جامعة المنصورة- كلية الهندسة
برنامج الميكاترونكس
Mechatronics program

Design & Manufacturing Of
Manual Vacuum Forming Machine

Presented to the faculty of Engineering at Mansoura University

Under the supervision of

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Developed by

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Chapter 1: Introduction

Technology is fundamentally changing the way we live, work, relate to one another and to the external world. The speed, breadth and depth of current breakthroughs has no historical precedent and is disrupting almost every sector in every country. Now more than ever, the advent of new technology has the potential to transform environmental protection.

The hunt for new smarter ways to support our development has always been a key driver of technological advancement. Today as our civilisation faces a new unprecedented challenge, technology can play a crucial role in decoupling development and environmental degradation.

Let's be clear. No human technology can fully replace 'nature's technology' perfected over hundreds of millions of years in delivering key services to sustain life on Earth. A productive, diverse natural world, and a stable climate have been the foundation of the success of our civilization, and will continue to be so in future. A fundamental issue in previous technological revolutions has been the lightness with which we have taken for granted healthy natural systems like forests, oceans, river basins (all underpinned and maintained by biodiversity) rather than valuing these as a necessary Condition to development.

In simple words the definition of technology is the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment from that definition the industrial technology was created.

1.1 Industrial Technology

Industrial technology is the use of engineering and manufacturing technology that seeks different ends from those of science. Engineering strives to design and manufacture useful devices or materials, defined as technologies, whose purpose is to increase our efficacy in the world and our enjoyment of it to make production faster, simpler and more efficient.

1.2 History of vacuum forming

Vacuum formed plastic was first conceived as a display and marketing tool when it was developed from a line of vacuum casting and moulding technologies through the 1940's and 50's.

It was in Birmingham, England in 1855 that Alexander Parkes who used steam to heat and shape celluloid. When cooled Parkes noted that the celluloid maintained its shape.
In the 1870s this pioneering work by Parkes with celluloid, the world's first recognised synthetic plastic, would be taken on by John Wesley Hyatt.
John Wesley Hyatt is seen as the father of modern-day plastics, and along with Charles Burroughs, they would use steam, and steel moulds, to make toys and bottles. Hyatt and Burroughs ideas expanded to the manufacture of relief maps, ice cube trays and ping pong balls.

The first "machine for making articles, such as display covers from thin plastic sheet material" was patented in 1950 and was followed by a series of vacuum moulding machines until a "plastic sheet vacuum forming machine" was finally perfected and patented in 1964.
All these thermoplastic and vacuum forming machines played off of an older concept of using vacuums in any kind of casting or moulding process to remove excess air. Trapped air creates weak spots in mouldings which quickly break; applying a vacuum took every bit of air out and ensured a perfect result every time.
By the 1970's the technology was being perfected into something very similar to current methods with a patent in 1974 for;

"*An improved vacuum moulding apparatus for forming plastic signs, with a heater which can be pulled over a sheet of plastic held in a frame to soften it, a forming bed on which moulds are placed including an upwardly extending edge, a vacuum system for removing air from the space between the bed and a softened sheet and means for raising and lowering the frame and sheet with channels for guiding air flow out of the system so that the sheet is quickly pulled onto the mould.*"

Since then, technical developments have focused on perfecting and enhancing the methods and equipment for higher outputs and guaranteed uniformity with an incredible range of plastics and thermoplastics now available, each bringing its own advantages.

Chapter 2: Vacuum Forming Process

In its simplest form the process consists essentially of inserting a thermoplastic sheet in a cold state into the forming clamp area, heating it to the desired temperature either with just a surface heater or with twin heaters and then raising a mold from below. The trapped air is evacuated with the assistance of a vacuum system and once cooled a reverse air supply is activated to release the plastic part from the mold. The process is shown in diagram form on page 13. In its advanced stage pneumatic and hydraulic systems complimented with sophisticated heat and process controllers allow high speed and accurate vacuum forming for those heavy duty and high-end volume applications.

The thermoforming industry has developed despite two fundamental shortcomings. Many other thermoforming processes use a resin base in powder or pellet form. Vacuum forming begins further down the line with an extruded plastic sheet which incurs an additional process and therefore an extra cost to reach this stage. In addition, there is generally an area of material which is cut away from the formed part which unless reground and recycled has to be considered as waste and accounted for in any costings made. However, these problems have been invariably resolved by strict control of sheet quality and by clever mold design to minimize the amount of waste material. Throughout this manual you will find useful hints and techniques to assist in maximizing the potential from this process.

Despite the above disadvantages vacuum forming offers several processing advantages over such others as blow, rotational and injection molding. Fairly low forming pressures are needed therefore enabling comparatively low-cost tooling to be utilized and relatively large size moldings to be economically fabricated which would be otherwise cost prohibitive with other processes. Since the molds witness relatively low forces, molds can be made of relatively inexpensive materials and mold fabrication time reasonably short. This results in comparatively short lead times. It provides the perfect solution for prototype and low quantity requirements of large parts as well as medium size runs utilizing multiple molds. (Molds are discussed in greater detail in section dealing with mold).

The typical process steps can be identified as follows: clamping, heating with sheet level activated, pre-stretch, forming with plug assist, cooling with air and spray mist, release and trimming. They are examined more closely under the sub headings on page 13.

2.1 Vacuum forming Process Steps

2.1.1 clamping:

The clamp frame needs to be sufficiently powerful enough to ensure the plastic sheet is firmly held during the forming process. It can handle the thickest material likely to be formed on the machine – up to 6mm with a single heater and up to 10mm with the twin heater machines. If an automated process is used the operation of the moving parts must be guarded and interlocked to avoid accidental damage. In addition, a safety guard must be provided to protect the machine operator at all times.

2.1.2 Heating:

Heaters are generally infra-red elements mounted within an aluminum reflector plate. In order to obtain the best vacuum forming results, using any material, it is essential that the sheet is heated uniformly over its entire surface area and throughout its thickness. In order to achieve this, it is necessary to have a series of zones that are controlled by energy regulators. Ceramics do have some disadvantage in that their high thermal mass makes them slow to warm up (approx. 15 minutes) and slow in their response time when adjustments are made.

More sophisticated quartz heaters are available which have less thermal mass enabling more rapid response time. Pyrometers enable accurate heat temperature control by sensing the melting temperature of the sheet and interacting with the operating process control. Precise temperature readout is also available with a computer-controlled system working in unison with the pyrometers. Twin heaters are also recommended when forming thicker materials as they assist in providing more uniform heat penetration and faster cycle times. times.

Twin quartz heaters are advisable when forming high temperature materials with critical forming temperatures. By close control of areas of heat intensity, heat losses around the edges caused by convection air currents and absorption from clamp areas can be fully compensated for and consistent results achieved on a continuous basis. Cost savings can also be considerable if quartz heaters are specified, as there is an adjustable percentage power drop when the heaters are in the rear position during the forming process.

Figure 1: Heating Oven (ON)

Figure 2: Heating Oven (OFF)

2.1.3 Pre-stretch (Bubble):

Once the plastic has reached its forming temperature or “plastic” state it can be pre-stretched to ensure even wall thickness when the vacuum is applied. The method of controlling the bubble height should be that consistent results are obtainable. Vacuum, air pressure, and optional aids such as a plug assist are then used to assist in molding the heated, stretched plastic.

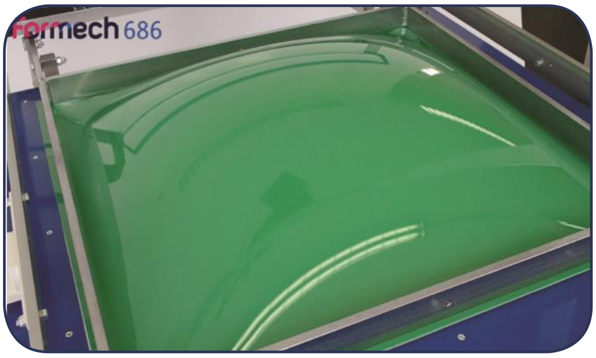


Figure 3: Pre-stretch bubble

2.1.4 Vacuum:

Once the material is suitably heated a vacuum can be applied to assist in forming the sheet. A vacuum pump is used to draw the air trapped between the sheet and the mold. The vacuum pumps vary from diaphragm pumps to dry and oil filled rotary vane pumps. With larger machines a vacuum reservoir is used in conjunction with a high-volume capacity vacuum pump. This enables a two-stage instantaneous vacuum to be applied ensuring rapid molding of the heated sheet (before the sheet temperature drops below its ideal forming temperature).

2.1.5 Plug Assist:

Plug assisted vacuum forming (molding) is used when straight vacuum forming is unable to distribute the thermoplastic sheet evenly to all areas of the mold. To help spread the sheet out more evenly, a device known as a plug is utilized to push the sheet into the mold before the vacuum is applied. This process enables more of the thermoplastic material to reach the bottom of the mold and thus more material is available to fill the corners of the mold and limit the plastic from thinning out.

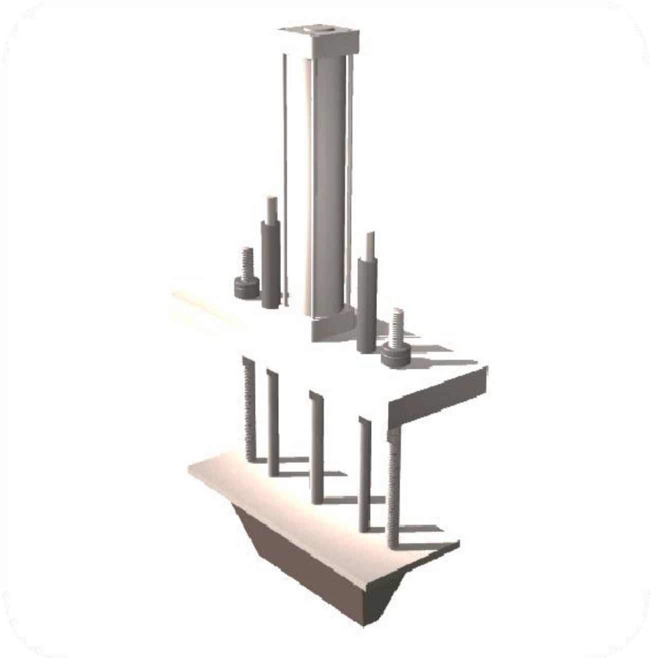


Figure 4: Plug assist

2.1.6 Cooling and Release:

Once formed, the plastic must be allowed to cool before being released. If released too soon then deformation of the molding will result in a reject part. To speed up the cooling cycle high speed, fans are fitted and activated once the part is formed. A spray mist option is also available whereby nozzles are attached to the fans and a fine mist of chilled water is directed onto the sheet. This, in conjunction with the fans can speed up the cooling cycle by up to 30%and is also beneficial in controlling the shrinkage of the molded parts.

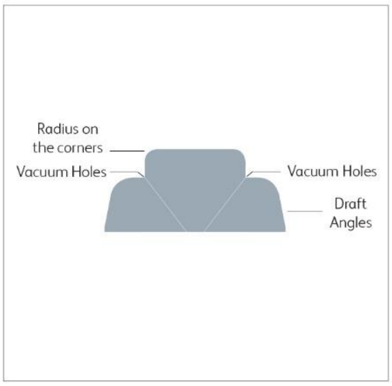
Figure 5: Heaters Box system

2.17 Trimming and finishing:

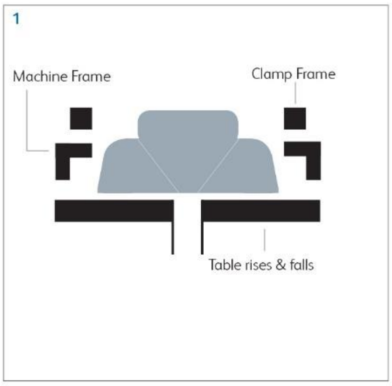
Once the formed part has cooled and been removed from the machine the excess material is removed. Holes, slots and cut-outs are then drilled into the part. Other post-forming processes include decoration, printing, strengthening, reinforcing and assembly.

A variety of different trimming methods are used to trim the product from the sheet. The type of equipment best suited depends largely on the type of cut, size of the part, draw ratio, thickness of material and the production quantity required. Thin gauge parts are normally trimmed on a mechanical trim press.

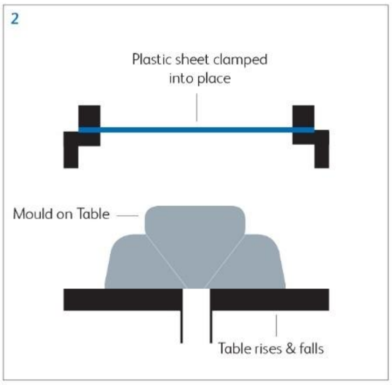
2.2 Basic principles of vacuum forming



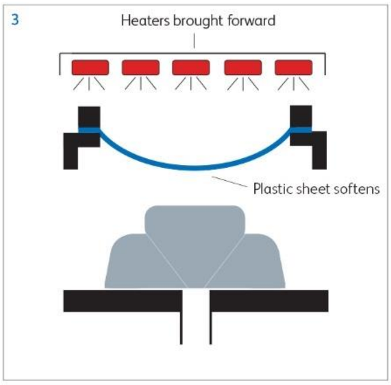
A suitable mould / tool carefully manufactured with draft angles and radiused corners.



Place your mould on the table and lower it down.



Once the table is down, securely clamp your plastic sheet between the clamp and machine frame.



The heaters warm the plastic sheet. Plastic becomes flexible when heated.

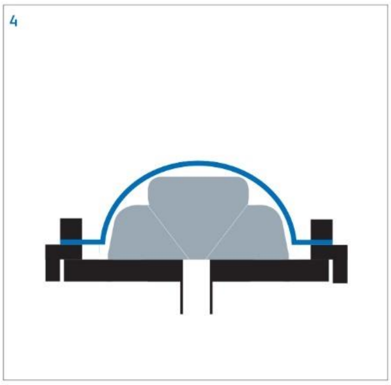
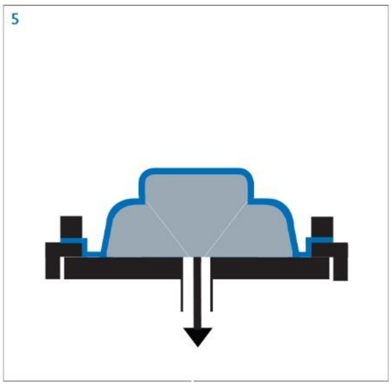
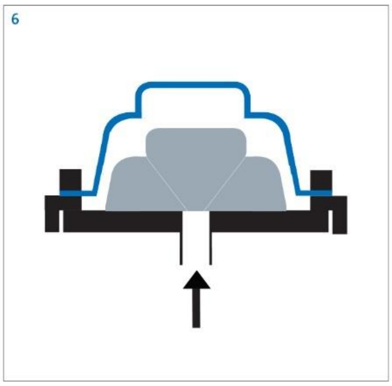


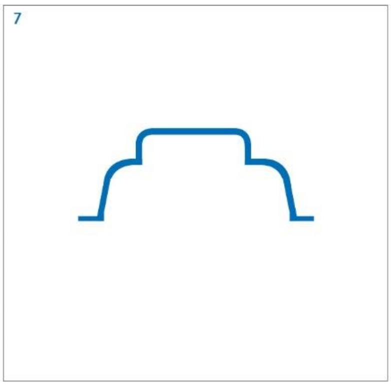
Table raised and locked.
The softened plastic
is stretched over the mould.



The vacuum pump removes all the air between the sheet and the mould to create the formed shape.



When the plastic has cooled, the air can be blown back to release the forming off the mould.



The formed part is then removed. Some trimming might be necessary to achieve the finished product.

2.3 Plastics materials and their characteristics

Plastics comprise a of a wide range of materials but fundamentally fall into two groups – thermoset and thermoplastic, the latter being a material which, due to the molecular structure, has the property of softening repeatedly when heated and hardening once cooled. Thermoplastics also have what is known as a ‘memory’ enabling a formed part to revert to its original state when reheated.

It is the thermoplastic type that is used specifically for thermoforming and therefore we will concentrate on this category in this section. Further information on the complete range of polymers can be obtained from the contacts listed at the end of this manual.

Polymers are made up of molecules which in turn are made up of atoms. These atoms have many different combinations which all have different properties and contain a wide range of additives to give each material its own characteristics. There is constant research being carried out to develop new materials suited to an ever-increasing range of applications. Later in this section we have provided a breakdown of the more common materials used for thermoforming, their characteristics and the applications to which they are most suited.

Thermoplastics are split into two different groups – amorphous and crystalline. Crystalline thermoplastics contain an ordered manner of molecules and amorphous contain a random arrangement.

Generally speaking, amorphous materials, e.g., Polystyrene and ABS are easier to vacuum form as they do not have such a critical forming temperature. When heat is applied amorphous materials becomes soft and pliable – when it reaches this state it is known as its Glass Transition Temperature (Tg). If heated to a higher temperature it reaches a Viscous state (Tv). The changes occur over a range of temperatures and enable the operator to have a fairly wide forming range.

Material	Glass Transition Temperature	Rec. mold temperature	Rec. forming temperature	Drying temperature
PS	94°C	82°C	150-175°C	70°C
ABS	88-120°C	82°C	150-180°C	70-80°C
PP	5°C	90°C	150-180°C	65°C
Acrylic / PVC	105°C	-	140-190°C	75°C
PC	150°C	127°C	170-205°C	90°C

Figure 6: Table of the most used materials in forming

2.4 Types of Molds and Mold Design

The thermoforming mold can be as simple as a wooden block or as sophisticated as an injection mold with all the ancillary elements to enable in mold trimming. They are one of the most important parts of the thermoforming cycle. One of the main advantages of vacuum forming is that the pressures used are significantly less compared to, for example, the injection molding process. The result is that vacuum formed tools can be produced economically and in a wide range of materials to suit different prototype and production requirements. In this manual we concentrate on molds ideally suited to the vacuum forming process. The prime function of a mold is to enable the machine operator to produce the necessary quantity of duplicate parts before degradation.

A wide range of materials can be used but it is important to determine the correct mold material and type most suitable for a particular application. In this section we look firstly at the different types of mold material available. We then look more closely at different types of molds, mold design and techniques and provide some useful tips and hints to assist the 'in house' production of molds.

2.4.1 Male and Female Moulds:

There are basically two kinds of molds:

1. Male molds
2. Female molds

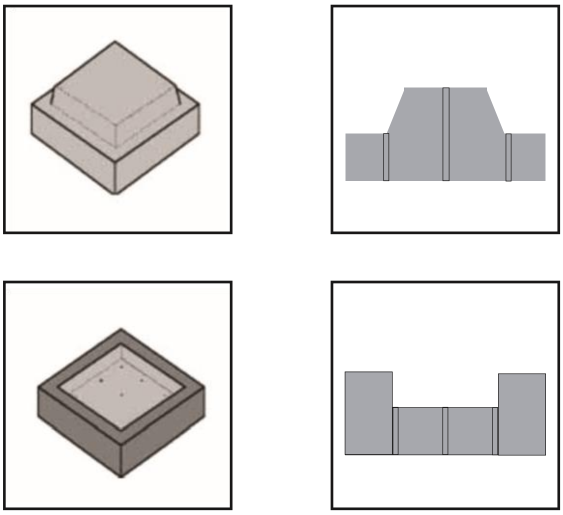


Figure 7: Difference Between Male & Female Molds

Several factors will affect the decision as to which is more suited and below, we provide a few useful pointers.

The top surface of a molding (the part not in contact with the mold) is invariably the better finished surface, since it cannot pick up any marks such as dust particles from the tool itself. This factor alone may dictate whether a male or female mold is required. Often a male tool is much easier to make and more suitable for a single deep-draw object. On the other hand, a compartment tray with divisions, would typically be of female construction.

Figure below shows a male and female forming and the effects of thinning to the plastic sheet

Figure 8: Difference between Male & Female Forming

A greater degree of definition is achieved on the side of the plastic in contact with the mold. The choice of a male or female should be considered so that the side requiring the highest definition is the one in contact with the mold especially thicker plastics.

In general, a mold cavity which is deeper than its diameter will give unacceptable thinning at the bottom corners. Negative molds will produce a forming progressively thinner towards the bottom, because, directly vacuum is applied, the material will cling to the sides of the mold and will tend to stretch like a piece of elastic. To produce a more uniform thickness a plug should be used to stretch the material mechanically before vacuum is applied. On a positive mold and especially if the Pre-Stretch (bubble) option is used this mechanical stretching is done automatically. It may be worth discussing your mold requirements with the material manufacturer if in any doubt.

2.4.2 Baseboards and Mounting:

Generally speaking, molds should be mounted onto baseboards prior to forming to assist release. However, from time to time and often when a quick prototype is required molds are placed directly onto the mold table and formed over. The main setback with this method is that when it comes to releasing the cooled part from the mold it often, due to shrinkage, sticks to the mold. It is then necessary to remove the part with the mold inside and physically split the two or trim the part whilst attached to the mold.

e.g., In the case of radiotherapy mask molds which have many undercuts and are placed directly on the table, the part and mold are removed together and trimmed out with an air powered hand operated slitting saw.

In most cases it is recommended to use a baseboard. The baseboard can be made from either MDF or aluminum. Its primary purpose is to locate and hold down the mold when using the reverse blow facility. We recommend that a thickness of between 3.00 – 4.00mm (1/8’’) thick is used to ensure it sits flush with the top of the forming area seal on the machine.

The vacuum hole can be 19.00 – 20.00mm (3/4’’) diameter and needs to be positioned 15mm forward of the center of the table. Dimensions can be different depends on which machine

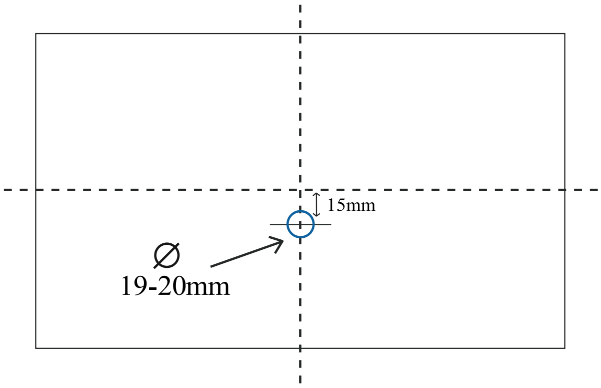


Figure 9: Platen of Mold

Depending on which machine you have will also have to determine which size the baseboard should be. The baseboard has to be 4mm shorter in both directions than the forming aperture of the machine e.g., if the forming aperture is 280mm x 430mm, the baseboard size will have to be 276mm x 426mm. To improve further the release the baseboard can be mounted directly to the table. In order to do this the table needs first to be drilled and tapped in the four corners which act as the location points for the baseboard. When mounting molds to the baseboard it is necessary to ensure there is some clearance for airflow between the mold base and the board. This can be done by either using a thin gauze or by incorporating channels.

Figure 11: Metal platen

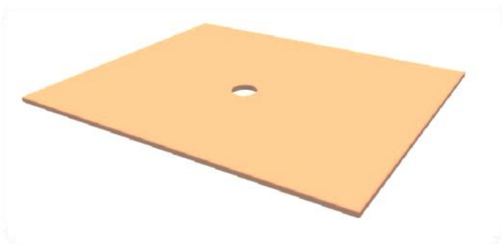


Figure 10: Wooden Platen

Chapter 3: Theoretical Portion

3.1 Arduino Mega 2560

The **Arduino Mega 2560** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila.

The Mega 2560 is an update to the Arduino Mega, which it replaces.

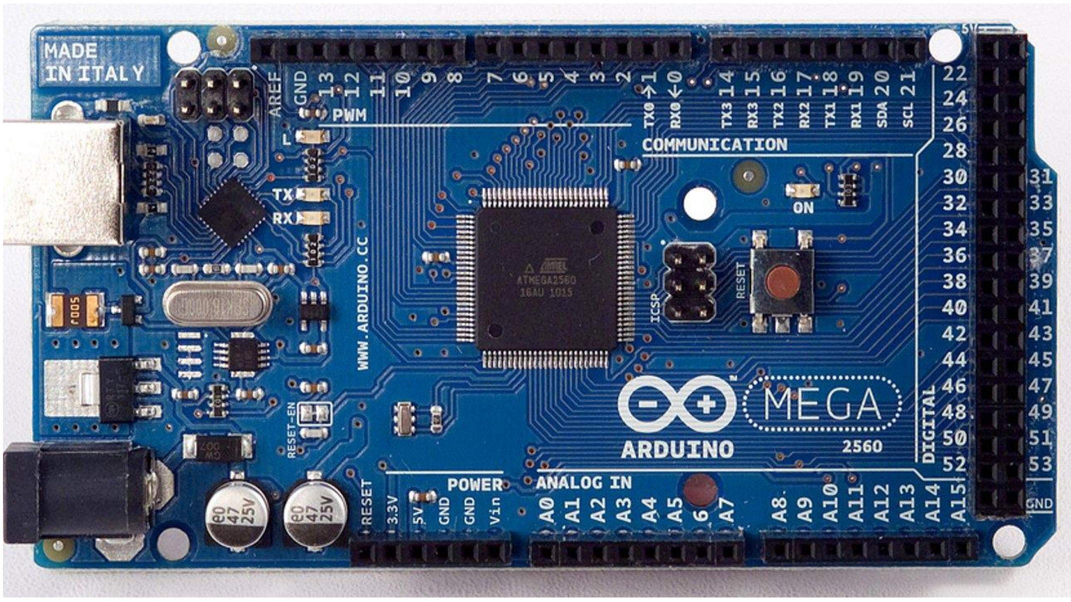


Figure 12: Arduino Mega microcontroller board (interface)

The Arduino Uno is a suitable, complete, and breadboard-friendly board based on the ATmega328P (Arduino Uno). It has more or less the same functionality of the Arduino Duemilanove, but in a different package. It lacks only a DC power jack, and works with USB cable.

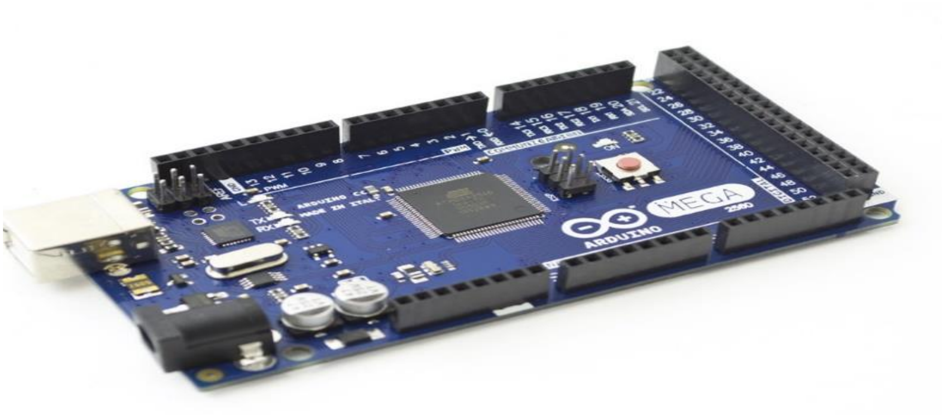


Figure 13: Arduino Mega microcontroller board (back view)

3.2 Specifications

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
LED_BUILTIN	13
Length	101.52 mm
Width	53.3 mm
Weight	37 g

Figure 14: Table of Arduino Specifications

3.3 Programming

The Mega 2560 board can be programmed with the Arduino Software (IDE). For details, see the reference and tutorials.
The ATmega2560 on the Mega 2560 comes preprogrammed with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header using Arduino ISP or similar; see these instructions for details.

The ATmega16U2 (or 8U2 in the rev1 and rev2 boards) firmware source code is available in the Arduino repository. The ATmega16U2/8U2 is loaded with a DFU bootloader, which can be activated by:

- On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2.
- On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader). See this user-contributed tutorial for more information.

3.4 Power

The Mega 2560 can be powered via the USB connection or with an external power supply. The power source is selected automatically.
External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the GND and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may become unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.
The power pins are as follows:

- **Vin**. The input voltage to the board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V**. This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. We don't advise it.
- **3V3**. A 3.3-volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND**. Ground pins.
- **IOREF**. This pin on the board provides the voltage reference with which the microcontroller operates. A properly configured shield can read the IOREF pin voltage and select the appropriate power source or enable voltage translators on the outputs for working with the 5V or 3.3V.

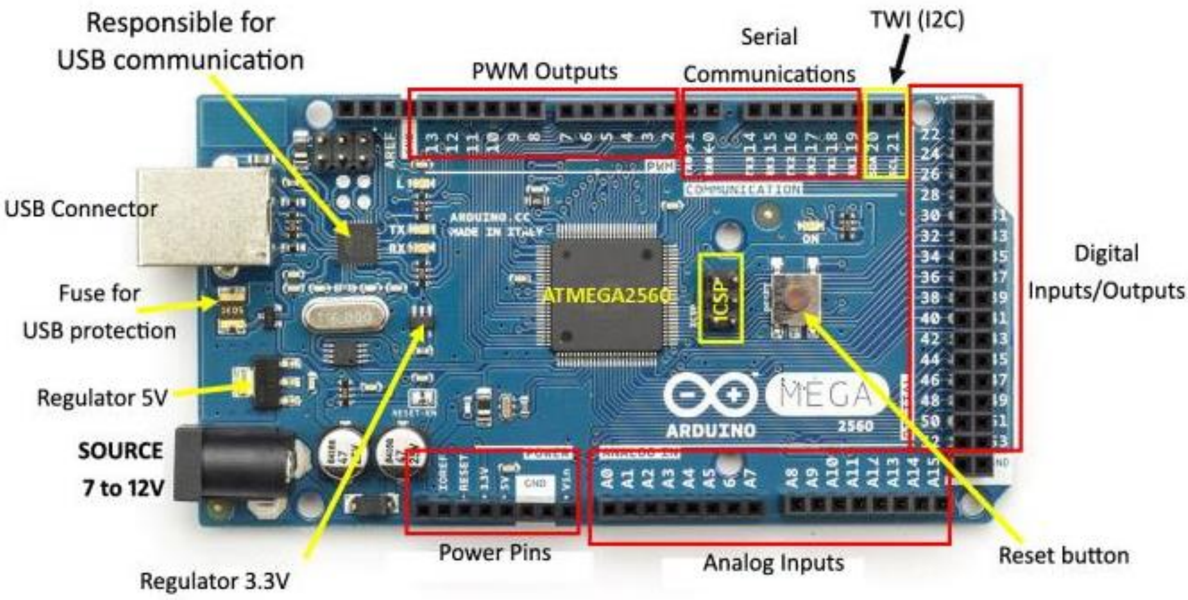


Figure 15: Arduino main parts name

3.5 Memory

The ATmega2560 has 256 KB of flash memory for storing code (of which 8 KB is used

for the bootloader), 8 KB of SRAM and 4 KB of EEPROM (which can be read and written

with the EEPROM library).

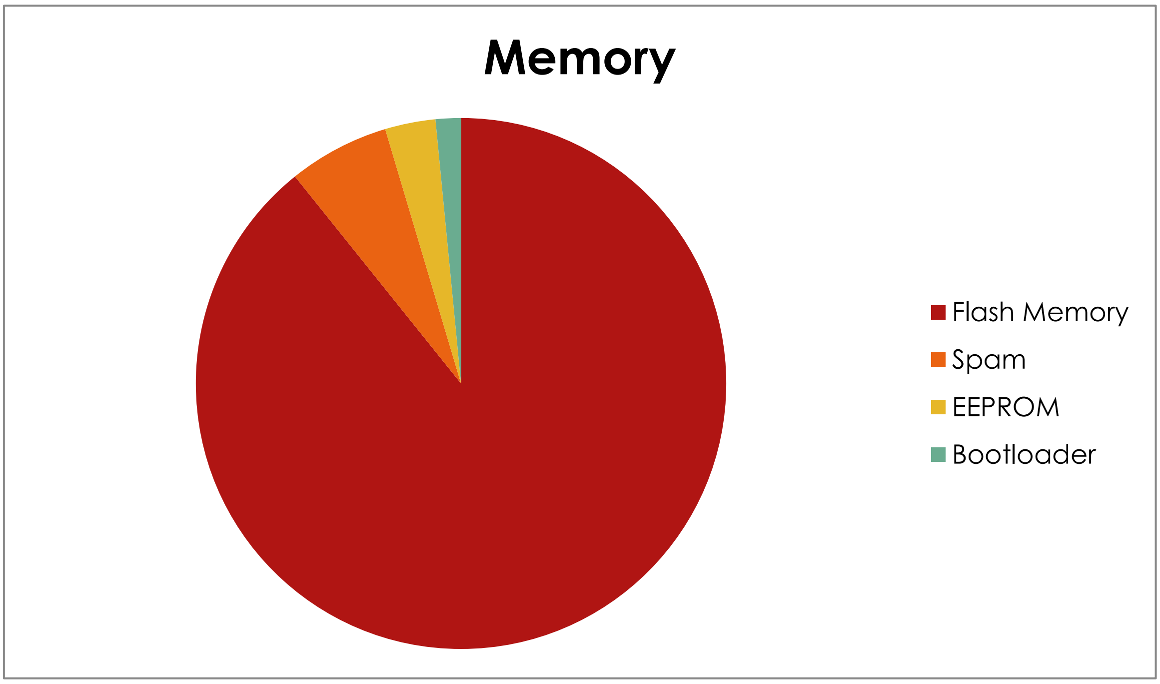


Figure 16: Mega 2560 – Memory

3.6 Arduino development "IDE"

The Arduino integrated development environment (IDE) is a cross-platform application written in Java, and is derived from the IDE for the Processing programming language and the Wiring projects. It is designed to introduce programming to artists and other newcomers unfamiliar with software development. It includes a code editor with features such as syntax highlighting, brace matching, and automatic indentation, and is also capable of compiling and uploading programs to the board with a single click. There is typically no need to edit make files or run programs on a command-line interface

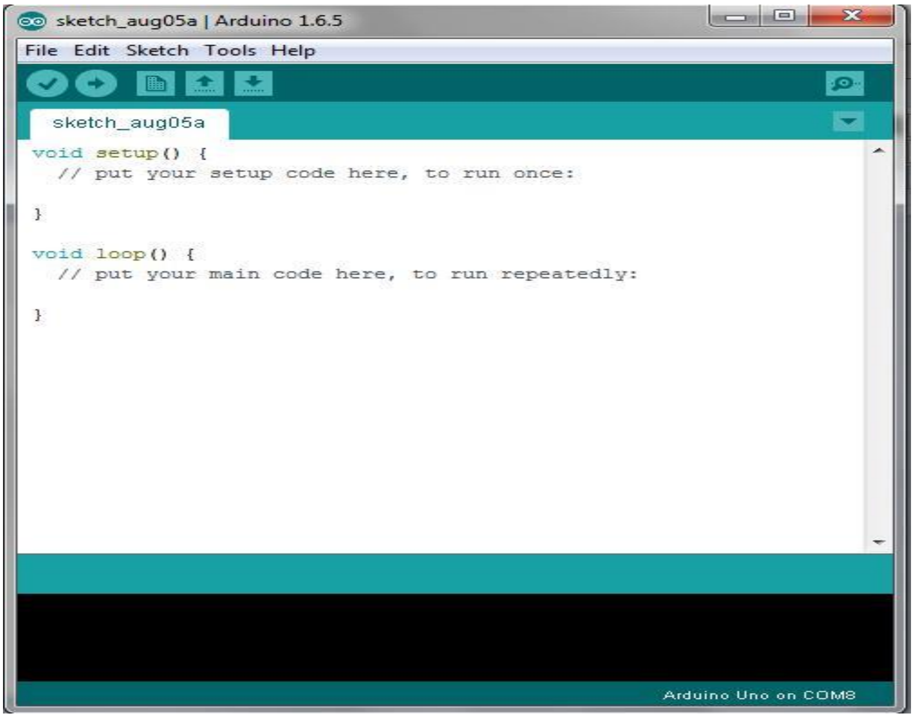


Figure 17: Interface Arduino Uno Program

Arduino programs are written in C or C++ The Arduino IDE comes with a software library called "Wiring" from the original Wiring project, which makes many common input/outputs.

Operations much easier. Users only need define two functions.

To make a runnable cyclic executive program:

- **Setup ():** a function run once at the start of a program that can initialize settings.

- **Loop ():** a function called repeatedly until the board powers off.

Chapter 4: Practical Portion

4.1 AC Portion

4.1.1 Circuit breaker:

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit. Its basic function is to interrupt current flow after a fault is detected. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.

Circuit breakers are made in varying sizes, from small devices that protect low-current circuits or individual household appliance, up to large switchgear designed to protect high voltage circuits feeding an entire city. The generic function of a circuit breaker, or fuse, as an automatic means of removing power from a faulty system is often abbreviated as OCPD (Over Current Protection Device).

Figure 18: Circuit Breaker

4.1.2 Solid State Relay (SSR):

A solid-state relay (SSR) is an electronic switching device that switches on or off when an external voltage (AC or DC) is applied across its control terminals. It serves the same function as an electromechanical relay, but has no moving parts and therefore results in a longer operational lifetime. SSRs consist of a sensor which responds to an appropriate input (control signal), a solid-state electronic switching device which switches power to the load circuitry, and a coupling mechanism to enable the control signal to activate this switch without mechanical parts. The relay may be designed to switch either AC or DC loads.

Packaged solid-state relays use power semiconductor devices such as thyristors and transistors, to switch currents up to around a hundred amperes. Solid-state relays have fast switching speeds compared with electromechanical relays, and have no physical contacts to wear out. Users of solid-state relays must take into consideration an SSR's inability to withstand a large momentary overload the way an electromechanical relay can, as well as their higher "on" resistance.

Figure 19: Solid State Relay

4.1.3 Infrared heater:

An infrared heater or heat lamp is a body with a higher temperature which transfers energy to a body with a lower temperature through electromagnetic radiation. Depending on the temperature of the emitting body, the wavelength of the peak of the infrared radiation ranges from 780 nm to 1 mm. No contact or medium between the two bodies is needed for the energy transfer. Infrared heaters can be operated in vacuum or atmosphere.

One classification of infrared heaters is by the wavelength bands of infrared emission.

- Short wave or near infrared for the range from 780 nm to 1.4 µm, these emitters are also named bright because still some visible light is emitted;
- Medium infrared for the range between 1.4 µm and 3 µm;
- Far infrared or dark emitters for everything above 3 µm.

Figure 20: Infrared heater

4.1.4 Selector (ON/OFF):

Selectors were used as a channel selector on television receivers until the early 1970s, as range selectors on electrical metering equipment, as band selectors on multi-band radios, etc.

Modern rotary switches use a "star wheel" mechanism to provide the switching positions, such as at every 30, 45, 60, or 90 degrees. Nylon cams are then mounted behind this mechanism and spring-loaded electrical contacts slide around these cams. The cams are notched or cut where the contact should close to complete an electrical circuit.

Some rotary switches are user-configurable in relation to the number of positions. A special toothed washer that sits below the holding nut can be positioned so that the tooth is inserted into one of a number of slots in a way that limits the number of positions available for selection. For example, if only four positions are required on a twelve-position switch, the washer can be positioned so that only four switching positions can be selected when in use.

Figure 21: Selector (ON/OFF)

4.1.5 AC lamp:

AC lamp is a light that illuminates under specific conditions, most commonly when an electrical circuit is energized. It may also be known as an indicator lamp or pilot light, although this should not be confused with a small flame kept burning in a gas appliance to provide a source for ignition when the appliance is turned on. Pilot lamps are used in a wide variety of settings and in some cases are required by law for safety reasons.

The pilot lamp can also be used on a variety of other types of circuits, including very small electrical circuits. Many electronics use a pilot lamp to indicate when the system is energized, or when there is a problem. The illumination behind the “power” button on many electronics is a simple example; when there's a light, people know the circuit is energized. Similarly, many systems use orange or red backlighting for the power button when the system is powering up or down, or when there is a problem.

Figure 22: AC lamp

4.2 DC Portion

4.2.1 Power Supply:

A power supply is an electrical device that supplies electric power to an electrical load. The primary function of a power supply is to convert electric current from a source to the correct voltage, current, and frequency to power the load. As a result, power supplies are sometimes referred to as electric power converters. Some power supplies are separate standalone pieces of equipment, while others are built into the load appliances that they power. Examples of the latter include power supplies found in desktop computers and consumer electronics devices. Other functions that power supplies may perform include limiting the current drawn by the load to safe levels, shutting off the current in the event of an electrical fault, power conditioning to prevent electronic noise or voltage surges on the input from reaching the load, power-factor correction, and storing energy so it can continue to power the load in the event of a temporary interruption in the source power (uninterruptible power supply).

All power supplies have a power input connection, which receives energy in the form of electric current from a source, and one or more power output connections that deliver current to the load. The source power may come from the electric power grid, such as an electrical outlet, energy storage devices such as batteries or fuel cells, generators or alternators, solar power converters, or another power supply. The input and output are usually hardwired circuit connections, though some power supplies employ wireless energy transfer to power their loads without wired connections.

Figure 23: Power Supply

4.2.2 Liquid Crystal Display (LCD):

A liquid-crystal display (LCD) is a flat-panel display or other electronically modulated optical device that uses the light-modulating properties of liquid crystals combined with polarizers. Liquid crystals do not emit light directly, instead using a backlight or reflector to produce images in color or monochrome. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and seven-segment displays, as in a digital clock. They use the same basic technology, except that arbitrary images are made from a matrix of small pixels, while other displays have larger elements. LCDs can either be normally on (positive) or off (negative), depending on the polarizer arrangement. For example, a character positive LCD with a backlight will have black lettering on a background that is the color of the backlight, and a character negative LCD will have a black background with the letters being of the same color as the backlight. Optical filters are added to white on blue LCDs to give them their characteristic appearance.

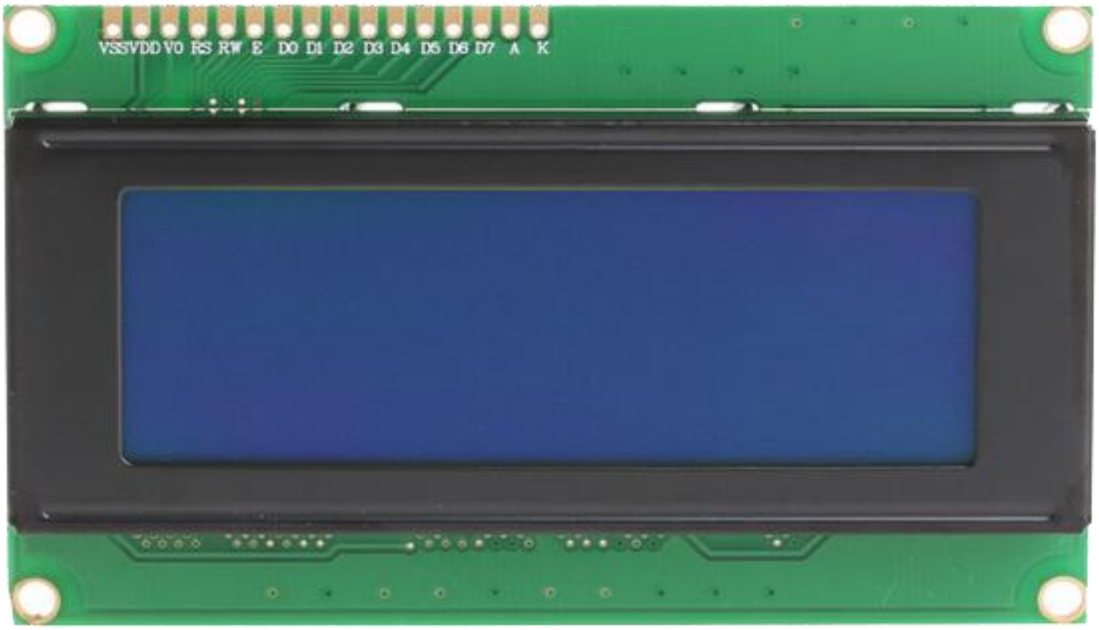


Figure 24: Liquid Crystal Display

4.2.3 Rotary Encoder:

A rotary encoder, also called a shaft encoder, is an electro-mechanical device that converts the angular position or motion of a shaft or axle to analog or digital output signals.

There are two main types of rotary encoder: absolute and incremental. The output of an absolute encoder indicates the current shaft position, making it an angle transducer. The output of an incremental encoder provides information about the motion of the shaft, which typically is processed elsewhere into information such as position, speed and distance.

Rotary encoders are used in a wide range of applications that require monitoring or control, or both, of mechanical systems, including industrial controls, robotics, photographic lenses, computer input devices such as optomechanical mice and trackballs, controlled stress rheometers, and rotating radar platforms.

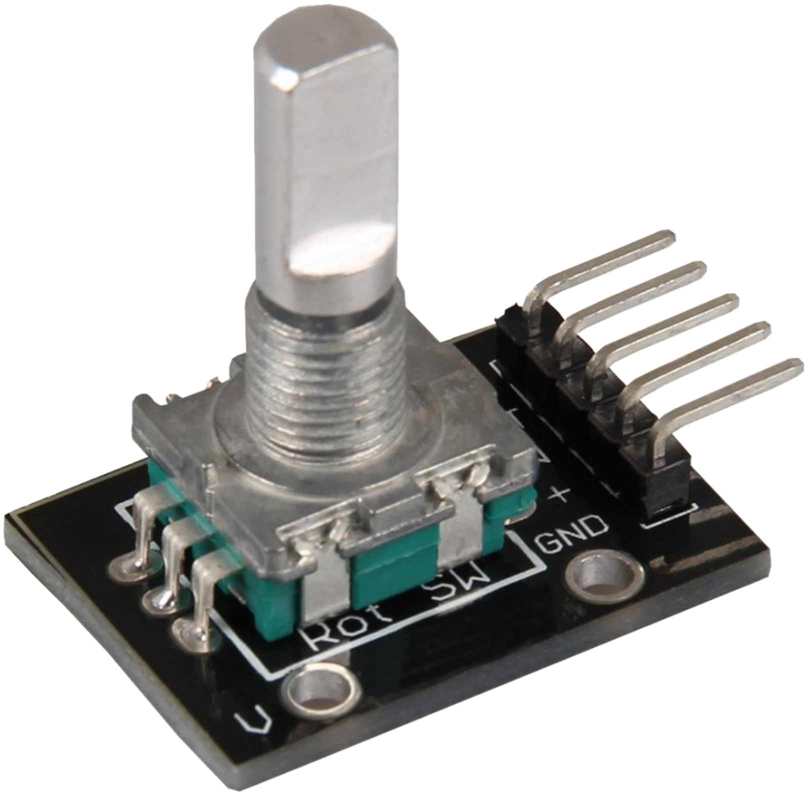


Figure 25: Rotary Encoder

4.2.4 Limit Switch:

In electrical engineering a limit switch is a switch operated by the motion of a machine part or presence of an object.

They are used for controlling machinery as part of a control system, as a safety interlocks, or to count objects passing a point. A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection.

Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. They were first used to define the limit of travel of an object; hence the name "Limit Switch".

Standardized limit switches are industrial control components manufactured with a variety of operator types, including lever, roller plunger, and whisker type. Limit switches may be directly mechanically operated by the motion of the operating lever. A reed switch may be used to indicate proximity of a magnet mounted on some moving part. Proximity switches operate by the disturbance of an electromagnetic field, by capacitance, or by sensing a magnetic field.

Figure 26: Limit Switch

Chapter 5: Power and Control Circuit

Power and control circuit are the main electric parts in machine, which show the electric connection between hardware parts and sequence of working. This figure (24) shows the main actual parts in hardware.

- Control Circuit: which exist in the gray box.
- Power Circuit: is the other connection.

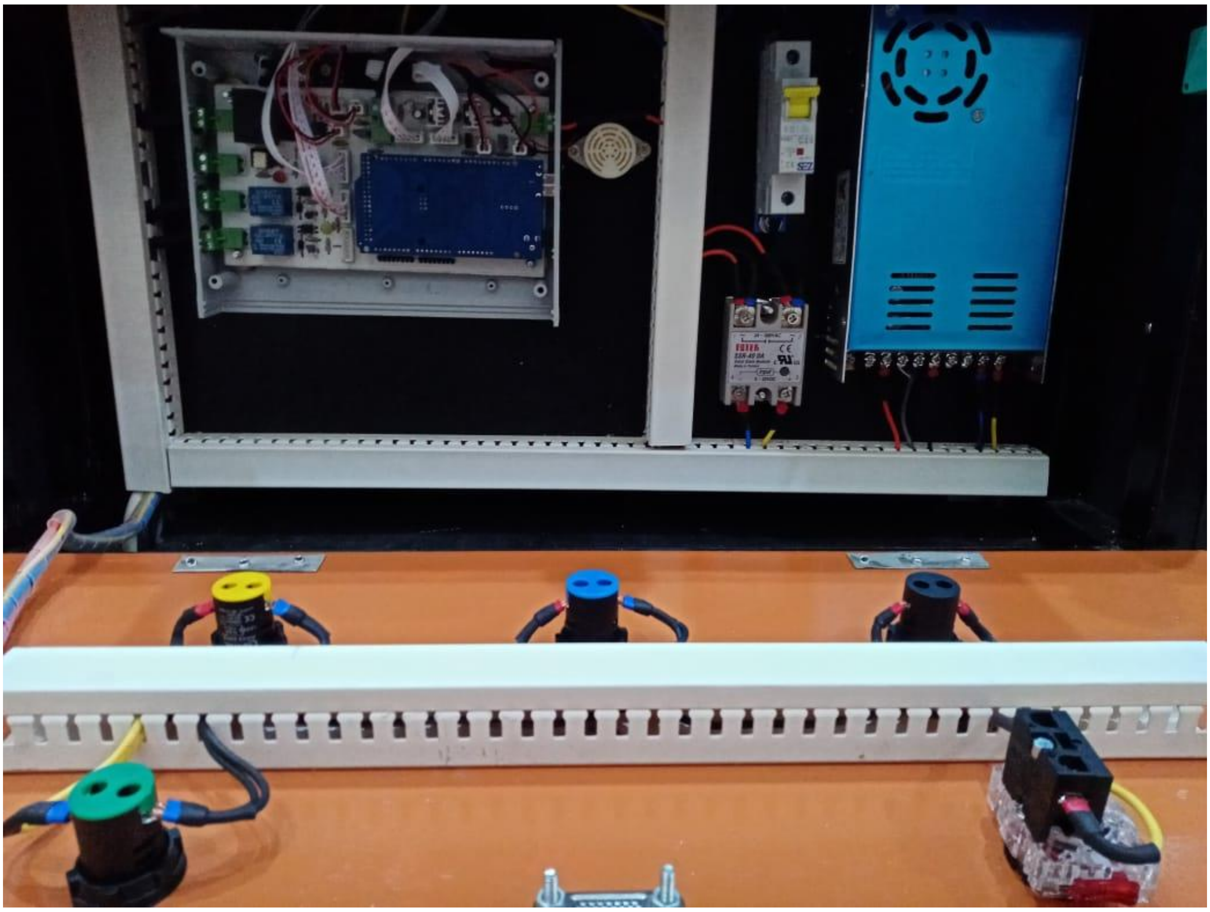


Figure 27: Power and Control board

5.1 Power Circuit

A power circuit provides significant electrical capacity to operate something that does a lot of work, for example high power heaters or multi-horsepower motors. There is a load or loads that consume X watts of power to perform a function. This usually implies 240VAC ~ 600VAC 3 phase. These types of circuits can draw in the kilowatts of power

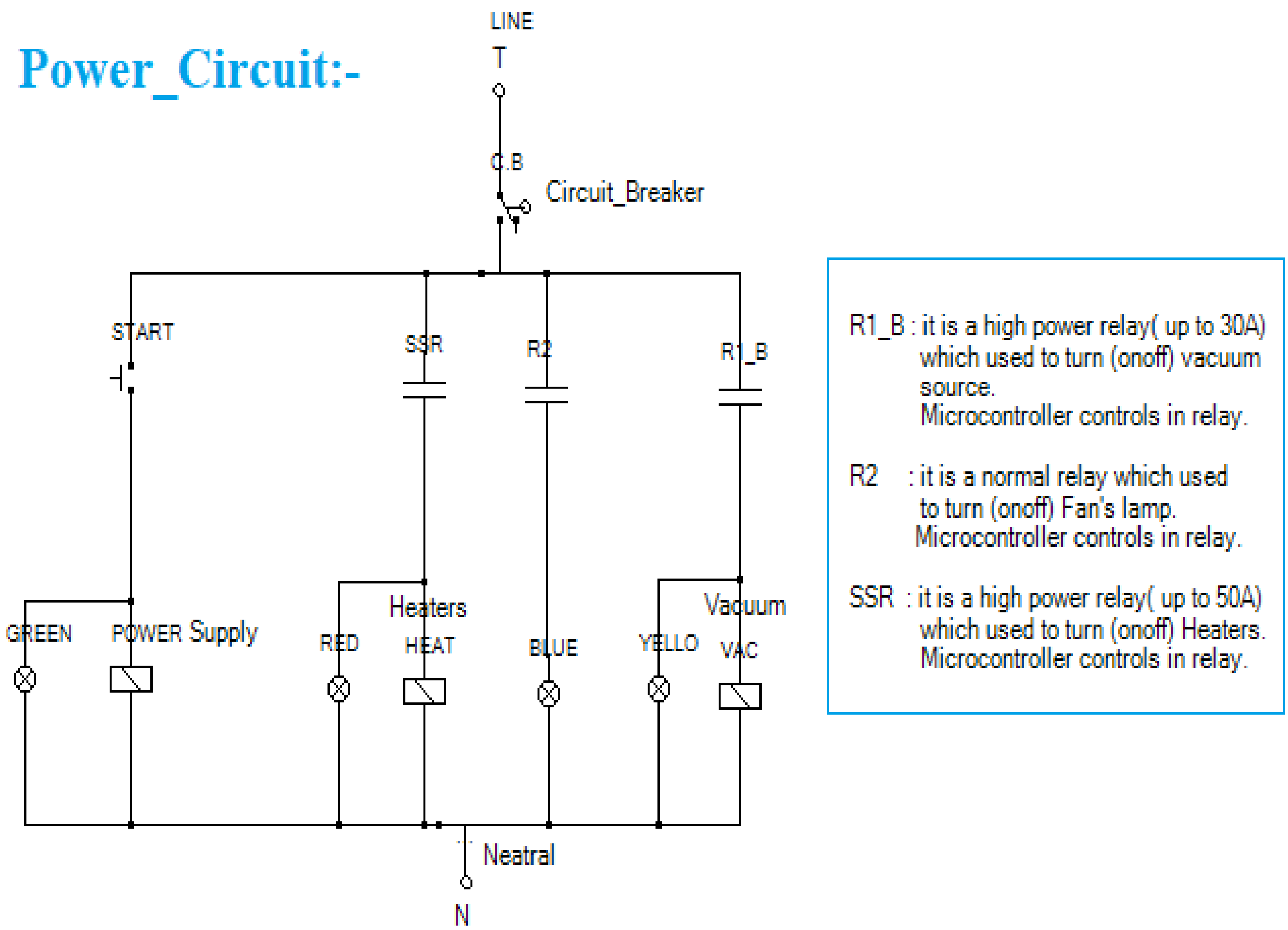


Figure 28: Power Connection

5.1.1 Component of Power Circuit:

- Heater's lamp (400W).
- Vacuum source (1200W).
- Power Supply (220V/30A).
- Circuit breaker (50A).
- AC indication lamps.
- Solid State Relay (SSR).
- Relay Normal Open Connection.

5.1.2 Connection of Power Circuit:

Power connection is used to control all high-power parts in the machine using signals from microcontroller.

First: User must close circuit breaker to supply the machine with AC current.

Second: User starts to turn on the machine from the selector (on/off), which power supply works, Green lamp is turned on and all remain

Third: - Heaters are connected to Solid State Relay (SSR).
- Vacuum is connected to High power relay (30A).
- AC indication lamps are connected to relay (10A).

"All relays receive signals from Arduino to work"

5.2 Control Circuit

A control circuit is a lower, single phase power line that could also be as low as 24V that provides a much lower level of power to operate control logic, contactors, displays, relays, and communications. A control circuit also draws on the AC power line but is usually just a few hundred watts at most. The important difference is that the devices in the control circuit are operating at 120 volts single phase or lower. It also should be pointed out that control power is usually derived from the resident power circuit by means of a step-down transformer.

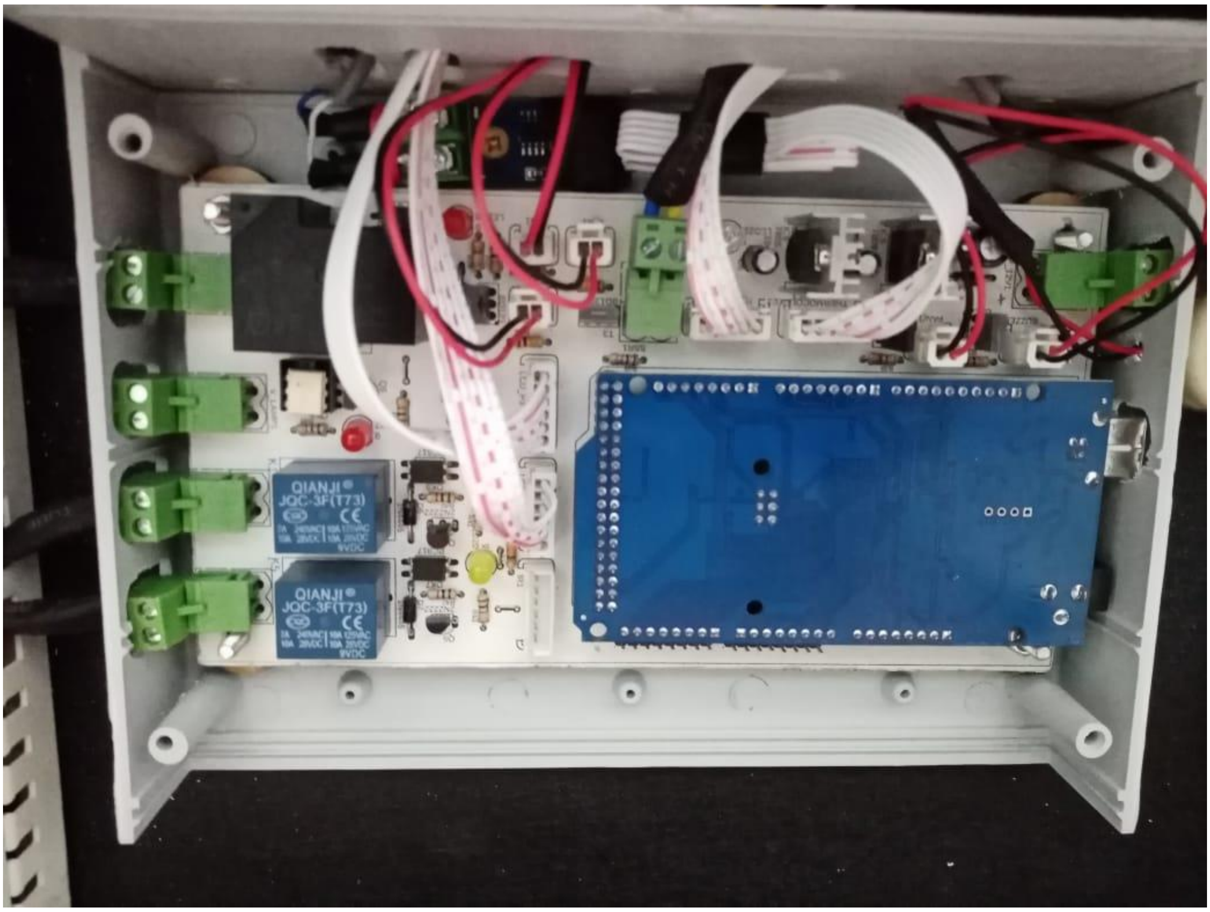


Figure 29: Control PCB board

5.2.1 Component of Control Circuit:

- Arduino Mega 2560.
- LCD Characters (4*20).
- Rotary Encoder Selector.
- High Power Relay (30A).
- Normal Relay (10A).
- Thermocouple Sensor with Amplifier (UP to 300 °C).
- Transistor NPN (BD135)
- Optocoupler (PC817).
- Resistors (1k, 10k, 330).
- Fans 12v.
- Connectors for wires (T-Block).
- LEDs for indications.
- Limit Switch.

5.2.2 Connection of Control Circuit:

Control circuit in the machine is a PCB "Printed Circuit Board", which included all component of control circuit in one plastic box as shown in the figure (29).

PCB is designed on eagle program, which is a software program to help you to design any board. This board is separated for two parts:

- First one is "Schematic".
- Second one is "Board"

5.2.3 Schematic of PCB:

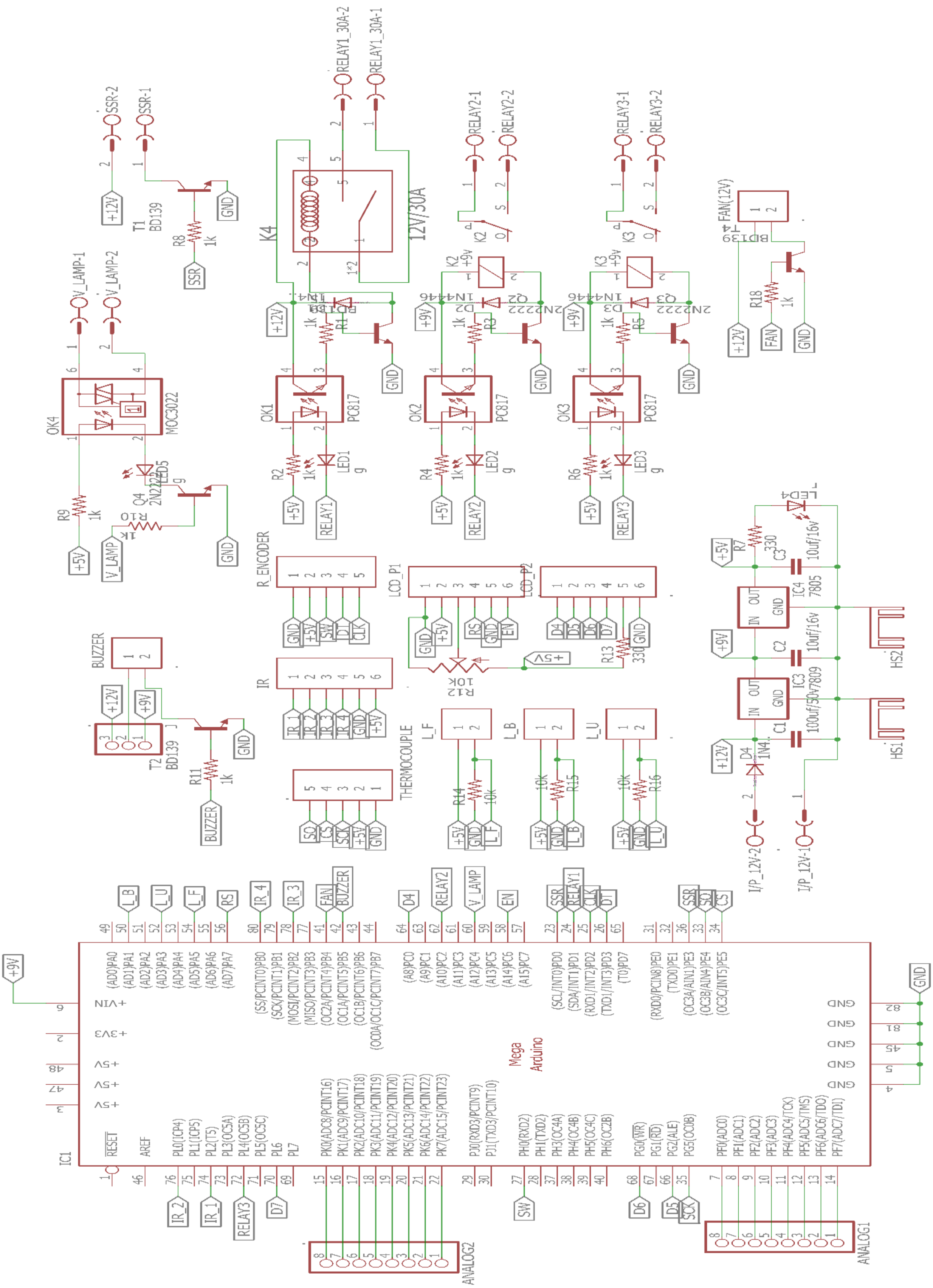


Figure 30: Schematic of PCB

5.2.4 Board of PCB:

This is the board of our PCB which is used to control in machine. it is

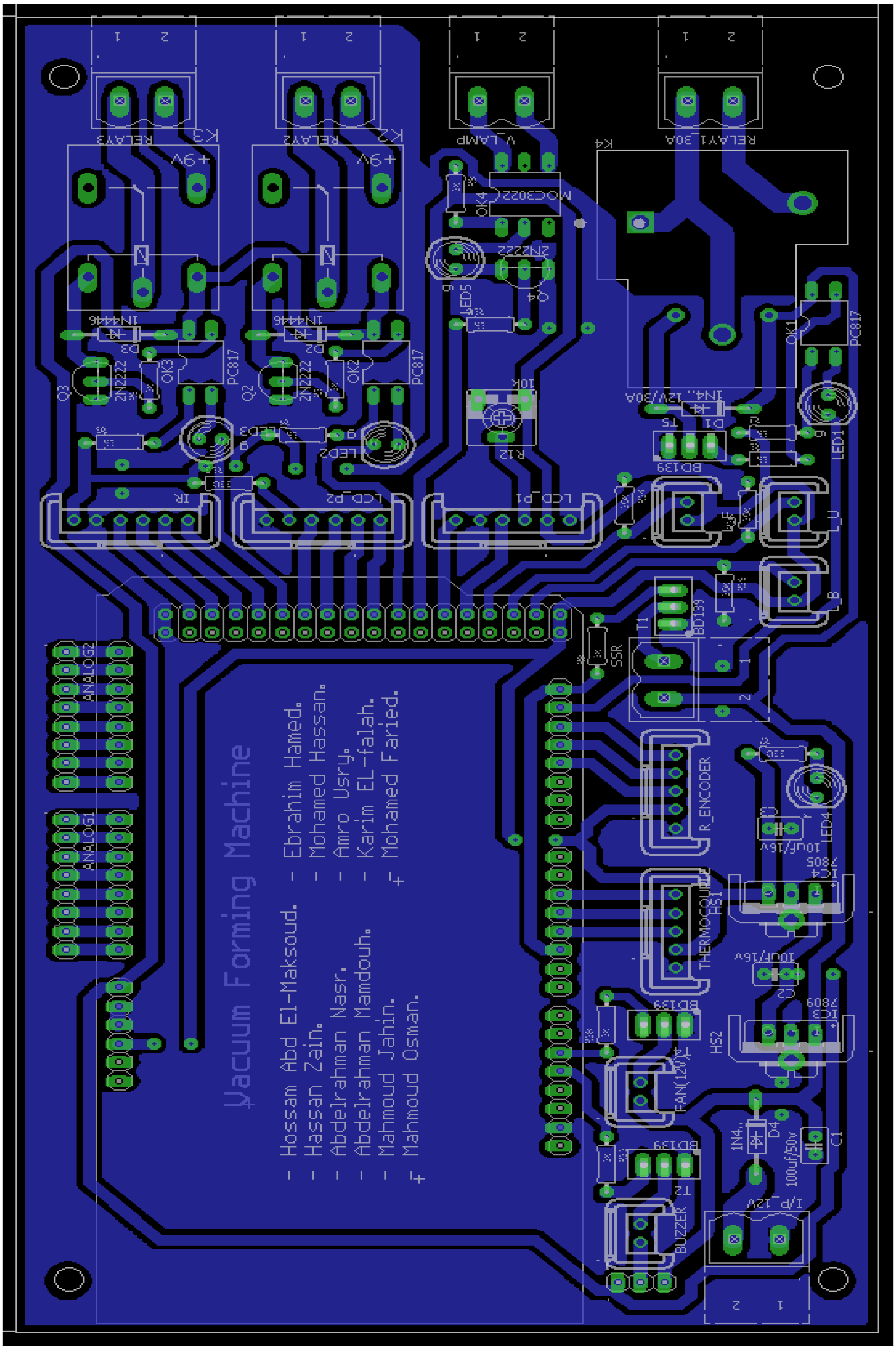


Figure 31: Design of PCB board on eagle

Chapter 6: Mechanical Portion

6.1 Introduction

This chapter will include the 3D Design for all the machine stages using **SOLIDWORKS** software. The sequence shown in this chapter is the machine sequence of operation that means it starts with pull plastic roll stage until the mold is completely ready.

The main mechanical structures are:

- Vacuum forming technique
- Frame
- Forming oven
- Mold platen mechanism
- Clamp frame

Way back when, we described thermoforming as taking a flat sheet of plastic, heating it up, and forming it into a shape. This is accomplished by employing any one of the various techniques of thermoforming. Depending on which one we select will dictate how sophisticated the equipment will be. Here is what we basically need to do this. First, we need something to hold the plastic sheet. It can be something as simple as metal piano frame or what is most frequently used namely a manual clamping frame. This is attached to some type of a trolley system that we can move in and out of a heating oven and position over a mold. We also need an oven to heat the sheet. This can be done by hot air, radiant type heaters or by gas flame heating. We will elaborate on this shortly. Next, we need some type of mechanism to hold the mold and make it possible to seal the hot plastic around the mold edges. We call this a platen. Finally, we need a vacuum system to force the hot plastic onto the mold.

6.2 Vacuum forming technique

There are many different thermoforming techniques that one can employ in the thermoforming process. The type of technique you choose will be determined by the geometry and shape of the part you are trying to make, along with the degree of difficulty of the part, and what your equipment is capable of doing. I would like to address each one individually by describing it and explaining why you would use each of these techniques

6.2.1 DRAPE FORMING – BOTTOM:

Essentially DRAPE FORMING - BOTTOM is clamping a piece of sheet plastic in some type of clamping mechanism, putting this material into a heating oven, heating the plastic sheet up to a desired temperature, retracting it from the oven, draping it over a mold, trapping the sheet just inside the clamping mechanism over the edge of the mold flange, and applying a vacuum to the mold chamber. This is quite simple and anyone can do it with very little capital investment. All one needs to do is acquire a basic heating oven, a rudimentary vacuum system and construct a mold out of any one of a number of inexpensive materials such as wood and you are in business.

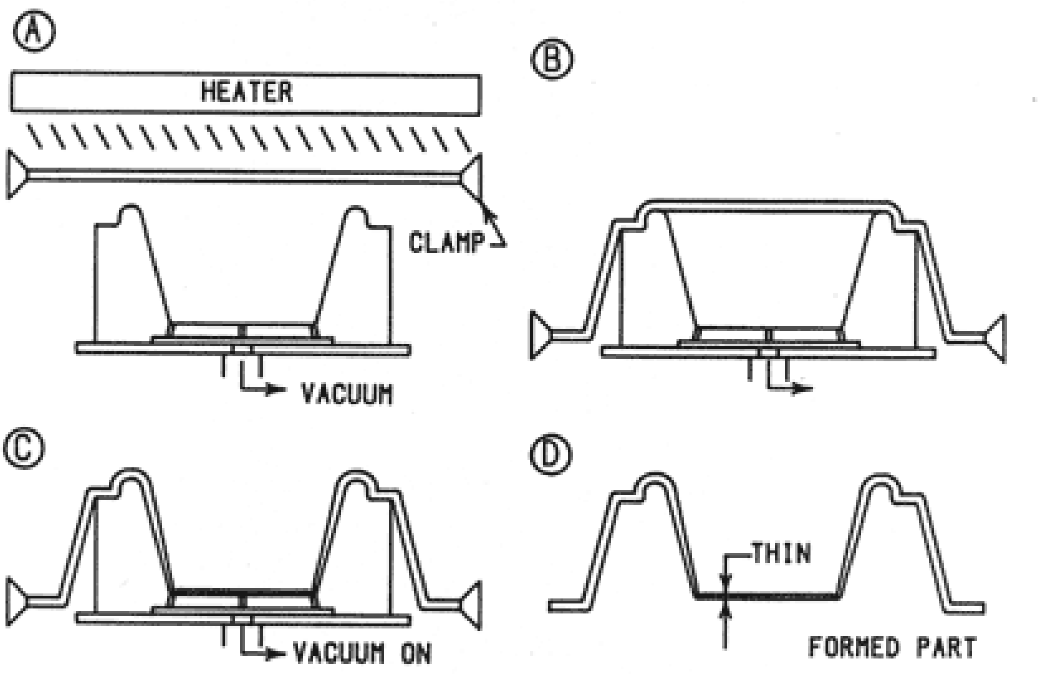


Figure 32: Drape forming bottom steps

Basically, what happens when you heat the sheet up in the oven, the sheet reaches a forming temperature but it ends up with a slightly uneven heat. This happens because the clamping mechanism acts somewhat as a heat sink and drafts in the oven or defective heating elements cause further heating disparities. This will be addressed later in the trouble-shooting section. As the sheet reaches approximate forming temperatures, it will sag somewhat in the clamp frame due to the thermal expansion properties of plastic, the actual softening of the plastic, and sheer gravity overcoming the hot strength of the plastic. Also, the actual surface of the plastic will be slightly hotter than the interior of the sheet. When you remove the plastic from the oven, the surface of the sheet will cool off very quickly so you do not have much time to actually form the material, usually only seconds. Next you actually drape the hot plastic sheet over the mold. This causes the plastic that touches the mold to cool very abruptly and freeze onto the mold surface wherever it actually touches the mold. This chilling may be 50° to 100° F on the areas that touch the mold on the mold surface side in just a matter of seconds. This makes the plastic considerably harder in these areas, and when you apply the vacuum to stretch the material over the rest of the mold, the plastic will stretch more easily from the hotter areas, thereby thinning those areas more readily. As you stretch the hot plastic over the mold and trap the edges next to the clamp frame to the mold flange, you further thin out the plastic. However, you have no choice in doing this, as you need to get a seal around the mold flange to be able to apply the vacuum. Finally, the vacuum is applied to force the rest of the plastic up against the mold to chill it. After a few minutes, the plastic contacting the mold will chill enough to be below its heat distortion point. This phenomenon will also occur on the surface side that is exposed to the air but at a much slower rate. At that point it can be removed from the mold and the excess trim removed to take on the dimensions of the designed part.

Generally speaking, there are some drawbacks to this technique in molding. First, you are going to have a lot of competitors and price pressures will be severe. As I indicated earlier, almost anyone can get into this business using this technique. Second, this technique is not capable of producing parts that are very complicated. Wherever the plastic touches the mold is essentially where it ends up. Consequently, any part that is a little more complicated could end up with some thinning in some areas that are not acceptable. You just do not have any control to move the plastic around to other areas of the part. This will also cause the thinning to be uneven and the texture may appear different on various areas of the part. Third, you are very likely to have chill marks on various areas on the part. This may be cosmetically unacceptable and other techniques may have to be employed to overcome this.

However, the other side of the equation shows that there are some quite beneficial aspects to this technique. First, you can produce parts via this method quite economically. It is probably the most economical thermoforming method we can use. Secondly, the parts produced via this method are normally totally acceptable for the application they are 4 being used even though they may have some cosmetic deficiencies. If you have a part that is not very difficult and has a relatively easy draw ratio (term to be defined later), not only is it likely to be the most economical technique, but it also likely to require less engineering work to get the whole thing designed and produced. Third, it does not require highly trained personnel to produce parts by this technique. And fourth, as with most vacuum forming techniques, you can make multiple parts on one mold. In many cases these parts will be quite different from one another. This would vary depending on the complexity of the parts and the general size that the vacuum forming machine is capable of handling. All in all, if you have a choice, this is probably the best method you could select provided the part geometry allows you to use this technique.

6.3 Frame

Light-weight frame structures are important, efficient structural elements in engineering design. This is especially the case in transportation vehicles, i.e., automotive, nautical, aeronautical and astronautical vehicles, which rely on such frames to provide structural integrity, stiffness and crashworthiness, amongst other criteria. While providing the structural function, they shall be as lightweight as possible.

The lighter such structures are, the more economical they are; often in all facets of the life cycle of such structures: **Lighter** means:

- Less use of material in the production.
- Less use of fuel in operation.
- Lower loads in operation, which lessen structural requirements.
- Less of which to recycle and dispose.

This is, therefore, twofold of importance: cost and environmental, both of which are driving aspects in the design of modern products.

So that to achieve the most outstanding frame design we managed to design a spaceframe that can handle the loads of vacuum forming efficiently.

The Vacuum forming machine frame generally consists of:

- Square space frame welded tubes
- Wooden plates to cover the frame

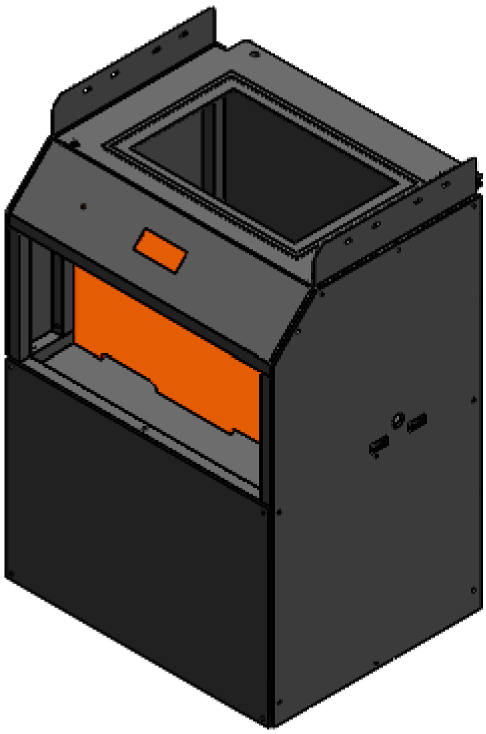


Figure 34: Assembled frame

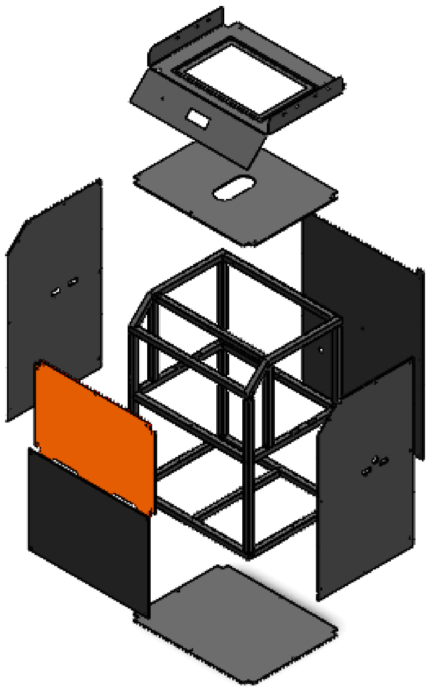


Figure 33: Disassembled frame

6.4 Forming oven

A forming oven is nothing more than a chamber with a heating source. We will discuss heating sources shortly. These ovens can be either open or closed. Most ovens these days are what we would describe as semi-closed or almost totally closed. They are usually insulated internally to prevent the heating elements from heating up the outside surface of the oven and making it dangerous. What do we mean by open, closed or semi- closed? A perfect example of a closed oven would be an air convection oven. This is an oven that has no air gaps anywhere and has hot air circulating throughout the oven that essentially heats the plastic. There are other ovens that are pretty much closed from all five sides and have a door in front of it that goes up and down as required by the loading process. These types of ovens have small gaps in the back of the oven where the clamp frame track extends and gaps in the front of the oven where the door opens and closes. These ovens are what we would call almost totally enclosed. They are pretty efficient but do allow some convective air to leak out and heat up the environment outside of the oven.

Finally, we have ovens that are considered open. Typically, they have heating elements on the top and bottom that are encased in some kind of a shell. The oven can be open from one, two or all four sides. Obviously, this will result in a lot of hot air escaping into the immediate surrounding area which makes these types of ovens sensitive to drafts and air currents that exist within the plant. However, I can assure you that there are a lot of machines built this way and if used properly, they work fine.

6.4.1 HEAT TYPES:

Before we get into heating elements and how the ovens work, we would like to talk about the types of heat available. There are only three types of heat, CONDUCTIVE, CONVECTIVE, and RADIANT. Plastic can be heated by any one, or all of these heating types, but some are more efficient than others are. It is probably easier to explain these heats using an example. If we take a red-hot metal rod and touch it against your skin it will cause you some immediate consternation. If we touch it against a piece of plastic, it will most likely scorch the plastic. This is conductive heat and to be effective, this heat source must be only slightly hotter than what you want the item to be heated. Now if we take the same red hot metal rod and hold it a few inches from your skin, you will feel the heat. Part of this heat is coming from the fact that the rod is heating up the air around it and the hot air is heating up your skin. This is convective heat and is usually associated with an air-circulating oven. However, some of this heat is caused from infrared heat waves and is known as radiant heat. Various wavelengths of energy exist everywhere but only a few of the wave lengths cause

things to heat up and only within certain ranges. Infrared waves have a range of .72 microns to 1000 microns on the electromagnetic spectrum.
A wavelength is measured in microns. One micron is equal to 1/1,000,000 of a meter or about 0.00004 inches (a human hair is about 50 microns in diameter).

From a plastics standpoint, we are only interested in the portion of the spectrum from about 0.1 to 100 microns as this is the region that most of the energy is radiated from a heater, we would use to heat up the plastic. The amount of energy radiated by a heater and the wavelength of this energy is determined by a heater's temperature and the surface area exposed. Thus, we need to be concerned about the type of heaters we would likely use, as various type of heaters put out different wavelengths of energy. We will address these 55 concepts in a little more depth shortly but first we need to talk about heating elements available for thermoforming ovens.

6.4.2 Heating elements:

QUARTZ HEATERS

This is another fairly popular heating element for thermoforming ovens. There are two types. One is a 'white light quartz' heater, which is merely a transparent quartz tube with a heating element running through it that is under vacuum. These heaters glow with an extremely hot almost white light. They are either totally on or totally off and give off a temperature of 1200° to 1400°F. This is an extremely short wavelength and is not good for radiant energy absorption for plastics. Most of the heat is convection and very harsh. We do not recommend this element for thermoforming. They were used pretty extensively fifteen to twenty years ago but have fallen out of favor. They are also pretty fragile. This may have been an additional reason for their demise.

The other type of quartz heater is a quite a bit more popular although not as much as some of the above heaters. They consist of about a one-half to a three-quarter inch diameter tube with a resistance wire inside of it backed up by an internal reflector. These heaters do not glow white as the above heaters but have more of an amber glow to them. Thus, the wavelength of the radiant energy is more medium range and is more effective than the above quartz element. It is also possible to control them with timers or solid-state relays so that the temperature can be adjusted up or down. This allows you to get the radiant energy wavelength to the most efficient it can be for this type of element.

These types of elements are also fairly easy to zone. Quite often you see three or four elements about a foot long banked as a group about four inches apart. The result is an area of about twelve inches by sixteen inches that is controlled by one heater bank. Thus, 63 your oven control can be similar to ceramic or solar panel heaters. The slight decrease in efficiency comes from the fact that the elements are about four inches apart and there isn't as much radiant energy given off. In other instances, these types of elements are installed as four- to six-foot-long tubes, similar to carload elements, with three to four elements on a single controller. Obviously, this does not afford as much oven control as the smaller banks. It does require fewer relay switches and therefore cuts the cost of oven construction. However, you are right back where you started in the sense that you have less oven control in heating the sheet. There are constant trade-offs that need to be made in terms of cost or efficiency.

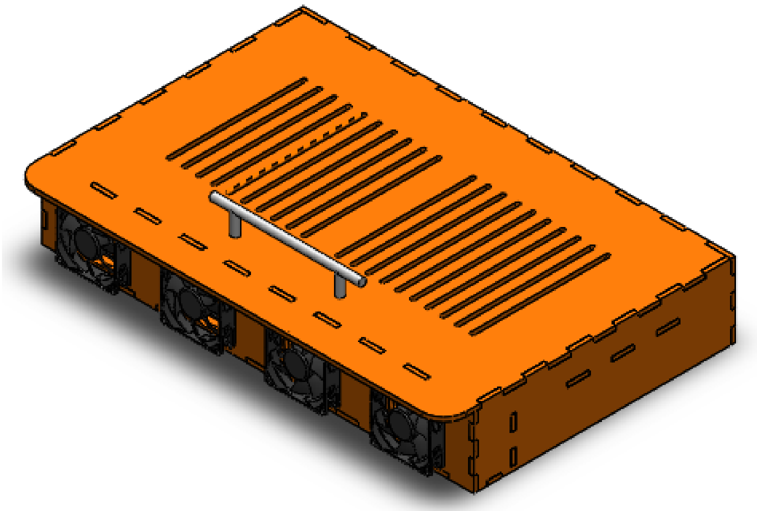


Figure 35: Isometric view of the heating oven

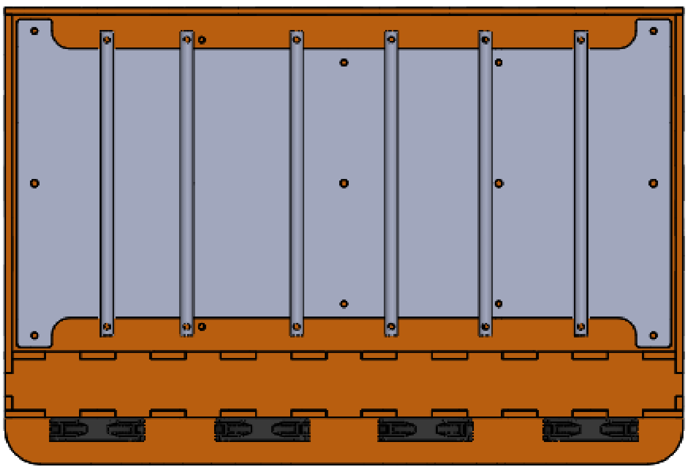


Figure 36: Down view of the heating oven

6.5 Mold platen mechanism

Platens are nothing more than a well-stabilized and securely built framework to move a mold up or down. On very simple machines we only have one of these frameworks on the bottom just off the shop floor. In its normal position, it is retracted so we will have enough clearance to be able to pull the clamping frame across the mold without dragging the hot plastic against the mold surface. Well, what moves these platens? The least sophisticated way would be to devise a mechanical means that you could operate manually, and I have seen this done. However, the three most common methods used when employing a machine are pneumatic, hydraulic or rack and pinion drive. Frequently, the rack and pinion drive are described as an electrically driven chain drive.

A pneumatically driven platen is just what it sounds like. It has an air cylinder attached to a framework of the platen and can be moved up or down by actuating an air valve at either end of the cylinder. This is a very popular method of moving a mold into the forming position on a vacuum forming machine. The primary reasons are because it is simple to install, simple to operate, and therefore the least expensive to construct. In most cases, it is adequate to do the job. However, there are some drawbacks. Whenever you operate something pneumatically that requires a certain amount of force, the response is not immediate. There is a very slight delay before full force is applied so you may get a somewhat “jerky” motion as you push the mold through the plastic or take the part off 51 of the molds. You may also have trouble getting the mold to seat in the same position relative to the clamp frame each time. On large parts this will sometimes cause you to lose your vacuum seal on the mold. In addition, if the mold is quite heavy, you will need a large air cylinder, something in the order of 10 inches in diameter to raise the mold properly.

Next, we would like to discuss chain drive platens, better known as electrically driven platens. In actuality they are rack and pinion drives. They have been around for many years but they are just now becoming the dominant mode for moving a mold into forming position. They have some very distinct advantages. The first advantage is power. Typically, you will have a platen closing pressure of five tons or more. This allows you to use the machine as a pressure former if the part is relatively small without investing in a specific pressure forming system. This makes your machine more versatile without the added cost of the pressure forming mechanism. Even though this system is more expensive than a pneumatically driven platen system, it is still not as expensive as the pressure forming package and it is mechanically much simpler than the pressure forming system. A second advantage is accuracy. Since this system is a direct drive that is tied into a micro-switch, it will stop at exactly the same place each time within a thirty second of an inch. This makes it the system of choice in pressure forming situations as the pressure box would stop at the identical spot each time and not cut too deeply into the hot plastic. As we have discussed, pressure forming requires tight tolerances in tooling and processing. Another advantage is the uniform speed that the platen moves up or down. If you are using the snapback technique and you are depending on timing to pre-draw the bubble, this system will give you the most consistent results. The more variables you can eliminate from a process, the more consistent your processing results will be. This system also allows you to use a plug more effectively. As a matter of fact, this system is so consistent that you can tie in the vacuum flow with the plug extension and often times eliminate webbing on difficult parts. As far as disadvantages are concerned, I can't think of any except cost. In my opinion, it is really worth the extra money.

A third system for moving the platens is a hydraulic system. This too is a quite accurate system and gives you an enormous amount of power if you are going to pressure form. It basically has all the advantages of an electrically driven platen system. In my opinion, the only criticism I can levy on this system is the simple fact that it is hydraulic. It is only a matter of time before you are going to leak oil from somewhere and probably even drip oil on your production parts. If you are willing to keep up with the necessary maintenance, this is an excellent system.

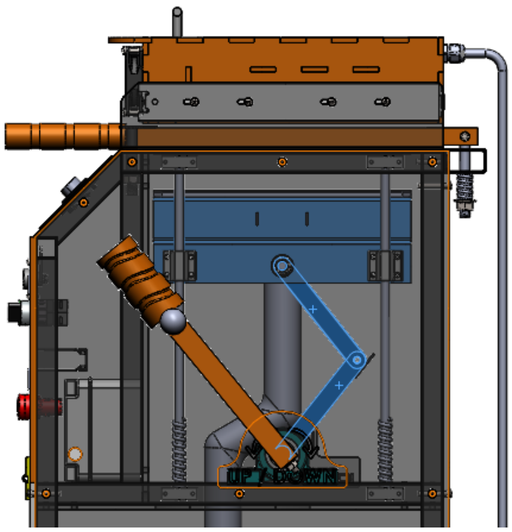


Figure 38: Side view of the mold platen mechanism

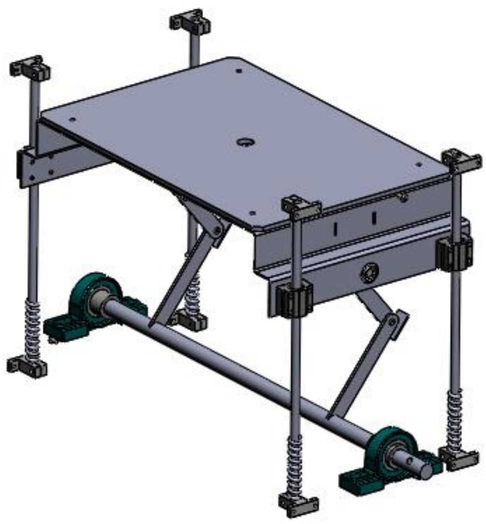


Figure 37: Detailed assembled platen mechanism

6.6 Clamp frame

As we indicated earlier, you have to have some method of holding the plastic sheet while you have it in the oven heating up. This is done with a clamping frame. Now on very simple forming systems, this can be done with something as simple as two metal frames on a hinge that trap the sheet between them when the mechanism is closed. Typically, 52 these frames have little nipples welded on the inside surfaces of the frame that are in contact with the plastic sheet that prevent the plastic from pulling out of the frame during the heating cycle. Most plastics have a built-in shrinkage within the sheet that takes effect when the sheet is heated up. Consequently, it is necessary to have good contact with the sheet to the plastic. After the sheet is heated to the proper temperature, the piano frame mechanism is removed from the oven and the hot plastic is dropped over the mold in such a manner as to pinch the plastic on the inside edge of the frame against the edge of the mold base. This provides a seal that allows the vacuum to evacuate the air in the mold and mold support chamber. As simple as this all seems, and it is, it is not very efficient.

Most vacuum forming machines have a clamping system that is attached to a shuttle cart that is operated pneumatically. It is usually comprised of two separate entities. The first is the actual shuttle cart. It is simply a large framework similar to a picture frame that covers most of the heating elements in the oven. It is usually supported by some metal wheels that fit into a track and are enclosed from both the top and the bottom to prevent the clamping frame from moving up or down. The cart or carriage is moved into or out of the oven area to the forming area by long slender pneumatic cylinders. On large machines this is normally done with a chain drive. Attached to the inside of the cart on both sides is a Unistrut that allows you to adjust the actual clamp frames to the size of the mold base.

This brings us to the clamp frames themselves. Normally they are comprised of a flat stationary base plate with a vertical support bar underneath it. Attached to the base plate are small pneumatically operated cylinders that have a gripping bar attached to the cylinders. When the cylinder pistons are extended, the gripping bar sandwiches the plastic sheet between the base plate and the gripping bar. This provides you with good gripping pressure and is very quick and efficient to operate and is far superior to a piano frame. The only negative is the fact that constant heating and cooling will eventually warp the clamp frames and the seals on the cylinders will ultimately wear out from heat and have to be replaced. However, the same warping happens with piano frames and they usually have to be replaced if heavily used too. The pneumatically operated clamp frames can be adjusted back and forth on the Unistrut and have adjustable blocks for the cross members. Consequently, it is not necessary to have a separate frame for each mold base as it is with piano frames. The pneumatically operated frames can be used for any number of similar sized molds. So now we have a method of holding the plastic sheet and a way of getting it in and out of the oven.

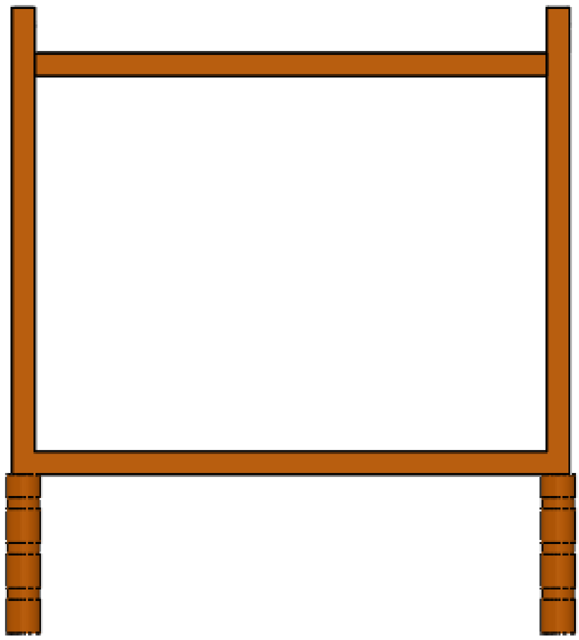


Figure 39: Clamp Frame

6.7 Final machine assembly

Figure 40: Rendered scene for the project assembly

Chapter 7: Software Portion

As programs or apps commonly known, consists of all the instructions that tell the hardware how to perform a task. Software is capable of performing many tasks, as opposed to hardware which can only perform mechanical tasks that they are designed for. Software provides the means for accomplishing many different tasks with the same basic hardware.

This software program is meant to accomplish the whole vacuum forming machine process, controlling every phase of process. There are some phases we get through to get the job done.

7.1 Programming criteria

7.1.1 Firstly:

Software gets user inputs via encoder including material name, its thickness and then temperatures of every material are known as stored in the program previously. The LCD displays the chosen options after the welcome message, then you can assure your choices or return. Now you have finished the first step.

7.1.2 Secondly:

It is heating phase. User puts the sheet he wants to form then programs check doing this right using sensors. When sheet is placed right and heaters reach minimum required temperature, buzzer is on to indicate pulling heaters to warm sheet up. When read, buzzer is off. We said that temperatures are saved thus we use maximum and minimum temperatures as boundaries during heating time. After it ends, buzzer is on then you push heaters. You lift the platen up to form the warmed sheet. Buzzer is off. Then you have finished the second step.

7.1.3 Finally:

Actually, there is no elapsed time among the three phases. Thus, we notice as soon as buzzer stops. When done vacuum starts its job to absorb the trapped air. Vacuum's lamp indicates it is on. Now we reach the final step of the whole process. During the last 25 seconds, after 15 seconds past the fan and its indicator are on. Then after 5 seconds the vacuum stops. This moment the job is totally done, but you just take the ready sheet. When sheet is delivered the fan and its indicator are off.

You have the opportunity to repeat the same process making another sheet, or you can return to choose another option.

To sum up, using this software enables user to detect every detail he wants, user is actually running the process the way he needs. He gets the products that benefits him. It serves several ways.

7.2 Programming Flow Chart

7.2.1 Main:

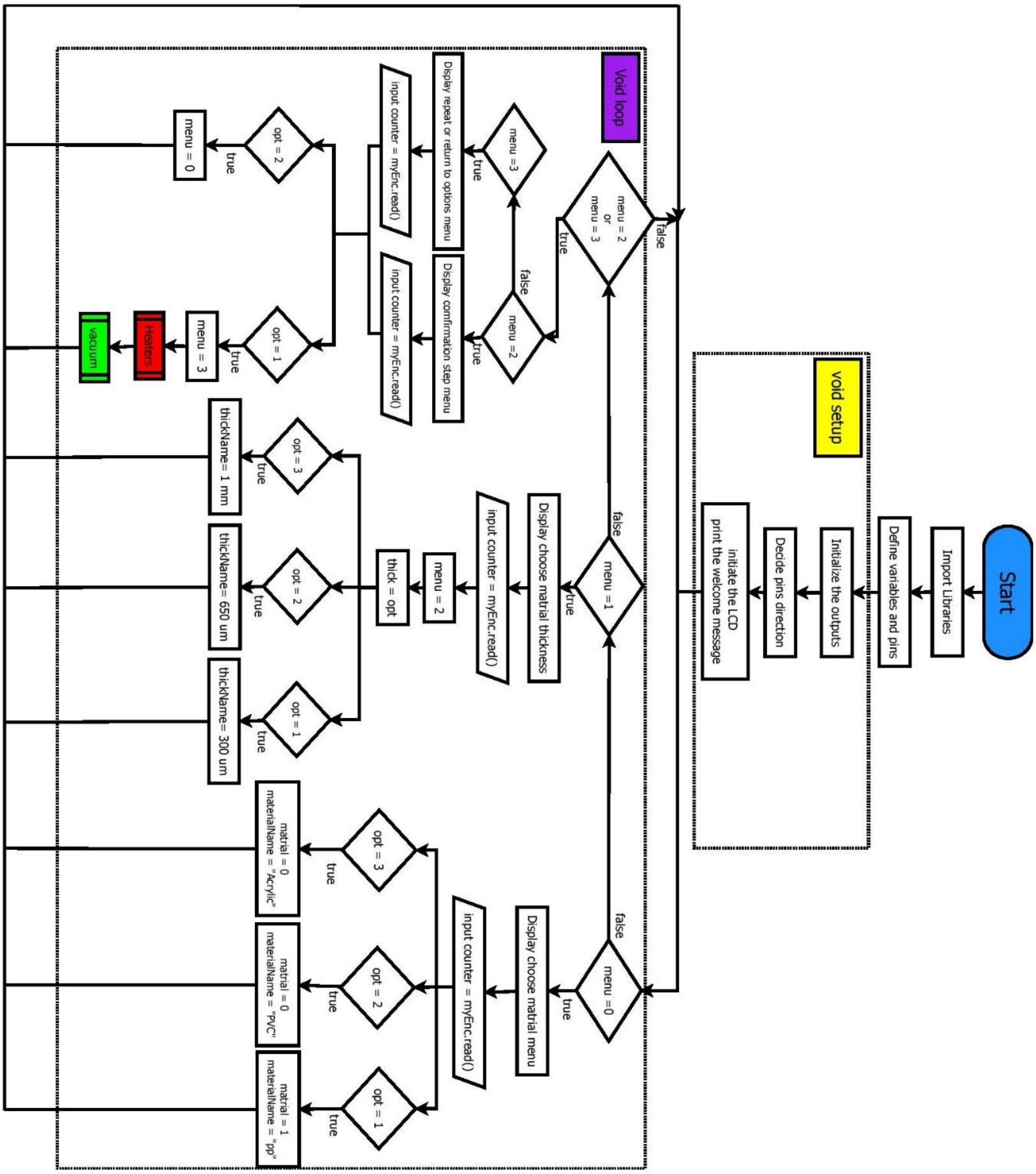


Figure 41: Main Flow Chart

7.2.2 Heaters:

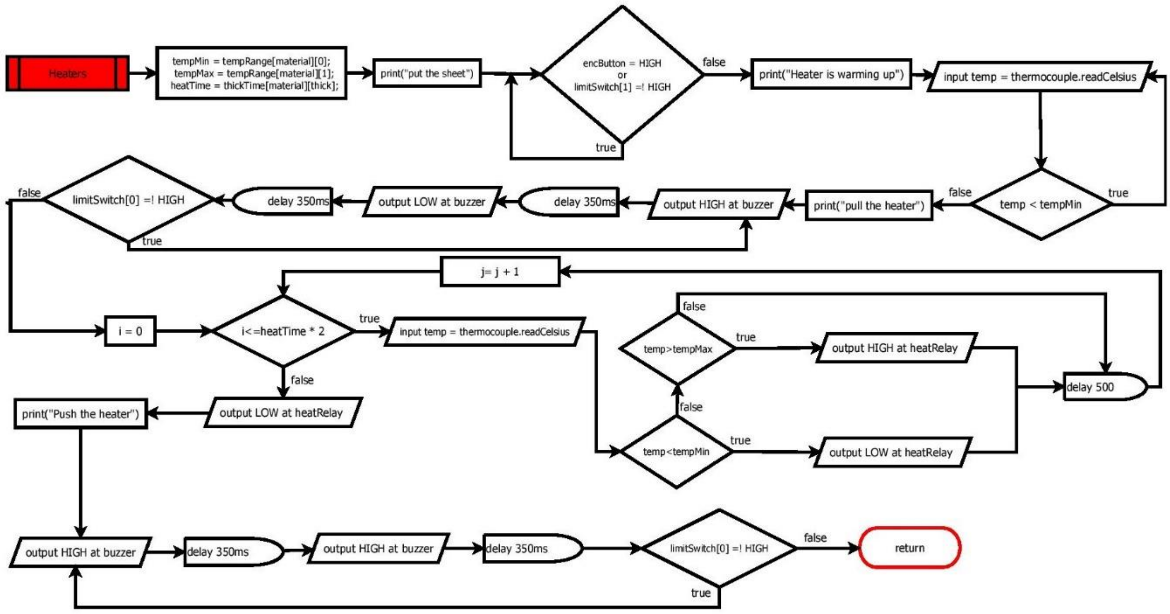


Figure 42: Heaters Flow Chart

7.2.3 Vacuum:

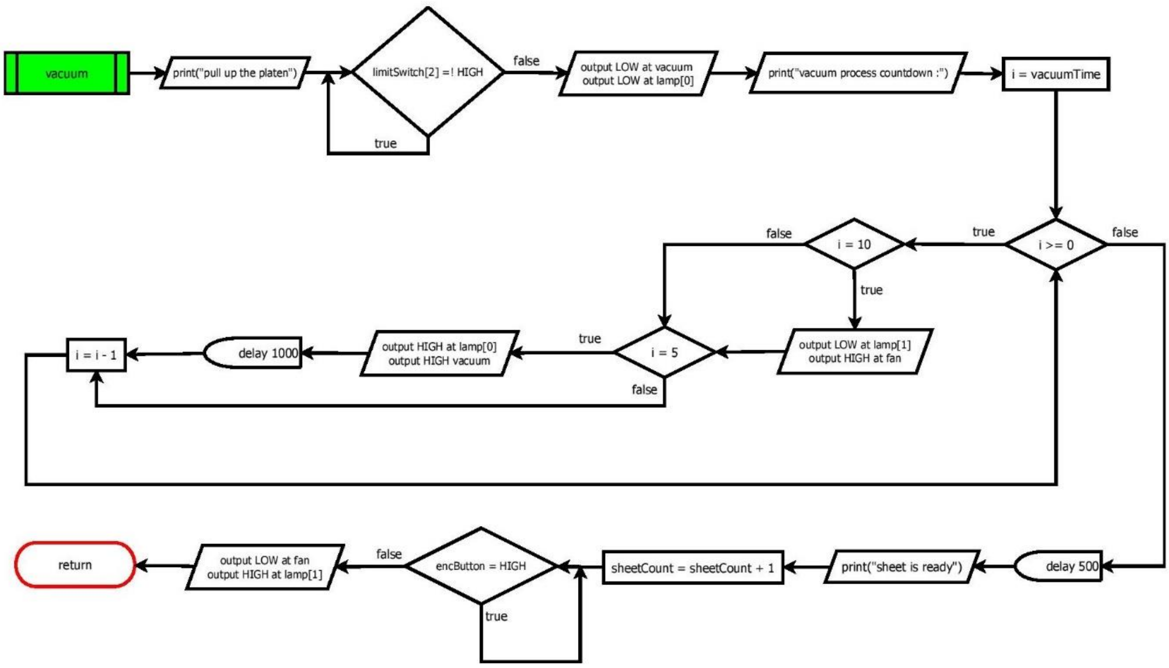


Figure 43: Vacuum Flow Chart

7.3 Algorithm

1. Import required libraries.
2. Assign due pins.
3. Initialize data variables (Material, Thickness & Temperatures).
4. Initialize LCD.
5. Display on LCD WELCOME message.
6. Display on LCD 1st Menu (Select Material).
7. Read encoder position.
8. Choose the material (PVC/Acrylic/PP).
9. Display on LCD 2nd Menu (Select thickness).
10. Read encoder position.
11. Choose the material thickness (300 µm / 650 µm / 1 mm).
12. Display on LCD 3rd Menu (Preview Chosen Data).
13. Read encoder position.
14. Choose (Continue or not):
    - Continue: Proceed to vacuum forming process.
    - Return: to 1st Menu.
15. Display on LCD put sheet instruction.
16. Read end limit switch (heaters) signal, until heater reaches.
17. Turn On the heater's relay, wait till it warmed up.
18. Turn On buzzer.
19. Display on LCD pull the heater instruction.
20. Read start limit switch (heaters) signal, until heater reaches.
21. Turn Off buzzer.
22. Start heating time count and Read Thermocouple signal:
    - Temp. > <u>Max. Temp.</u>: Turn Off the heater's relay.
    - Temp. < <u>Min. Temp.</u>: Turn On the heater's relay.
23. When heating time count ends:
    - Turn Off the heater's relay.
    - Display on LCD push heaters instruction.
    - Turn On buzzer.
24. Read end limit switch (heaters) signal, until heater reaches.
25. Turn Off buzzer.
26. Display on LCD pull up platen instruction.
27. Read limit switch (platen)signal, Until Platen reaches.
28. Turn on Vacuum & its lamp.
29. Display on LCD Vacuum Process Countdown.
30. <u>After 15 seconds:</u>
    - Turn On fan.
    - Turn On fan's lamp.
31. <u>After 20 seconds:</u>
    - Turn Off Vacuum.
    - Turn Off Vacuum's lamp.

32.Display on LCD to take the sheet instruction.
33.Read encoder button until pressed.
34.Turn Off fan and its lamp.
35.Display on LCD 4th Menu (Sheet Count).
36.Display on LCD sheet numbers.
37.Read encoder position.
38.Choose:

- Make another sheet: Proceed to vacuum forming process.
- Return to options: go to 1st Menu.

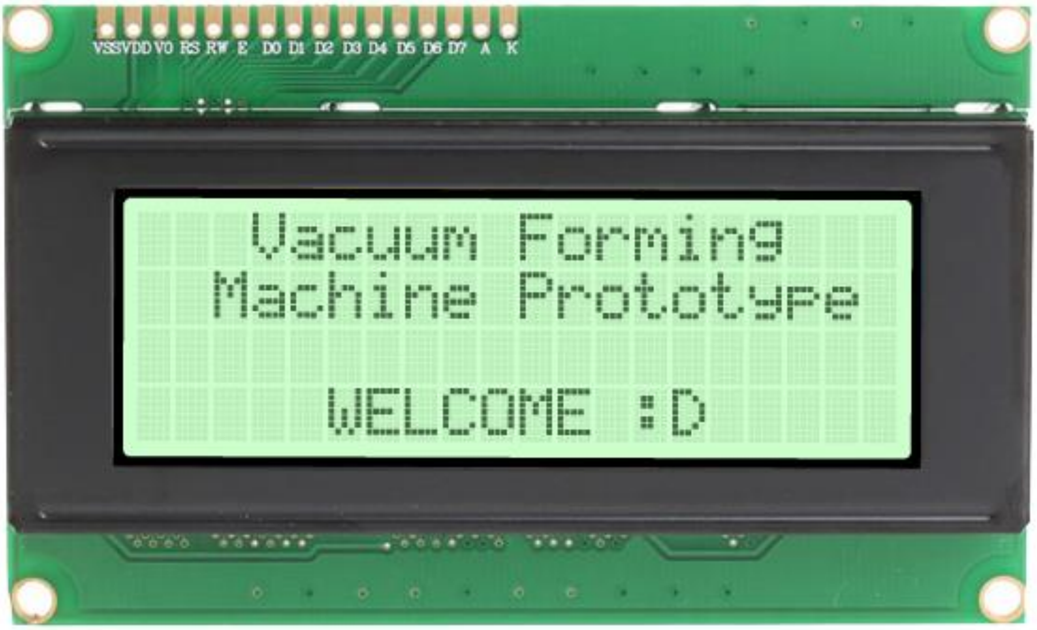


Figure 44: Start Screen

Chapter 8: Applications

Below we have allocated sub-headings to a wide range of industries using vacuum forming for a multitude of applications. The list is fairly comprehensive and although there are many other potential applications, we have attempted to highlight the most popular.

Aeronautical Manufacturers:

- Interior Trim Panels, Covers and Cowlings Internal sections for NASA Space Shuttle.

Agricultural Suppliers

- Seed Trays, Flower Tubs, Animal Containers, Clear Growing Domes.
- Calf Milking Receptacles, Machines Parts.
- Lawnmower Enclosures and Covers.

Architectural Model Makers

- Production of Miniature Parts for Architectural Models;
- Prototypes.

Automotive and Vehicular Industry

- Wheel Hub Covers, Ski-Boxes and Storage Racks Wind Tunnel Models, Parts for All Terrain Vehicles Truck Cab Door Interiors, Wind and Rain Deflectors.
- Scooter Shrouds, Mudguards, Bumpers and Protective Panels
- Battery and Electronic Housings, Prototype and Development work
- Utility Shelves, Liners, Seat Backs, Door Inner liners and Dash Surrounds
- Windshields, Motorcycle Windshields, Golf Cart Shrouds, Seats and Trays
- Tractor Shrouds & Door Fascia, Camper Hardtops and Interior Components

Building and Construction Industry

- Drainpipe Anti Drip fittings
- Roof Lights, Internal Door Liners, PVC Door Panels Producing Molds for Concrete Paving Stones and Special Bricks
- Molded Features for Ceilings, Fireplaces, Porches and other items.

Hospitals and Medical Applications

- Radiotherapy Masks for Treatment of Cancer Patients
- Pressure Masks for Burn Victims
- Dental Castings
- Prosthesis Parts
- Parts for Wheelchairs and Medical Devices for the Disabled

Packaging and related Industries

- Point of Purchase
- Trays and Plates
- Cosmetic Cases and Packages
- Electronics and Cassette Holders
- Blister Pack Products, Skin Pack Products Food Trays, Cups and Fast-Food Containers

Design Industry

- Production of prototypes and Pre-Production Runs
- Prototype Concepts for other Plastic Processes

Chocolate industry

- Manufacture of Chocolate Molds for Specialized Chocolates
- Easter Eggs etc. and Packaging

Computer Industry

- Manufacture of Screen Surrounds
- Soft Transparent Keyboard Covers Enclosures and Ancillary Equipment

Sanitary Industry

- Bathroom Fittings
- Bathtubs, Jacuzzis and Whirlpools Bath
- Shower Surrounds, Shower Trays and Retrofit Shower Components

Film and Media Industry

- Manufacture of Costumes and Sets
- Animation Models and Mock Ups for Computer Simulation

Mask HIPS **Compact mini**

Packaging HIPS - **300XQ**

Medical mask PETG - **686**

Motorcycle Parts Acrylic capped ABS - **686**

Air conditioning units ABS - **686**

Helmet HIPS **1372**

Luggage Acrylic capped ABS - **1372**

Radio controlled car body shelf PC Lexan - **1372**

POS Display HIPS/PETG - **1372**

POS Display HIPS/PETG -**1372**

Props Acrylic Capped ABS - **FMDH660**

Guitar case ABS **1500**

Bicyle case HDPE - **1250**

Blister PETG **TF Series**

HIPS **TF Series**

Marine pod Acrylic Capped ABS **HD Series**

References

[1] A Low-Cost Vacuum-Forming System Paper "James P. O'Leary ,1976"

[2] A thermo forming manual

[3] Shigley's Mechanical Engineering Design

[4] Machinery's Handbook, Large Print

[5] Book of Festo Company "Standards based bearings DSBC to ISO 15552"

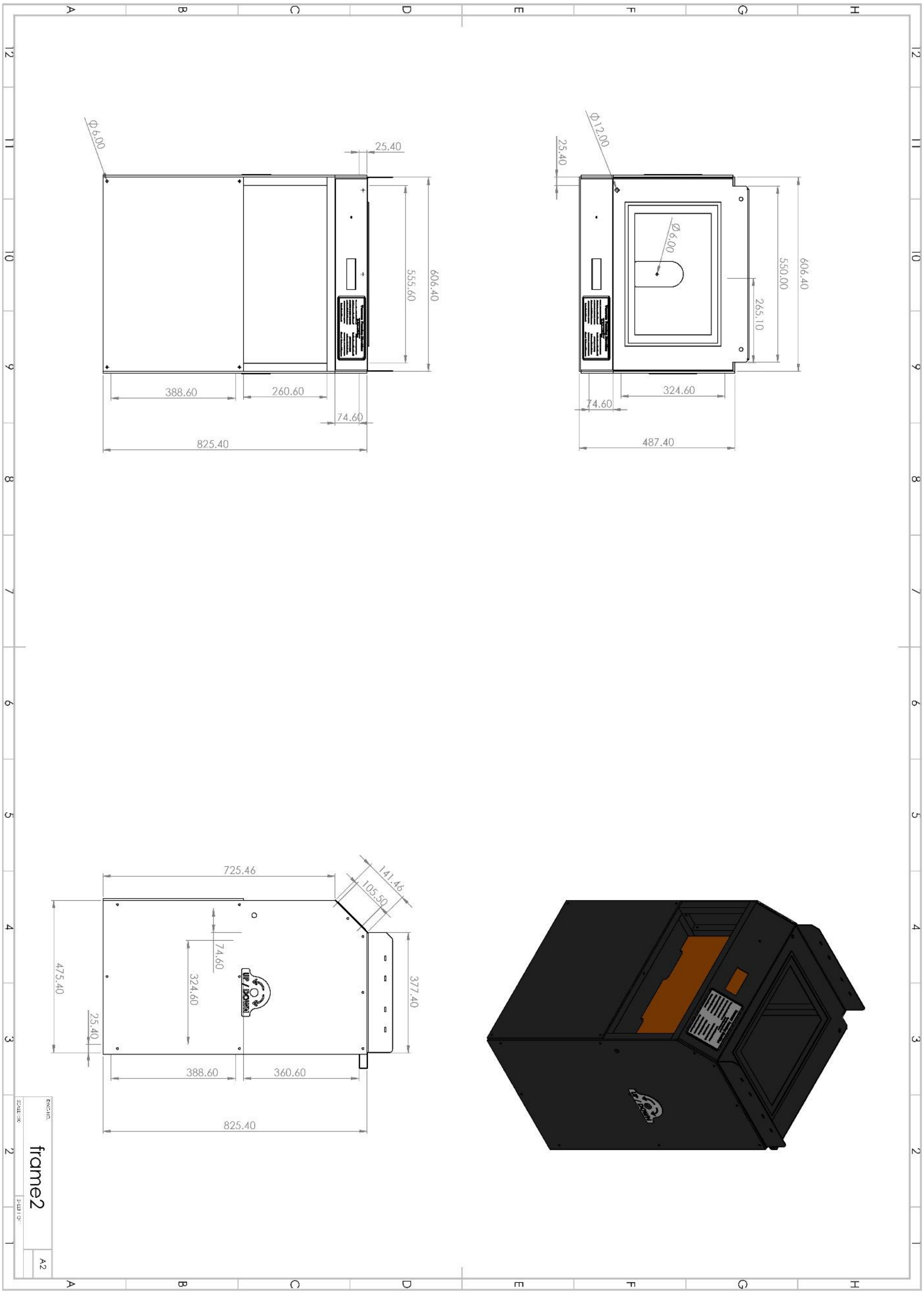
[6] J.V. Miro, A.S. White, Modeling and industrial manipulator a case study, Simulation practice and theory, 9(2002) 293-319.

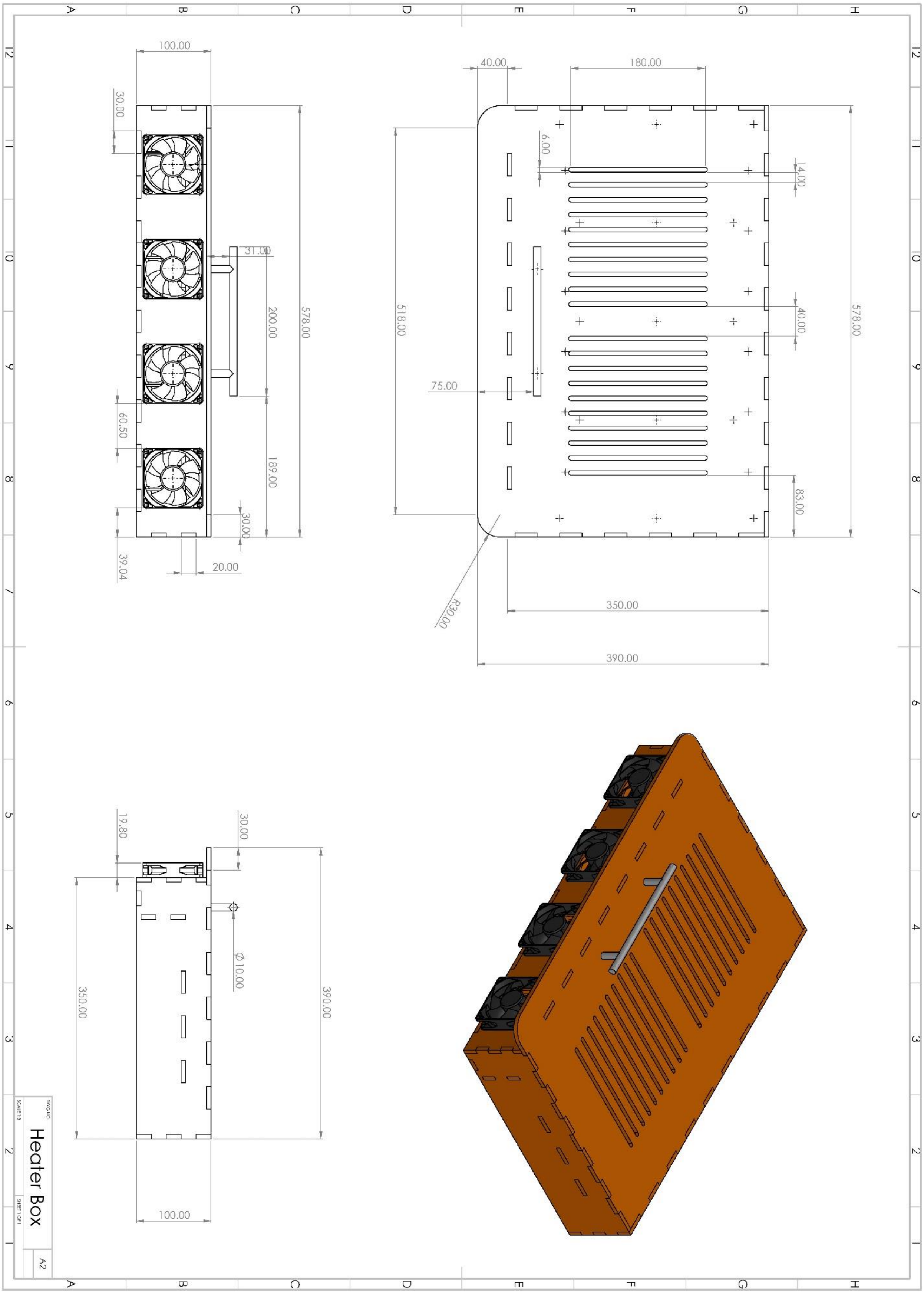
[7] https://lastminuteengineers.com/

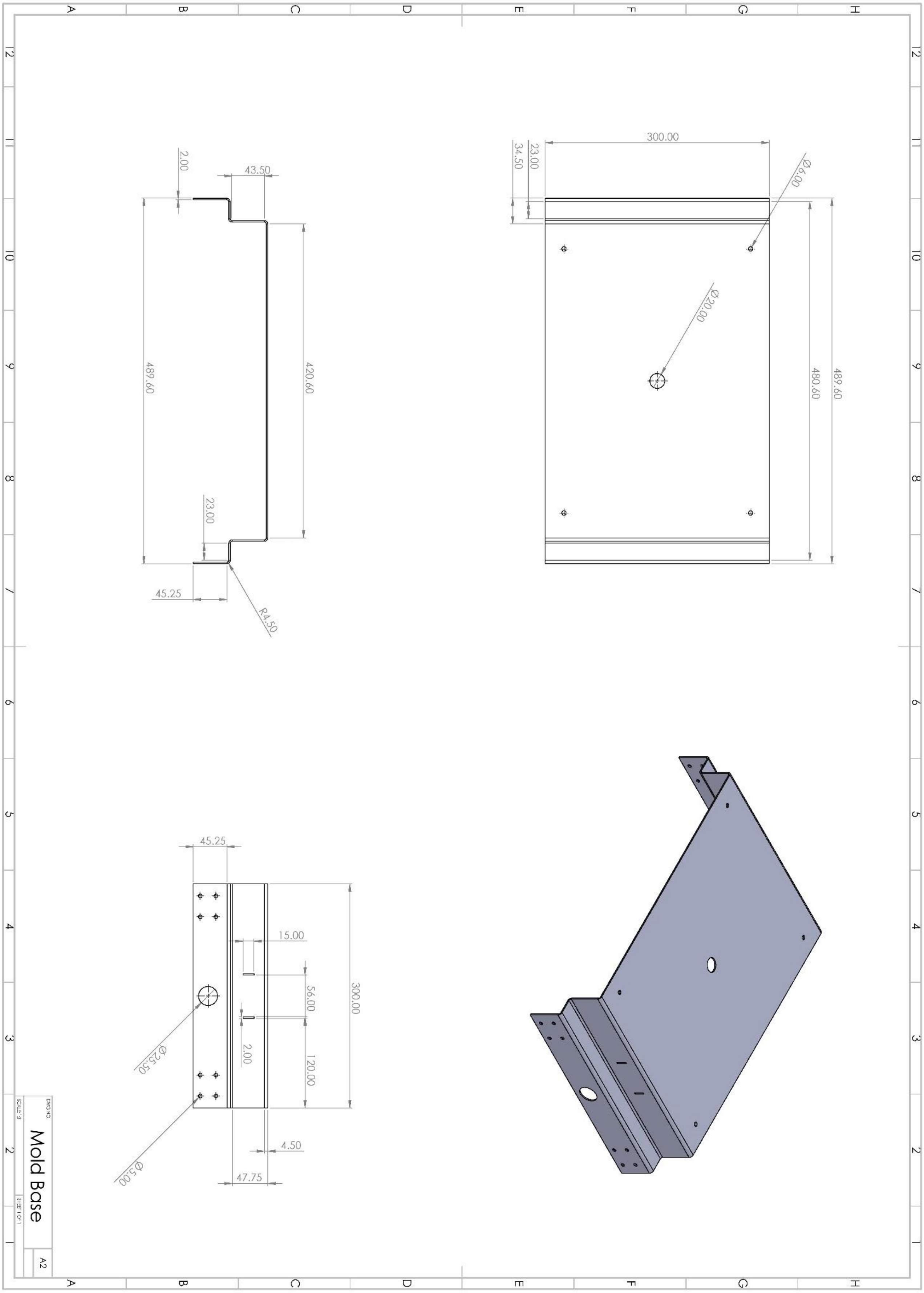
[8] https://www.arduino.cc/

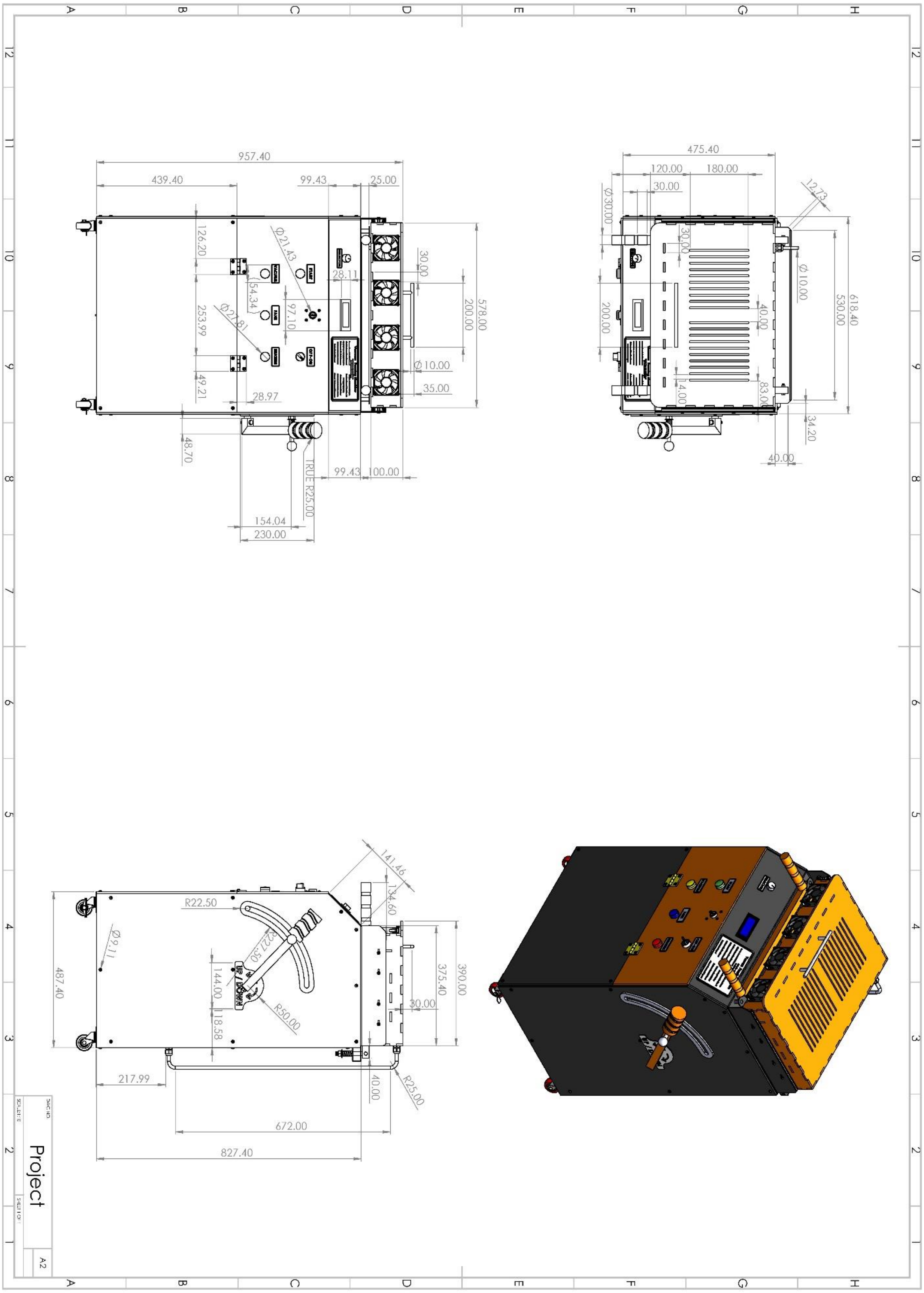
Appendix (A)

Mechanical drawings:




Heater Box
A2
100.00
30.00
31.00
200.00
578.00
60.50
189.00
30.00
39.04
20.00
40.00
180.00
6.00
14.00
518.00
40.00
578.00
75.00
83.00
R30.00
350.00
390.00
19.80
30.00
Ø10.00
350.00
390.00
100.00


Mold Base
A2
300.00
34.50
23.00
Ø6.00
Ø20.00
480.60
489.60
2.00
43.50
420.60
489.60
23.00
45.25
R4.50
45.25
15.00
56.00
300.00
120.00
2.00
Ø25.50
Ø5.00
4.50
47.75


Project
A2
957.40
439.40
99.43
25.00
475.40
120.00
180.00
30.00
578.00
200.00
618.40
530.00
487.40
390.00
375.40
672.00
827.40
217.99
141.46
134.60
R22.50
R50.00
R25.00
TRUE R25.00
154.04
230.00

Appendix (B)

Programming code:

```
/*
 *- Project neame: Vacuum forming machine prototype.
 *- Programmers: Abdelrahman Nasr Maaroof, Mahmoud Ali Abdalmonem, Mahmoud Ibrahim Osman.
 *- Revision history: V4.6
 *- Description: Manual vacuum forming machine used to shape plastic materials. During the vacuum forming process, a sheet of plastic is heated and then pulled around a single mould using suction.
 *- Development details:
      MCU: Arduino Mega, SW: Arduino IDE.
 *- Notes: A program to take the user input fot the sheet material type and its thickness then start the vacuum forming process with heating the sheet first then vacuum air to shape it after the
           placed Mould with all the information and instructions displayed on LCD and 4 lamps for indications.
 */

//Including required libraries:
#include <LiquidCrystal.h> //LCD library included with arduine IDE
#include <max6675.h> //Thermocouple Temperature Sensor K Type with the Maxim MAX6675 K-Thermocouple to digital converter IC library by Adafruit
#include <Encoder.h> //Encoder library by Paul Stoffregen
//Pins variables:
LiquidCrystal lcd(29, 31, 37, 39, 41, 43); //LCD pins (rs, en, d4, d5, d6, d7)
Encoder myEnc(18, 19); //Encoder signal pins (interrupt pins for best performance)
MAX6675 thermocouple(4, 3, 2); //Thermocouple Temperature Sensor K Type signal pins (thermoCLK, thermoCS, thermoDO)
const int encButton = 17; //Encoder push button
const int lamp[2] = {45, 35}; //Index(0): for vacuum lamp, Index(1): for fans lamp
const int heatRelay = 21; //For heaters and its lamp
const int buzzer = 11;
const int limitSwitch[3]={27, 23, 25}; //Index(0,1): start and end for heaters, Index(2): end for platen
const int fan = 10;
const int vacuum = 20; //The vacuum source relay
//Data variables:
int material = 0; //Acrylic-PVC:0, PP:1
String materialName = "";
int thick = 0;
String thickName = "";
float temp = 0.0;
float tempMax = 0.0, tempMin = 0.0; //The temperature range for forming the sheet
int heatTime = 0; //The time needed for the sheet to be formed
int heatTimeCount = 0;
int sheetCount = 0;
int vacuumTime = 25; //The vacuum time
//LCD Menues variables:
long counter = 0; //Encoder position
int menu = 0;
int opt = 0;
long lastCounter = -999;
bool pushed = true;
//Material and thickness heat forming data:
```

```
const float tempRange[2][2] = {{150.0, 190.0}, {150.0, 180.0}}; //tempMin =
tempRange[material][0], tempMax = tempRange[material][1]
const int thickTime[2][4]={{0, 19, 29, 39}, {0, 20, 30, 40}}; //heatTime =
thickTime[material][thick]
//LCD special characters:
uint8_t arrow[8] = {0x00, 0x04, 0x06, 0x1f, 0x06, 0x04, 0x00, 0x00}; //Arrow
char
uint8_t checked[8] = {0x00, 0x10, 0x10, 0x14, 0x12, 0x1F, 0x02, 0x04};
//Checked char
uint8_t slash[8] = {0x00, 0x10, 0x18, 0x0C, 0x06, 0x03, 0x01, 0x00};
//Backslash char


void setup() {
  // put your setup code here, to run once:
  //The pins mode (Input or Output)
  pinMode(encButton, INPUT);
  pinMode(heatRelay, OUTPUT);
  pinMode(buzzer, OUTPUT);
  pinMode(fan, OUTPUT);
  pinMode(vacuum, OUTPUT);
  for(int i = 0; i < 3; i++){
    if(i < 2)
    {
      pinMode(lamp[i], OUTPUT);
      digitalWrite(lamp[i], HIGH);
    }

    pinMode(limitSwitch[i], INPUT);
  }
  //Initialize the outputs
  digitalWrite(heatRelay, LOW);
  digitalWrite(buzzer, LOW);
  digitalWrite(fan, LOW);
  digitalWrite(vacuum, HIGH);
  //Initialize the LCD
  lcd.begin(20, 4);
  lcd.createChar(1, checked); //Create the checked symbol
  lcd.createChar(2, arrow);   //Create the arrow symbol
  lcd.createChar(3, slash); //Create the backslash symbol
  lcd.home();                 //Home the LCD

  //Display the welcome message
  lcd.clear();
  lcd.setCursor(3, 0);
  lcd.print("Vacuum Forming");
  lcd.setCursor(2, 1);
  lcd.print("Machine Prototype");
  lcd.setCursor(5, 3);
  lcd.print("WELCOME :D");
  delay(3000);
  lcd.clear();
}

void loop() {
  // put your main code here, to run repeatedly:
  counter = myEnc.read(); //Read the encoder position

  //Limit the position range
  if(counter > 17){
    counter = 17;
  }
  if(counter < 0){
```

```
    counter = 0;
  }
  //Display menus when encoder rotate or is pushed:
  if(counter != lastCounter || pushed){
    pushed = false;
    //1st menu (choose material: PVC, Acrylic or PP):
    if(menu == 0)
    {
      if(0 <= counter && counter < 6)
      {
        lcd.setCursor(0,0);
        lcd.print("Select material:");
        lcd.setCursor(0,1);
        lcd.write(2);
        lcd.print("PVC");
        lcd.setCursor(0,2);
        lcd.print(" Acrylic");
        lcd.setCursor(0,3);
        lcd.print(" PP");
        opt = 1;
      }
      if(6 <= counter && counter < 12)
      {
        lcd.setCursor(0,0);
        lcd.print("Select material:");
        lcd.setCursor(0,1);
        lcd.print(" PVC");
        lcd.setCursor(0,2);
        lcd.write(2);
        lcd.print("Acrylic");
        lcd.setCursor(0,3);
        lcd.print(" PP");
        opt = 2;
      }
      if(12 <= counter && counter < 18)
      {
        lcd.setCursor(0,0);
        lcd.print("Select material:");
        lcd.setCursor(0,1);
        lcd.print(" PVC");
        lcd.setCursor(0,2);
        lcd.print(" Acrylic");
        lcd.setCursor(0,3);
        lcd.write(2);
        lcd.print("PP");
        opt = 3;
      }
    }
    //2nd menu (choose thickness: 300µm, 650µm or 1mm):
    if(menu == 1)
    {
      if(0 <= counter && counter < 6)
      {
        lcd.setCursor(0,0);
        lcd.print("Select thickness:");
        lcd.setCursor(0,1);
        lcd.write(2);
        lcd.print("300 \xe4m");
        lcd.setCursor(0,2);
        lcd.print(" 650 \xe4m");
        lcd.setCursor(0,3);
        lcd.print(" 1 mm");
        opt = 1;
```

```
    }
    if(6 <= counter && counter < 12)
    {
      lcd.setCursor(0,0);
      lcd.print("Select thickness:");
      lcd.setCursor(0,1);
      lcd.print(" 300 \xe4m");
      lcd.setCursor(0,2);
      lcd.write(2);
      lcd.print("650 \xe4m");
      lcd.setCursor(0,3);
      lcd.print(" 1 mm");
      opt = 2;
    }
    if(12 <= counter && counter < 18)
    {
      lcd.setCursor(0,0);
      lcd.print("Select thickness:");
      lcd.setCursor(0,1);
      lcd.print(" 300 \xe4m");
      lcd.setCursor(0,2);
      lcd.print(" 650 \xe4m");
      lcd.setCursor(0,3);
      lcd.write(2);
      lcd.print("1 mm");
      opt = 3;
    }
  }
  //3rd menu (comformition step)
  if(menu == 2)
  {
    if(0 <= counter && counter < 9)
    {
      lcd.setCursor(0,0);
      lcd.write(1);
      lcd.print("Material: ");
      lcd.print(materialName);
      lcd.setCursor(0,1);
      lcd.write(1);
      lcd.print("Thickness: ");
      lcd.print(thickName);
      lcd.setCursor(0,2);
      lcd.write(2);
      lcd.print("Continue");
      lcd.setCursor(0,3);
      lcd.print(" Return");
      opt = 1;
    }
    if(9 <= counter && counter < 18)
    {
      lcd.setCursor(0,0);
      lcd.write(1);
      lcd.print("Material: ");
      lcd.print(materialName);
      lcd.setCursor(0,1);
      lcd.write(1);
      lcd.print("Thickness: ");
      lcd.print(thickName);
      lcd.setCursor(0,2);
      lcd.print(" Continue");
      lcd.setCursor(0,3);
      lcd.write(2);
      lcd.print("Return");
```

```
        opt = 2;
      }
    }
    //4th menu (repeat or return to options)
    if(menu == 3)
    {
      if(0 <= counter && counter < 9)
      {
        lcd.setCursor(0,0);
        lcd.print("Total sheet count:");
        lcd.setCursor(0,1);
        lcd.write(1);
        lcd.print("  ");
        lcd.print(sheetCount);
        lcd.print("  sheets      ");
        lcd.setCursor(0,2);
        lcd.write(2);
        lcd.print("Make another sheet");
        lcd.setCursor(0,3);
        lcd.print(" Return to options");
        opt = 1;
      }
      if(9 <= counter && counter < 18)
      {
        lcd.setCursor(0,0);
        lcd.print("Total sheet count:");
        lcd.setCursor(0,1);
        lcd.write(1);
        lcd.print("  ");
        lcd.print(sheetCount);
        lcd.print("  sheets      ");
        lcd.setCursor(0,2);
        lcd.print(" Make another sheet");
        lcd.setCursor(0,3);
        lcd.write(2);
        lcd.print("Return to options");
        opt = 2;
      }
    }
  }

  lastCounter = counter;
  //The menus different options actions
  if(!digitalRead(encButton)){
    delay(500);
    pushed = true;
    myEnc.write(0);
    lcd.clear();
    //1st menu save the material number and name
    if(menu == 0)
    {
      menu = 1;

      if(opt == 1)
      {
        material = 0;
        materialName = "PVC";
      }
      if(opt == 2)
      {
        material = 0;
        materialName = "Acrylic";
      }
```

```
      if(opt == 3)
      {
        material = 1;
        materialName = "PP";
      }
    }
    //2nd menu save the thickness
    else if(menu == 1)
    {
      menu = 2;
      thick = opt;
      if(opt == 1)
      {
        thickName = "300 \xe4m";
      }
      if(opt == 2)
      {
        thickName = "650 \xe4m";
      }
      if(opt == 3)
      {
        thickName = "1 mm";
      }
    }
    //3rd and 4th menus preform the vacuum forming process
    else if(menu == 2 || menu == 3)
    {
      if(opt == 1)
      {
        menu = 3;
        heaters();
        Vacuum();
      }
      if(opt == 2)
      {
        menu = 0;
      }
    }
  }

}

void heaters() {
  //The heaters section:
  tempMin = tempRange[material][0];
  tempMax = tempRange[material][1];
  heatTime = thickTime[material][thick];
  //Display place the sheet instruction
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print("Push back the Heater");
  lcd.setCursor(0,1);
  lcd.print("Then place the Sheet");
  lcd.setCursor(6,2);
  lcd.print("Please..");
  lcd.setCursor(0,3);
  lcd.write(2);
  lcd.print("Continue");
  //Read the limit switch till the heaters are pushed
  while(digitalRead(encButton) || !digitalRead(limitSwitch[1]));
  //Wait till the heaters warm up
  digitalWrite(heatRelay , HIGH);
  lcd.clear();
```

```
  lcd.setCursor(0,0);
  lcd.print("Heater is warming up");
  lcd.setCursor(3,1);
  lcd.print("Please Wait...");
  lcd.setCursor(0,3);
  lcd.print("Temp: ");
  lcd.print(tempMin);
  lcd.write(3);
  do{
    temp = thermocouple.readCelsius();
    lcd.setCursor(13,3);
    lcd.print(temp);
    delay(500);
    lcd.print(" ");
  }while(temp < tempMin);
  //Display pull the heaters instruction
  lcd.clear();
  lcd.setCursor(2,1);
  lcd.print("Pull the Heaters");
  lcd.setCursor(2,2);
  lcd.print("forward Please..");
  //Turn on the buzzer and read the start limit switch for the heaters till
it reaches
  do{
    digitalWrite(buzzer, HIGH);
    delay(350);
    digitalWrite(buzzer, LOW);
    delay(350);
  }while(!digitalRead(limitSwitch[0]));
  //Turn off buzzer after completing
  digitalWrite(buzzer, 0);
  //The forming time countdown
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print("Forming  Temperature");
  lcd.setCursor(2,1);
  lcd.print("has been reached");
  lcd.setCursor(3,3);
  lcd.print("Countdown : ");
  lcd.print(heatTime);

  for(heatTimeCount = 0; heatTimeCount <= heatTime * 2; heatTimeCount++){
    temp = thermocouple.readCelsius();
    delay(500);
    if(heatTimeCount % 2 == 0)
    {
      lcd.setCursor(15,3);
      lcd.print(heatTime - (heatTimeCount / 2));
      lcd.print("  ");
    }
    if(temp > tempMax)
    {
      digitalWrite(heatRelay , LOW);
    }
    else if(temp < tempMin)
    {
      digitalWrite(heatRelay , HIGH);
    }
  }
  //Turn off heaters after completing
  digitalWrite(heatRelay , LOW);
  lcd.clear();
  lcd.setCursor(2,0);
```

```
  lcd.print("Heating  process");
  lcd.setCursor(1,1);
  lcd.print("has been completed");
  lcd.setCursor(0,2);
  lcd.print("Push back the Heater");
  lcd.setCursor(3,3);
  lcd.print("again Please..");
  //Turn on the buzzer and read the end limit switch for the heaters till it
reaches
  do{
    digitalWrite(buzzer, HIGH);
    delay(350);
    digitalWrite(buzzer, LOW);
    delay(350);
  }while(!digitalRead(limitSwitch[1]));
  //Turn off buzzer after completing
  digitalWrite(buzzer, 0);
}



void Vacuum() {
  //The vacuum section:
  //Display pull up the platen instruction
  lcd.clear();
  lcd.setCursor(1,1);
  lcd.print("Pull up the Platen");
  lcd.setCursor(6,2);
  lcd.print("Please..");
  //Read the end limit switch for the platen till it reaches
  while(!digitalRead(limitSwitch[2]));
  //Trun on the vacuum and its lamp after completing
  digitalWrite(vacuum, LOW);
  digitalWrite(lamp[0], LOW);
  lcd.clear();
  lcd.setCursor(3,0);
  lcd.print("Vacuum Process");
  lcd.setCursor(3,1);
  lcd.print("in progress ..");
  lcd.setCursor(3,2);
  lcd.print("Countdown : ");
  lcd.begin(20, 4);
  //Vacuum time countdown
  for(int i = vacuumTime; i >= 0; i--){
    //Turn on fans and its lamp
    if(i == 10)
    {
      digitalWrite(fan, HIGH);
      digitalWrite(lamp[1], LOW);
      lcd.begin(20, 4);
    }
    //Turn off vacuum source and its lamp
    if(i == 5)
    {
      digitalWrite(vacuum, HIGH);
      digitalWrite(lamp[0], HIGH);
      lcd.begin(20, 4);
    }
    lcd.begin(20, 4);
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print("   Vacuum Process   ");
```

```
    lcd.setCursor(0,1);
    lcd.print("   in progress ..   ");
    lcd.setCursor(0,2);
    lcd.print("   Countdown :      ");
    lcd.setCursor(15,2);
    lcd.print(i);
    lcd.setCursor(0,3);
    lcd.print("                    ");
    delay(1000);
  }
  delay(500);
  //Display take out the sheet instruction
  lcd.begin(20, 4);
  lcd.createChar(1, checked);
  lcd.createChar(2, arrow);
  lcd.createChar(3, slash);
  lcd.clear();
  lcd.setCursor(3,1);
  lcd.print ("Sheet is Ready");
  lcd.setCursor(1,2);
  lcd.print("You can take it ..");
  lcd.setCursor(0,3);
  lcd.write(2);
  lcd.print("Continue");
  sheetCount++;
  //Wait till the sheet is taken out
  while(digitalRead(encButton));
  //Turn off fans and its lamp
  digitalWrite(fan, LOW);
  digitalWrite(lamp[1], HIGH);
  lcd.begin(20, 4);
  lcd.createChar(1, checked);
  lcd.createChar(2, arrow);
  lcd.createChar(3, slash);
  delay(500);
}
```