s) as shown in Figure 2 (Groover, 2010).

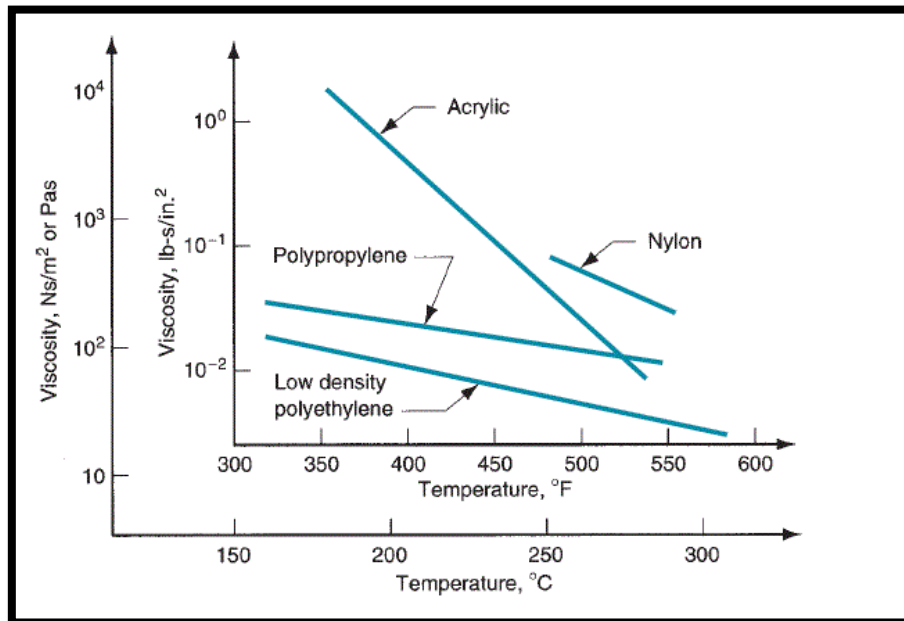


Figure 2: Viscosity as a function of temperature for selected polymers (Groover, 2010).

The selected types of thermoplastics pellets for this project are as follows (Groover, 2010):

1. Polypropylene (PP): A versatile polymer used in applications from films to fibers with a worldwide demand of over 21 million pounds.
2. Low-density polyethylene (LDPE): Combines high impact strength, toughness, and ductility to make it the material of choice for packaging films, which is one of its largest applications.
3. High-density polyethylene (HDPE): is known for its large strength-to-density ratio. The density of HDPE can range from 930 to 970 kg/m³. Although the density of HDPE is only marginally higher than that of low-density polyethylene, HDPE has little branching, giving it stronger intermolecular forces and tensile strength than LDPE. The difference in strength exceeds the difference in density, giving HDPE a higher specific strength.

Thermoplastics mechanical and physical properties are shown in Table 1.

Table 1: Thermoplastics properties (Harper, 2000).

Plastics	T_m (°C)	T_g (°C)	T_d (°C)	Tensile strength (MPa)	Compressive strength (MPa)	Density (g/cm³)
Polypropylene	168-175	-20	107-121	31.0-41.4	37.9-55.2	0.900-0.910
Low-density polyethylene	98-115	-25	40-44	8.3-31.4	-	0.917-0.932
High-density polyethylene	130-137	-	79-91	22.1-31	18.6-24.8	0.952-0.965

Where,

T_m: is crystalline melting temperature (some plastics have no crystallinity and are said to be amorphous).

T_g: is glass transition temperature (the plastic becomes brittle below this temperature).

T_d: is heat distortion temperature.

2.2. Concurrent solutions

There are 5 different types of plastic forming machines:

Injection molding machine as shown in Figure 3 (Groover, 2010) uses thermoplastics to produce solid pieces such as plastic products. The plastic injection molding process produces large numbers of parts of high quality with great accuracy, very quickly. Plastic material in the form of granules is melted until soft enough to be injected under pressure to fill a mold. The result is that the shape is exactly copied.

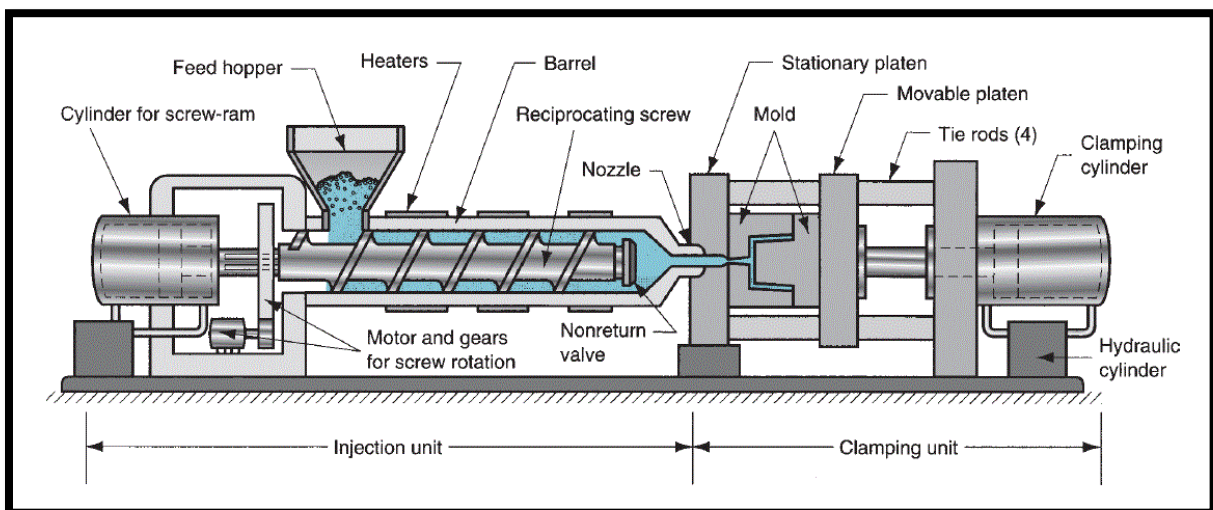


Figure 3: Diagram of an injection molding machine (Groover, 2010).

Extrusion process as shown in Figure 1 which is one of the few molding methods that can be performed on hot or cold material. The extrusion process is a simple process in which molten polymer is forced through a shaped die using pressure. The pressure is generated from the action of screw rotation against the barrel wall.

Injection Blow molding as shown in Figure 4 (Groover, 2010), this is used for the production of hollow glass and plastic objects in large quantities. Material granules for the part is fed via a hopper into a heated barrel, melted using band heaters and the frictional action of a reciprocating screw barrel. The plastic is then injection through a nozzle into a mold cavity where it cools and hardens to the configuration of the cavity.

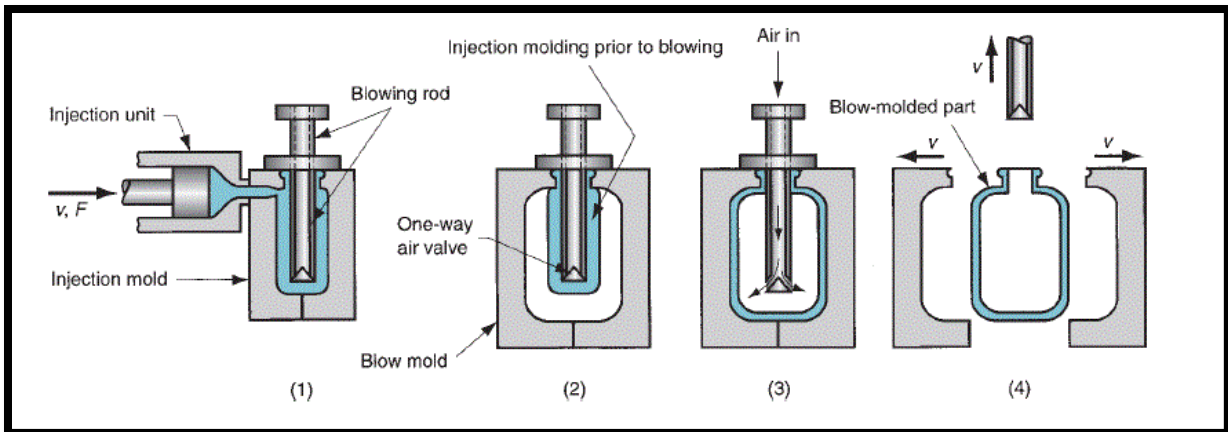


Figure 4: Injection blow molding: (1) parison is injected molded around a blowing rod; (2) injection mold is opened and parison is transferred to a blow mold; (3) soft polymer is inflated to conform to the blow mold; and (4) blow mold is opened, and blown product is removed (Groover, 2010).

Compression molding as shown in Figure 5 (Groover, 2010), the most common process used with thermosetting materials and is usually not used for thermoplastics. Compression molding is the process of molding in which a preheated polymer is placed into an open, heated mold cavity. The mold is then closed with a top plug and compressed in order to have the material contact all areas of the mold.

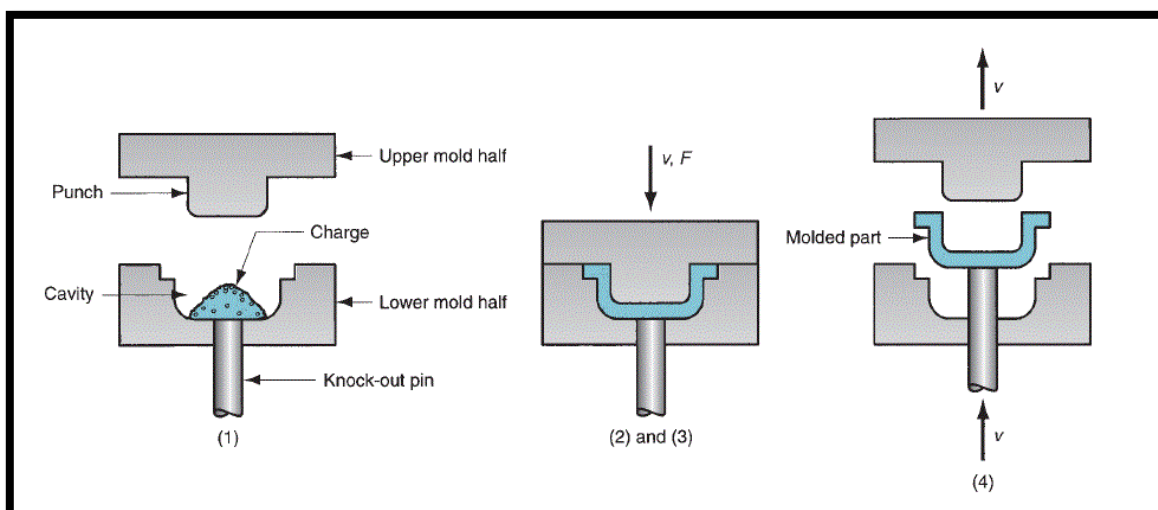


Figure 5: Compression molding for thermosetting plastics: (1) charge is loaded; (2) and (3) charge is compressed and cured; (4) part is ejected and removed (Groover, 2010).

2.3. Comparisons of the concurrent solutions

In this section, all the concurrent solutions mentioned above will be discussed thoroughly with a decision matrix showing why the chosen solution in each category is the most suitable for the following application.

Comparisons on the most common plastic processing technology (Extrusion, Injection molding, and Blow molding):

Injection Molding is a manufacturing process for producing parts in large volume. It is most typically used in mass-production processes where the same part is being created thousands or even millions of times in succession. The principal advantage of injection molding is the ability to scale production in mass. Once the initial costs have been paid the price per unit during injection molded manufacturing is extremely low. The price also tends to drop drastically as more parts are produced. Meanwhile, the front costs tend to be very high due to design, testing, and tooling requirements. If you are going to produce parts in high volumes, you want to make sure you get the design right the first time. That is more complicated than it might sound. The two major downsides to injection molding are its high tooling costs and large required lead times.

The second type being extrusion is used when dealing with products having a consistent cross-section. The advantages offered by the extrusion machine are its low cost, high flexibility and the capability of post extrusion alteration, however, the disadvantages are as follow; Size variances in the final product as well as product limitations. The downsides to this process might be crucial when dealing with mass production, but in our case, they don't carry that much importance.

The third type which is the blow molding machine, mainly used to make hollow plastic containers such as bottles, and jars. Milk containers, shampoo, and soda bottles, and watering cans are examples of products that are typically blow molded. The gains of this process are, low tooling costs, recyclable products, high production rate, and intricate geometries are possible. The downside is that the parts manufactured must always be hollow and controlling wall thickness is difficult.

The criteria matrix shown in Table 2 will illustrate how the decision was taken and state the factors considered with their importance.

Table 2: Criteria matrix for plastic forming machines selection.

Legend 1→ worst 10→ Best	Priority	Importance (weight)	Injection molding	Blow molding	Extrusion
Low cost	1	10	8	10	10
Machinability	2	8	8	6	8
Low Lead timing	4	4	6	8	8
Flexibility	3	6	6	8	10
High production rate	5	2	10	6	6
Weighted total			224	240	<u>268</u>

2.4. Engineering standards of the concurrent solutions

1. ISO 527: specifies the test conditions for the determination of the tensile properties of plastic.
2. ASTM D695: Standard test method for compressive properties of rigid plastics.
3. ASTM D618: Standard practice for conditioning plastics for testing.
4. ASTM D790: Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials.

The standards shown above are only some of the plastic standards used. Standards for plastic are usually categorized into many various groups; the types used for our application are as follows:

1. Analytical Method.
2. Cellular materials {plastic and elastomers}.
3. Durability of plastic.
4. Environmentally degradable plastics and bio-based products.
5. Thermosetting materials.
6. Thermoplastic materials.
7. Terminology.

CHAPTER 3 -DESIGN and ANALYSIS

3.1. Selected design

The selected shaping process of polymer for this project is the extrusion process with a single extruder screw. Plastic extrusion machine configuration and each part/component numbering is shown in Appendix F. The selected design of each part/component will be illustrated in the following sections.

3.1.1 Extruder barrel

Extruder barrel is a metal cylinder that surrounds the screw. One end fastens to the feed throat and the opposite end connects directly to the die adapter. Since extruder barrels must withstand high pressures, they are usually made from standard tool steels, with special tool steels required for corrosive polymers.

The internal diameter of the extruder barrel typically ranges from 25 to 150 (mm). The barrel is long relative to its diameter, with L/D ratios usually between 10 and 30. The higher ratios are used for thermoplastic materials, whereas lower L/D values are for elastomers (Groover, 2010). Since melting occurs over a longer transition zone, longer barrels provide increased output. However, the longer screws require larger drive system power and cause greater screw deflection. Table 3 shows selected extruder barrel design specifications.

The clearance between the barrel and screw flights is typically 0.08 to 0.13 (mm). To reduce barrel wear, barrels are nitrided. Nitriding is the surface hardening of the barrel. This process initially produces higher hardness but loses that advantage as the barrel wears. Nitriding also provides poor abrasion and only moderate corrosion resistance.

The relation between the nitrided alloy steel and the polymer type (Harper, 2000) is as follows:

1. Good for Acetates, polyethylene (PE), polypropylene (PP), polystyrene (PS), PET.
2. Satisfactory for ABS, polyacetals, acrylics, polyamides, PVC, polycarbonates, polyesters, SAN.
3. Poor for Resins containing up to 30% glass, mineral, flame-retardant and other filler material.
4. Not recommended for Fluoropolymers, phenolics, resins containing more than 30% glass, mineral, flame-retardant and other filler material.

Table 3: Extruder barrel design specifications.

Barrel length	947 mm
Barrel internal diameter (D)	30 mm
Barrel (L/D) ratio	$L/D = 947/30 = 31.567$
Barrel material	Nitrided alloy steel
Barrel material grade	38CrMoAIA
Barrel material tensile strength	0-980 MPa
Barrel material yield strength	0-835 MPa
Nitrided hardness	950-1050HV
Surface roughness	Ra 0.4 μm

3.1.2 Extruder screw

The material is conveyed through the barrel toward the die opening by the action of the extruder screw. The screw (flighted section) serves several functions and is divided into sections that correspond to these functions. The zones and functions are the (1) feed zone, in which the stock is moved from the hopper port and preheated; (2) transition or compression zone, where the polymer is transformed into liquid consistency, air entrapped amongst the pellets is extracted from the melt, and the material is compressed; and (3) metering zone, in which the melt is homogenized and sufficient pressure is developed to pump it through the die opening.

In metering screws, the feed zone has a constant channel depth as does the metering zone. However, the channel depth gradually decreases in the transition zone. Since molten polymer requires less volume than the solid particles, the metering zone channel depth is shallower than the depth of the feed (Harper, 2000).

Screws are treated, coated, or plated to reduce the coefficient of friction between screw and polymer. Table 4 shows selected screw specifications. Pitch (p) is the axial distance from the center of one flight to the center of the next flight, whereas lead is the axial distance the screw moves in one full rotation.

The screw flight angle **A** can be calculated as

$$A = \tan^{-1}\left(\frac{p}{\pi D}\right) = \tan^{-1}\left(\frac{30}{\pi \times 30}\right) = 17.7^\circ$$

Equation 1
(Groover, 2010)

Table 4: Extruder screw design specifications.

Screw type	Square-pitched metering screw
Screw overall length (L_s)	971 mm
Screw flight diameter (D)	30 mm
Screw feed section length	476 mm
Screw compression section length	112 mm
Screw metering section length	145 mm
Screw flight length	733 mm
Screw shank length	238 mm
Screw flight land width (w_f)	4 mm
Screw channel width (w_c)	24.8 mm
Screw metering zone channel depth (L_m)	1.5 mm
Screw pitch (p)	30 mm
Screw flight angle (A)	17.7°
Screw material	Nitrided alloy steel
Screw material grade	38CrMoAIA
Screw material tensile strength	0-980 MPa
Screw material yield strength	0-835 MPa
Nitrided hardness	950-1050HV
Linearity of screw	0.015 mm/m

3.1.3 Drive system

Extruder drive motors must turn the screw, minimize the variation in screw speed, permit variable speed control (typically 50 to 150 rpm), and maintain constant torque. In selecting drive motors, the three major factors are: (1) base speed variation, (2) the presence or absence of brushes, and (3) cost. The speed variation of a drive motor is based on the maximum speed available for the motor.

The power supply converts three-phase AC line voltage to variable voltage DC power and then back to controlled AC frequency. The voltage-to-frequency ratio is adjusted to provide constant torque from the ac motor. The high-speed drive motor is coupled to the low-speed screw using a gearbox (reducer). Switching to larger gears increases the torque but reduces the screw speed. Figure 6 shows the extruder motor. Also, Table 5 shows the design specification of the selected motor for this project.



Figure 6: Extruder motor.

Table 5: Selected motor and gearbox design specifications (GAMAK, 2016).

System configuration	AC Motor combined with a gearbox
Rated current	8.2 A
Rated voltage	400 V AC, 3-phase
Supply frequency	50 Hz
Motor rated output	4 kW
Motor speed	1455 rpm
Motor torque	26.3 Nm
Motor approximate weight	30 kg
Gearbox reduction ratio	25:1
Gearbox lubrication	ISO VG 320 SNT 1.00 LT

The gearbox shaft and extruder screw are connected using jaw coupling as shown in Figure 7. Power transmission coupling is used to protect system components by damping system vibrations and accommodating any misalignment.



Figure 7: Jaw coupling.

3.1.4 Control system

The selected control system for the extrusion machine will include temperature controllers, and drive motor speed controller.

3.1.4.1 Temperature controller

To accurately control process temperature without extensive operator involvement, a temperature control system relies upon a controller, which accepts a temperature sensor such as a thermocouple as input. It compares the actual temperature to the desired control temperature, or setpoint, and provides an output to a control element.

A temperature Sensor measures the temperature of a location where the temperature control is required. It converts the temperature to a physical quantity of a voltage or resistance and outputs that. A thermocouple is a temperature sensor that uses a phenomenon (the seebeck effect) that generates a thermo-electromotive force according to the temperature difference between the joint end and the open end of different types of metal that have been joined together at one end. The combination of metals with high and stable thermo-electromotive force is called a thermocouple (Ormon industrial automation, 2018). The selected thermocouple design for this project is Tense TK-3 as shown in Figure 8 (Tense Electric and Electronic, 2019)



Figure 8: TK-13 thermocouple (D = 6 mm, wire length = 3 m) (Tense Electric and Electronic, 2019).

To control the temperature of heaters, contactors are used as a connection between heaters and controllers. This is because controllers can't turn on or off the heaters directly. There must be a connection between them. The controllers give a signal to contactors to either pass the current to heaters or not, based on the readings of thermocouples. By this, the controllers can turn on or off the heaters. Figure 9 shows the contactors used in the temperature control unit.

The operating principle of a contactor is very simple. Whenever the electromagnetic coil is energized, an electromagnetic field is produced. This electromagnetic field attracts the metallic rod (armature) towards the gap in the hollow cylindrical magnet. In contactors with split electromagnets, the movable half of the electromagnet is attracted towards the fixed electromagnet. This action closes the contacts. The contacts remain closed as long as the electromagnet remains excited. When the coil is de-energized, moving contact is pushed back to its normal position by the spring. Contactors are designed to open and close contacts rapidly (Electrical Classroom, 2018).



Figure 9: Temperature control unit contactors.

The selected controller for this project is the Autonics TCN4M-24 R temperature controller as shown in Figure 10 (Autonics Corporation, 2018). Also, controller data are shown in Table 6.



Figure 10: Autonics TCN4M-24 R temperature controller (Autonics Corporation, 2018).

Table 6: Autonics TCN4M-24 R temperature controller data (Autonics Corporation, 2018).

Power supply	(100-240) V, AC 50/60 Hz
Maximum current	0.0208 A
Control method	ON/OFF control, P, PI, PD, PID control
Input specification	Thermocouple – various types
Display method	4-digit 7-segment LED
Control period	0.5 to 120.0 sec
Manual reset	0.0 to 100.0%
Weight	Approximately 133 g

3.1.4.2 Variable frequency drive controller

A variable frequency drive (VFD) is a particular kind of adjustable-speed drive that is used to control the speed of an AC motor. In order to control the motor's rotational speed. VFD characteristics are as follows (Anaheim automation, inc., 2018):

- A variable frequency drive controls the frequency of the electrical power supplied to the motor. When complete voltage is applied to an AC motor, it accelerates the load and drops torque initially, keeping current especially high until the motor reaches full speed.
- A variable frequency drive converts power through three different stages. First, AC power is converted to DC power, followed by the switching on and off of the power transistors, causing a voltage waveform at the desired frequency. This waveform then adjusts output voltage according to the preferred designated value.

The selected VFD controller is Easton DC1-349D5NB-A20CE1 - Variable frequency drive as shown in Figure 11 (Eaton Industries GmbH, 2019). Table 7 shows selected VFD controller data.



Figure 11: Eaton VFD controller (Eaton Industries GmbH, 2019).

Table 7: Eaton VFD controller data (Eaton Industries GmbH, 2019).

System configuration	AC supply systems with earthed center point
Function	Variable frequency drive with internal DC link and IGBT inverter
Rated operational voltage	400 V AC, 3-phase
Rated operational current	9.5 A
Assigned motor rating	400 V, 50 Hz, 4 kW
Supply frequency	50/60 Hz
Output frequency (screen value)	0 - 50/60 Hz

The VFD controller is further connected to a cam switch, potentiometer switch, and emergency stop (E-stop) button. By this, the control process becomes simpler and safer. The function of these switches are as follows:

1. Cam switch: allows for controlling the direction of rotation, either clockwise (CW) or counterclockwise (CCW). In order to get the forward motion of polymer in the extruder, the direction of rotation must be **CCW**.
2. Potentiometer: this switch controls the motor frequency and thus, the screw speed.
3. E-stop button: this button cuts the current passing to the motor and thus, completely stops the motor in hazardous situations.

Figure 12 shows the motor control unit and temperature control unit. As can be seen from the figure, the motor control unit consists of a cam switch (bottom left corner), a potentiometer (bottom right corner), and E-stop button (top middle). While, the temperature control unit consists of 3 temperature controllers for the 3 screw-zones: feed zone, compression zone, and metering zone. Each of these controllers is connected to an ON/OFF switch.

Motor control unit

Temperature control unit

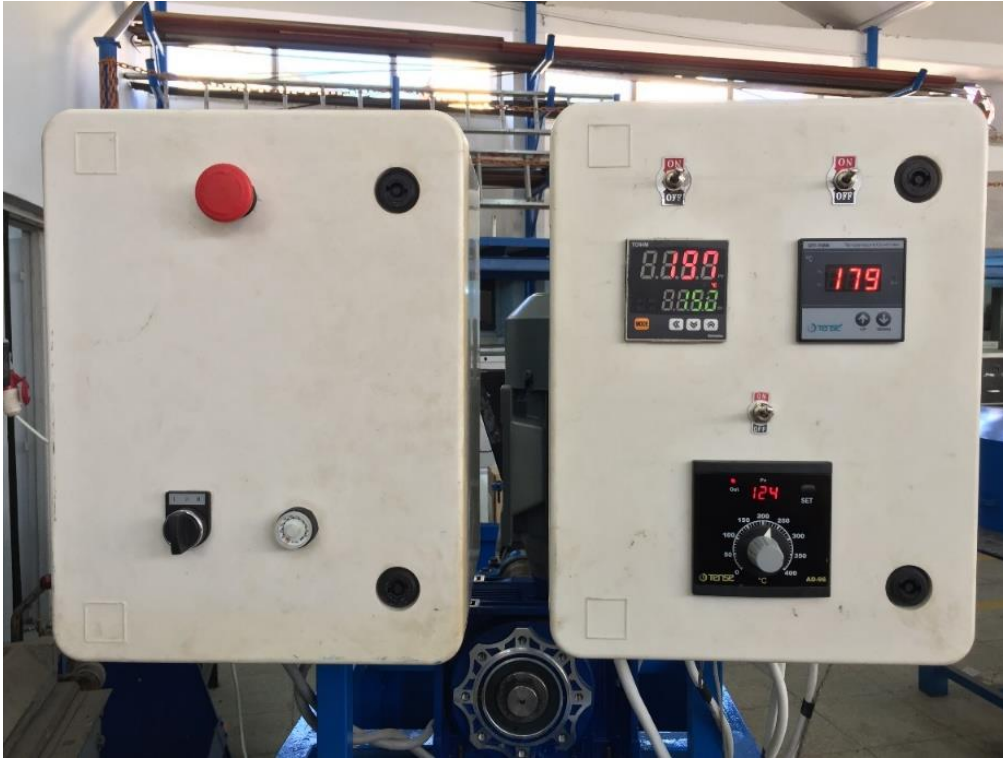


Figure 12: Motor and temperature control units.

3.1.5 Cooling system

The cooling system is composed mainly of a water bath through which the extrudate travels and fixed pulleys through which the extrudate is forced to pass underwater. In addition, when the extrudate is sufficiently cooled, it is wound on a reel. The selected cooling water bath design specifications are as follows:

- Material: High-density polyethylene (HDPE).
- Length = 775 (mm).
- Width = 310 (mm).
- Height = 280 (mm).

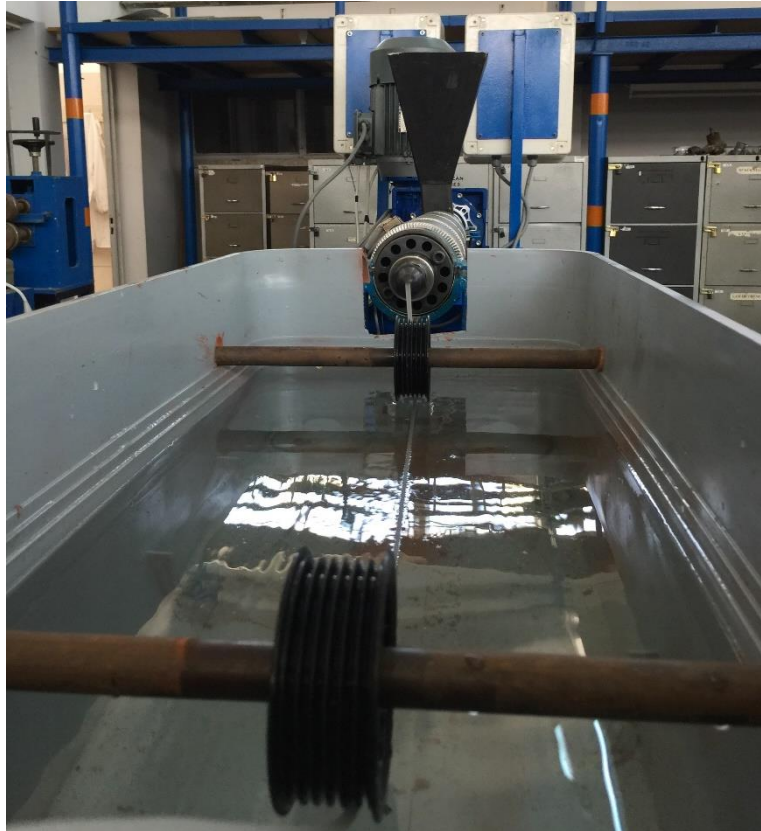


Figure 13: Cooling system configuration.

3.1.6 Band heaters

Barrels and dies are heated to bring them to operating temperatures and to maintain set temperatures during operation. Band heaters are typically used for heating extruder barrels and dies. Subsequent mixing and mechanical working of the material generate additional heat, which maintains the melt. There are four types of band heaters used in plastics processing: (1) mica, (2) aluminum, (3) ceramic, and (4) bronze band heaters. Table 8 shows criteria matrix for band heaters selection based on cost, maximum produced temperature, performance, produced energy, and service life (Harper, 2000).

Ceramic insulated band heaters are very energy efficient since they have a standard $\frac{1}{4}$ inch (6.35 mm) thick insulation. Table 9 shows the design specification of the selected ceramic band heater for this project. Also, Figure 14 shows the configuration of the selected ceramic band heaters.

Table 8: Criteria matrix for band heaters selection.

Legend: 1→ worst 10→ best	Priority	Importance (weight)	Mica	Aluminum	Ceramic	Bronze
Cost	1	9	4	3	10	5
Energy efficiency	2	8	6	7	7	5
Maximum temperature	4	6	7	4	9	10
Performance	2	8	7	10	5	10
Service life	3	5	5	6	10	8
Weighted total			207	217	290	265

Table 9: Ceramic insulated band heaters design specifications.

Ceramic band heater size (90x150)		Ceramic band heater size (90x100)	
Voltage	220 (V)	Voltage	220 (V)
Current	6.82 (A)	Current	5.68 (A)
Power	1.5 (kW)	Power	1.25 (kW)
Surface width	150 (mm)	Surface width	100 (mm)
Surface thickness	11.9 (mm)	Surface thickness	11.9 (mm)
External diameter	41.9 (mm)	External diameter	41.9 (mm)
Internal diameter	30 (mm)	Internal diameter	30 (mm)

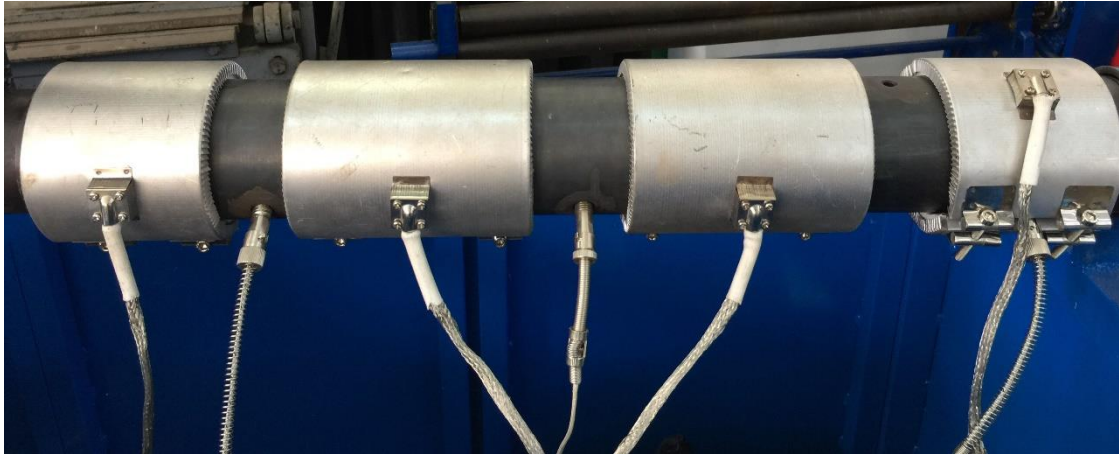


Figure 14: Ceramic band heaters assembly.

3.1.7 Extrusion die

The shape of the extrusion die (orifice) as shown in Figure 15 determines the cross-sectional shape of the extrudate. The designed extrusion die opening (2.7 mm) produces a continuous plastic filament with a diameter of 3 (mm). The polymer melt flows into a converging die entrance, the shape designed to maintain laminar flow and avoid dead spots in the corners that would otherwise be present near the orifice. The die opening is made long enough to remove some of the memory in the polymer melt (Groover, 2010).



Figure 15: Selected extrusion die design.

3.1.8 Hopper

The feed hopper feeds material to the extruder, single-screw extruders are usually fed gravimetrically through rectangular hoppers. The selected hopper design is rectangular hopper with the following dimensions:

- Hopper upper rectangular dimensions 180x180 (mm).
- Hopper lower rectangular dimensions 52x52 (mm).
- Hopper feed opening diameter 80 (mm).

The hopper is fixed on the extruder barrel using U-clamps. One side of the U-clamp is welded with the hopper frame, while the other side is joined using mechanical fasteners: bolts and nuts as shown in Figure 16.



Figure 16: Selected hopper design.

3.1.9 Table

The selected table design is shown in Figure 17. Also, table dimensions are as follows:

1. Table length 1.5 (m).
2. Table width 0.6 (m).
3. Table height 1 (m).

Table design included the following structures:

1. C-channel steel beams for motor supports since the motor requires strong supports.
2. The table frame is 4x4 square steel tubing.

Also, the table is attached with casters as it holds heavy loads.



Figure 17: Plastic extrusion machine table. Note: complete table design configuration and dimensions are illustrated in Appendix J.

3.2 Engineering standards

The engineering standards of each selected design for this project are shown in Table 10.

Table 10: Selected designs engineering standards.

Part/Component	Standard	Description
Extruder screw and barrel	EN 41 CrAlMo7-10	Nitriding steel standard
Drive motor	DIN/EN 60 034-1	Motor rating and performance
Drive motor	DIN/EN 60 034-8	Terminal markings and direction of rotation.
VFD controller	IEC/EN61800-3	Product standard
VFD controller	IEC/EN61800-5	Product standard
VFD controller	IEC/EN 61800-2	Specification for general requirements
VFD controller	IEC/EN 61800-5-1	Safety requirements
Band heaters	AIC 62321-1: 2013	Test standard
E-stop button	EN 60947-5-1	Product standard
E-stop button	EN IEC 60947-5-5	Emergency stop switch compact, foolproof

3.3. Design calculations

In this section, mathematical models are used to describe several aspects of polymer extrusion analysis. Calculations are to be carried out for determining the following:

1. Polymer melt flow rate in the extruder and extrusion capacity.
2. Gearbox output analysis.
3. Energy contribution by band heaters.

3.3.1 Polymer melt flow rate in the extruder

The rotating screw pushes material along the walls of the stationary barrel creating drag flow. This drag flow provides the forward conveying action of the extruder, and, in the absence of a die, is effectively the only flow present. The addition of a die restricts the open discharge at the end of an extruder and produces a large pressure gradient along the extruder. Since the pressure is greatest just before the die, this head pressure creates two other flows, pressure flow Q_p and leakage flow Q_L . Since they both counter the forward motion of the melt, pressure and leakage flow are often lumped together as back flow Q_b . As shown in Figure 18 (Harper, 2000) drag flow conveys the polymer along the barrel walls, whereas pressure flow forces the material near the screw back toward the hopper.

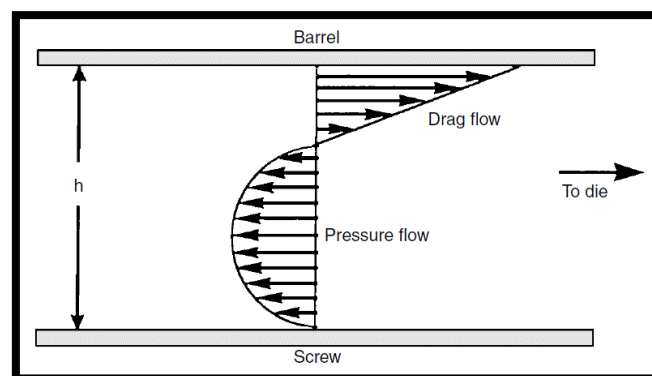


Figure 18: Drag and pressure flow in the metering zone of a single screw extruder (Harper, 2000). Note: symbol h here represents screw flight diameter (D).

A simple mathematical modeling of extrusion assumes that: (1) the extruder is at steady state, (2) the melt is Newtonian, (3) the extruder is isothermal, and (4) the metering zone make the only contribution to output, (5) there is minimal leak flow through the clearance between flights and barrel (Harper, 2000). Figure 19 (Groover, 2010) shows details of an extruder screw inside the barrel.

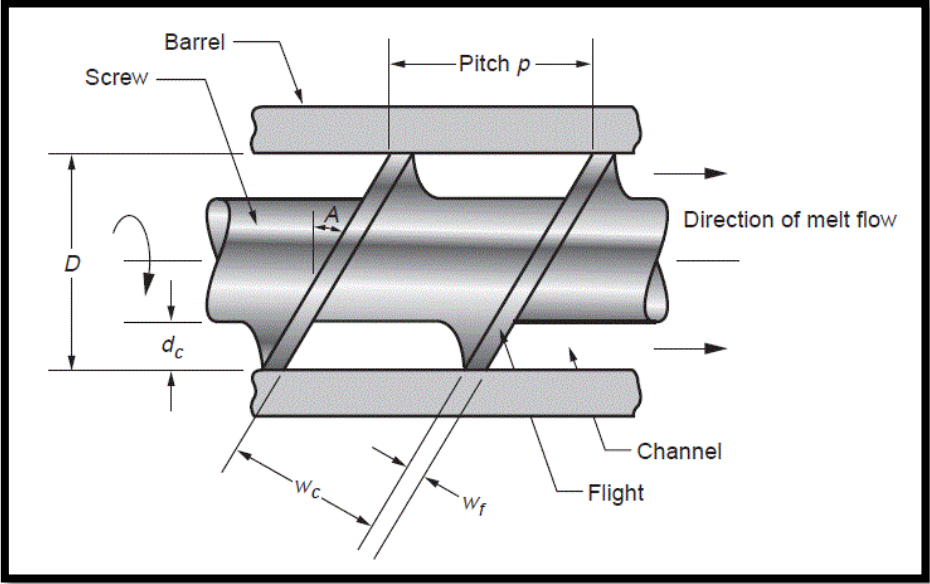


Figure 19: Details of an extruder screw inside the barrel (Groover, 2010).

The **net output flow rate** of the extruder can be expressed as the difference between the drag flow and back pressure flow as follows:

$$Q_x = Q_d - Q_b \tag{Equation 2}$$

(Groover, 2010)

Where,

Q_x = the resulting flow rate of polymer melt in the extruder (m³/s).

Q_d = volume drag flow rate (m³/s).

Q_b = back pressure flow (m³/s).

$$Q_d = 0.5 \pi^2 D^2 N d_c \sin A \cos A$$

Equation 3
(Groover, 2010)

Where,

D = screw flight diameter (m).

N = screw rotational speed (rev/s).

d_c = screw channel depth in the metering zone (m).

A = screw flight angle (degree).

$$Q_b = \frac{p \pi D d_c^3 \sin^2 A}{12 \eta L_m}$$

Equation 4
(Groover, 2010)

Where,

p = head pressure in the barrel (MPa).

L_m = length of the metering zone (m).

η = viscosity of polymer melt, N-s/m² (Pa-s).

If back flow is zero, so that melt flow is unrestrained in the extruder, then the flow would equal drag flow given by Equation 3. This is the maximum possible flow capacity of the extruder.

Denoted as Q_{max} :

$$Q_{max} = 0.5 \pi^2 D^2 N d_c \sin A \cos A$$

Equation 5
(Groover, 2010)

If back pressure were so great as to cause zero flow, then back pressure flow would equal drag flow. By equating both expressions for drag and back pressure flows and solving for head pressure gives the maximum head pressure. Denoted as p_{max} :

$$p_{max} = \frac{6 \pi D N L_m \eta \cot A}{d_c^2}$$

Equation 6
(Groover, 2010)

Therefore, the resulting flow rate of polymer melt in the extruder can be rewritten as:

$$Q_x = Q_{max} - \left(\frac{Q_{max}}{P_{max}} \right) p \quad \text{Equation 7}$$

(Groover, 2010)

Flow rate through the die depends on the size and shape of the opening and the pressure applied to force the melt through it. Denoted as Q_{Die} :

$$Q_{Die} = K_s p \quad \text{Equation 8}$$

(Groover, 2010)

Where,

K_s = shape factor for the die ($m^5/N\cdot s$). For a circular die opening of a given channel length, the shape factor is:

$$K_s = \frac{\pi D_d^4}{128 \eta L_d} \quad \text{Equation 9}$$

(Groover, 2010)

Where,

D_d = die opening diameter (m).

L_d = die opening length (m).

Above equations contains two types of parameters: (1) design parameters, and (2) operating parameters. Table 11 shows both design parameters and operating parameters for the extruder of this project.

Table 11: Extruder design and operating parameters.

Design parameters	Operating parameters
Screw flight diameter $D = 30$ mm	Screw rotational speed $N = 0.97 \frac{rev}{sec}$
Screw metering zone length $L_m = 145$ mm	Polymer melt viscosity (an average value for thermoplastics) $\eta = 100$ Pa-s
Screw metering zone channel depth $d_c = 1.5$ mm	-
Flight angle $A = 17.7^\circ$	-
Screw pitch $p = 30$ mm	-
Flight land width $w_f = 4$ mm	-
Screw channel width $w_c = 24.8$ mm	-
Die opening diameter $D_d = 2.7$ mm	-
Die opening length $L_d = 74$ mm	-

Now, using the values from Table 11, and substituting in Equation 5:

$$Q_{max} = 0.5 \pi^2 (0.03)^2 (0.97) (0.0015) \sin(17.7^\circ) \cos(17.7^\circ) = 1.872 \times 10^{-6} \left(\frac{m^3}{s} \right)$$

And, using the values from Table 11, and substituting in Equation 6:

$$p_{max} = \frac{6\pi (0.03) (0.97) (0.145) (100) \cot(17.7^\circ)}{(0.0015)^2} = 11.076 \text{ (MPa)}$$

Substituting the values of Q_{max} and p_{max} in Equation 7:

$$Q_x = (1.872 \times 10^{-6}) - \left(\frac{1.872 \times 10^{-6}}{11.076 \times 10^6} \right) p = (1.872 \times 10^{-6}) - (1.690 \times 10^{-13})p \quad (1)$$

Using the values from Table 11 and substituting in Equation 9:

$$K_s = \frac{\pi (0.0027)^4}{(128) (100) (0.074)} = 1.76 \times 10^{-13} \left(\frac{m^5}{N-s} \right)$$

Substituting the value of K_s in Equation 8:

$$Q_{Die} = (1.76 \times 10^{-13})p \quad (2)$$

Equating both equations **(1) and (2)**, and solving for p :

$$(1.872 \times 10^{-6}) - (1.690 \times 10^{-13})p = (1.76 \times 10^{-13})p \rightarrow p = 5.426 \text{ (MPa)}$$

Solving for Q_x using Equation 7:

$$Q_x = (1.872 \times 10^{-6}) - \left(\frac{1.872 \times 10^{-6}}{11.076 \times 10^6} \right) (5.426 \times 10^6) = 0.955 \times 10^{-6} \left(\frac{m^3}{s} \right)$$

Therefore, the resulting flow rate of polymer melt in the extruder at 56 (rpm) is

$$Q_x = 0.955 \times 10^{-6} \left(\frac{m^3}{s} \right)$$

3.3.2 Extrusion capacity

The capacity can be calculated using an average value of thermoplastics densities and the maximum flow rate of the polymer melt in the extruder.

An average value of densities of LDPE, HDPE, and PP thermoplastics (Harper, 2000) is

$$\frac{920 \left(\frac{kg}{m^3} \right) + 950 \left(\frac{kg}{m^3} \right) + 900 \left(\frac{kg}{m^3} \right)}{3} \cong 923 \left(\frac{kg}{m^3} \right)$$

Therefore, the capacity is

$$Capacity = 923 \left(\frac{kg}{m^3} \right) \times 0.955 \times 10^{-6} \left(\frac{m^3}{s} \right) \times 3600 \left(\frac{seconds}{hour} \right) \cong 3 \left(\frac{kg}{h} \right)$$

3.3.3 Gearbox output analysis

The drive motor power can be calculated using the following equation:

$$P = N T \text{ or } T = \frac{P}{N} \quad \text{Equation 10} \\ \text{(Harper, 2000)}$$

Where,

P = power (Watts)

N = screw speed (rad/s)

T = torque (Joules).

Gearbox reduction ration is 25:1. Therefore, gearbox output speed is

$$\frac{\text{Motor rotational speed}}{\text{Gearbox reduction ration}} = \frac{1455}{25} = 58.2 \text{ (rpm) or } 6.095 \left(\frac{\text{rad}}{\text{s}}\right)$$

Substituting motor power and gearbox output speed values in Equation 10:

$$T = \frac{P}{N} = \frac{4000 \left(\frac{\text{Nm}}{\text{s}}\right)}{6.095 \left(\frac{\text{rad}}{\text{s}}\right)} = 656.3 \text{ (Nm)}$$

3.3.4 Energy contribution by band heaters

The energy contribution by each of the band heaters can be calculated by the following equation:

$$E = P t \quad \text{Equation 11}$$

Where,

E = energy (Joules)

P = power (Watts)

t = time (seconds).

From Table 9 the power values are:

For the first size of heaters (90×150), $P_1 = 1.5$ (kW).

For the second size of heater (90x100), $P_2 = 1.25$ (kW).

Using these values and substituting in Equation 11, the energy produced by 1 heater in one-hour period is:

$$E_1 = \left(1500 \frac{Nm}{s}\right) \left(\frac{60s}{min}\right) \left(\frac{60min}{hour}\right) = 5.4 \text{ (MJ per hour)}$$





And, for the second size with P_2 :

$$E_2 = \left(1250 \frac{Nm}{s}\right) \left(\frac{60s}{min}\right) \left(\frac{60min}{hour}\right) = 4.5 \text{ (MJ per hour)}$$

Therefore, the total energy produced by four ceramic insulated band heaters (two from each size) in one-hour period is:

$$E_T = (2)(5.4) + (2)(4.5) = 19.8 \text{ (MJ per hour)}$$

3.4 Cost analysis

Item #	Part #	Qty	Name	Material	Source	Cost	Picture
1	1-1-1 1-1-2 1-1-6	1	Screw and barrel set	Alloy steel 38CrMoAl A	Zhoushan Jinmao Machinery Factory. Xihou Industrial Park, Zhoushan, Zhejiang, China. Tel : +86-580-8050975	\$460	
2	1-1-4	4	Ceramic Band Heaters	Aluminum and Ceramic	Yancheng Laiyuan Electric Equipment Co., Ltd. Location: Jiangsu, China (Mainland) Tel: +86-15851048592	\$64	
3	1-2-1	1	3 Phase AC Motor 4 kw with Gear Box	Various	Özkaramanli Elektrik LTD. Location: Leafkosh, TRNC. Tel: 03922255391	\$495	
4	1-3	1	Motor Control Unit	Various	Özkaramanli Elektrik LTD. Location: Leafkosh, TRNC. Tel: 03922255391	\$650	






Item #	Part #	Qty	Name	Material	Source	Cost	Picture
5	1-4	1	Temperature Control Unit	Various	Özkaramanli Elektrik LTD. Location: Leafkosh, TRNC. Tel: 03922255391	\$195	
6	1-2-2	1	Shaft Coupling	Cast Iron	AliYakar Ve Oğulları Ltd. Location: marash, Famagusta, TRNC Tel: 3923664519	\$30	
7	1-5	1	Table	Steel	Fuat Curcur Location: big industrial are, Famagusta, TRNC Tel: 3652265	\$400	
8	1-5-7	28	Mechanical Fasteners	Steel	Sennaroğlu LTD. Location: small industrial area, Famagusta, TRNC Tel: 03923668457	\$30	
9	1-6-1	1	Water Bath	Plastic	Genç Yapi market Location: small industrial area, Famagusta, TRNC	\$15	

Table 12: Capital investment.

	Quantity	Unit price	Total
Vernier caliper	1	\$20	\$20
Gloves	5	\$2	\$10
Safety glasses	5	\$2	\$10
Spanner set	1	\$10	\$10
Hammer	1	\$6	\$6
Allen keys set	1	\$6	\$6
Screw drivers set	1	\$2	\$2
Cleaning equipment	1	\$15	\$15
Plastic cover	1	\$15	\$15
Cable ties	1	\$5	\$5
Silicon injector	1	\$5	\$5

Table 13: Other expenses.

Category	Cost
Food	\$150
Transportation	\$200

CHAPTER 4 – MANUFACTURING PLAN

4.1 Manufacturing process selection

For the manufacturing of the selected single screw plastic extruder, the majority of the work accomplished was done by means of assembly and welding. What may be an assembly at one point may however be a subassembly of another. In our design the work revolved around adjusting three main components/systems in such a way that our design meets the stated goals and objectives, which are the control system, rolling and support systems and the motor.

4.1.1 Extruder barrel

The extruder barrel was manufactured by the means of centrifugal casting. The barrel was fixed to the barrel stand by the means of mechanical fasteners. The selection matrix shown in Table 14 illustrates the criteria’s considered when comparing the given manufacturing methods.

Table 14: Criteria matrix for extruder barrel manufacturing method selection.

Legend 1→ worst 10→ Best	priority	Importance	forging	Centrifugal casting
Strength	3	6	10	10
Reliability	2	8	8	8
Cost effectiveness	1	10	4	10
Weighted total			164	<u>224</u>

4.1.2 Extruder screw

The extruder screw was manufactured using a CNC extruder screw turning machine and plasma welding as a refurbishment. The extruder screw was attached to the barrel by the means of insertion with the aid of adhesives. The criteria matrix shown in Table 15 illustrates the criteria's considered when comparing the given manufacturing methods.

Table 15: Criteria matrix for extruder screw manufacturing method selection.

Legend 1→ worst 10→ Best	Priority	Importance	Automatic screw machine	CNC turning machine
High precision	1	20	6	10
Cost effectiveness	2	10	8	8
Weighted total			200	<u>280</u>

4.1.3 Control system

The control box was fixed to the table by the means of mechanical fasteners (bolts, screws, and nuts). The cables and sensors were attached to the table by the means of insertion.

4.1.4 Drive system motor

The motor was fixed to the table by the means of mechanical fasteners. The motor and the screw were assembled by the means of insertion with the aid of a coupling junction that was machined to meet to fit the required specifications. The screw steel shaft connection (coupling) was manufactured using the horizontal milling machine. Table 16 shows the milling selection matrix for coupling machining.

Table 16: Milling selection matrix.

Legend 1→ worst 10→ Best	Priority	Importance (weight)	Horizontal Milling	Vertical Milling
efficiency	1	10	8	6
Easier alignment	3	6	8	4
Less space	4	4	6	6
Deformation	2	8	10	4
Weighted total			<u>232</u>	140

4.1.5 Cooling system

The Water bath is made up of high-density polyethylene (HDPE). The Reels (pulleys) were attached to the tank by means of insertion.

4.1.6 Band heaters

- The heater bands were attached to the barrel by the means of insertion.
- The heater bands were fixed to the barrel by the means of mechanical fastener

4.1.7 Extrusion die

- The orifices die which is made up of H13 tool steel was manufactured by the means of wire electrical discharge machining (EDM) and drilling.
- The orifice die was fitted into the barrel by the means of insertion.

4.1.8 Hopper

- The hopper was made out of SAE 4130 Steel sheets that were bent and cut to a certain extent.
- The metal sheets were joined by the means of shield metal arc welding and spot welding.
- The hopper was fixed to the barrel by the means of mechanical fasteners.

Geometric fasteners were chosen as the best alternative, due to its low cost and high reliability, which are vital in terms of avoiding any uncertainties during the feeding process. The criteria matrix shown in Table 17 illustrates the criteria's considered when comparing the given assembly methods.

Table 17: Criteria matrix for hopper welding method selection.

Legend 1→ worst 10→ Best	priority	Importance	Shield metal arc Welding	Geometric Fasteners
strength	1	10	10	4
Reliability	2	8	6	8
Cost	3	6	4	8
Weighted total			<u>172</u>	152

4.1.9 Table

- The legs and frame are made out of SAE 4130 steel tubes.
- The steel bars and sheets were assembled by the means of tungsten arc welding.

The following criteria matrix shown in Table 18 will show why tungsten arc welding was chosen over Gas metal arc welding.

Table 18: Criteria matrix for table welding method selection.

Legend 1→ worst 10→ Best	priority	Importance (weight)	Gas tungsten Arc welding	Gas metal arc welding
Good surface finish	2	8	8	4
High production rate	3	6	4	10
Weighted total			188	152

4.2 Detailed manufacturing process

4.2.1 Extruder barrel

As mentioned before, the extruder barrel was manufactured using centrifugal casting. In the centrifugal casting process, molten metal is poured into a preheated, spinning die. The die may be oriented either on a vertical or horizontal axis depending on the configuration of the desired part. By spinning a mold while molten metal is poured into it, centrifugal force acts to distribute the molten metal in the mold at pressures approaching 100 times the force of gravity. The combination of this applied pressure and the engineering mechanics of controlled solidification and secondary refining produces components of superior quality.

4.2.2 Extruder screw

The extruder screw was manufactured by CNC turning which is a manufacturing process in which bars of material are held in a chuck and rotated while a tool is fed to the piece to remove material to create the desired shape.

A turret (shown center), with tooling attached, is programmed to move to the bar of raw material and remove material to create the programmed result. This is also called “subtraction machining” since it involves material removal. If the center has both turning and milling capabilities, such as the one above, the rotation can be stopped to allow for milling out of other shapes.

4.2.3 Control system

The control box was attached to the table by the means of mechanical fasteners, which are nuts, bolts, and screws. The holes were drilled using a power drill after all the required measurements were taken. The mechanical fasteners used were certified by ASTM standards. The wires and sensors were installed by the means of insertion as mentioned before. Figure 20 shows how the control stands were drilled using a hand drill in order to fix them to the table.



Figure 20: Material removal process of the control system stands using a hand drill.

4.2.4 Drive system motor

In this section, the only component that was manufactured is the screw shaft connection, which was manufactured using the vertical milling machine with the aid of the shaft key cutter.

The motor was assembled to the table by the means of mechanical fasteners meanwhile the coupling was assembled to the motor shaft and screw by the means of insertion. Figure 21 illustrate the previous facts. Figure 22 shows how the coupling holds the screw and motor shaft together to allow one direction rotation.

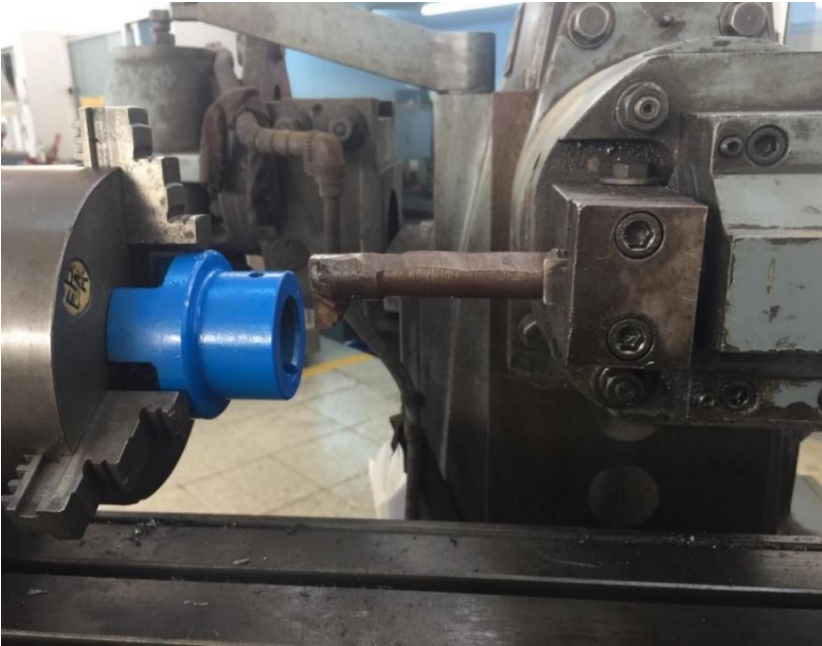


Figure 21: Machining the coupling using the vertical milling machine with the aid of the shaft key cutter.

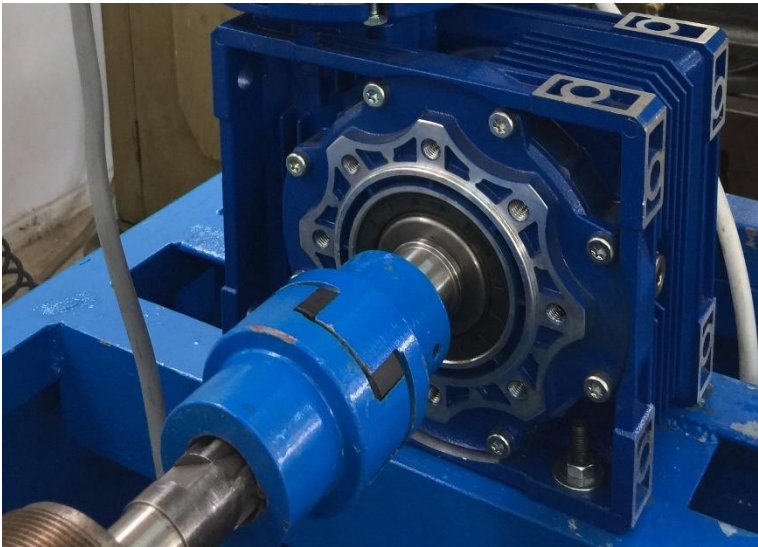


Figure 22: The screw shaft connection (coupling).

4.2.5 Cooling system

The Water bath is made up of high-density polyethylene (HDPE) as it is known for its high strength and reliability. The reels were fixed to the bath by the means of insertion by drilling 2 holes from each side as shown in Figure 23 using a hand drill. The metal rods were cut using the automated hacksaw which helped in saving time and energy plus its more accurate than manually cutting them as shown in Figure 24.



Figure 23: The manufacturing of the cooling tank.



Figure 24: Automated hacksaw.

4.2.6 Band heaters

The heater bands were attached to the barrel by the means of insertion with the help of clamps and mechanical fasteners such as nut, bolts, and screws.

4.2.7 Extrusion die

The orifice die was manufactured by the means of wire Electrical Discharge Machining. Electrical Discharge Machining (EDM) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion. In this process, an electric spark is used as the cutting tool to cut (erode) the type H13 tool steel piece to produce the finished part which is the die.

4.2.8 Hopper

The SAE 4130 Steel sheets were joined using shield metal arc welding. The arc is struck between the metal rod (electrode) and the steel sheets, both the rod and sheets surface melt to form a weld pool. Simultaneous melting of the flux coating on the rod will form gas and slag which protects the weld pool from the surrounding atmosphere. The slag will solidify, and the cool is chipped off the weld bead as soon as the weld run is complete (or before the next weld pass is deposited). After the metal sheets were welded together the hopper was fixed to the Spot-welding machine to make sure the sheets are completely fixed to each other to avoid any feeding uncertainties. Figure 25 shows the manner in which the hopper was fixed to the machine plus the end product.



Figure 25: Spot welding machine.

4.2.9 Table

The table's frame and legs were made up of SAE 4130 steel ducts as mentioned before. The frame was assembled using gas tungsten arc welding (GTAW), which is an electric arc welding process where an arc is produced between the non-consumable electrode and the steel ducts. The weld is shielded from the atmosphere by a shielding gas that forms an envelope around the weld area. In addition, control system stands were attached to the table frame using mechanical fasteners. Figure 26 shows the machining process of the control system stands using a portable abrasive cut-off machine.

The wheels were assembled by the means of mechanical fasteners with the aid of a machined metal base used as a platform where the mechanical fasteners are fixed. Figure 27 shows the drilling process using a drill press.



Figure 26: Cutting using portable abrasive cut-off machine.



Figure 27: Drilling process for table wheels using a drill press machine.

CHAPTER 5 - PRODUCT TESTING PLAN

5.1 Verification plan of the objectives of the project

Several tests were conducted to validate the compatibility of the machine to the objectives of the design and ensure that the requirements and expectations of the user are met.

- A demonstration was performed to test the ergonomics of the machine. While operating the machine team members checked if the designed height of the table and components is comfortable to the operator and that the controllers and E-stop are within reach as needed.
- The main mission of the machine is to produce a continuous flow of plastic as illustrated in Figure 28, this was verified by letting the machine to operate continuously for an extended period of time, at this period the melt flow was observed to check if there is interruption or discontinuity in the flow.

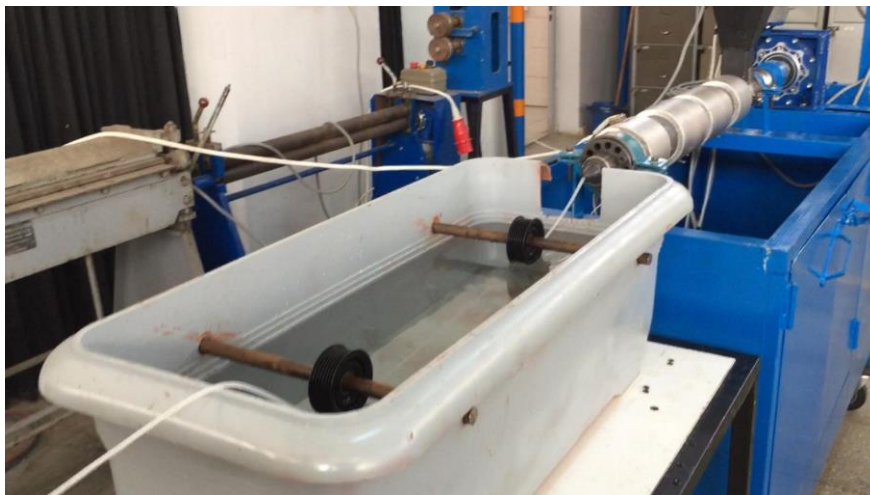


Figure 28: Continuous flow plastic.

- The main product of the machine is 3D printer filament of 3 mm diameter, so the capability of the machine to produce the desired diameter was tested by measuring the diameter of the product after cooling with a Vernier caliper, this was done at several periods of machine operation and for the different types of plastics.

5.2 Verification plan of the applied engineering standards

In order to assess the compatibility of the machine to the design specifications and engineering standards, the following tests were performed:

- Verification of the designed plastic melt flow from the extruder was done by measuring the volume of an extruded section and the time of extrusion (the volume is calculated for a cylindrical section with length and diameter as the length of the extruded section in and die orifice diameter), then basically dividing the volume by the time to come up with the volumetric flow rate and compare it with the theoretical value.
- The alignment of the motor and the screw was assured, first by placing an Allen key on the coupling as shown in Figure 29 and checking if there is any misalignment between the two sides of the coupling, then by operating the motor and observing the rotation and vibration while gradually increasing the speed of rotation of the motor.

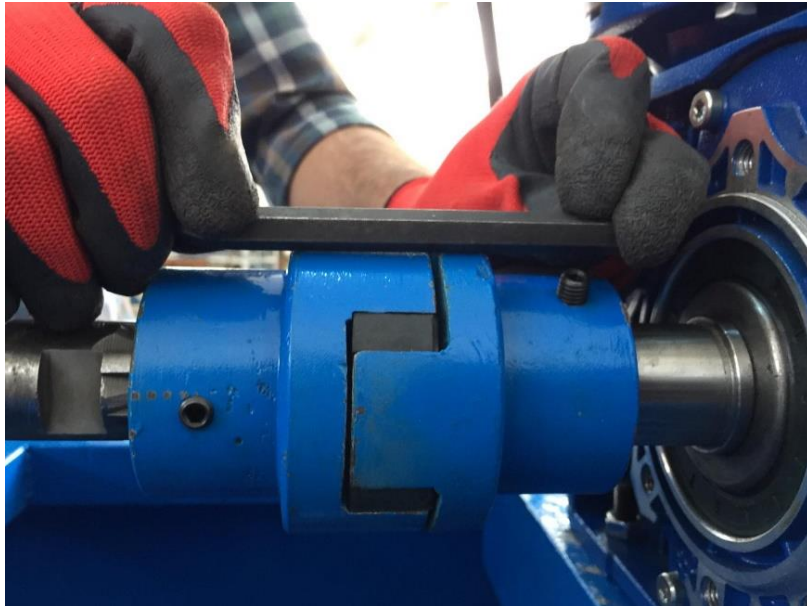


Figure 29: Aligning of the motor and screw with an Allen key.

- Testing to find the optimum motor speed range was performed. The motor was operated at different speeds, for each the melt flow was observed to check whether the flow is uniform and continuous or not.
- Testing to select suitable temperatures for the different extruder zones as conducted. Various temperature ranges were set for each zone, then the quality of the melt flow and the final product were observed. This was done for the different types of plastic.
- The efficiency of the cooling system to cool the product as required was verified for the different plastics types by physically handling (touching) the product after it is out of the water bath.
- Effectiveness of the E-stop button to cut the current on the motor as put to test by operating the motor at different speeds, pressing the button and noting if there is any nonresponding or delay in the process.

CHAPTER 6 - RESULTS and DISCUSSIONS

6.1. The results

6.1.1 Polymer melt flow rate

The experimental value of the resulting polymer flow rate in the extruder can be calculated using the observed data during the testing of the machine as following:

Time interval (0 – 3.39 seconds), extrudate diameter = 3 (mm), extrudate length = 1.16 (m).

Now, using the above data, the volume of the extrudate is

$$Volume = \frac{\pi}{4} d^2 L = \frac{\pi}{4} (0.003)^2 m^2 \times (1.16) m = 8.20 \times 10^{-6} (m^3)$$

And, the volumetric flow rate is

$$\begin{aligned} Q_{x,experimental} &= \frac{Volume}{time} = \frac{8.20 \times 10^{-6} (m^3)}{3.39 (s)} = 2.42 \times 10^{-6} (m^3 \text{ per } 3.5 \text{ seconds}) \\ &= 0.71 \times 10^{-6} \left(\frac{m^3}{s} \right) \end{aligned}$$

The relative error can be calculated as

$$\% Error = \frac{|Experimental\ value - theoretical\ value|}{theoretical} \times 100 \quad \text{Equation 12}$$

$$\text{Experimental value } Q_{x,exp} = 0.71 \times 10^{-6} \left(\frac{m^3}{s} \right)$$

$$\text{Theoretical value } Q_x = 0.955 \times 10^{-6} \left(\frac{m^3}{s} \right)$$

Therefore, the relative error using Equation 12 is

$$\% Error = \frac{|(0.71 \times 10^{-6}) - (0.955 \times 10^{-6})|}{0.955 \times 10^{-6}} \times 100 = 25.65\%$$

The testing results confirmed the project design objectives. This is because the obtained extruder output is continuous plastic filament with a diameter of 3 mm. The experimental flow rate value obtained was based on the maximum screw speed (58.2 rpm). Extruder output (extrudate) increases linearly with screw speed. However, head pressure also increases with screw speed resulting in higher pressure flow. But the dominant factor which affects the extruder output depends on melt viscosity. With high-viscosity melts, the flow pressure is minimized. In contrast, low- viscosity melts produce greater flow pressure. Thus, reducing the extruder output.

6.1.2 Drive system

The plastic pellets melting occurs through two concurrent methods: (a) band heaters, and (b) shear force caused by the motion of the plastic against the barrel.

The testing results showed that in order to obtain a uniform polymer melt, the screw speed should be **at least 40%** of the total motor speed (23.28 rpm, VFD controller output frequency 20 Hz). This is because as the screw speed increases, the friction and the shear force between the molten plastic and the barrel increases. While decreasing screw speed decreases mechanical shearing, thus minimizing the reduction in molecular weight. As a result, **sharkskin** defect occurs.

The term sharkskin refers to when an extrudate loses surface gloss. sharkskin defects originate near the die exit. In that region, critical shear stress in conjunction with a critical screw speed results in skin rupture of the extrudate. However, this defect can be avoided by setting proper heaters temperature and motor speed. Figure 30 shows the polymer melt profile (sharkskin defect) at low motor speed, and Figure 31 shows the extrudate profile (smooth surface) at sufficient motor speed.



Figure 30: Extrudate profile (sharkskin defect) at low motor speed.

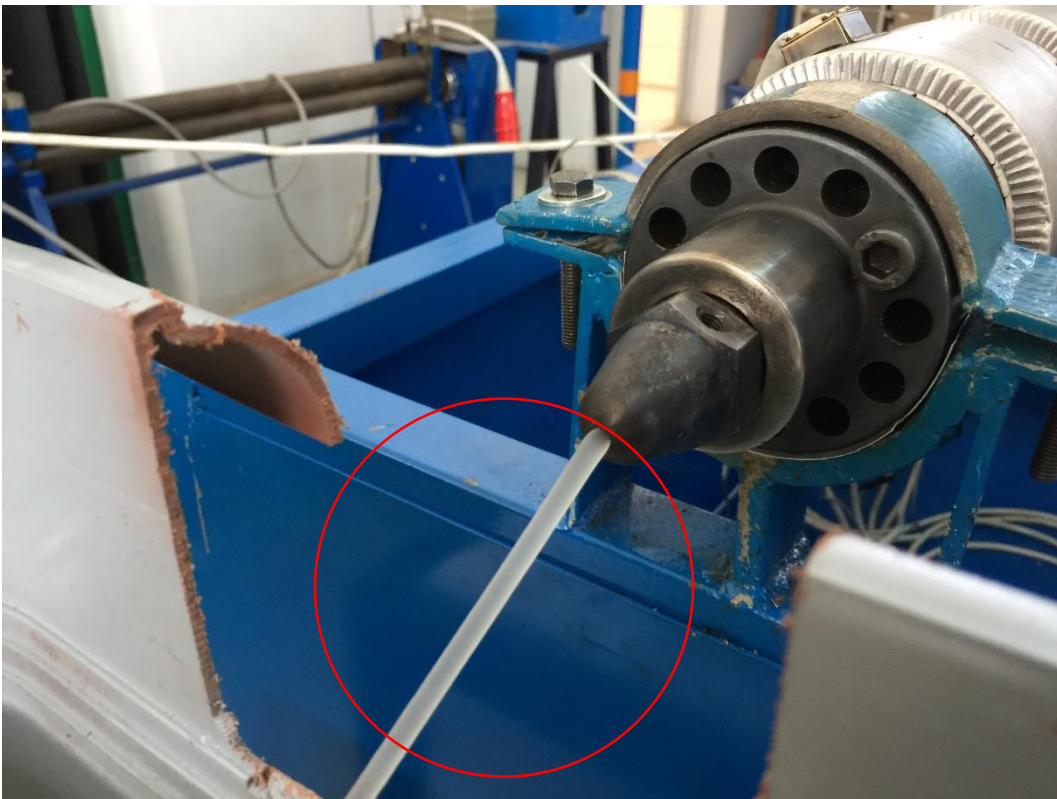


Figure 31: Extrudate profile (smooth surface) at sufficient motor speed.

6.1.3 Band heaters

The testing results showed the direct dependence of the extrudate on the temperature of heaters. The testing included two different types of thermoplastics: (1) low-density polyethylene (LDPE), and (2) high-density polyethylene (HDPE). The results confirmed that the temperature distribution over the screw zones to obtain uniform polymer melt varies depending on the type of polymer. Table 19 shows the observed proper temperature values for LDPE and HDPE thermoplastics.

Table 19: Temperature distribution over screw zones for different thermoplastics.

Screw zone	Thermoplastic	
	LDPE	HDPE
Feed zone	170 °C	190 °C
Compression zone	180 °C	200 °C
Metering zone	190 °C	220 °C

6.2. The engineering standards

Table 20: Testing engineering standards.

Standard	Description
ISO 14001:2004	Environmental management systems
OHSAS 18001:2007	Occupational health and safety
ISO 9692-3:2016	Standard specification for welding and allied process

ASTM D618	Standard practice for conditioning plastics for testing
ISO 527	Specifies the test conditions for the determination of the tensile properties of plastic
ANSI/SPI B151.7-2014	Plastic machinery – safety requirements for extrusion machines
AIC 62321-1:2013	Test standard for heating elements
EN IEC 60947-5-5	Emergency stop switch compact, foolproof
ISO 13850	Emergency systems standards

6.3. The constraints

- Redesign: the screw and barrel set which were bought by the previously was restrictive in terms of designing and purchasing the other components, for instance, the motor and its VFD controller.
- Availability: Limited markets and companies in the local area.
- Economic: Limited budget which had to be taken into account to avoid exceeding the costs of similar machines in the market.
- Manufacturability: Limited machines in the workshop which slightly affected the quality and reliability of the machine
- Sustainability: an enormous amount of heat energy is supplied to the surrounding, mainly from the band heaters. Lots of electricity is also wasted while running the machine for long periods of time.

CHAPTER 7 - CONCLUSIONS and FUTURE WORKS

7.1. The conclusions

Plastic extrusion is one of the important shaping processes of plastic which results in producing a continuous flow of plastic that is going to be shaped into the desired product using a die or by many other techniques. This report illustrated the design process of a single screw plastic extrusion machine that is used to produce plastic filament. The design objectives were safety, cost, assembly, performance, and environment.

The extruder consists of a barrel with a 30mm internal diameter and 947mm length and a screw of 30mm flight diameter and 971mm length which is divided into feed zone, compression zone and metering zone, with each zone serving a distinct function. Both the barrel and screw are made from Nitrided alloy steel 38CrMoAlA to withstand generated pressure and to resist wear. A die is connected to the barrel head in order to shape the plastic into a continuous filament with 3mm diameter.

The motor was selected to be 4 kW 3-phase AC motor with a gearbox of reduction ratio of 25:1 in order to deliver both the desired speed and torque to the extruder screw. In addition, a control unit was provided for the motor consisting of a variable frequency drive, switch to control the speed of rotation (rpm), switch to control the direction of rotation and emergency stop.

Ceramic band heaters two of 1.25 kW and two of 1.5 kW was chosen to effectively supply heat to the extruder that is required to melt the plastic. Each plastic has its own melting temperature, so the machine was equipped with a temperature control unit consists of three temperature controllers each connected to a thermocouple to sense the temperature at the associated point of the extruder, to a contactor and to an ON/OFF switch, these controllers provides decent control on the temperature in each zone of the of the extruder separately.

Basically, heaters corresponding to the different extruder zones are connected to the associated controller through the contactor which is responsible for passing or cutting current to the heaters depending upon the signal it receives from the temperature controller, in order to maintain the desired temperature in the zone.

The Table was designed to withstand loads of the motor, the extruder, and other components, also a storage area was provided to store the raw material and equipment, moreover, the table was equipped with wheels to ease movement of the machine around. The control units were placed to be within reach and to provide comfortable control for the operator.

The cooling system is composed of plastic bath (that can hold up to 45L of water), two pulleys to direct the melt flow inside the water and a reel to take the cooled filament out of the water and wind it up.

The working principle of the machine is simply as follows: the temperature controllers are switched on which in return will turn on the heaters and heating of the extruder will begin, the temperatures should be set according to the type of plastic to be used, when the desired temperatures are reached plastic pellets are poured into the hopper and the motor is turned on, speed of the motor is gradually increased to the adequate value. Rotation of the screw will push the plastic pellets forward from the hopper to the barrel head, along the way the plastic pellets are melted and crushed and transferred into viscous flow of plastic, when the flow comes out of the die it is pulled into the cooling water beneath the pulleys and up to the reel which is rotated to pull and wind up the produced plastic filament.

Several tests were conducted to test the machine's ability to produce continuous filament and with the desired diameter, also to find the suitable zones temperatures and motor speed associated with the different plastic types.

7.2. The future works

Various components can be added to the machine to make it more effective, versatile and safer:

- The cooling system can be equipped with a water circulating system, the function of this system is to cool down the water as it gets heated by the produced filament. It is suggested that the circulating system simply consists of a set of pipes that run beneath the water bath and a pump that sucks water from the bath and pass it through the pipes and back to the bath which helps in chilling the water. The estimated cost is \$60 - \$70.
- Automation of the winding up reel is advised. Redesigning of the reel to work with a DC motor will enhance the quality of the product as the winding force will be more consistent and it will decrease the number of people needed to operate the machine. The DC motor should be supported on the same height as the reel and the shafts of the reel and the motor are connected by a coupling. The estimated cost is \$30 - \$50.
- In order to raise the productivity, dies and molds of different cross-sections and shapes can be provided to the machine, this will increase the number of products produced and help to benefit more from the machine capabilities. Since the machine does not inject plastic, it is not suggested to use molds with sharp edges and complex shapes. A steel cylindrical rod can be machined to have the same diameter and threading as for the threaded part of the extrusion die, then it should be welded on a steel plate and drilled all the way through the steel plate. After that, the plate can be drilled to have holes so the mold can be fastened directly to the plate. The estimated cost is \$10 - \$20.
- Supplying the machine with a shredder that can cut various products and objects made of thermoplastic onto small flakes suitable to be used as raw material, will enhance the usage of recyclable plastic in the machine production. The shredder comes as a separate small machine with a tray to collect the plastic after shredding. The estimated cost is \$200 - \$300.

- The band heaters can be equipped with air blower fans to serve the function of cooling down the barrel when the desired temperature in the zone is exceeded, in order to have more precise control on the temperatures in each of the extruder zones. The estimated cost is \$60 - \$90.
- Applying insulation between the barrel and its supports to decrease flowing of heat to the table frame and to enhance the safety of the machine. Simply a layer of heat insulating material such as glass wool can be mounted on the barrel support. The estimated cost is \$5 - \$10.

REFERENCES

- Anaheim automation, inc.* (2018). Retrieved December 12, 2018, from AC motor guide:
<https://www.anaheimautomation.com/manuals/forms/ac-motor-guide.php>
- Autonics Corporation.* (2018). Retrieved from TCN4M-24 R:
<https://www.autonics.com/model/A1500001066#n>
- EAO switch corporation.* (2018). Retrieved December 12, 2018, from EAO series 61:
<http://products.eao.com/index.php?IdTreeGroup=125&IdProduct=68982>
- Eaton Industries GmbH.* (2019). Retrieved from DC1-349D5NB-A20CE1 - Variable frequency drive:
https://datasheet.eaton.com/datasheet.php?model=185733&locale=en_GB&_lt=
- Electrical Classroom.* (2018). Retrieved from Contactor – Construction, Operation, Application and Selection: <https://www.electricalclassroom.com/contactor-construction-operation-application-and-selection/>
- GAMAK.* (2016). Retrieved from AGM2E 112 M 4: <http://www.gamak.com/en-US/content/product/products/low-voltage-motors/standard-motors/three-phase-motors/single-speed-motors/ie2/aluminium/4-pole/agm2e-112-m-4>
- Golander.* (2018). Retrieved December 12, 2018, from Temperature control:
<http://www.golanderusa.com/universal-1-16din-digital-pid-temperature-controller.html>
- Groover, M. P. (2010). Shaping processes for plastics. In *Fundamentals of modern manufacturing* (4 ed., pp. 9, 268, 271-278, 287, 296, 297, 299, 300, 301). New York: Wiley.
- Harper, C. A. (2000). Processing of thermoplastics. In *Modern plastics handbook* (pp. 5.24, 5.28, 5.29, 5.42). McGraw-Hill.
- Huanyang electrical co., ltd.* (2018). Retrieved December 12, 2018, from Products: Variable frequency drive: <https://huanyangelectrical.en.ec21.com/Products--6878300.html>

Omega engineering inc. (2018). Retrieved December 12, 2018, from PID & process temperature controllers: <https://in.omega.com/prodinfo/temperaturecontrollers.html>

Ormon industrial automation. (2018). Retrieved December 12, 2018, from Overview of temperature controllers: <https://www.ia.omron.com/support/guide/53/introduction.html>

Sakai, T. (2013). *Industrial chemistry research institute.* Retrieved from Polimery, No 11-12/2013: <http://en.www.ichp.pl/Screw-extrusion-technology>

Tense Electric and Electronic. (2019). Retrieved from TK-13: <http://tense.com.tr/%C3%BCr%C3%BCnler/s%C4%B1cakl%C4%B1k-kontrol-r%C3%B6leleri/termokupllar/item/370-tk-3>

Yancheng Laiyuan Electric Equipment Ltd. (2017). Retrieved from Band heaters: <http://www.china-laiyuan.com/bh>

APPENDIX A: Electronic Media

Brief Description of the plastic extrusion machine, pictures, and videos of conducted manufacturing processes, testing, and demonstrations, also CAD models and engineering drawings of the machine are all available on the following web site:

<http://www.plasticextrusionmachine.epizy.com/>

APPENDIX B: Constraints

Constraints	Yes	No
Redesign	X	
Economic	X	
Availability	X	
Manufacturability	X	
Sustainability	X	
Ethical	X	
Environmental		X
Health & safety	X	
Political		X
Social		X
Efficiency		X
Reliability		X
Performance		X
Serviceability		X

APPENDIX C: Standards

Standards	Definition
ISO 14001:2004	Environmental management systems
OHSAS 18001;2007	occupational health and safety
ASTM A 450/A 450M	specification for general requirements for carbon, ferritic alloy, and austenitic alloy steel tubes
ASTM F467 - 13(2018)	Standard Specification for Nonferrous Nuts for General Use
ASTM B209 - 14	Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate
AMS6348	Standard Specification for steel alloy bars
ISO 9692-3:2016	Standard Specification for Welding and allied processes
ISO 9692-2:1998	Standard Specification for Submerged arc welding of steels
ASTM D618	Standard Practice for Conditioning Plastics for Testing
ISO 527	Specifies the test conditions for the determination of the tensile properties of plastic.
AISI H13	Tool steel standard specifications
ANSI/SPI B151.7-2014	Plastics Machinery - Safety Requirements for Extrusion Machines
EN41CrAlMo7-10	Screw and barrel nitriding steel standards
AIC 62321-1:2013	Test standards for heating elements
EN IEC 60947-5-5	Emergency stop switch compact, foolproof

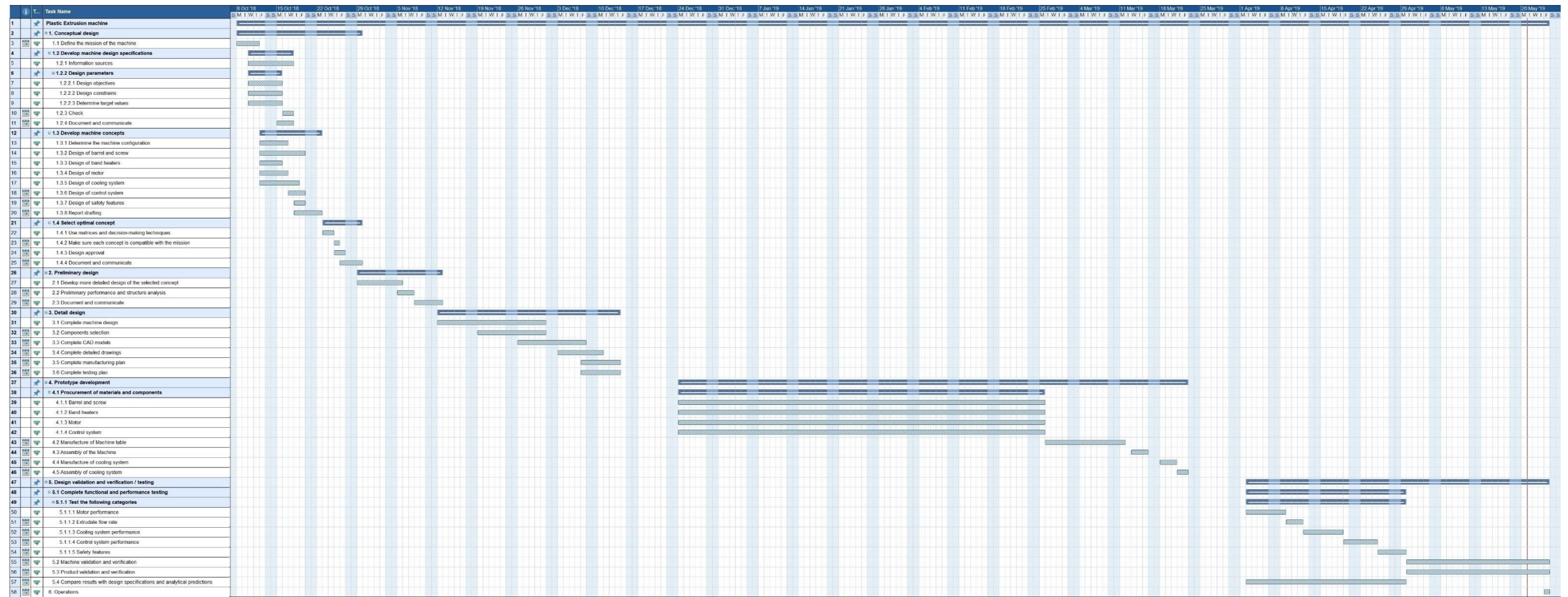
APPENDIX D: Logbook

Report writing	Written by	
	Name, Surname	Student Number
Report format	HASHEM ALHARTHI	143230
Report editing	HASHEM ALHARTHI	143230
Abstract	HASHEM ALHARTHI	143230
Chapter 1	HASHEM ALHARTHI	143230
Chapter 2	TARIG MAKKI	15700833
Chapter 3 (section 3.1, 3.2, 3.3)	HASHEM ALHARTHI	143230
Chapter 3 (section 3.4)	HUSSAIN SHAWISH	15700444
Chapter 4	TARIG MAKKI	15700833
Chapter 5	HUSSAIN SHAWISH	15700444
Chapter 6 (section 6.1)	HASHEM ALHARTHI	143230
Chapter 6 (section 6.2, 6.3)	TARIG MAKKI	15700833
Chapter 7	ABDULRAHMAN ABOUHANY HUSSAIN SHAWISH	143115 15700444

Report writing	Written by	
	Name, Surname	Student Number
References	HASHEM ALHARTHI	143230
Appendix A	HUSSAIN SHAWISH	15700444
Appendix B	TARIG MAKKI	15700833
Appendix C	TARIG MAKKI	15700833
Appendix D	HASHEM ALHARTHI	143230
Appendix E	HUSSAIN SHAWISH	15700444
Appendix F	ABDULRAHMAN ABOUHANY HUSSAIN SHAWISH	143115 15700444
Appendix G	HUSSAIN SHAWISH	15700444
Appendix H	HASHEM ALHARTHI HUSSAIN SHAWISH	143230 15700444
Appendix I	TARIG MAKKI	15700833
Appendix J	ABDULRAHMAN ABOUHANY	143115

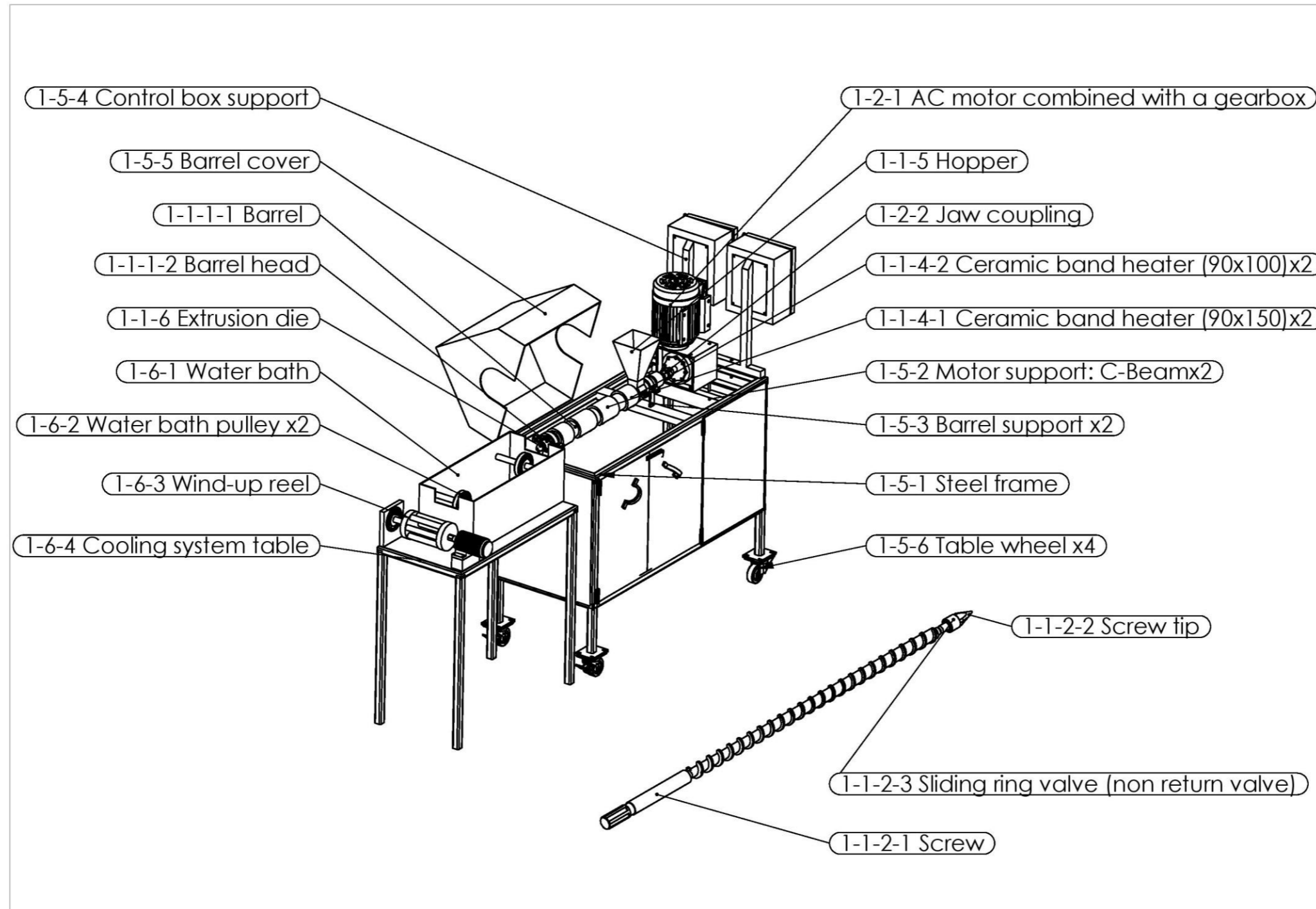
Date	Brief description of the performed work
From 18/02/2019 to 22/02/2019	Temperature controllers design
From 25/02/2019 to 1/03/2019	Temperature controllers design and selection
From 4/03/2019 to 8/03/2019	Drive motor design
From 11/03/2019 to 15/03/2019	Drive motor design and selection
From 18/03/2019 to 22/03/2019	VFD controller design
From 25/03/2019 to 29/03/2019	VFD controller design and selection
From 1/04/2019 to 5/04/2019	Cleaning extruder barrel and screw
From 8/04/2019 to 12/04/2019	Machine table design
From 15/04/2019 to 19/04/2019	Machine table manufacturing
From 22/04/2019 to 26/04/2019	Machine table manufacturing
From 29/04/2019 to 3/05/2019	Machine assembly
From 6/05/2019 to 10/05/2019	Cooling system design
From 13/05/2019 to 17/05/2019	Cooling system manufacturing Product testing
From 20/05/2019 to 24/05/2019	Product testing Finalizing report writing
From 27/05/2019 to 31/05/2019	Project demonstration and presentation

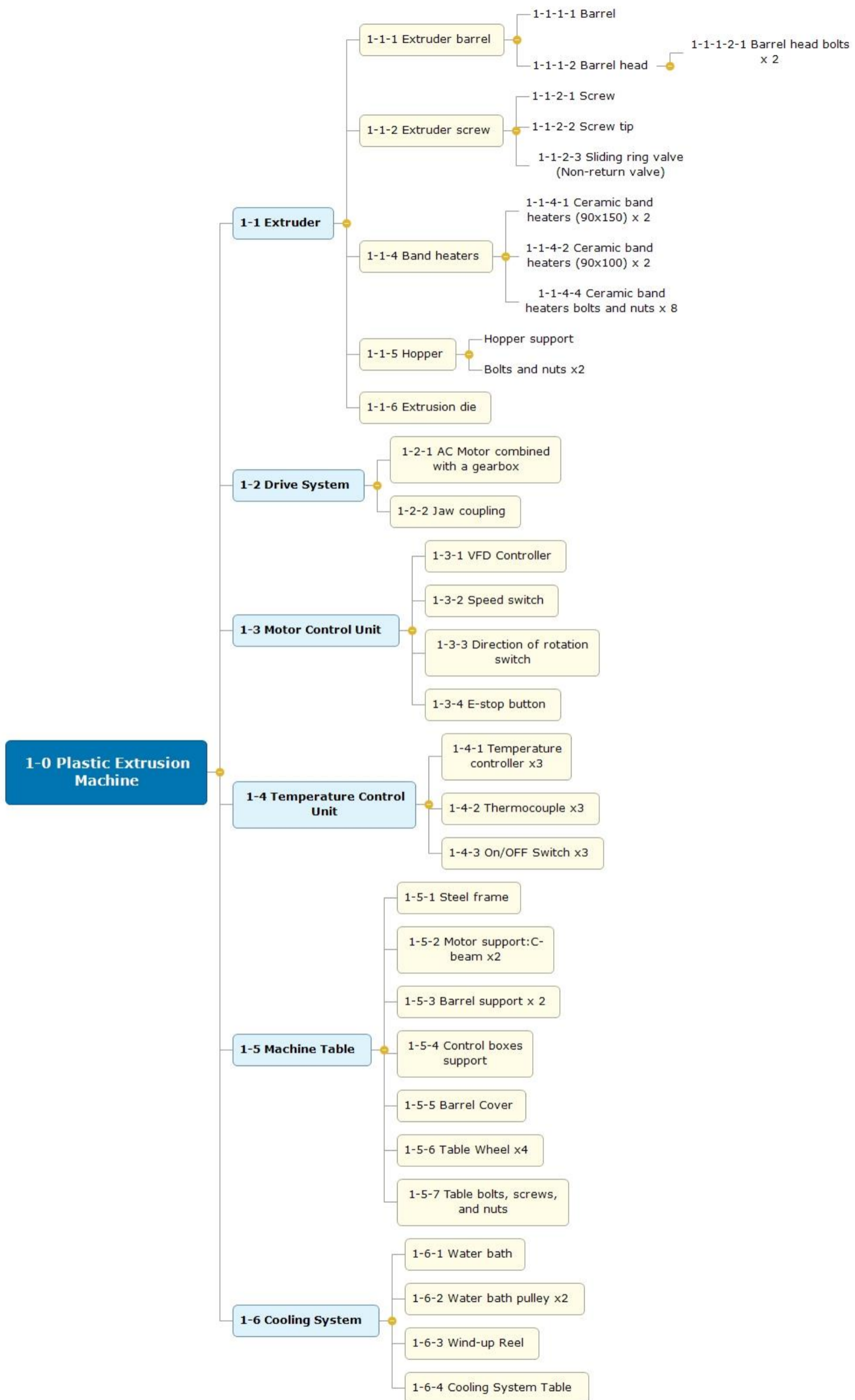
APPENDIX E: Project Timeline



APPENDIX F: Product Breakdown Structure

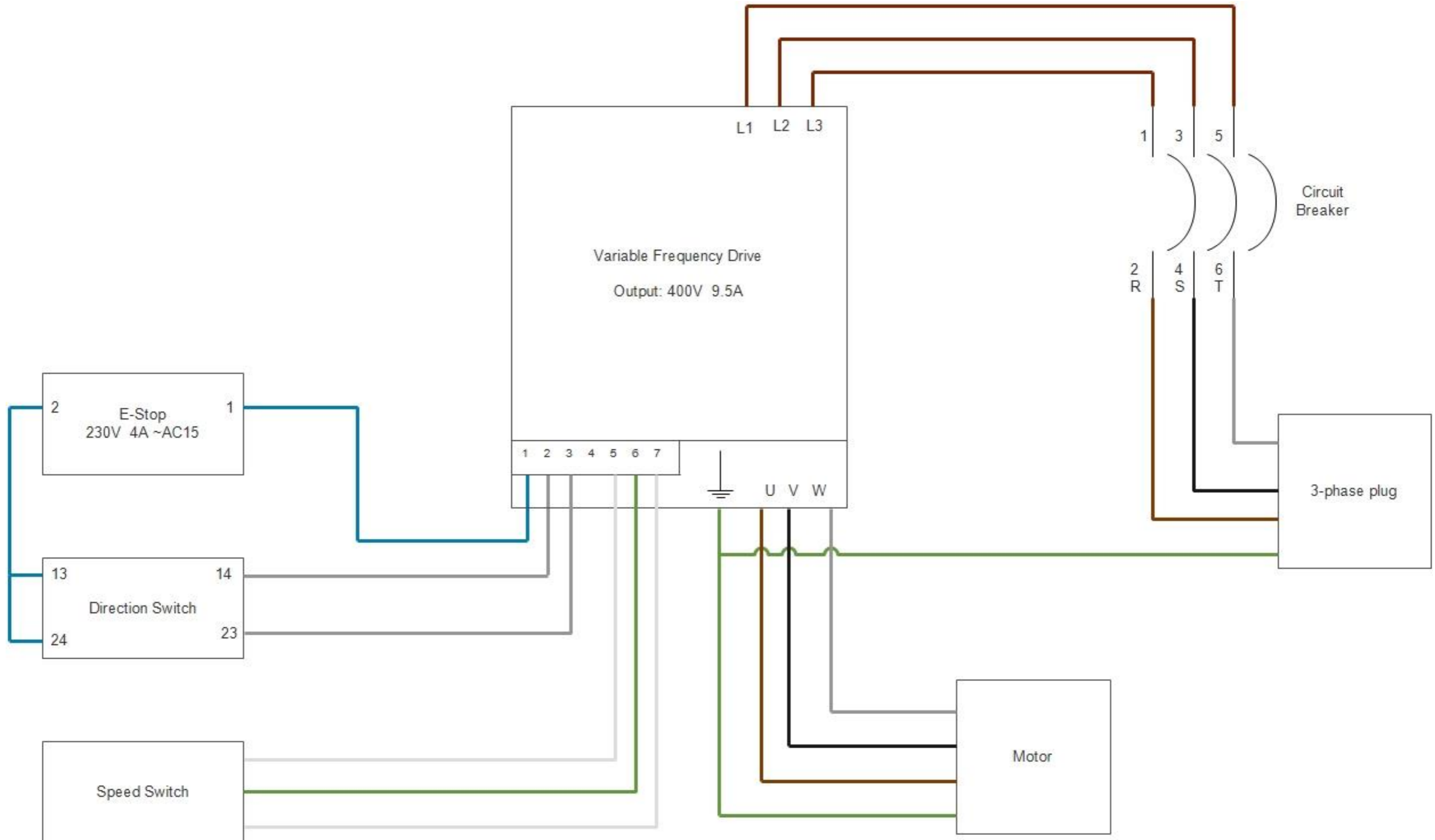
Appendix F is divided into two sections. First, the general configuration of the designed plastic extrusion machine is shown then a product breakdown structure showing each part/component numbering is provided.

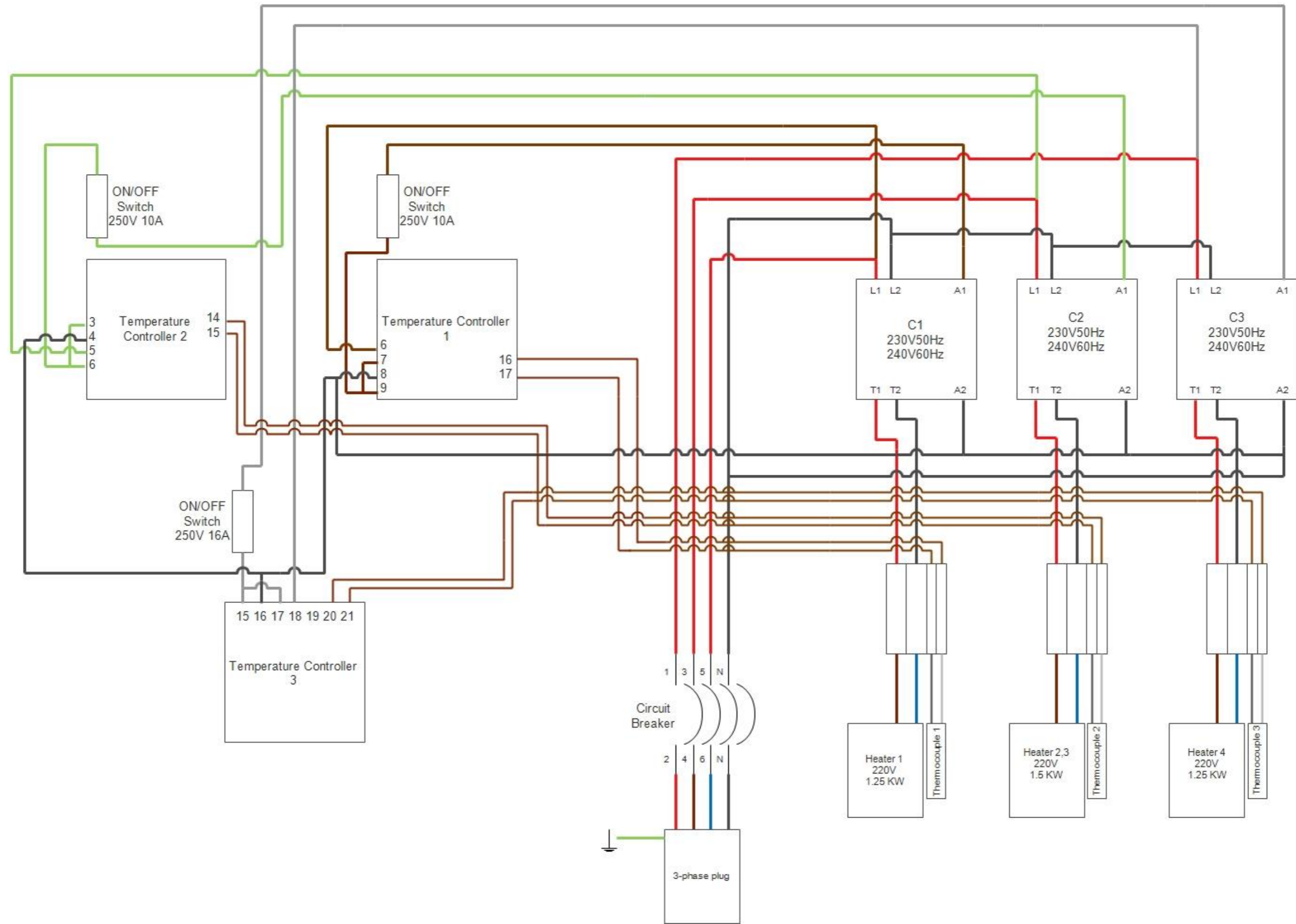




APPENDIX G: Wiring diagrams of the control system

The wiring diagrams are divided into two sections: (1) VFD controller wiring diagram, and (2) temperature controllers wiring diagram.





APPENDIX H: Assembly Instructions

The plastic extrusion machine consists of:

- Extruder barrel and screw.
- Drive, control, and cooling system.

The assembly procedure for each part/component is as follows:

Extruder barrel and screw:

1. The sliding ring (Non-return valve) is inserted to the screw tip.
2. The screw tip is fastened to the screw.
3. The extruder screw is inserted to the barrel.
4. The barrel head is bolted to the extruder barrel with two bolts.
5. The barrel is rested on the semi-circular supports.
6. The barrel is bolted in place with the provided clamps.
7. The extrusion die is attached to the barrel head.
8. The hopper is supported on the extruder barrel using 2 bolts.
9. The band heaters are inserted around the barrel and fixed in place with 2 bolts for each.

Drive system:

1. The gearbox is supported on the C-channel steel beams using 4 bolts.
2. The screw is connected to the gearbox shaft using a jaw coupling.
3. The jaw coupling is fixed using a set screw (Metric 8).

Control and cooling system:

1. The control boxes are fixed to the control unit supports using 4 bolts for each.
2. The water bath is just placed on a table.
3. The pulleys are inserted to the shafts in the water bath.

APPENDIX I: Operating Instructions

The operating instructions are as follows:

1. Plug the main electricity cords and switch on the circuit breakers.
2. Turn on the temperature controllers and set the temperatures to the required preferences.
3. Give the band heaters enough time to reach the required temperatures.
4. Make sure the plastic is molten before turning on the motor.
5. Turn on the motor and control its speed and make sure it's set to the anticlockwise rotation (II-direction in the direction switch).
6. Pour the plastic pellets in the hopper and fill it up.
7. Wait for the product to come out.
8. Fix the product to the first roller in the cooling tank and allow it to cool.
9. Finally, wind the plastic filament on the winding reel.

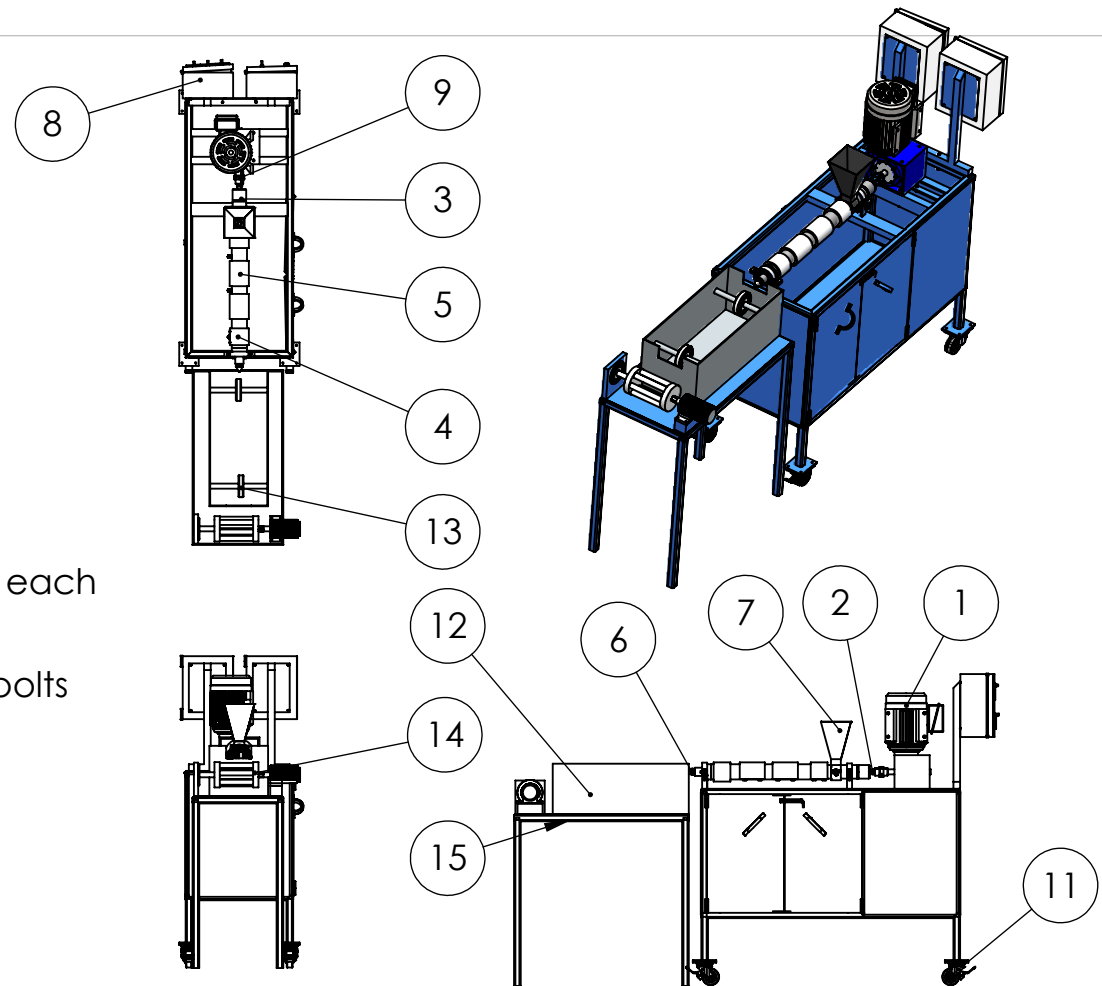
APPENDIX J: Engineering drawings

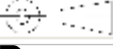

Drawings start on the next page.

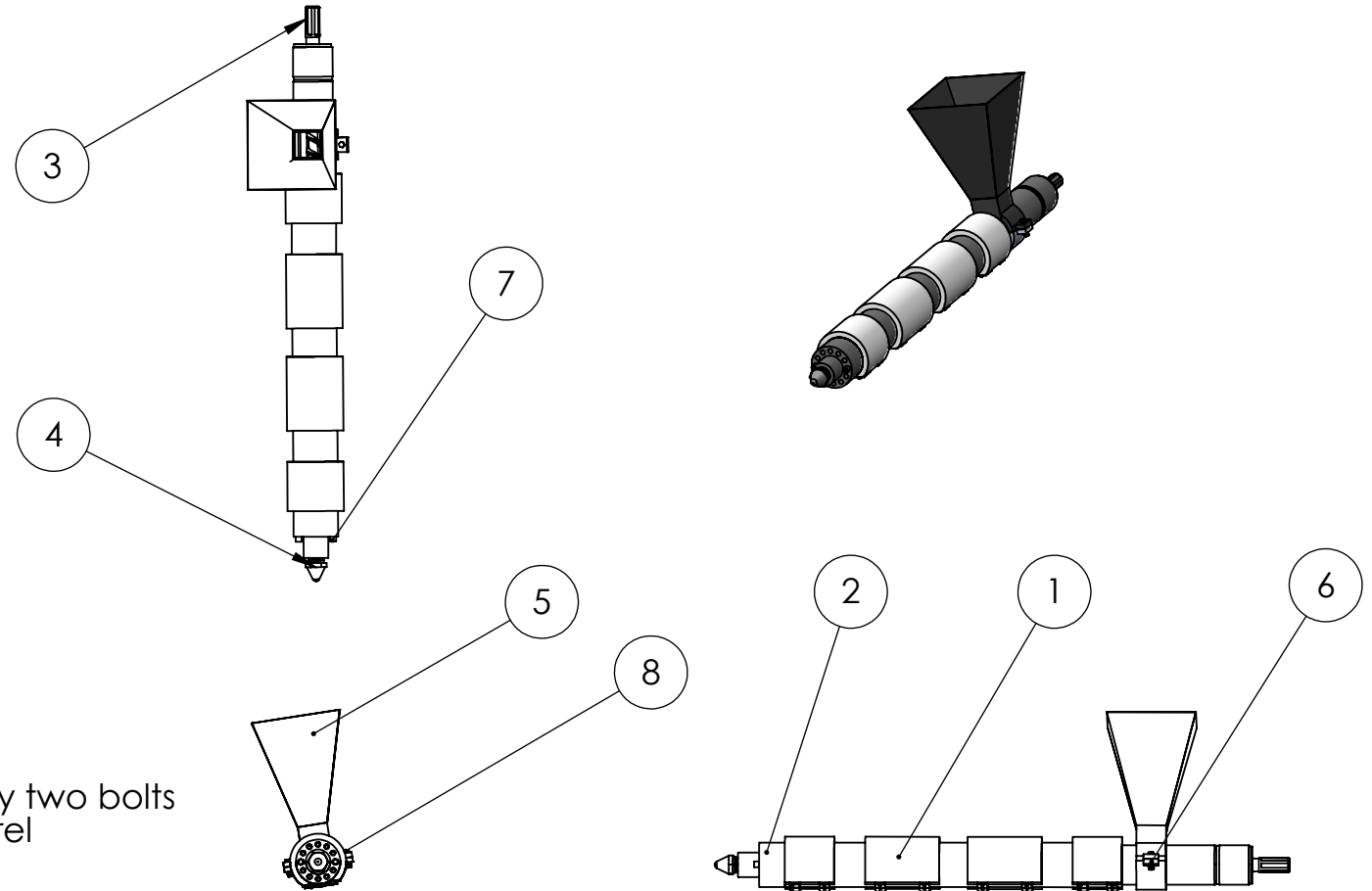
INSTRUCTION :

- Table frame is welded
- AC motor is bolted to its stand with 4 bolts
- Screw is connected to the AC motor by jaw coupling
- Barrel is rested on a semi circular supports and bolted in place with additional holders
- Hopper is fastened around the barrel with semi circular support by 2 bolts
- Heater bands are fixed around the barrel with 2 bolts each
- Extrusion die is fastened to the barrel head
- Pulleys are inserted to the shaft in the water bath
- Control box is fixed to the control box support with 4 bolts

NO.	Part Name
15	Cooling system table
14	Wind-up reel
13	Pulley
12	Water bath
11	Wheel
10	Barrel cover
9	Jaw coupling
8	Control box
7	Hopper
6	Extrusion die
5	Heater band 90x150
4	Heater band 90x100
3	Extruder barrel
2	Extruder screw
1	AC motor with gear box




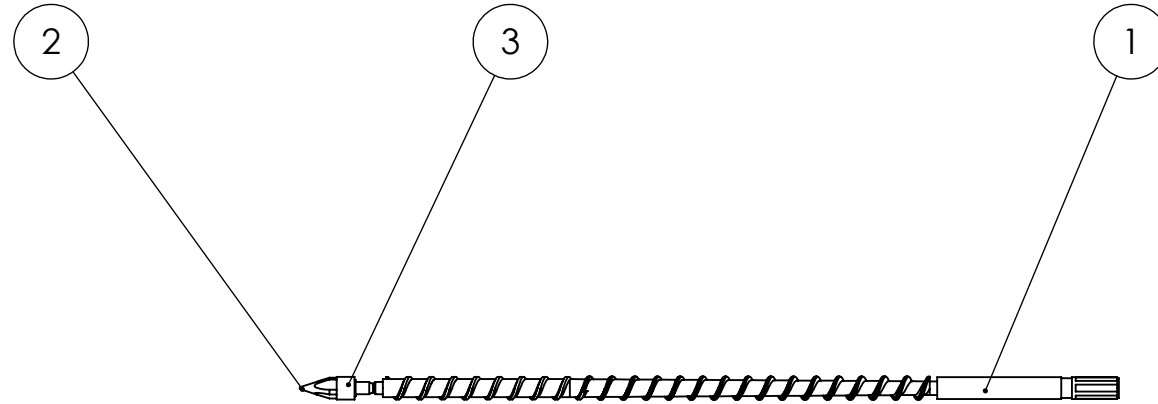
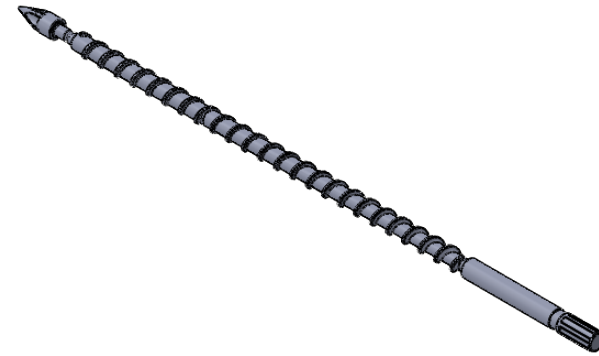
	NAME	SIGN	DATE	
 Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Checked By:	JURY		29-05-19	
Scale: 1:45	Title: Plastic extrusion machine assembly	Part No.: 1-0	Dimensions in millimeters and Degrees Tolerance 180-9001	



INSTRUCTION :
 Barrel head is bolted to the barrel by two bolts
 Extruder screw is inserted to the barrel
 Die is fastened in the barrel head
 Hopper is bolted to its support

NO.	Part Name
8	Hopper support bolts
7	Barrel Barrel head boltshead
6	Hopper support
5	Hopper
4	Die
3	Extruder screw
2	Barrel head
1	Barrel

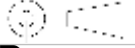

NO.	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale:	Title:	Part No.:	Dimensions in millimeters and Degrees Tolerance 180-9001	
1:15	Extruder assembly	1-1		

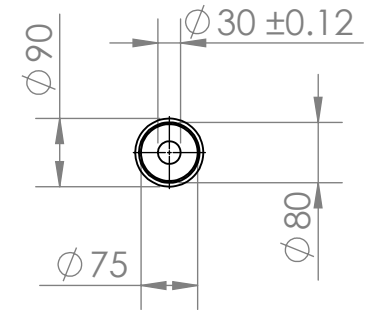
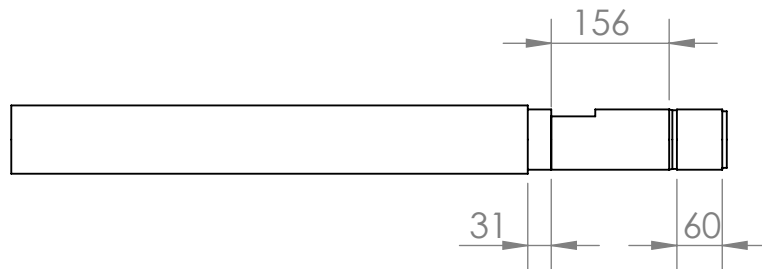
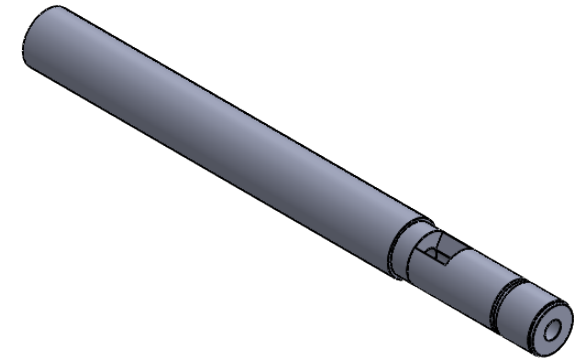
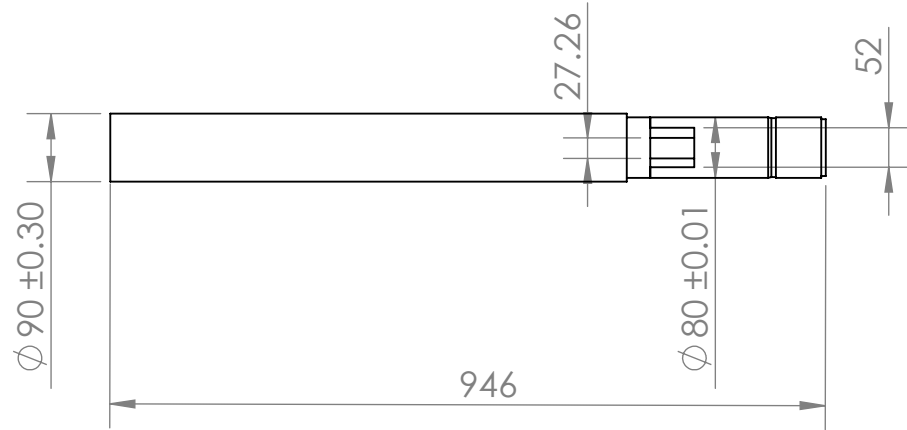


INSTRUCTION :

Sliding ring is inserted to the screw tip
Screw tip is fastened to the screw

NO.	Part name
3	Sliding ring valve (non return valve)
2	Screw tip
1	Screw

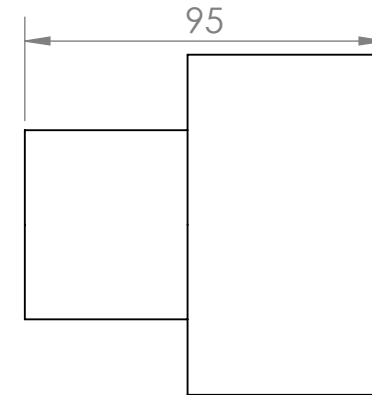
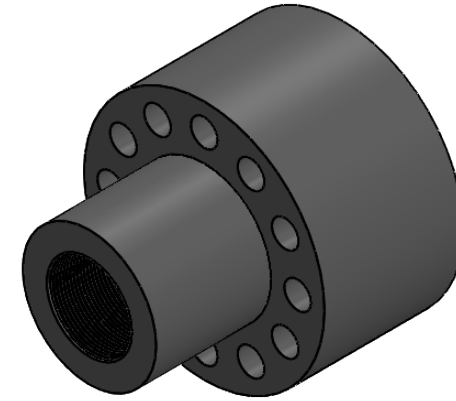
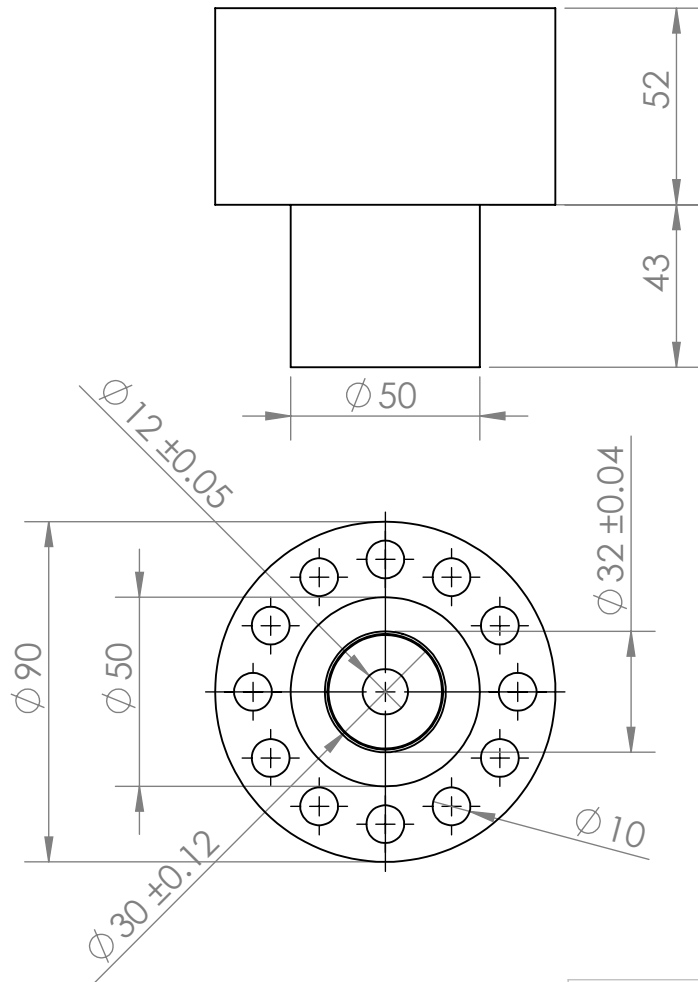
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	19-05-19	
Checked By:	JURY		22-05-19	
Scale: 1:10	Title: Extruder screw assembly	Part No.: 1-1-2	Dimensions are in millimeters Tolerance 180-9001	



NOTE

Material : Alloy steel
38CrMoAlA

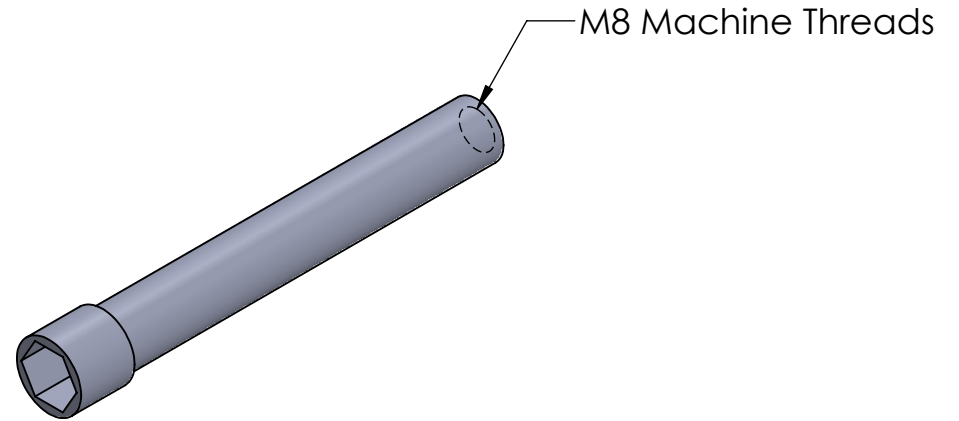
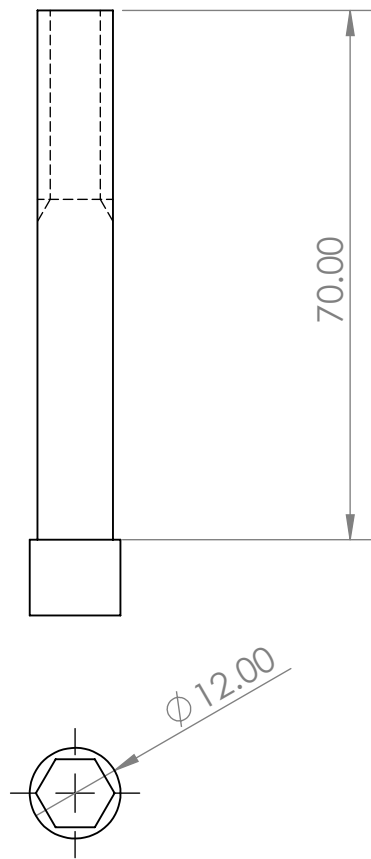
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:10	Title: Barrel		Part No.: 1-1-1-1	Dimensions are in millimeters Tolerance 180-9001



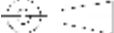

NOTE

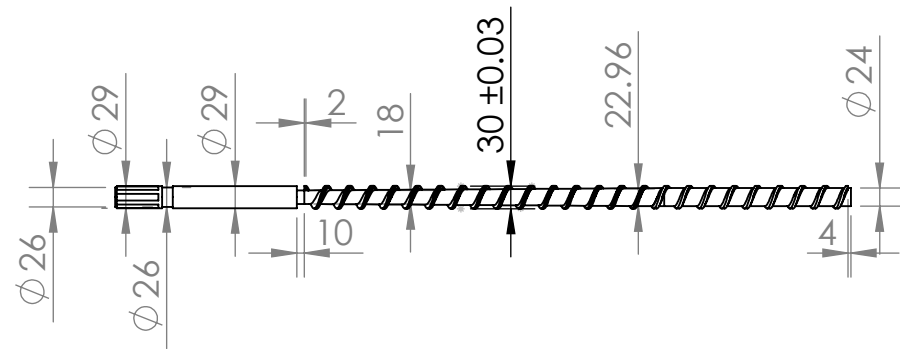
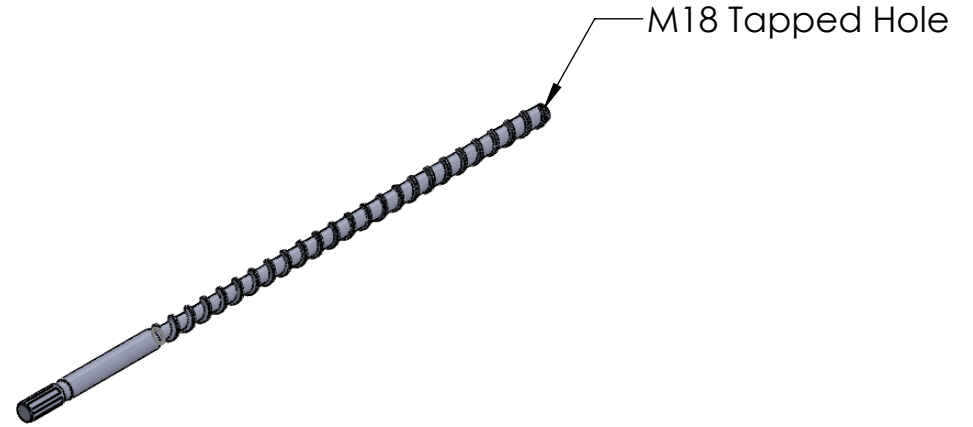
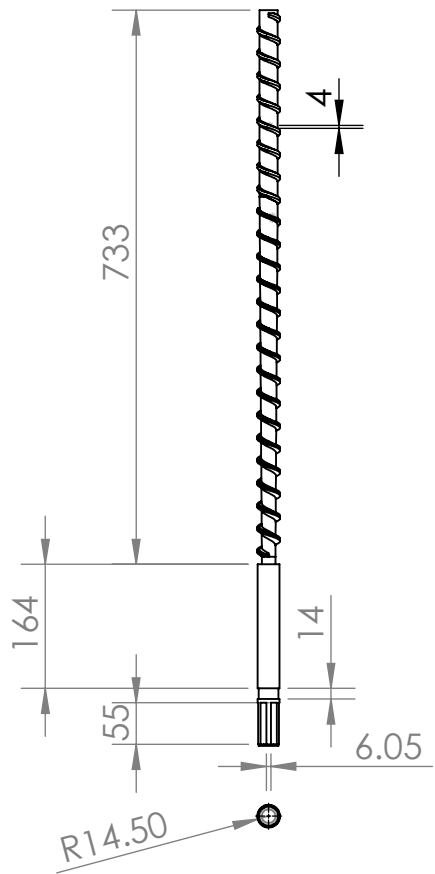
Material : Alloy steel
38CrMoA1A

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:2	Title: Barrel head		Part No.: 1-1-1-2	Dimensions are in millimeters Tolerance 180-9001



NOTE
Material : Steel

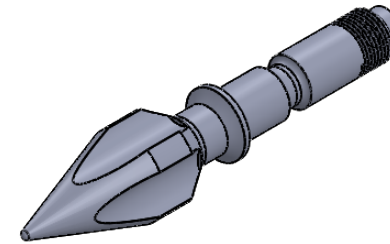
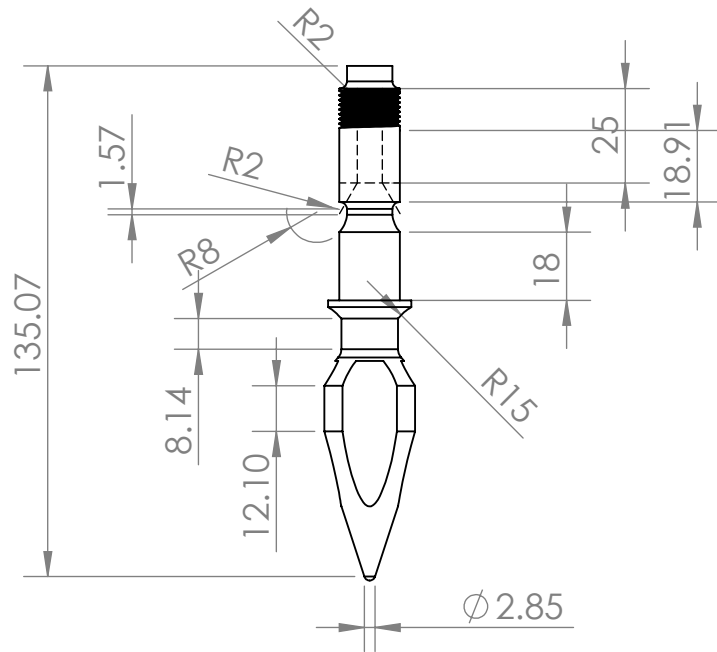
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:1	Title: Barrel head bolt		Part No.: 1-1-1-2-1	Dimensions in millimeters and Degrees Tolerance 180-9001



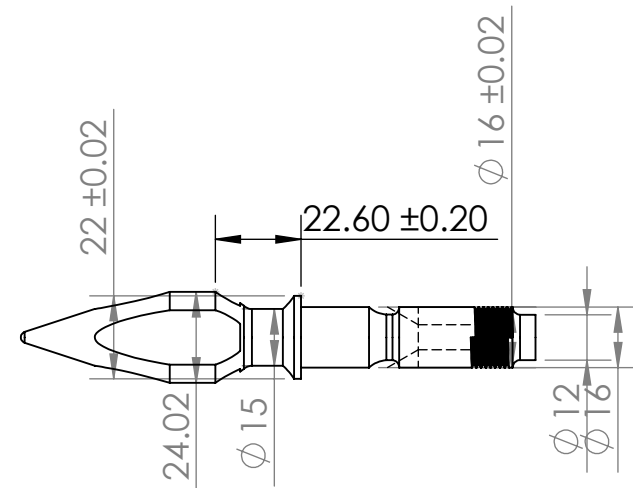
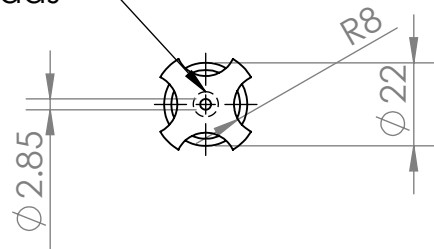
NOTE

Material : Alloy steel
38CrMoA1A

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:10	Title: Screw		Part No.: 1-1-2-1	Dimensions are in millimeters Tolerance 180-9001

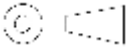


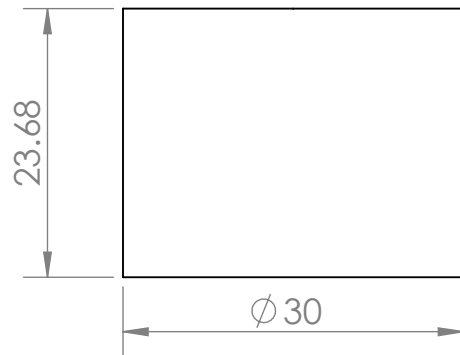
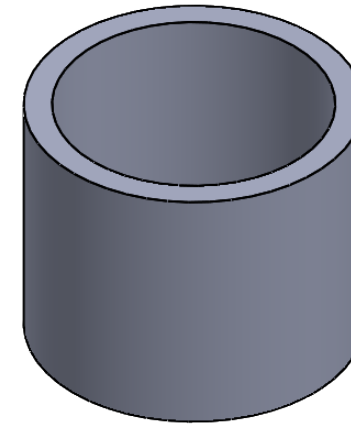
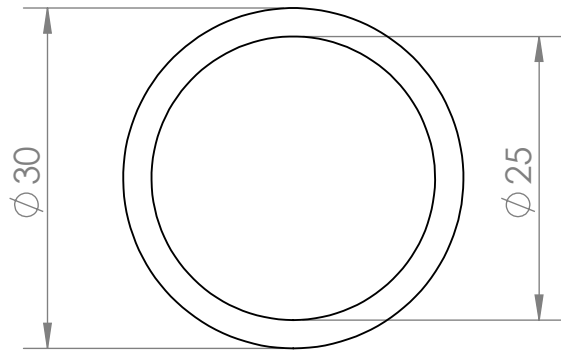
M8 Machine Threads



NOTE


Material : Alloy steel
38CrMoAlA

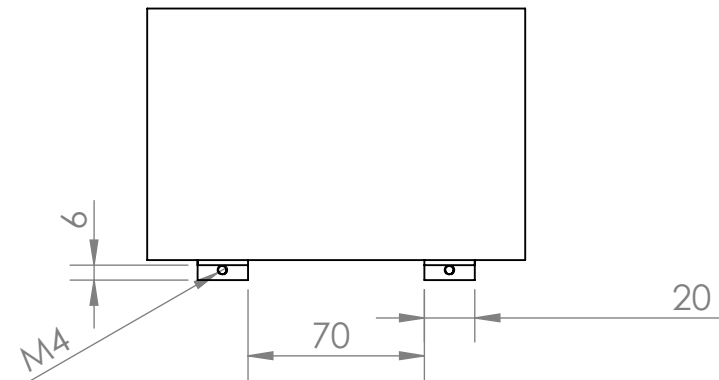
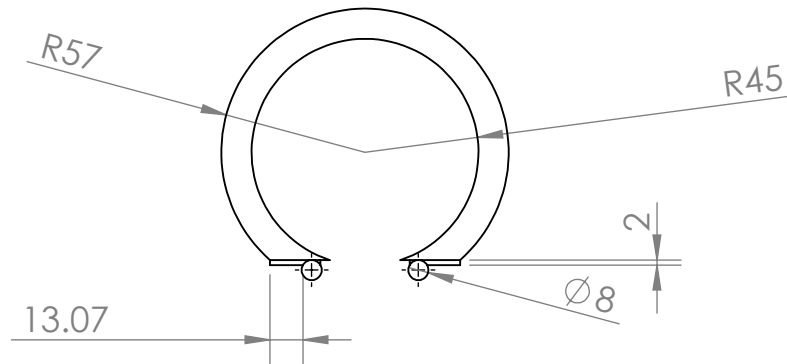
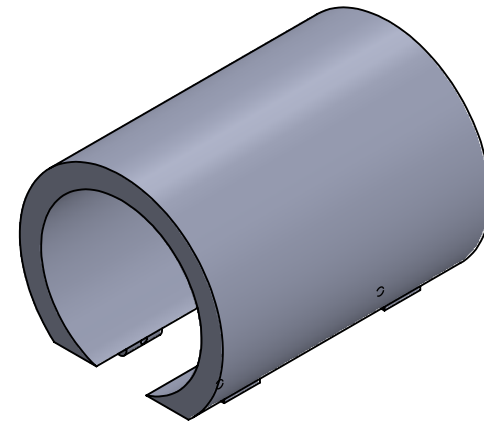
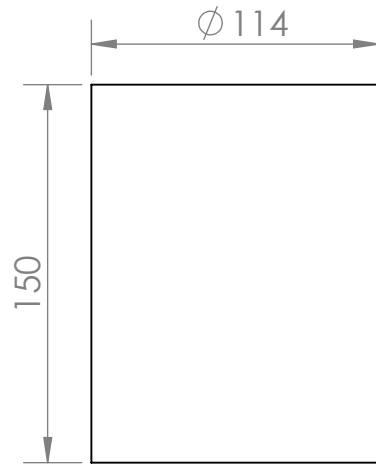
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:2	Title: Screw tip		Part No.: 1-1-2-2	Dimensions are in millimeters Tolerance 180-9001



NOTE

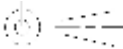

Material : Alloy steel
38CrMoAlA

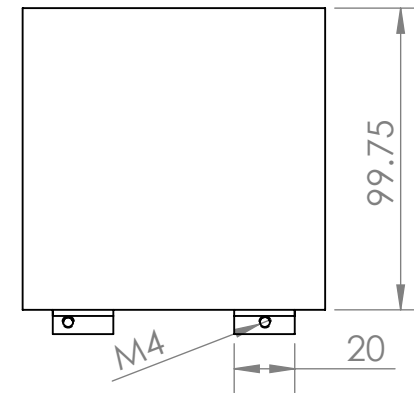
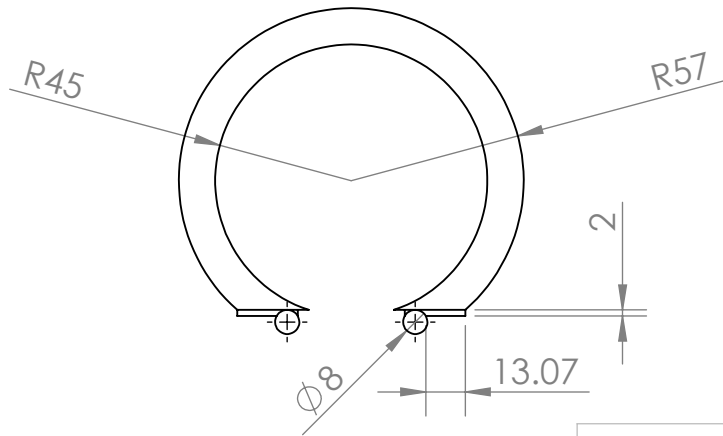
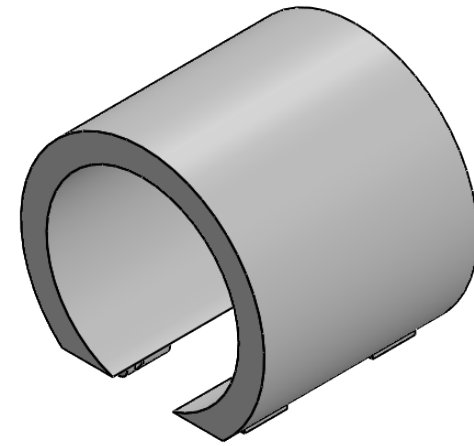
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 3:2	Title: Sliding ring valve (Non-return valve)		Part No.: 1-1-2-3	Dimensions are in millimeters Tolerance 180-9001



NOTE


Material : Aluminum
and ceramic

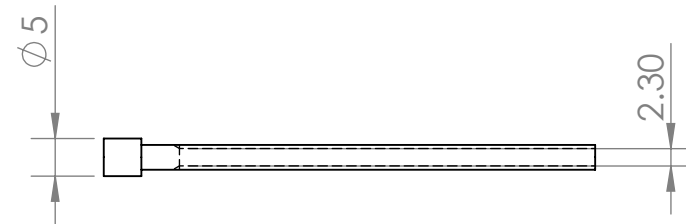
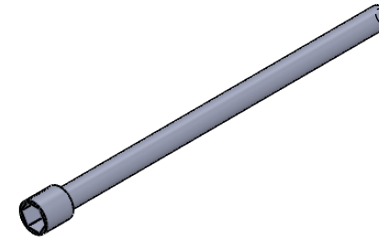
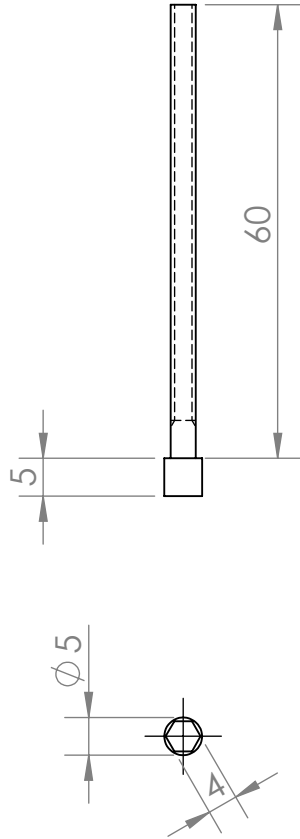
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:5	Title: Ceramic band heater (90x150)		Part No.: 1-1-4-1	Dimensions are in millimeters Tolerance 180-9001



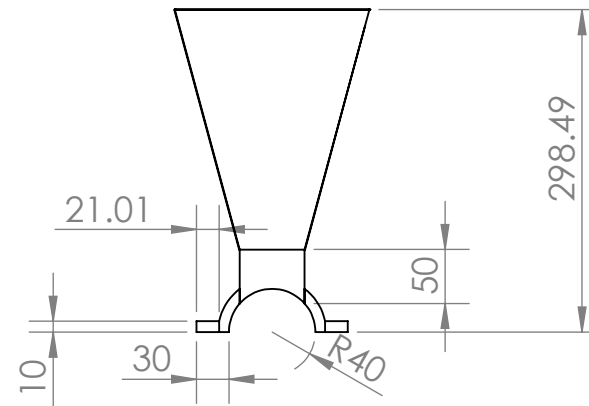
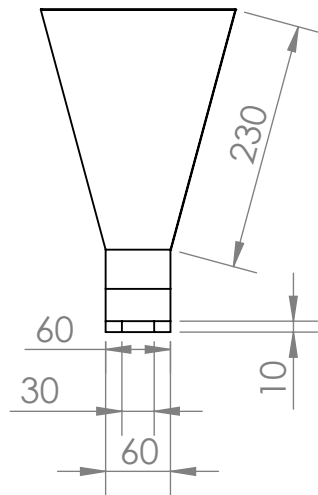
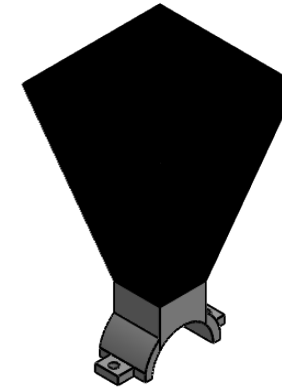
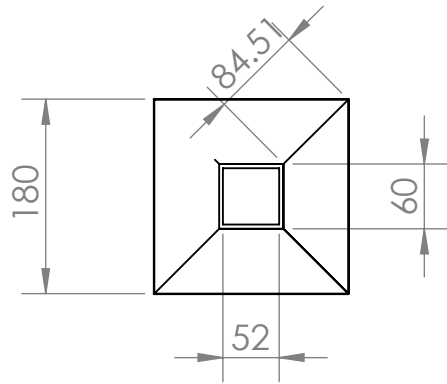
NOTE

Material : Aluminum
and ceramic

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:2.5	Title: Ceramic band heater (90x100)		Part No.: 1-1-4-2	Dimensions are in millimeters Tolerance 180-9001

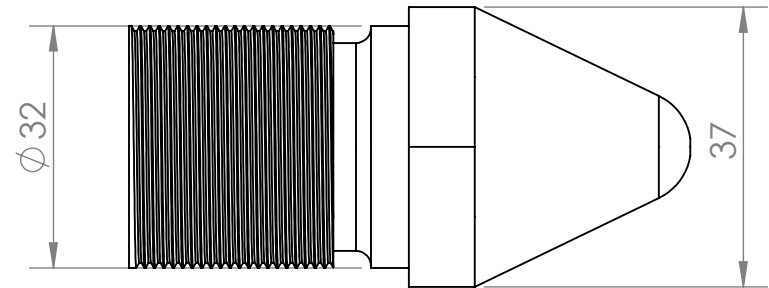
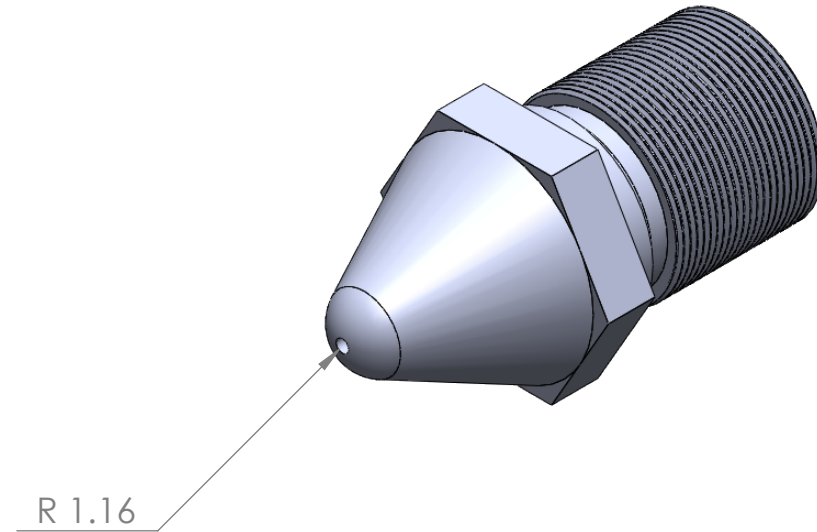
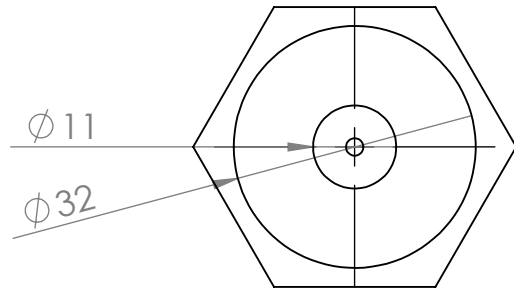
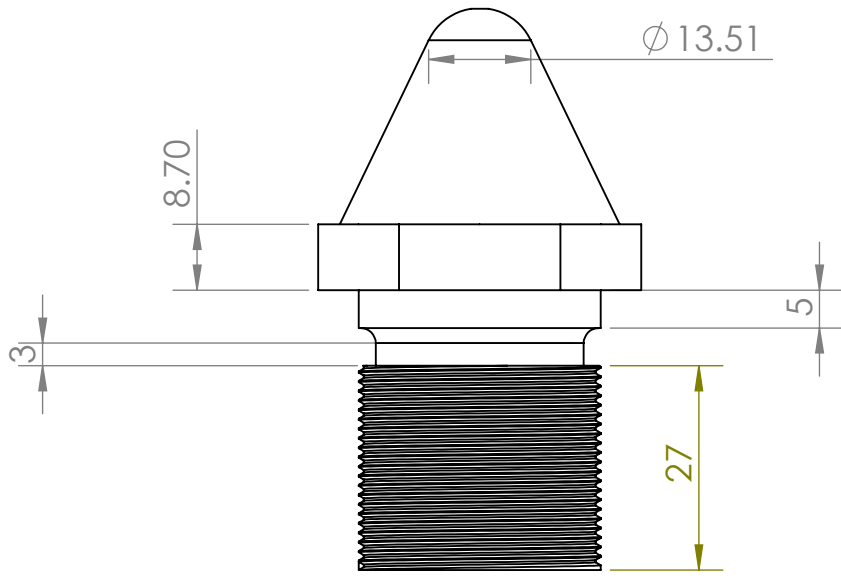


	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:1	Title: Ceramic band heater bolt		Part No.: 1-1-4-4	Dimensions are in millimeters Tolerance 180-9001

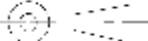



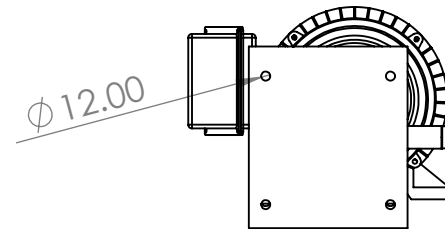
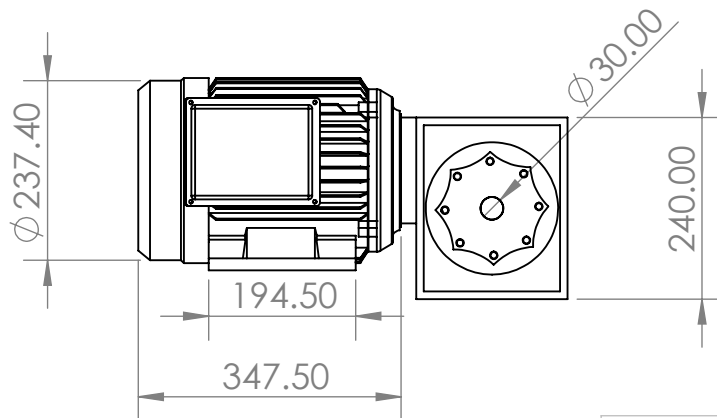
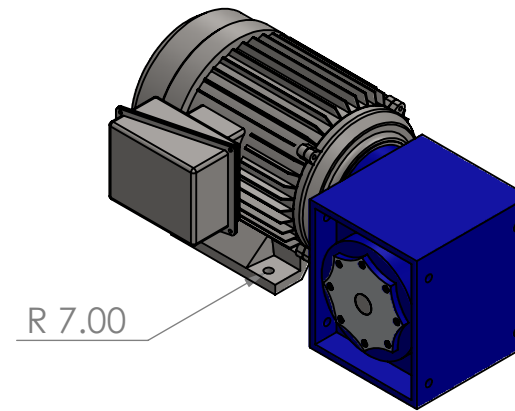
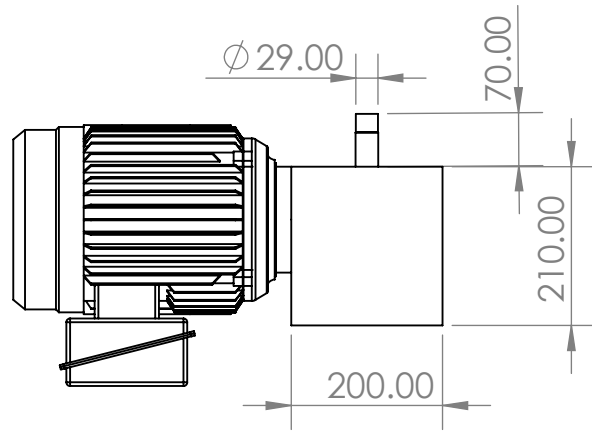
NOTE
Material : Steel

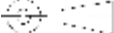

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	Mechanical Engineering Department
Checked By:	JURY		29-05-19	
Scale: 1:6	Title: Hopper		Part No.: 1-1-5	Dimensions are in millimeters Tolerance 180-9001

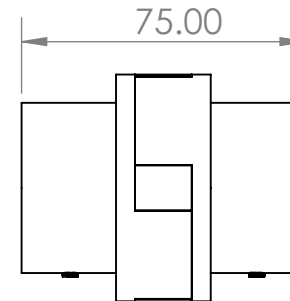
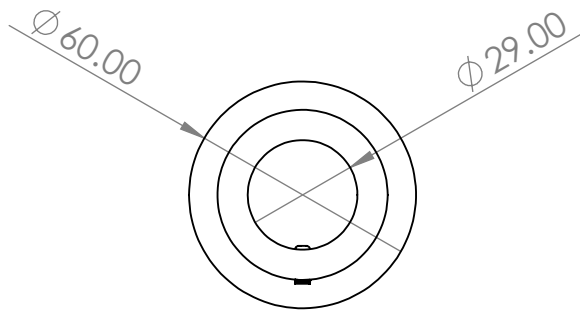
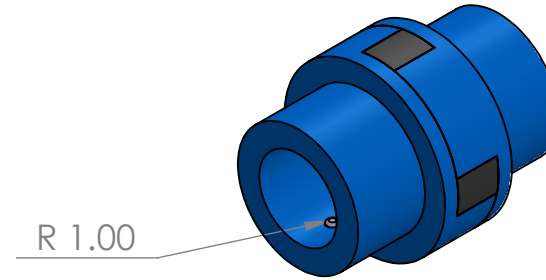
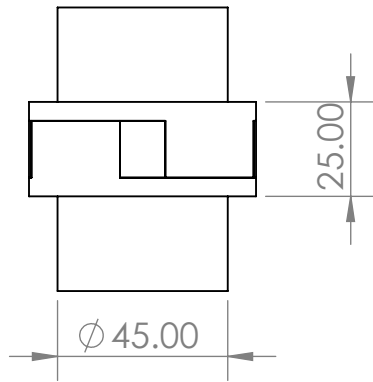


NOTE
Material : Steel

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	Mechanical Engineering Department
Checked By:	JURY		29-05-19	
Scale: 1:1	Title: Extrusion die		Part No.: 1-1-6	Dimensions are in millimeters Tolerance 180-9001

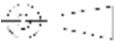



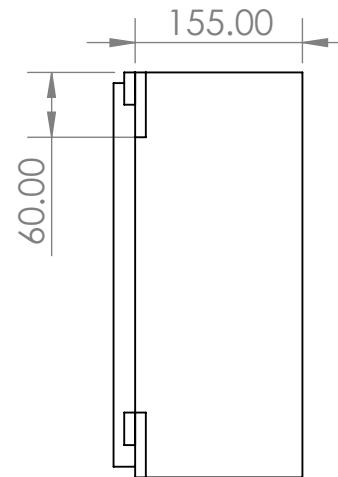
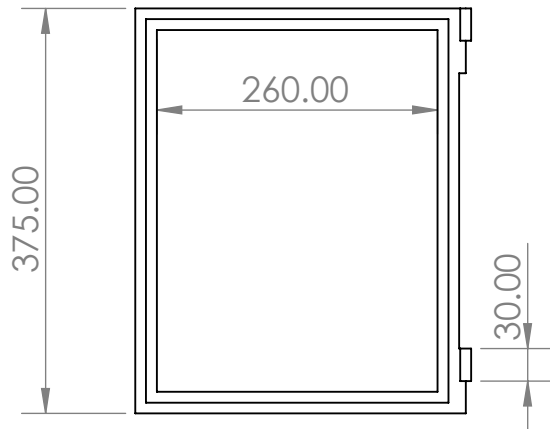
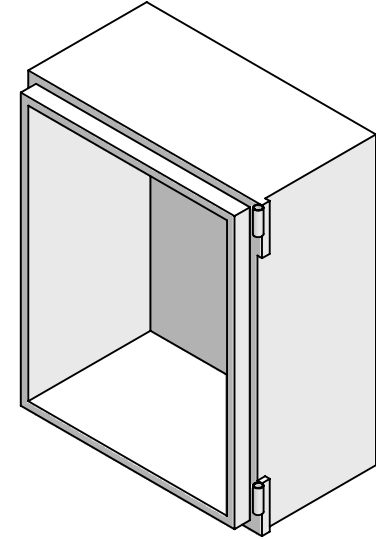
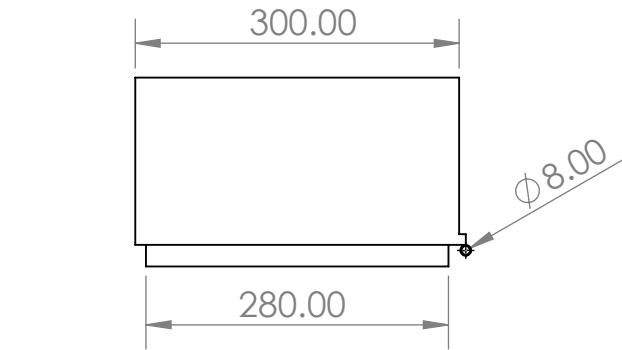
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:10	Title:AC Motor with a gear box		Part No.: 1-2-1	Dimensions in millimeters and Degrees Tolerance 180-9001



NOTE

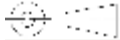

Material : Cast iron

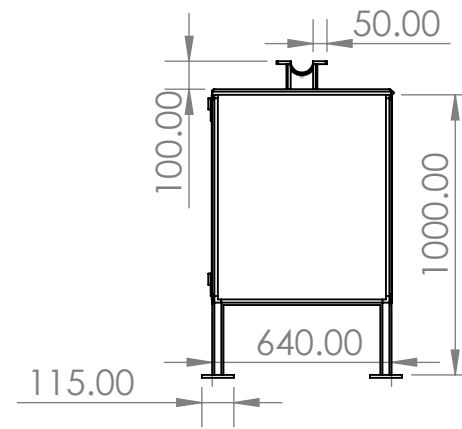
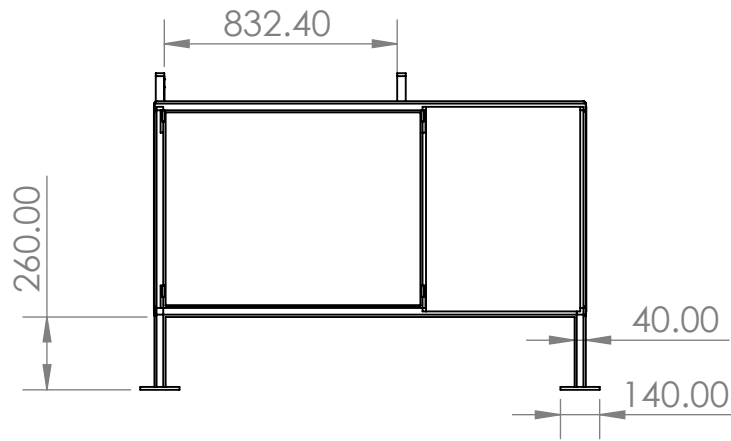
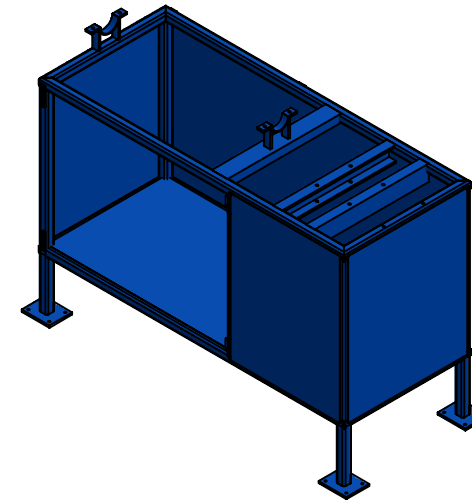
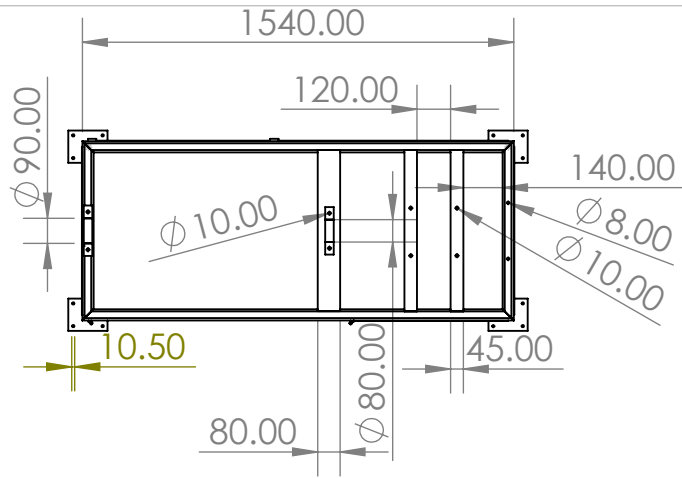
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:2	Title:Jaw coupling	Part No.: 1-2-2	Dimensions in millimeters and Degrees Tolerance 180-9001	



NOTE


Material : Plastic

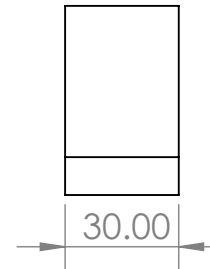
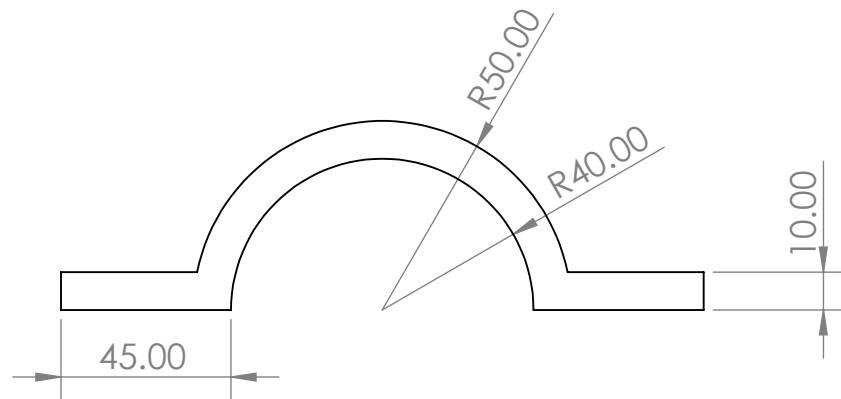
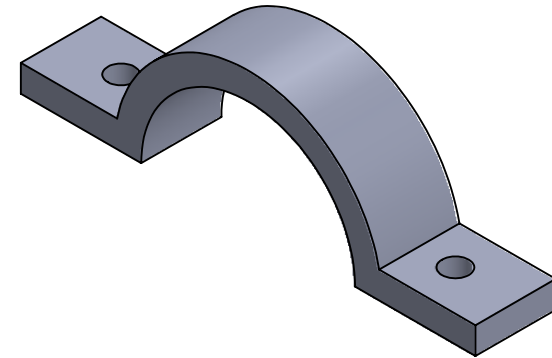
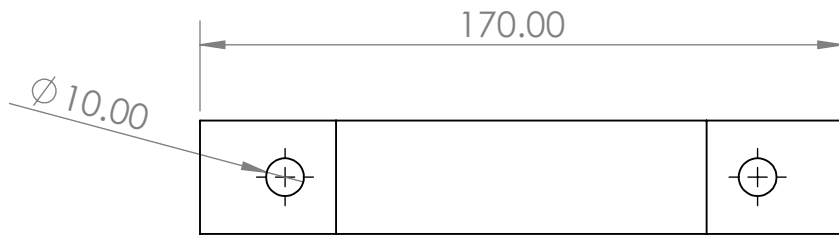
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:7	Title:control box		Part No.:	Dimensions in millimeters and Degrees Tolerance 180-9001



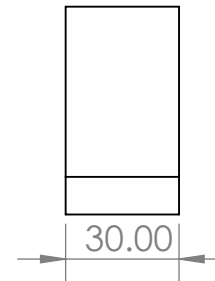
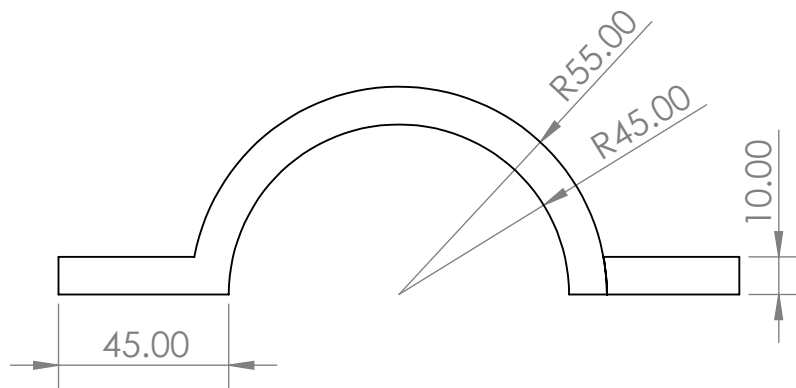
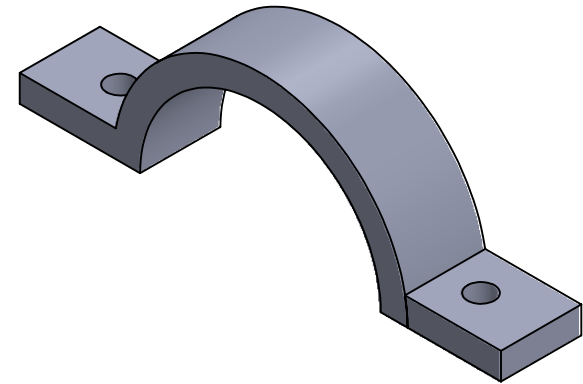
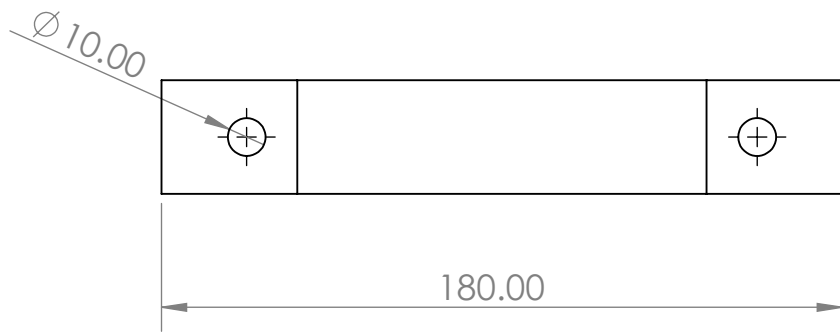
NOTE

Material : Steel

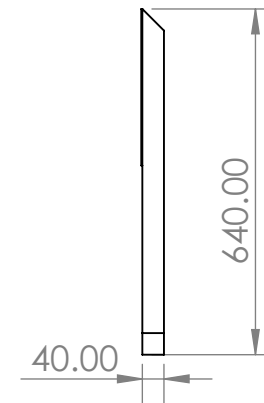
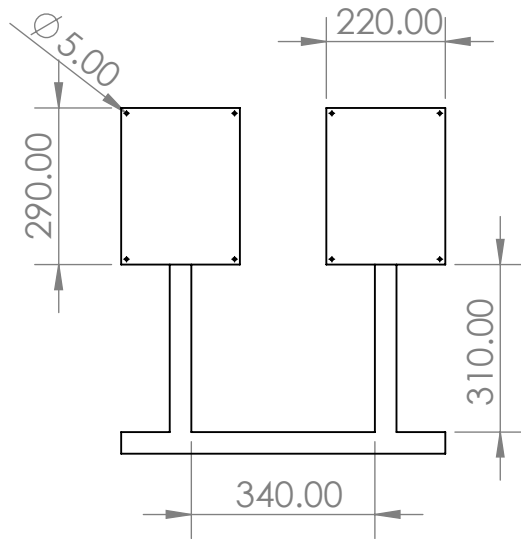
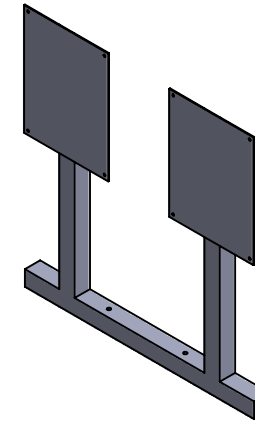
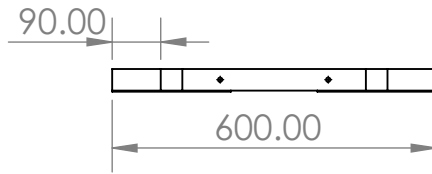
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:27	Title:Machine table		Part No.: 1-5-1 1-5-2	
				Dimensions in millimeters and Degrees Tolerance 180-9001



	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	Dimensions in millimeters and Degrees Tolerance 180-9001
Scale: 1:2	Title: Barrel support 1		Part No.: 1-5-3	



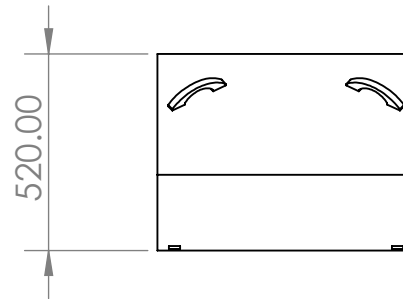
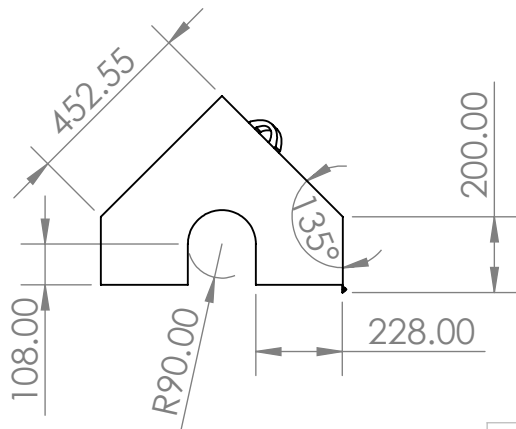
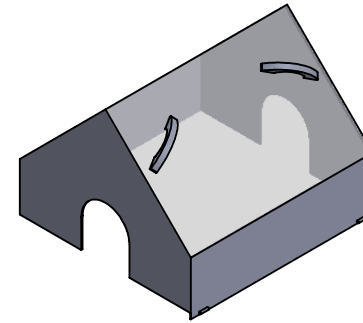
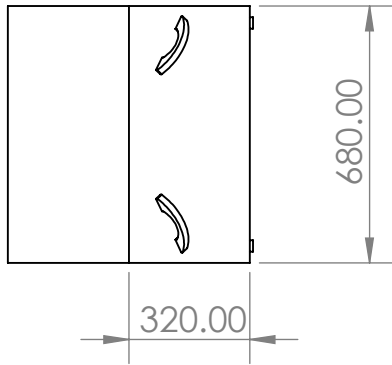
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:2	Title: Barrel support 2		Part No.: 1-5-3	Dimensions in millimeters and Degrees Tolerance 180-9001



NOTE

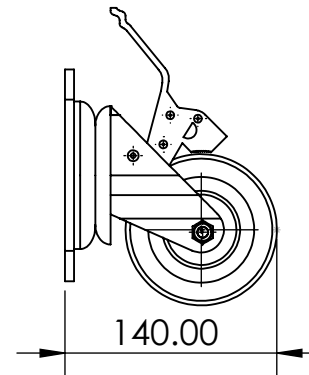
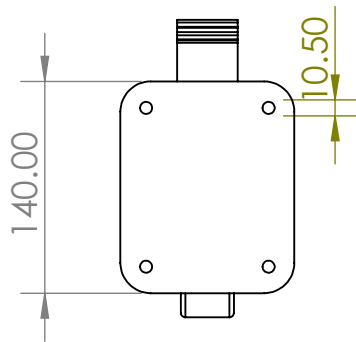
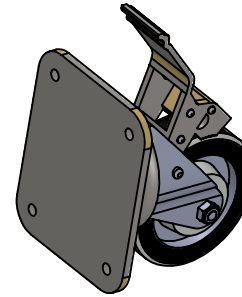
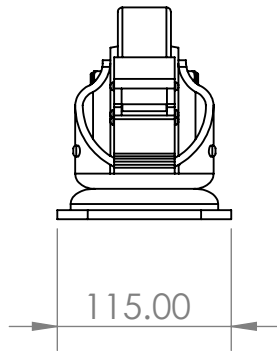
Material : Steel

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1-14	Title: control boxes support		Part No.: 1-5-4	Dimensions in millimeters and Degrees Tolerance 180-9001

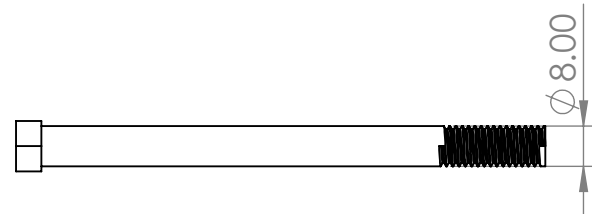
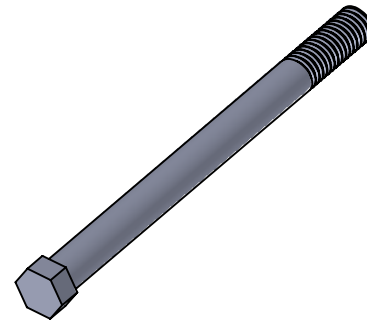
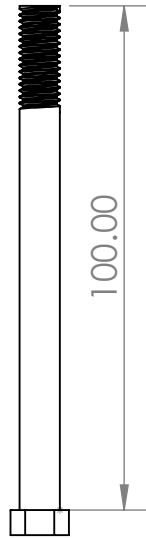


NOTE
Material : Steel

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:20	Title: Barrel cover		Part No.: 1-5-5	Dimensions in millimeters and Degrees Tolerance 180-9001

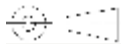



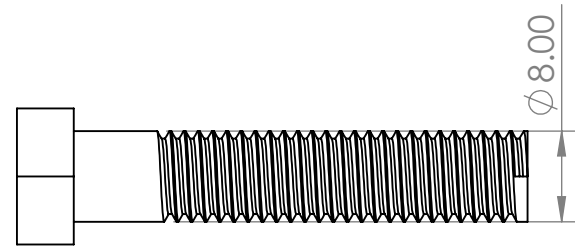
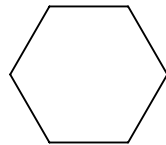
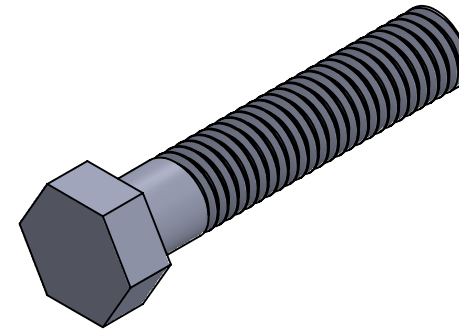
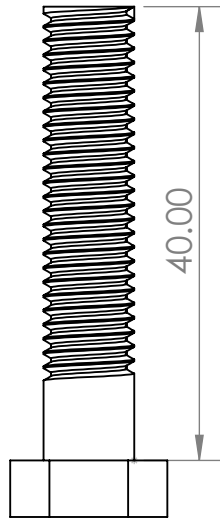
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	Dimensions in millimeters and Degrees Tolerance 180-9001
Scale: 1:5	Title: Table Wheel		Part No.: 1-5-6	



NOTE

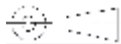

Material : Steel

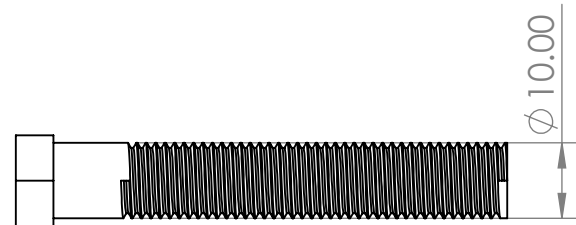
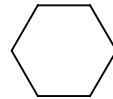
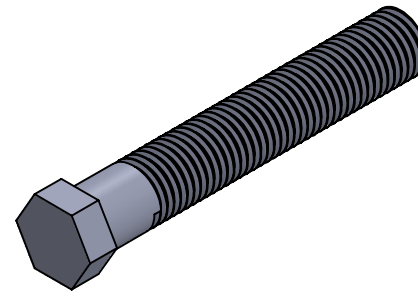
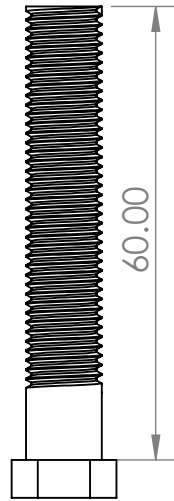
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 2:3	Title: M8 x2 Bolt		Part No.: 1-5-7	Dimensions in millimeters and Degrees Tolerance 180-9001



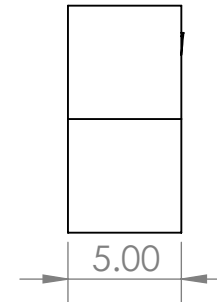
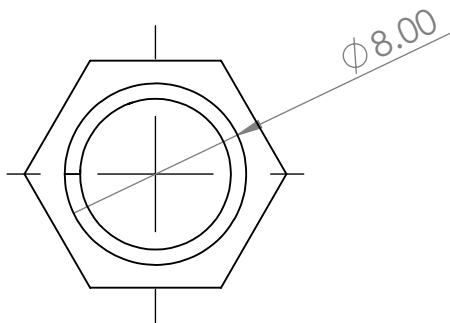
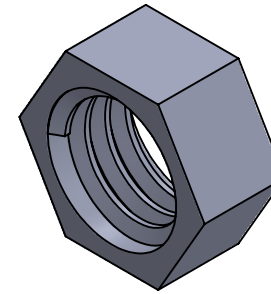
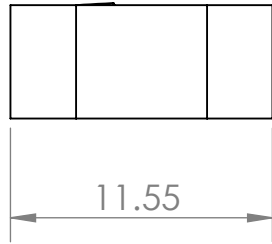
NOTE

Material : Steel

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 3:2	Title: M8 x18 Bolt		Part No.: 1-5-7	Dimensions in millimeters and Degrees Tolerance 180-9001

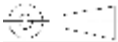



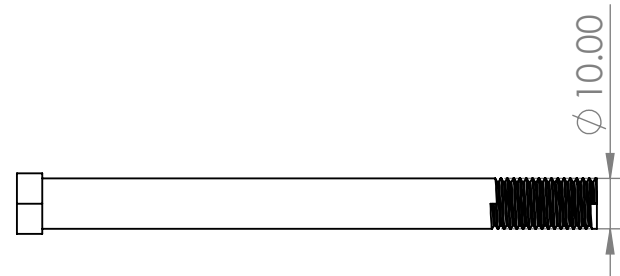
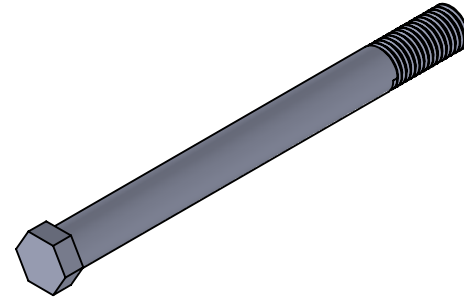
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:1	Title: M8 x4 Bolt		Part No.: 1-5-7	Dimensions in millimeters and Degrees Tolerance 180-9001



NOTE

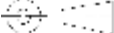

Material : Steel

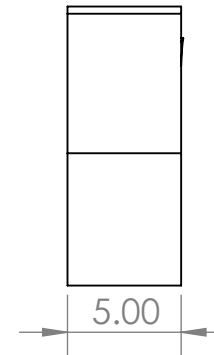
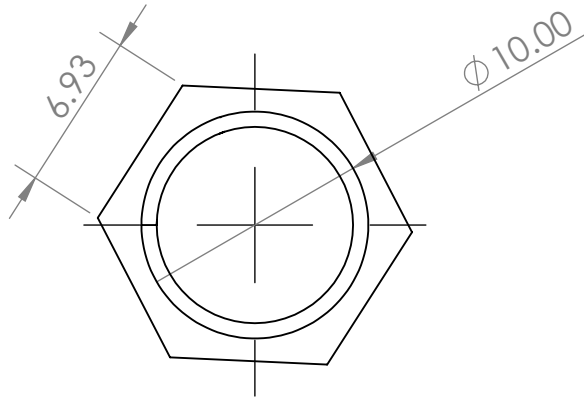
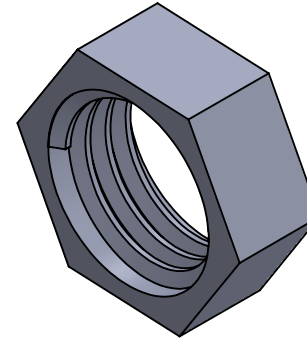
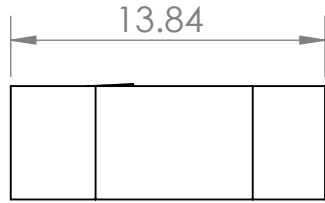
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	Mechanical Engineering Department
Scale: 3:1	Title: M8 x 24 Hex Nut		Part No.: 1-5-7	Dimensions in millimeters and Degrees Tolerance 180-9001



NOTE

Material : Steel

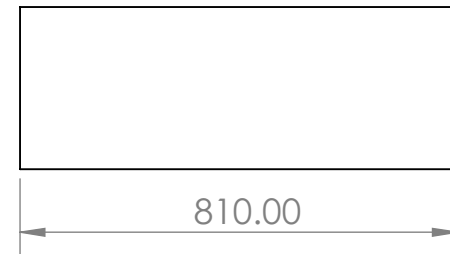
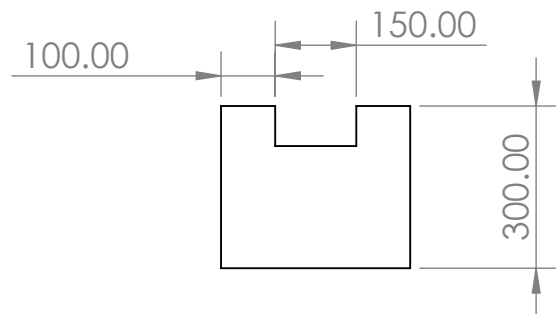
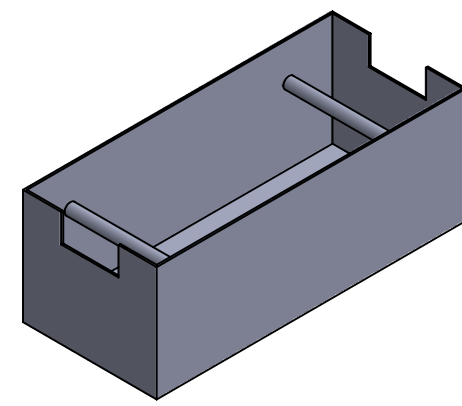
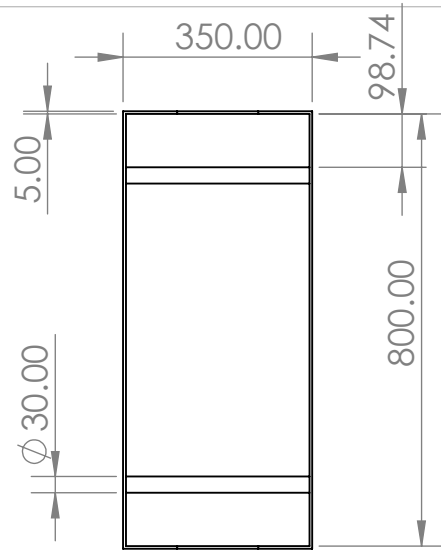
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:2	Title: M10 x4 Bolt		Part No.: 1-5-7	Dimensions in millimeters and Degrees Tolerance 180-9001



NOTE

Material : Steel

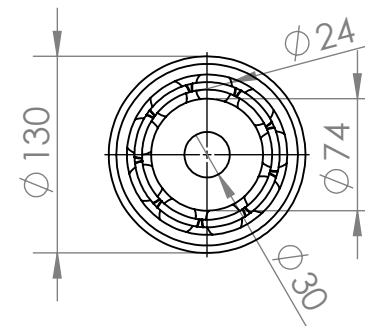
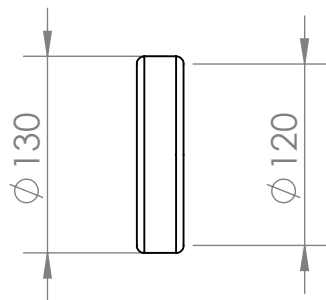
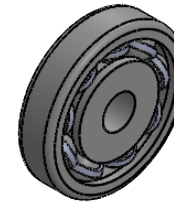
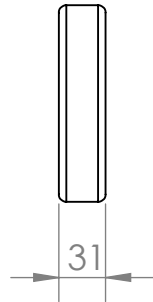
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	Dimensions in millimeters and Degrees Tolerance 180-9001
Scale: 3:1	Title: M10 x4 Hex Nut		Part No.: 1-5-7	



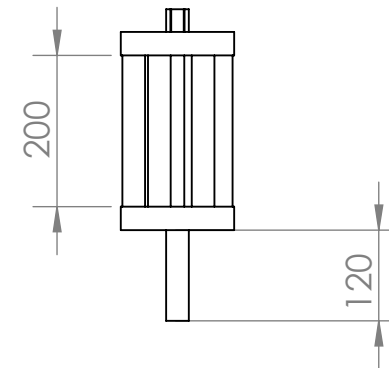
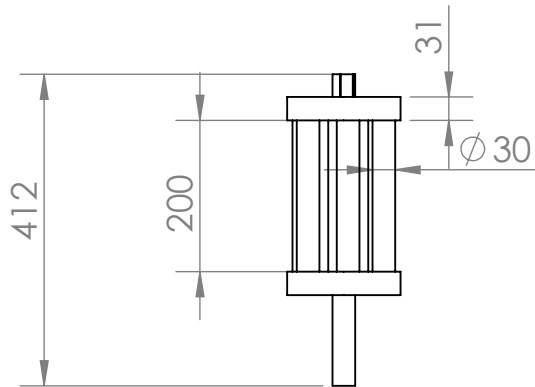
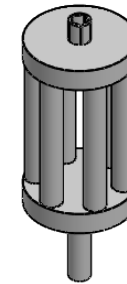
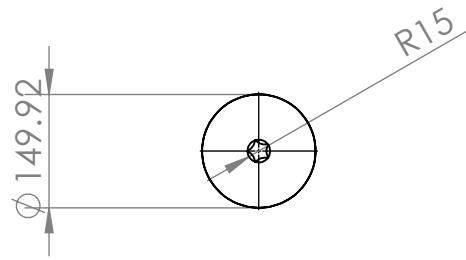
NOTE

Material : Plastic

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i>
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	Dimensions in millimeters and Degrees Tolerance 180-9001
Scale: 1:14	Title:Water bath		Part No.: 1-6-1	

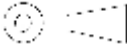



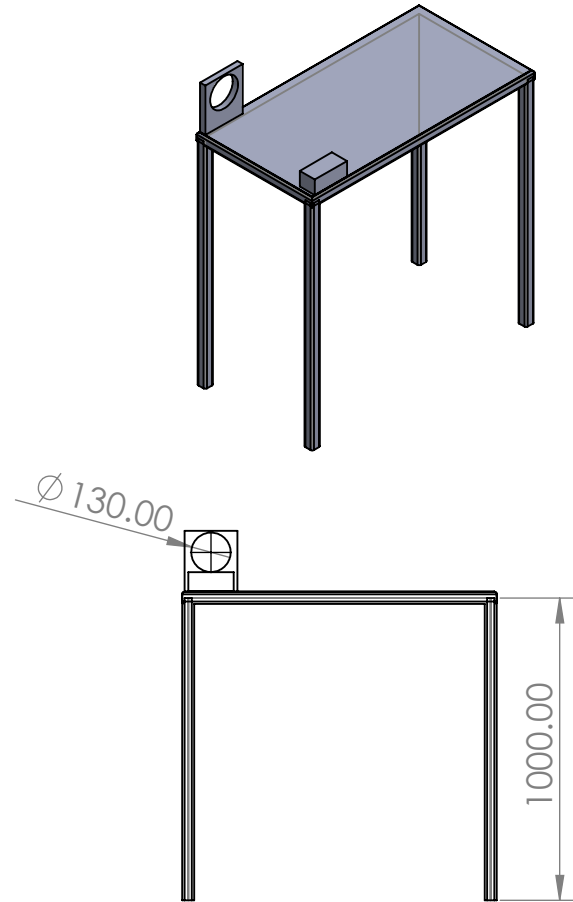
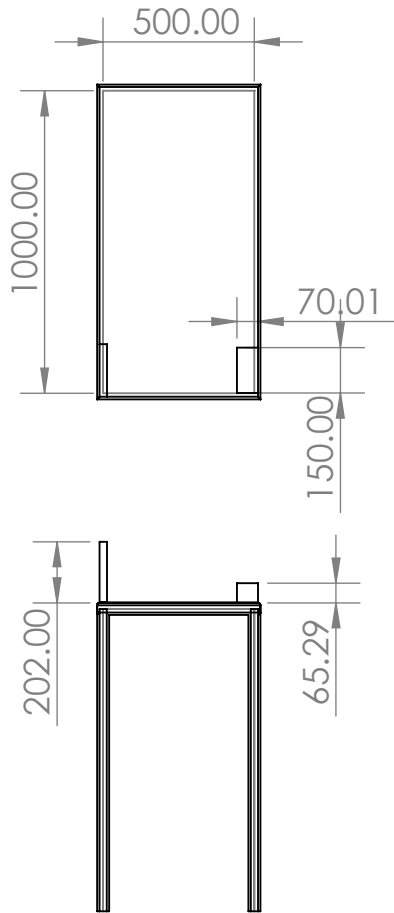
	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:5	Title: Water bath pulley		Part No.: 1-6-2	Dimensions are in millimeters Tolerance 180-9001



NOTE

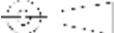

Material : Aluminum alloy 6061 T6

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:10	Title: Reel wheel		Part No.: 1-3-3-1	Dimensions are in millimeters Tolerance 180-9001



NOTE

Material : Steel

	NAME	SIGN	DATE	 Eastern Mediterranean University <i>"For Your International Career"</i> Mechanical Engineering Department
Drawn By:	Abdulrahman Abouhany	A.M.A	22-05-19	
Checked By:	JURY		29-05-19	
Scale: 1:25	Title:cooling system table		Part No.: 1-6-4	Dimensions in millimeters and Degrees Tolerance 180-9001