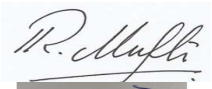
Form TH-4

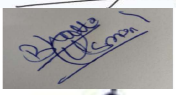
National University of Sciences & Technology (NUST)

MASTER'S THESIS WORK

We hereby recommend that the dissertation prepared under our supervision by: Mubashir Nazir (00000317921)
Titled: Design & Development of Pneumatic Based PVC Pipe Bending Machine. be accepted in partial fulfillment of the requirements for the award of MS in Mechanical Engineering degree.

Examination Committee Members

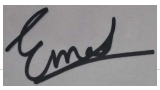
1. Name: Riaz Ahmed Mufti Signature: 

2. Name: Muhammad Usman Bhutta Signature: 

3. Name: Jawad Aslam Signature: 

Supervisor: Mian Ashfaq Ali Signature: 

Date: 08 - Aug - 2023



Head of Department

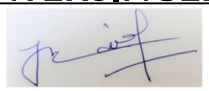
08 - Aug - 2023

Date

COUNTERSINGED

08 - Aug - 2023

Date



Dean/Principal

Design and Development of Pneumatic Based PVC Pipe Bending Machine

Author

Mubashir Nazir

Reg. # 00000317921

Supervisor

Dr. Mian Ashfaq Ali

DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY,

ISLAMABAD

JUNE 2023

Design and Development of Pneumatic Based PVC Pipe Bending Machine

Author

Mubashir Nazir

Reg. # 00000317921

A thesis submitted in partial fulfillment of the requirements for the degree of

MS Mechanical Engineering

Thesis Supervisor:

Dr. Mian Ashfaq Ali

Thesis Supervisor's Signature: 

DEPARTMENT OF MECHANICAL ENGINEERNG

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY,

ISLAMABAD

JUNE 2023

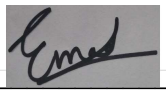
THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by Mr. Mubashir Nazir, Registration No.317921 of SMME has been vetted by undersigned, found complete in all aspects as per NUST Statutes/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature with stamp: 

Name of Supervisor: Dr. Mian Ashfaq Ali

Date: 08-Aug-2023

Signature of HoD with stamp: 

Date: 08-Aug-2023

Countersign by

Signature (Dean/Principal): 

Date: 08-Aug-2023

Declaration

I certify that this research work titled "*Design and Development of Pneumatic Based PVC Pipe Bending Machine"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student

MUBASHIR NAZIR

2019-NUST-MS-Mech-317921

Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical, and spelling mistakes. Thesis is also according to the format given by the university.

Signature of Student

MUBASHIR NAZIR

2019-NUST-MS-Mech-317921

Signature of Supervisor

Proposed Certificate for Plagiarism

It is certified that MS Thesis Titled **Design and Development of Pneumatic Based PVC Pipe Bending Machine** by **MUBASHIR NAZIR** has been examined by us. We undertake the follows:

a. Thesis has significant new work/knowledge as compared already published or are under consideration to be published elsewhere. No sentence, equation, diagram, table, paragraph or section has been copied verbatim from previous work unless it is placed under quotation marks and duly referenced.
b. The work presented is original and own work of the author (i.e., there is no plagiarism). No ideas, processes, results or words of others have been presented as Author own work.
c. There is no fabrication of data or results which have been compiled/analyzed.
d. There is no falsification by manipulating research materials, equipment or processes, or changing or omitting data or results such that the research is not accurately represented in the research record.
e. The thesis has been checked using TURNITIN (copy of originality report attached) and found within limits as per HEC plagiarism Policy and instructions issued from time to time.

Name & Signature of Supervisor

Dr. MIAN ASHFAQ ALI

Signature**:** 

Copyright Statement

Acknowledgements

I am thankful to my Creator Allah Subhana-Watala to have guided me throughout this work at every step and for every new thought which Your setup in my mind to improve it. Indeed, I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

I am profusely thankful to my beloved parents who raised me when I was not capable of walking and continued to support me throughout in every department of my life.

I would also like to express special thanks to my supervisor **DR. MIAN ASHFAQ ALI** for his help throughout my thesis. From the beginning he had confidence in my abilities to not only complete this thesis but to complete it with excellence. He is always being available whenever I require his guidance as well as for motivating me throughout the research work. Without his help it was not possible to complete this thesis in befitting manner.

I would also like to pay special thanks to my GEC members **Dr. Riaz Ahmad Mufti, Dr. Jawad Aslam** and **Dr. Muhammad Usman Bhutta** for his tremendous support and cooperation. Each time I got stuck in something; he came up with the solution. Without his help I wouldn't have been able to complete my thesis. I appreciate his patience and guidance throughout the whole thesis.

Finally, I would like to express my gratitude to all the individuals especially **Faizan Hussain, Mr. Mohsin Shah** and **Mr. Ghulam Adil** who have rendered valuable assistance to my study.

Dedicated to my exceptional parents, adored siblings and mentors whose tremendous support and cooperation led me to this wonderful accomplishment.

Abstract

As the name suggests, this thesis is about the design and development of a machine that is used for the bending of PVC pipes. This machine is used to bend a 7-inch length of PVC pipe into a curved shape and to perform socketing operation at both ends of a PVC pipe for joining purposes. Basically, we want to make an elbow because it has a wide range of applications, especially in electrical conduits. Elbows are used in pipe fittings as a joint to redirect the straight pipe at an angle of 90 degrees. The size of the machine is very convenient for portable work. The machine is available worldwide but is very expensive. We wanted to manufacture a customized version for our local market that could be serviced locally at a minimum cost. The aim of this thesis was to develop a PVC pipe bending machine that is used to bend PVC pipes with a diameter up to 0.75 inch and a wall thickness up to 1.4 mm. The machine also performs socketing operation at both ends of a PVC pipe. This is not a novel idea but a transfer of technology to Pakistan using reverse engineering. Currently, there is no company in Pakistan that can work on these moderately advanced technologies with the aim of indigenization and local production. The developed machine has consistent superior quality, a pipe heating system, socket pins, sliding guides, pneumatic cylinders, a die, linear bearings, plates, a distribution panel, and a simple user interface. These small components were integrated to make a fully functioning, stand-alone, cost-effective PVC pipe bending machine. The machine was designed with the objective that it should be easy to operate by a common, unskilled operator.

During the production of this machine, parts and sub-assemblies were outsourced for production. It is important to point out that there was no need to build a new plant or assembly line for the manufacturing of this machine, as it was made at various mechanical fabrication shops that had good fabrication facilities. The critical part of this development lies in system integration. We designed and developed a customized solution in the form of a PVC pipe bending machine that is not only beneficial for our local industry but also has potential for export to other countries. This selection was based on extensive interaction, during which we realized that there was a strong need for this in our local market. Moreover, this project strengthened industry-university linkages and developed a trend of cooperation. This cooperation is the need of the hour. There are very few companies in Pakistan that have this technology, but most of the small players do not have access to it. This locally developed machine can be repaired in Pakistan with ease and will be tailored and sized for our local market's needs. The use of this machine will create jobs and reduce unemployment in the country.

Key Words: Die, PVC Pipe, PVC Pipe Bending, Pipe Bending Machine, Pneumatic Cylinders, Elbow, Guide and Socket Pins.

TABLE OF CONTENTS

Declaration i
Language Correctness Certificate ii
Proposed Certificate for Plagiarism iii
Copyright Statement iv
Acknowledgements v
Abstract vii
TABLE OF CONTENTS viii
Chapter 01: Introduction 1
1.1 Background 1
1.2 Pipe Bending Process 1
1.3 Importance 2
1.4 Applications 3
1.5 Motivation 4
1.6 Advantages 5
1.7 Objective 5
1.8 Technical Specifications of Machine 6
Chapter 02: Literature Review 7
2.1 Hardware Components 7
2.1.1 Pneumatic Cylinder 7
2.1.2 Pneumatic Solenoid Valve 9
2.1.3 Air Compressor 11
2.1.4 Air Pipe, Pneumatic Fittings & Cable Ties 12
2.1.5 Temperature Sensor 14
2.1.6 Proximity Sensor 15
2.1.7 Distribution Panel 16
2.2 Already Existing Machines 17
2.3 Pneumatic Cylinder Specifications 18
Chapter 03: Methodology 19
3.1 Engineering Materials 19
3.1.1 Selection of material for designing a component: 19

3.1.2 Mild Steel: 20
3.1.3 Advantages: 21
3.2 Machine Design 21
3.2.1 Design of DIE 21
3.2.2 Main Frame 22
3.2.3 Base Table 23
3.2.4 Socketing Pin 24
3.2.5 Guide Pin 24
3.2.6 Die Plate 25
3.2.7 Punch Plate 26
3.2.8 Side Plate 27
3.2.9 Cylinder Plate 27
3.2.10 Distribution Box / Distribution Panel 28
3.2.11 3D CAD Model of Machine 38
3.2.12 Heating Element 38
3.2.13 Heating Capacity 39
3.2.14 Heater Design 40
3.2.15 Heater Outer Casing Design 41
3.3 Wiring Diagram 41
3.3.1 Elaboration of Wiring Diagram 43
Chapter 04: Results and Conclusion 44
4.1 Manufacturing 44
4.2 MANUFACTURING ASSISTANCE 48
4.2.1 MRC 48
4.2.2 Tribology Lab 49
4.2.3 Local Market Vendors 50
4.3 Energy Consumption for Heater 51
4.4 Production and Testing 52
4.5 Conclusion 54
References 55

LIST OF FIGURES

Figure 1 Work Piece [1] 2
Figure 2 Different Shapes and Sizes of PVC Bends 3
Figure 3 Double Acting Pneumatic Cylinder [2] 8
Figure 4 Pneumatic Solenoid Valve 9
Figure 5 Air Compressor [2] 11
Figure 6 Air Pipe, Cable Ties and Pneumatic Fittings [2] 12
Figure 7 Temperature Sensor 14
Figure 8 Proximity Sensor 15
Figure 9 Distribution Panel 16
Figure 10 Existing PVC Pipe Bending Machines 17
Figure 11 Pneumatic Cylinder Specifications [3] 18
Figure 12 Material Properties 20
Figure 13 Mild Steel 20
Figure 14 Mild Steel Properties 21
Figure 15 3D CAD Model of DIE 22
Figure 16 Punch and Die 22
Figure 17 Main Frame 3D Model 23
Figure 18 Base Table 3D Model 23
Figure 19 Socket Pin 3D Model 24
Figure 20 Guide Pin 3D Model 25
Figure 21 Die Plate 3D Model 26
Figure 22 Punch Plate 3D Model 26
Figure 23 Side Plate 3D Model 27
Figure 24 Cylinder Plate with Linear Bearings & Guide Pins 28
Figure 25 Distribution Box 3D Model 29
Figure 26 Switching Power Supply 30
Figure 27 Single Pole Circuit Breaker 30
Figure 28 Two-Pole Circuit Breaker 31
Figure 29 On-Delay Timer [4] 32
Figure 30 General Purpose Relay [5] 32

Figure 31 Control Panel LED Indicators....33
Figure 32 Temperature Control Process....33
Figure 33 Temperature Controller....34
Figure 34 Start Switch....35
Figure 35 Emergency Stop Switch....36
Figure 36 PVC Electrical Strip Connector....36
Figure 37 Contactor....37
Figure 38 3D CAD Model of Machine....38
Figure 39 Heating Element....39
Figure 40 Heater Design....40
Figure 41 Heater Outer Casing 3D Model....41
Figure 42 Wiring Diagram....42
Figure 43 Manufactured Pipe Bending Machine 1....44
Figure 44 Manufactured Pipe Bending Machine 2....45
Figure 45 Manufactured Pipe Bending Machine 3....46
Figure 46 Manufactured Pipe Bending Machine 4....47
Figure 47 MRC NUST....48
Figure 48 Tribology Lab....49
Figure 49 Local Vendors....50
Figure 50 Testing Results....52
Figure 51 Poor Quality Pipe Samples without Air Blow....53

Chapter 01: Introduction

There are numerous types of bending. Pneumatic and hydraulic bending are the most common. Nevertheless, pneumatic bending is preferred to hydraulic bending. The speed of pneumatic bending is its main benefit. Because pneumatic bending is ten times faster than hydraulic bending, they can complete various tasks more quickly and effectively. Because pneumatic bending is so adaptable, it can be installed in a factory in any necessary position, even upside down. With the aid of a punch, which applies a lot of force to the work piece clamped on the die, the bend has been created [2].

Now a days, with all the resources available, it is necessary to reduce labor work and time due to technological advancements. When we contrast human labor with automation, several issues become apparent. The bending machine used in this research study is a semi-automatic bending machine, meaning that the PVC pipe must be manually loaded and unloaded before it may be bent pneumatically [2].

The user's manual effort will be reduced by the pneumatic PVC pipe bending machine. The user will find a pneumatic PVC pipe bending machine helpful in managing and producing accurate results for PVC pipe at the time of bending. In comparison to executing it manually, it will take less time. The machine is designed with the objective that it should be easy to operate by a common unskilled operator. PVC pipe bending machines are widely used in the PVC piping industry to make elbows used in pipe fittings.

1.1 Background

PVC pipe bending was already carried out by using manual approach. In manual approach, the trick is to fill the pipe with sand before heating the plastic and bending it. The sand prevents the pipe from pinching closed in regions where it is curved. You simply pour out the sand after the heat forming is finished. Pipe bending was also done by simple heating method as well as with the help of boiling water. The PVC pipe bending using manual approaches is time taking and tedious. Those manual approaches are obsolete now. To handle these problems, we wanted to develop a semi-automatic machine used to bend PVC pipes and perform socketing operation at both ends of pipes. Also, we want to reduce production time and cost.

1.2 Pipe Bending Process

- Attach the compressor pipe to the machine and turn on the machine, the compressor, and the heater.
- Cut a 10-foot length of PVC pipe into seven-inch-long pieces.
- Heat the piece using a heater to a temperature of 100 $^{\circ}$C for one minute.
- Place the work piece between the slots of a die for bending after heating.
- Press the start button (Green Button) to start the process.
- After that, bending force is applied with a pneumatic punch.
- After bending, it begins socketing a PVC pipe at both ends.

- Our work piece is ready to be used after the socketing process.

Figure 1 *Work Piece* [1]

1.3 Importance

This research project has an impact on our local society in terms of creating business & job opportunities and problem solutions i.e., value creation. In Pakistan, the demand for PVC bends is very high due to its use in various applications like electrical conduits and irrigation piping, etc. Pakistan is still importing these types of simpler machines. We as a community have failed so far. I accept it. The development of this machine is also useful for industrial issues and the local market needs.

Polyvinyl chloride pipe, or PVC pipe for short, is widely recognized for its multiple advantages in a variety of domestic, agricultural, and industrial applications around the world. You can find PVC pipe and its variations used in many different types of industrial applications for drinking water transportation, plumbing, irrigation, and liquid transportation and distribution. PVC is currently considered the third most commercially produced plastic in the world.

There are a few things which one should consider before going for pipe bending process.

- Market survey i.e., demand of the product in market.
- Product development budget.
- Design complexity of machine.
- Material selection.
- Precision.

You should decide how precise your final product must be after production. If you are looking for a top-quality finish with a low budget, then PVC pipe bending machine is the best option available for you.

1.4 Applications

The PVC bends are extensively used because they are eco-friendly, durable, easy to install, resistant to corrosion, light in weight, have a long service life, inexpensive, and extensively accepted by codes. The top places where PVC bends can be used are:

- ✓ Water plumbing and water pipes
- ✓ Waste handling and control
- ✓ Rainwater management
- ✓ Agriculture
- ✓ Fire sprinklers
- ✓ Industrial use
- ✓ Chemical Handling
- ✓ Irrigation systems
- ✓ Building infrastructure and structural material
- ✓ Coatings and cable insulation
- ✓ Used for fittings
- ✓ Drinking water distribution
- ✓ Sewage & underground drainage
- ✓ Electrical conduits

PVC pipe bending is essential for a wide variety of industries such as:

- ✓ Commercial Vehicles
- ✓ Ship Building
- ✓ Industrial
- ✓ Aviation & Aerospace
- ✓ Other Industries
- ✓ Architectural
- ✓ Automotive etc.

Polyvinyl chloride (PVC) is the third most commonly manufactured plastic polymer in the world. PVC rigid forms are used to make PVC pipes that have a variety of uses. Polyvinyl chloride (PVC) pipe is the most commonly used plastic pipe material. PVC pipes are manufactured in various dimensions and sizes.

Figure 2 *Different Shapes and Sizes of PVC Bends*

They are widely used in sewage systems, irrigation, water supply lines, drain holes and various industries. The properties of PVC pipe regarding safety, robustness, cost-effectiveness, environmental sustainability and recyclability allow it to be used for a variety of purposes, from transporting water to treating industrial or chemical waste. PVC pipes can be used both underground and above ground in any building. They are unaffected by commonly used chemicals such as salts, acids, oxidants and bases.

1.5 Motivation

There are many technological solutions available worldwide which has not been utilized in Pakistan for the reason of being expensive and its viability for small businesses. PVC pipe bending machine is a similar example that is available in the international market, but it is expensive. Pakistan population and hence demand in many sectors is growing day by day but due to the lack of technical expertise we rarely see any local company that work on the transfer of technology and provide any customized solutions with cost effectiveness. Customized solution matters because a machine available in the international market has many features and eventually becomes expensive whereas our local demand may require a few features among those. A machine if tailored for our requirements with limited required features will have a much lower price and will be much cost-effectively customized. But making such a customized solution can only be done after carrying complete R&D of the existing machine and consultation with local industry partner a solution can be tailored for our local market. Over the past few years, we have interacted with many industrial partners and small vendors to know about their key issues. Most of the industry is not willing to adopt the high-tech solution and machinery as it is expensive, and it does not seem viable to them due to their small business size. One can list a dozen of diverse types of semi-automatic machines that can be made locally in Pakistan with little R&D effort such as PVC pipe bending machine, wheel balancing machine, wheel alignment machine, automatic hose crimping machine etc. Pakistan is still importing these machines from China and other countries. The development of these machines is system integration which requires the knowledge of sensors, actuators, software, and data acquisition. We have the capability of using sensor, actuators, software, and system integration for any requirement.

Currently many companies are making PVC bends manually using hand-made methods of fabrication. This manual manufacturing method suffers from low quality and low production. The local piping industry needs modern pipe bending technology which has been adopted globally with promising production and superior quality. The problem is that this machine is expensive, and many companies are unable to afford it. This justified the local and indigenous development of this machine.

Impact on Local Industry

Utilization of local raw materials:

Most of the local raw materials were utilized for fabrication of main frame and mechanical guide's mechanism, DB box, plates and socket pins, heater, base table, die manufacturing and painting etc. All types of machining services were done locally.

Creation of Employment:

It created new jobs and opportunities in the making of this machine, and it will surely create more in the coming future. Technical staff and engineers were involved initially, followed by marketing professionals. Machine production created indirect jobs in several ways.

Utilizing current skills or creating new skills:

The development of this machine required the skill of mechanical engineer design and manufacturing skills which are basic. However, to reverse engineer a certain machine we were required to carry R&D, where new skills and vital information were learned as we progressed. The overall project resulted in better understanding of the technical staff of the partnering industry on this machine and the specialized skills were imparted to the technicians and engineers working at our university.

Impact on local manufacturing or service cluster:

This product significantly improved the quality of bends manufactured with this machine in comparison with hand-made bends. Further the machine has a high production rate and as a result small companies will now be able to do business with new companies that need high production. The machine is not only required by the partnering industry, but many similar companies are looking for such a viable and suitable product.

Solution to current local problems:

Currently, the PVC elbow manufacturing companies in Pakistan are making PVC bends of different shapes and sizes manually. These hand-made products suffer from inadequate quality and a low production rate. This low-cost machine can be employed by many companies for their business growth. This machine can make high quality bends when operated by any common unskilled operator.

1.6 Advantages

Some of the advantages are as follows:

- Easy to operate
- Low maintenance
- Pneumatic based
- Semi-Automatic
- Made in Pakistan

1.7 Objective

The objective of this machine is to bend PVC pipes having length of 7 inches with a diameter up to 0.75 inch and a wall thickness up to 1.4 mm.

The machine should be:

- Able to perform socketing operation at both ends of a PVC pipe.
- Easy to operate by a common unskilled operator.

1.8 Technical Specifications of Machine

The technical specifications of the machine are given below:

- Product Name: PVC Pipe Bending Machine
- Operating voltage: 220V AC (Single phase)
- Operating frequency: 50 Hz
- Length of bending: 7 Inches
- Pipe Diameter: 0.75 Inch
- Wall Thickness: 1.4 mm
- Operation Mode: Semi-Automatic
- Bending: 90 Degrees
- Socketing: Both sides
- Compressor pressure: 6 Bar
- Machine Dimension: 915×605×735 mm
- Pipe Brand: ADAM JEE
- Heating Temperature: 100 ℃
- Machine Type: Fully Pneumatic
- Max. Air Pressure: Pneumatic cylinders can sustain up to 10 Bar or 1.0 MPa
- Machine Weight: >100kg
- Country of Origin: Made in Pakistan
- Controller: Temperature controller with Timer & Relays
- Machine speed: 1 Piece /10 seconds, 360 Pieces / hour
  OR 3600 Pieces /10 hours

Chapter 02: Literature Review

With recent technological growth, the piping sector offers great opportunities. As part of the piping industry, your requirements change daily. Manual pipe bending cannot meet the increasing market demands in terms of quality, quantity and cost. PVC pipe is a better and environment friendly option than traditional piping systems. PVC pipe is made of low-carbon plastic and requires minimal resources and energy to manufacture. PVC pipe has high level of inertness and is resistant to corrosion, making it ideal for transporting drinking water. PVC pipes require minimal maintenance, last long and are easily recycled [6].

PVC is a synthetic plastic polymer. About 40 million tons of PVC products are manufactured annually. Most PVC products are made at 45- and 90-degree angles. In many cases, building structures require PVC products at different angles and need to be bent. PVC softens at about 121 ℃, liquefies at 176 ℃, and carbonized at 218 ℃. Most PVC pipes can be safely bent. Bending PVC pipe with the right amount of heat and pressure allows you to change angles without damaging it. It is important to understand how much the pipe can bend. A rule of thumb is: Take a pipe and bend it. The amount a pipe naturally bends is approximately the amount it safely and permanently bends when exposed to heat. In particular, this machine used compressed air to perform the bending process. This makes the machine or process much more efficient than manual bending. The bending radius is possible within the limits of this machine.

2.1 Hardware Components

A customized PVC pipe bending machine driven by pneumatic actuators is designed and developed. There are several hardware components that are being used for this machine. Below is the list of hardware components which we have used for our machine to give a brief overview of what we have built.

1) 3 × Pneumatic Cylinders
2) Pneumatic Solenoid Valve
3) Air Compressor
4) Air Pipe, Pneumatic Fittings & Cable Ties
5) Temperature Sensor
6) 3 × Proximity Sensors
7) Distribution Box

2.1.1 Pneumatic Cylinder

A pneumatic cylinder, also known as an air cylinder, is a mechanical device that utilizes the power of compressed gas to create the force of reciprocating linear motion. Like a hydraulic cylinder, something is attempting to move the piston in the desired direction. A piston is a disc or cylinder, and a piston rod transmits the force generated by it to a moving object. Engineers may prefer to use air pressure as it is quieter, cleaner and does not take up much space for fluid storage. Because the working fluid is a gas, a leak from a pneumatic cylinder will not drip or contaminate the surroundings, making pneumatics desirable where cleanliness is required [7].

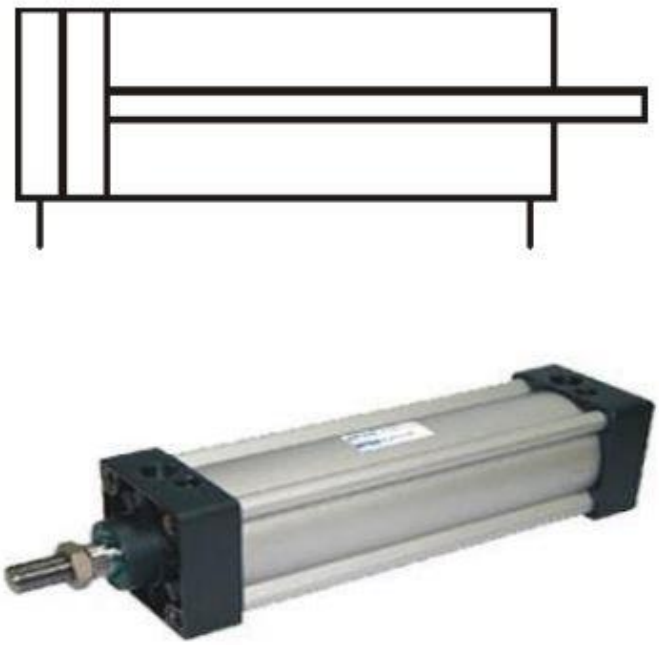


Figure 3 *Double Acting Pneumatic Cylinder* [2]

A pneumatic cylindrical actuator is a device that compresses air and converts its energy into mechanical motion. They are highly preferred over other alternatives for safety reasons as they do not require combustion or electrical connections. Their maintenance costs are also almost negligible. There are basically three types of pneumatic cylinders, which are as follows [8]:

1. Single Acting Pneumatic Cylinders
    a. Push type single acting cylinder
    b. Pull type single acting cylinder
2. Double Acting Pneumatic Cylinders
    a. Through rod cylinder
    b. Cushion end cylinder
    c. Tandem cylinder
    d. Impact cylinder
    e. Cable cylinder
    f. Rotary or turn cylinder
3. Telescopic Pneumatic Cylinders
    a. Tie rod cylinder
    b. Flanged type
    c. One-piece welded
    d. Threaded end

2.1.2 Pneumatic Solenoid Valve

A pneumatic solenoid operating valve is an electromechanically operated valve. The valve is controlled by current through a solenoid. Two-port valves turn the flow on or off. The outflow is switched between two outlet ports with the help of a three-port valve. We can place multiple solenoid valves together on a manifold. The most often utilized control elements in fluidics are solenoid valves. Their duties include turning off, releasing, dosing, distributing, and mixing fluids. They are utilized in numerous areas of application. Fast and secure switching, long service life, high reliability, good medium compatibility of the materials employed, low control power, and compact design are all advantages of solenoids.

Basically, there are three types of control valves based on their function in the pneumatic system. They are classified as follows [9]:

- Flow Control Valves
- Pressure Control Valves
- Direction Control Valves

Figure 4 *Pneumatic Solenoid Valve*

A directional control valve (DCV) regulates the flow direction in a pneumatic circuit, as its name suggests. To put it another way, direction control valves (DCVs) govern which way the fluid flows in a pneumatic circuit. A five-port two-position directional control valve has two exhaust ports, two working ports and one pressure port. A five port, two position valve known as a "5/2 way"

allows air or fluid to enter one end of a double acting device while also enabling the other end to exhaust. Pneumatic cylinder actuators are operated by a 5/2-way (5 Port 2 Position) solenoid valve. The specifications of the direction control solenoid valve that we have used in our machine are as follows [10]:

- Product Name: Pneumatic Solenoid Valve
- Brand Name: GPH VALVE
- Model: 4V210-08
- Working Pressure: 0.15 ~ 0.8 MPa
- Port Size: G 1/4″
- Working Fluid: Air
- Color: Silver
- Valve Type: 5/2 way (5 Port 2 Position)
- Operating Voltage: DC24V
- Operating Power: 4.0 W
- Operating Current: 165 mA
- Material of Body: Aluminum Alloy
- Temperature: -20 ~ 70°C
- Media: Gas
- Weight (g): 220 g
- Max. Frequency: 5 cycles/sec
- Packing: Box
- Place of Origin: Zhejiang, China.

2.1.3 Air Compressor

An air compressor is a pneumatic device that transforms power into potential energy stored in pressurized air (also known as compressed air) using an electric motor, diesel engine, gasoline engine, etc. By employing one of several methods to force more and more air into the container, an air compressor increases the pressure in a storage tank. The air compressor turns off when tank pressure reaches its maximum level. The tank stores the compressed air until it is needed. Utilizing the kinetic energy of the air when it is released and the tank depressurizes, the energy contained in the compressed air can be utilized for a variety of uses. The air compressor restarts and pressurizes the tank when tank pressure falls below its minimum level. Electric or gas/diesel driven air compressors are the two most popular types. HP (Horsepower) and CFM (Cubic Feet of Air per Minute) are the units used to express a compressor's power. You can determine how much compressed air is "in reserve" by looking at the tank's gallon capacity [11].

Figure 5 *Air Compressor* [2]

The upper surface of the device has a head valve that controls the inlet of the discharge valves. When the pressure inside the chamber is low, the piston moves to the bottom position, creating a vacuum in the top position of the chamber. In order to fill the upper section of the chamber, outside air that has atmospheric pressure is drawn into the chamber via an inlet valve. When a piston moves upward, the air inside the higher section is compressed. By discharging, the compressed air moves into the storage chamber, increasing the pressure inside. Inside the chamber, a pressure regulation switch monitors the pressure and turns it off when it exceeds the maximum level set by the manufacturer. There is a safety valve that activates if the apparatus malfunctions.

Types of Air Compressors

Basically, there are two major types of air compressor.

1. Positive Displacement
    a. Rotary
        i. Lobe
        ii. Screw
        iii. Liquid Ring
        iv. Scroll
        v. Vane
    b. Reciprocating
        i. Diaphragm
        ii. Single Acting
        iii. Double Acting
2. Dynamic
    a. Axial
    b. Centrifugal
    c. Mixed

2.1.4 Air Pipe, Pneumatic Fittings & Cable Ties

1. Air Pipe

A pipe is a tubular portion or hollow cylinder that is typically, but not always, circular in cross section and is used to transport things including liquids, gases, slurries, powders, and masses of tiny particulates. Additionally, it can be used for structural applications because hollow pipe is significantly more rigid per unit weight than solid components. We have used air piping in order to provide compressed air to the pneumatic cylinders for their operation.

Figure 6 *Air Pipe, Cable Ties and Pneumatic Fittings* [2]

2. **Pneumatic Fittings**
   Pneumatic fittings are components used in pneumatic (pressurized gas) systems to join segments of pipe, tube, and hose. When compared to hydraulic fittings, pneumatic fittings generally provide tighter seals and lower pressure requirements. They are extensively employed in pneumatic instrumentation and logic control systems. In any pneumatic system, fittings act as the vital connection between components.

3. **Cable Ties**
   A cable tie, often referred to as a zip tie or tie-wrap, is a type of fastener that can be used for a broad range of purposes, including bundling and organizing cables and wires to prevent damage. The nylon cable tie's basic design is a section of tape with triangular teeth that slope in one direction. When the tape is inserted, the cable tie's head features a slot with a flexible pawl that travels irreversibly up the slope of these teeth. To prevent the removal of the tape, the pawl grips the backside of these teeth. Cable ties are available in various materials, colors, and sizes. The specifications of the cable tie that we have used in our machine in order to bundle wires and air pipes are as follows:

   - Model: CV-165
   - Type: Cable tie for bundling of cables & wires
   - Size: 6 Inch
   - Dimensions (L x W): 165 x 2.5 mm
   - Material: Nylon
   - Color: White
   - Brand: KSS
   - Brand Origin: Taiwan
   - Quantity: 100 pcs in one packet

Properties:

- Strong and thick material
- High durability
- Multipurpose (Tie two things together)
- Good tensile strength and insulation
- Not easy to get aging

2.1.5 Temperature Sensor

Any temperature sensor with chromel (Nickel-Chromium) and alumel (Nickel-Alumel) conductors that satisfies the output specifications outlined in ANSI/ASTM E230 or IEC 60584 for Type-K thermocouples is referred to as a Type-K thermocouple. This could be a wire, a surface sensor, an immersion sensor, or another style of sensor or cable. The Type-K thermocouple is the most popular one. It has broad temperature range, is affordable, accurate, and dependable. Type-K thermocouples typically have a measurement range of -200 to 1260°C, or -326 to 2300°F [12].

Figure 7 *Temperature Sensor*

Properties [13]**:**

- It is inexpensive.
- Have a fast response.
- Reliable, durable and accurate.
- Highly stable output.
- Small in size.
- Different cable lengths.
- Wide measurement range.

2.1.6 Proximity Sensor

The existence of nearby objects can be detected by proximity sensors without any physical contact. An electrical signal is produced when the object enters the sensor area, which aids in object detection. Inductive proximity sensors are gadgets that use basic principles of electromagnetic induction to detect metal objects. Eddy currents produced on a conductive surface by an external magnetic field are used to detect magnetic loss. Eddy currents produced on a metallic object are detected by changing the impedance, which is done by creating an AC magnetic field on the detector coil [14].

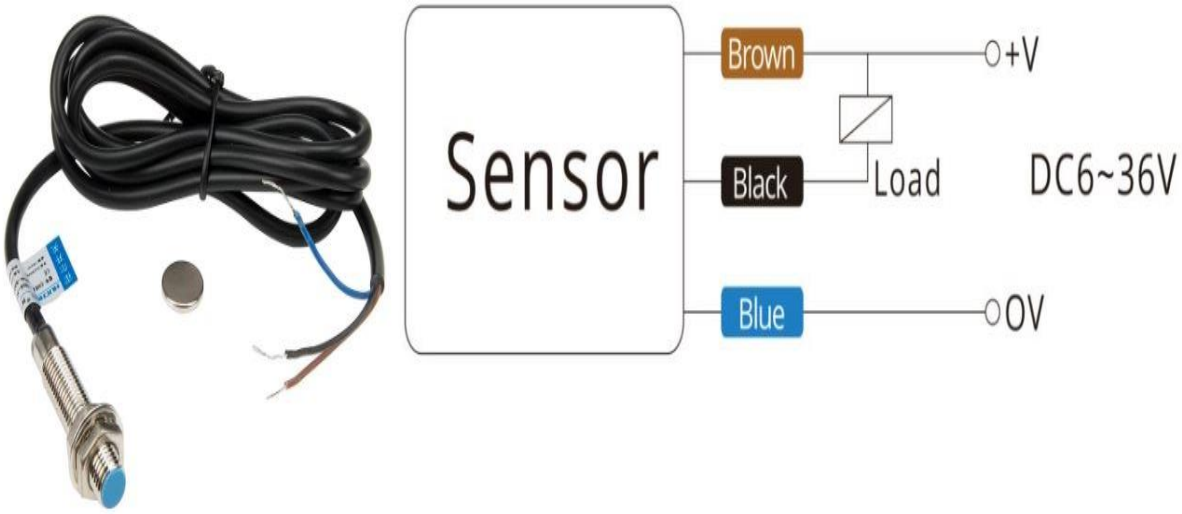


Figure 8 *Proximity Sensor*

The specifications of the proximity sensors that we have used in our machine in order to detect metal objects are as follows:

- Model Number: NJK-5001C
- Device Name: Hall Effect Proximity Switch Sensor
- Detection Distance: 10 mm ± 10 %
- Type: NPN
- Contact Form: NO (Normally Open)
- Supply Voltage: 24 VDC
- Indicator: Red LED
- Number of Wires: 3 Wires
- Switching Frequency: 200 Hz
- Consumption Current: ≤ 15mA
- Load Current: ≤ 200mA
- Manufacturer: China

2.1.7 Distribution Panel

It can be considered a controller for our machine as all the controls and power distribution is provided to components with the help of this box. It houses components like power supply, timer for timing delay, temperature controller for the measurement of temperature on the thermocouple, start and emergency stop switches, relays, LED indicators and circuit breakers. It has wire connectors to provide wire connection to wires from components like solenoid valve, proximity sensors, and temperature sensor.

Figure 9 *Distribution Panel*

The Standard Wire Gauge (SWG), usually referred to as the British Standard Gauge or Imperial Wire Gauge, in the United Kingdom. This standard is used to indicate wire and sheet metal thickness. The material used to manufacture the DB box is galvanized sheet of SWG18. The thickness of the 18 gauge galvanized sheet is 0.048 inches or 1.219 mm [15].

2.2 Already Existing Machines

Several PVC pipe bending machines are already developed in foreign countries. PVC pipe bending machines are being manufactured and used globally. The PVC pipe bending machine as shown in the figure below is our reference system for design and manufacturing of our machine. This reference machine comprises a solenoid valve, pneumatic cylinder actuators, and guides with linear bearing, die, socket pins, heating system, air compressor and base structure for providing support for assembly. This reference machine is basically manufactured in Hyderabad, India by "Sun Automation Systems" [16].

Figure 10 *Existing PVC Pipe Bending Machines*

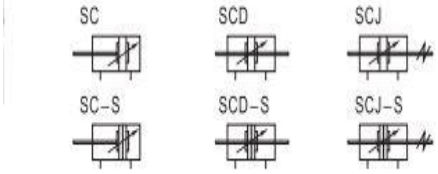
2.3 Pneumatic Cylinder Specifications

In order to transform fluid power into mechanical power, pneumatic cylinders function as linear actuators. They also go by the names JACKS or RAMS. Pneumatic cylinders are only capable of holding roughly 10 bar of pressure because gas is an unexpansive substance and using them at higher pressures is hazardous. As a result, they are made of lighter materials like brass and aluminum. The specifications of the cylinders that we have used in our machine are as follows [3]:

- Product Name: 5M PNEUMATIC CYLINDER
- Model: SC 80×200
- Type: SC Type (Double Acting)
- Bore Size: 80 mm
- Stroke Length: 200 mm
- Rod Type: Single Rod

SC Series

Symbol



Product feature

1. Standard cylinder manufactured by our enterprise.
2. The seal of piston adopts heterogeneous two way seal structure. It's dimension is tight and it has the function of grease reservation.
3. It is tie rod cylinder. The cylinder barrel and front/rear cap is jointed by tie rods with high reliability.

Specification

Bore size(mm)		32	40	50	63	80	100
Acting type		Double acting					
Fluid		Air(to be filtered by 40 μ m filter element)					
Mounting type	SC	Basic FA FB CA CB LB TC TCM1					
	SCD, SCJ	Basic FA LB TC TCM1					
Operating pressure		0.1~1.0MPa(15~145psi)(1.0~10.0bar)					
Proof pressure		1.5MPa(215psi)(15bar)					
Temperature ℃		-20~80					
Speed range mm/s		30~800					
Stroke tolerance		$0\sim250^{+1.0}_{0}$ $251\sim1000^{+1.4}_{0}$ $1001\sim1500^{+1.8}_{0}$					
Cushion type		Variable cushion					
Adjustable cushion stroke mm		21				28	29
Port size ①		1/8"	1/4"		3/8"		1/2"

① PT thread, NPT thread and G thread are available.
Add) Refer to P419~442 for detail of sensor switch.

Stroke

Bore size (mm)	Standard stroke (mm)	Max. std stroke	Max. stroke
32	25 50 75 80 100 125 150 160 175 200 250 300 350 400 450 500	1000	2000
40	25 50 75 80 100 125 150 160 175 200 250 300 350 400 450 500 600 700 800	1200	2000
50	25 50 75 80 100 125 150 160 175 200 250 300 350 400 450 500 600 700 800 900 1000	1200	2000
63	25 50 75 80 100 125 150 160 175 200 250 300 350 400 450 500 600 700 800 900 1000	1500	2000
80	25 50 75 80 100 125 150 160 175 200 250 300 350 400 450 500 600 700 800 900 1000	1500	2000
100	25 50 75 80 100 125 150 160 175 200 250 300 350 400 450 500 600 700 800 900 1000	1500	2000

Note) If the stroke is ≥1600mm within the maximum stroke scope, it is treated as non-standard one.
Please contact the company for other special strokes.

Figure 11 *Pneumatic Cylinder Specifications* [3]

Chapter 03: Methodology

First of all, a market survey and cost estimation were carried out about the product. Then market viability is checked for this machine, i.e., is there any need for this machine in the market? Then I got the input of industrial experts and people from the commercial market. Then a survey of prices is carried out. Then a literature survey was carried out to see how many existing models were already available in the market. Then we agreed on a model that we were going to develop. Then the modelling of that model is carried out. Then we started sequential fabrication, starting with the die and then the remaining parts one by one. At the end, we assemble all these parts, and then testing and commissioning are carried out.

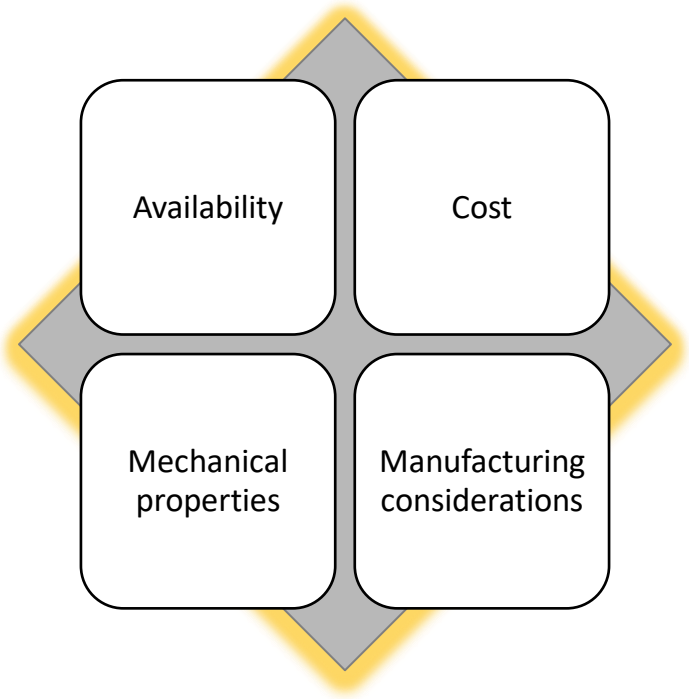
3.1 Engineering Materials

The information about materials and their properties is of significant importance and machine components ought to be made of such a material which holds properties appropriate for the required operational conditions.

Engineering materials can be classified into two main groups. First class is of metals and their alloys which include aluminum, copper, steel, iron etc. Second class is of non-metals that include rubber, plastic, glass etc. The metals may be further grouped as ferrous and non-ferrous metals.

3.1.1 Selection of material for designing a component:

Machine design starts with selection of materials which is a significant step in the design process. The optimum material is the one which can serve the planned objective at least cost. Selection was done after considering the following variables:



Machining capacity of a particular material is vital to be considered before selection. A cheaper material is of no use if it is hard to machine. An expensive material that is easy to machine can be more cost effective where complex shapes and casting properties are required.

Material	Modulus of Elasticity E		Modulus of Rigidity G		Poisson's Ratio ν	Unit Weight w		
	Mpsi	GPa	Mpsi	GPa		lbf/in^3	lbf/ft^3	kN/m^3
Aluminum (all alloys)	10.4	71.7	3.9	26.9	0.333	0.098	169	26.6
Beryllium copper	18.0	124.0	7.0	48.3	0.285	0.297	513	80.6
Brass	15.4	106.0	5.82	40.1	0.324	0.309	534	83.8
Carbon steel	30.0	207.0	11.5	79.3	0.292	0.282	487	76.5
Cast iron (gray)	14.5	100.0	6.0	41.4	0.211	0.260	450	70.6
Copper	17.2	119.0	6.49	44.7	0.326	0.322	556	87.3
Douglas fir	1.6	11.0	0.6	4.1	0.33	0.016	28	4.3
Glass	6.7	46.2	2.7	18.6	0.245	0.094	162	25.4
Inconel	31.0	214.0	11.0	75.8	0.290	0.307	530	83.3
Lead	5.3	36.5	1.9	13.1	0.425	0.411	710	111.5
Magnesium	6.5	44.8	2.4	16.5	0.350	0.065	112	17.6
Molybdenum	48.0	331.0	17.0	117.0	0.307	0.368	636	100.0
Monel metal	26.0	179.0	9.5	65.5	0.320	0.319	551	86.6
Nickel silver	18.5	127.0	7.0	48.3	0.322	0.316	546	85.8
Nickel steel	30.0	207.0	11.5	79.3	0.291	0.280	484	76.0
Phosphor bronze	16.1	111.0	6.0	41.4	0.349	0.295	510	80.1
Stainless steel (18-8)	27.6	190.0	10.6	73.1	0.305	0.280	484	76.0
Titanium alloys	16.5	114.0	6.2	42.4	0.340	0.160	276	43.4

Figure 12 *Material Properties*

3.1.2 Mild Steel:

Mild steel is a specific type of carbon steel. It has a low amount of carbon, which is why it is also named "low carbon steel". Typically, the amount of carbon content by weight is in a range of 0.05 to 0.25 percent, while higher-carbon steel has a range of 0.3 to 2.0 percent. Any further carbon content found in carbon steel can be classified as cast iron. Less carbon content will make steel more ductile and weldable. It will also be easier to machine than higher-carbon steels [17].

Figure 13 *Mild Steel*

3.1.3 Advantages:

Mild steel has no alternative when it comes to cost-effectiveness and versatility. It is the most considered form of steel dominating the engineering industry by a margin. Its applications are very vast, and it is used in many of the key areas of everyday life. It can easily be cut and modified according to the requirement which makes it a fair choice for most engineering applications.

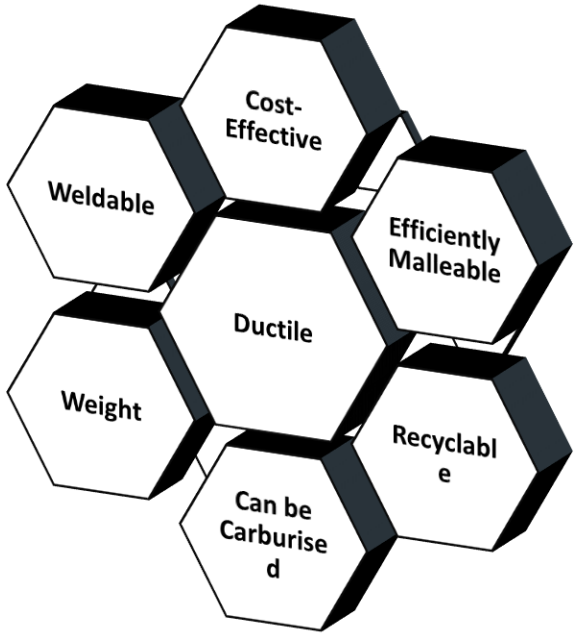


Figure 14 *Mild Steel Properties*

3.2 Machine Design

A design process follows a very flexible pattern that can be done according to the requirement. There is no specific pattern but in a general way it can be followed as [18].

Identify	***Consider***	***Select***	***Build***	***Test***	***Optimize***	***Share***
Problem	*Solutions*	*Model*	*Model*	*Evaluate*	*Design*	*Solution*

3.2.1 Design of DIE

Die design was the first thing we finalized to continue the design process. The die is made up of aluminum alloy 6061-T6, which has relatively high strength, good workability and high resistance to corrosion. It consists of an upper die (a punch) and a lower die, both of which are machined using CNC. The upper portion of the die is mounted with a pneumatic actuator with the help of a punch plate. The lower portion of the die rests on the base plate, and both are mounted on the base table via L-key bolts. Guide pins are used to align both the upper die (Punch) and lower die. All parts of the machine are designed in SolidWorks software [19].

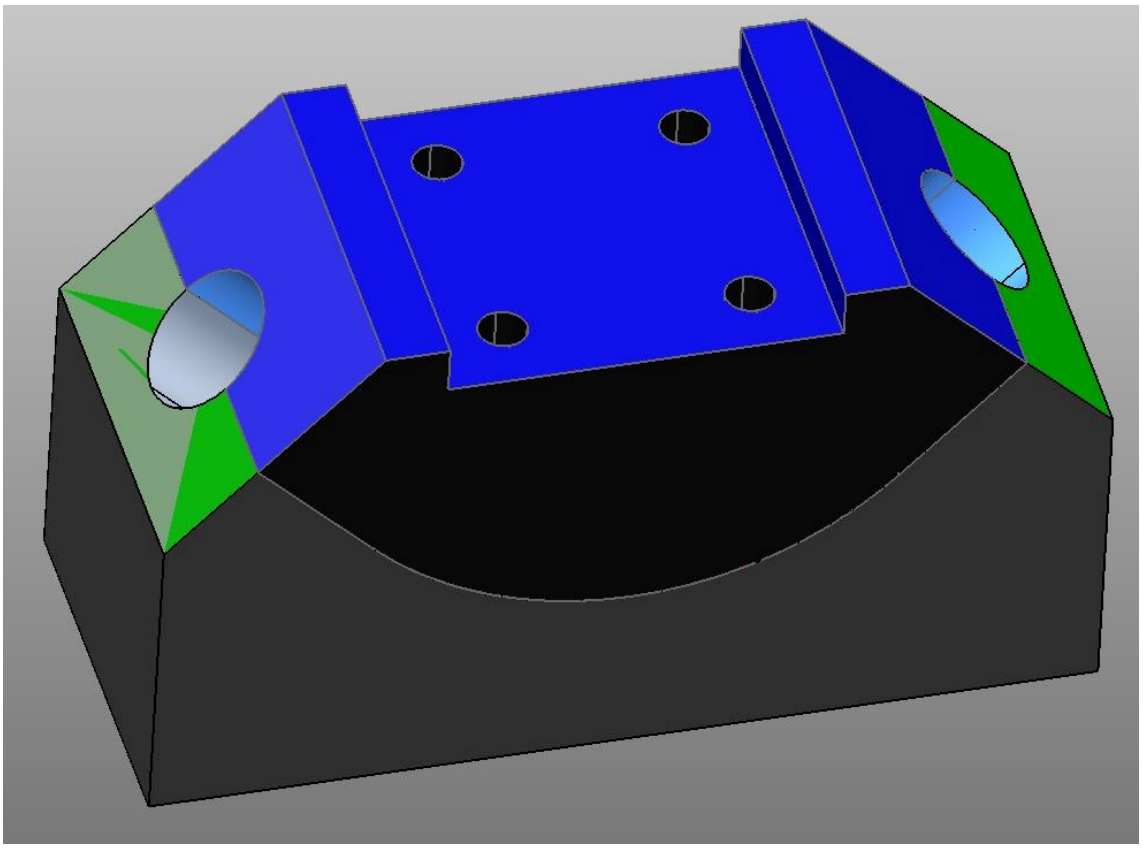


Figure 15 *3D CAD Model of DIE*

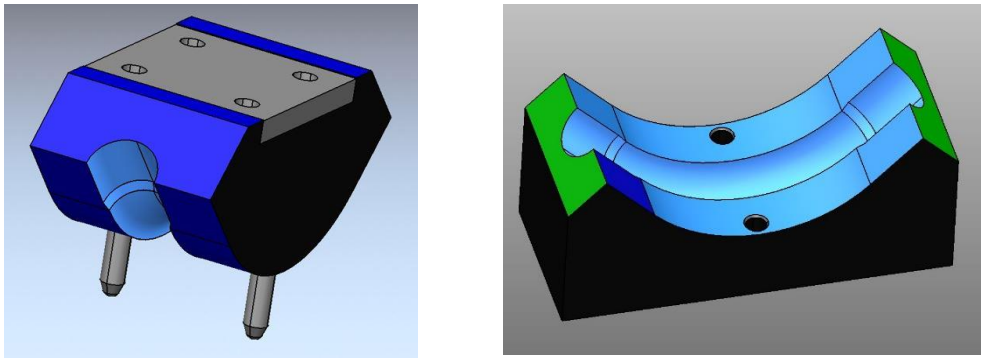


Figure 16 *Punch and Die*

3.2.2 Main Frame

A rigid M.S (Mild Steel) main frame was designed and fabricated using angle iron of 1.5 × 1.5 inches with a thickness of 4.8 mm. Different lengths of angle iron were joined together through welding in order to make a strong main frame on which all three cylinders are mounted via cylinder plates. The cylinders, plates, and pins assembly are supported by this main frame, which is

mounted and welded to the base table. The main frame is mounted with the proximity sensors, cylinder plates, and pins assembly. The top cylinder is attached with a punch (upper die), and the side cylinders are attached with socket pins.

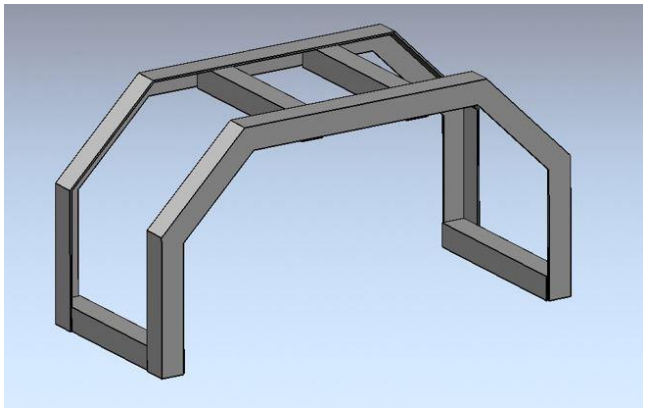


Figure 17 *Main Frame 3D Model*

3.2.3 Base Table

A rigid M.S (Mild Steel) base table was designed and fabricated using flat rectangular bars and sheets of different dimensions, and supports were given where required to increase the strength and stiffness of the base table during the process. The base table was designed to accommodate all the components that were to be installed. The dimensions of the table are as follows:

Length = 915 mm, Width = 605 mm, Height = 735 mm

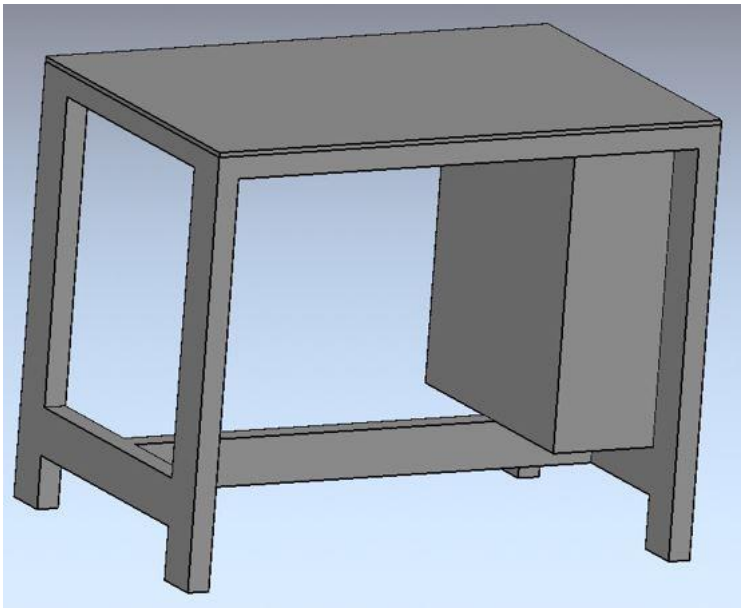


Figure 18 *Base Table 3D Model*

3.2.4 Socketing Pin

The machine also performs socketing operation at both ends of a PVC pipe for joining purpose. We need two socket pins in order to make sockets on both ends. The socket pins are made up of M.S (Mild Steel) material. An air blow mechanism is provided through the socket pin in order to maintain the round shape of the workpiece.

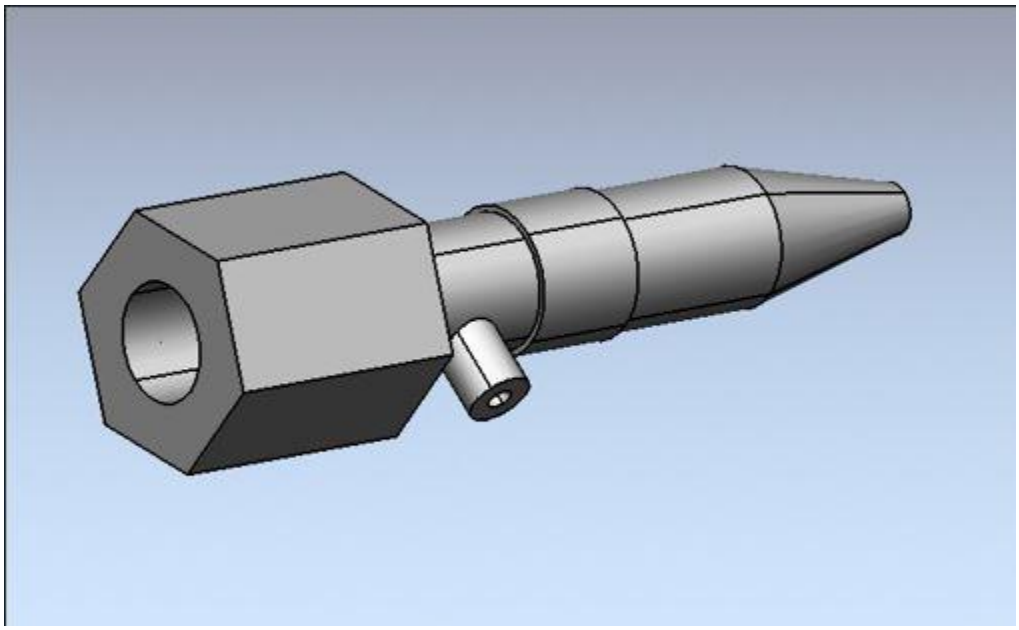


Figure 19 Socket Pin 3D Model

3.2.5 Guide Pin

Guide pins are used to align the top cylinder at 90 degrees and the side cylinders at 45 degrees with the die. A total of six guide pins (two for each cylinder) were designed and manufactured using M.S (Mild Steel) material. Guide pins slide in linear bearings that are fixed in cylinder plates in order to reduce friction. A stopper is used with each guide pin to avoid material damage and stop unnecessary movement.

Figure 10 Guide Pin 3D Model

3.2.6 Die Plate

This is basically the base plate for the die. The lower portion of the die rests on the base plate, and both are mounted on the base table via L-key bolts. Die plate is made up of aluminum alloy 6061-T6. A base plate is used for the following reasons:

- To give base support to the die.
- To give height to the die according to requirements.
- It’s easy to mount the lower die to the base table via the base plate.

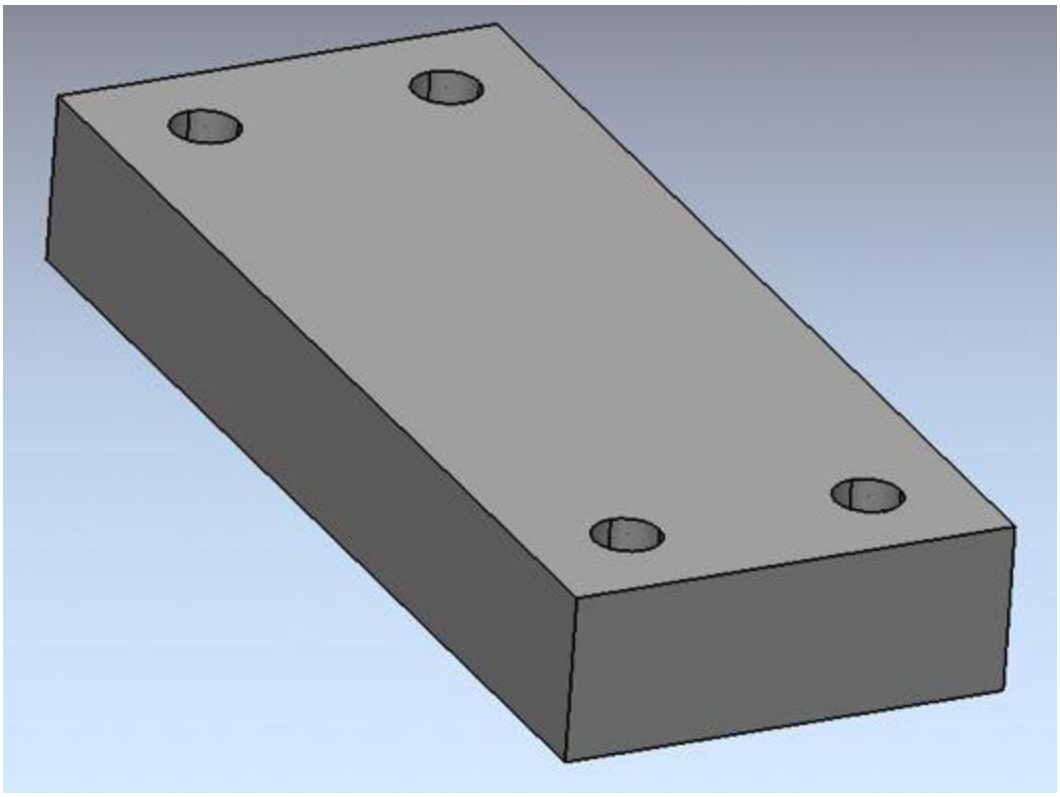


Figure 21 Die Plate 3D Model

3.2.7 Punch Plate

The upper portion of the die (Punch) is mounted with a pneumatic actuator (Top Cylinder) with the help of a punch plate. The punch plate contains a hole on both sides for guide pins to slide through. It is manufactured using M.S (Mild Steel) material.

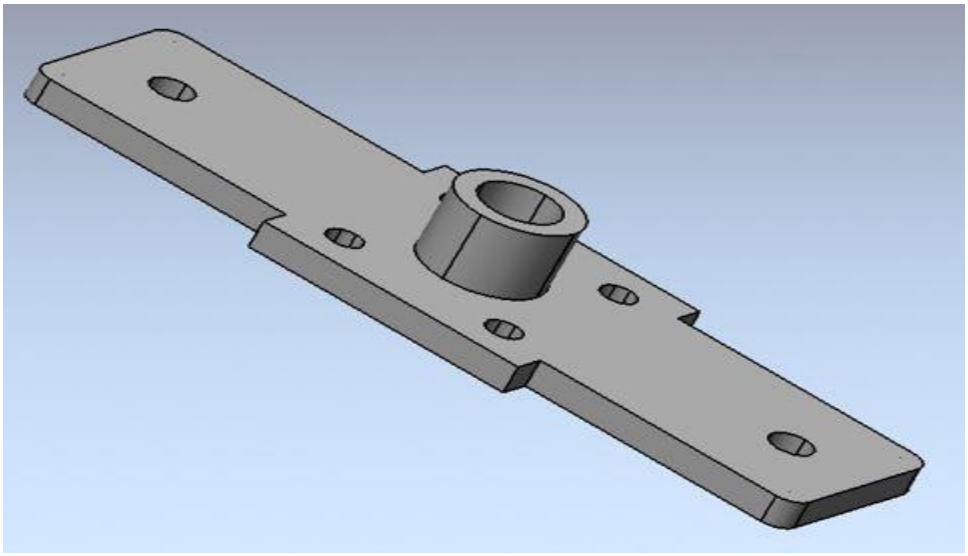


Figure 22 *Punch Plate 3D Model*

3.2.8 Side Plate

Side plates are manufactured in order to mount socket pins with pneumatic cylinders. A total of two side plates (one for each side cylinder) were designed and manufactured using M.S (Mild Steel) material. The side plate contains a hole on both sides for guide pins to slide through.

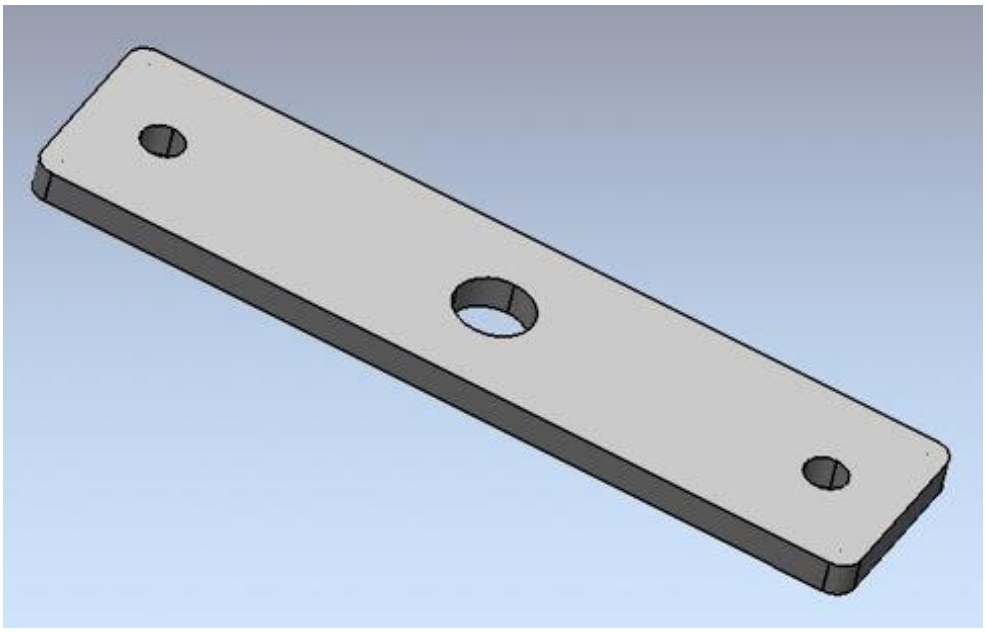


Figure 11 *Side Plate 3D Model*

3.2.9 Cylinder Plate

Cylinder plates are used to attach all three cylinders to the main frame. Cylinder plates are directly attached to the main frame. A total of three cylinder plates (one for each cylinder) were designed and manufactured using M.S (Mild Steel) material. The cylinder plate contains a hole on both sides for guide pins to slide through. Guide pins move in linear bearings that are fixed in cylinder plates in order to reduce friction. We made a slot for the cylinder connection in the middle of the cylinder plate.

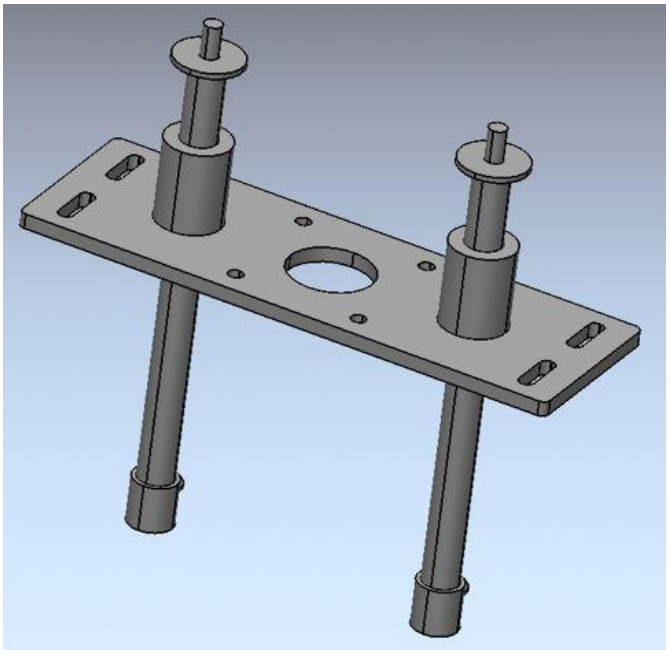


Figure 12 *Cylinder Plate with Linear Bearings & Guide Pins*

3.2.10 Distribution Box / Distribution Panel

It can be considered a controller for our machine as all the controls and power distribution is provided to components with the help of this box. It houses components like power supply, timer for timing delay, temperature controller for the measurement of temperature on the thermocouple, start and emergency stop switches, relays, LED indicators and circuit breakers. It has wire connectors to provide wire connection to wires from components like solenoid valve, proximity sensors, and temperature sensor. The DB box is operating at 220 VAC.

The Standard Wire Gauge (SWG), usually referred to as the British Standard Gauge or Imperial Wire Gauge, in the United Kingdom. This standard is used to indicate wire and sheet metal thickness. The material used to manufacture the DB box is galvanized sheet of SWG18. The thickness of the 18 gauge galvanized sheet is 0.048 inches or 1.219 mm [15].

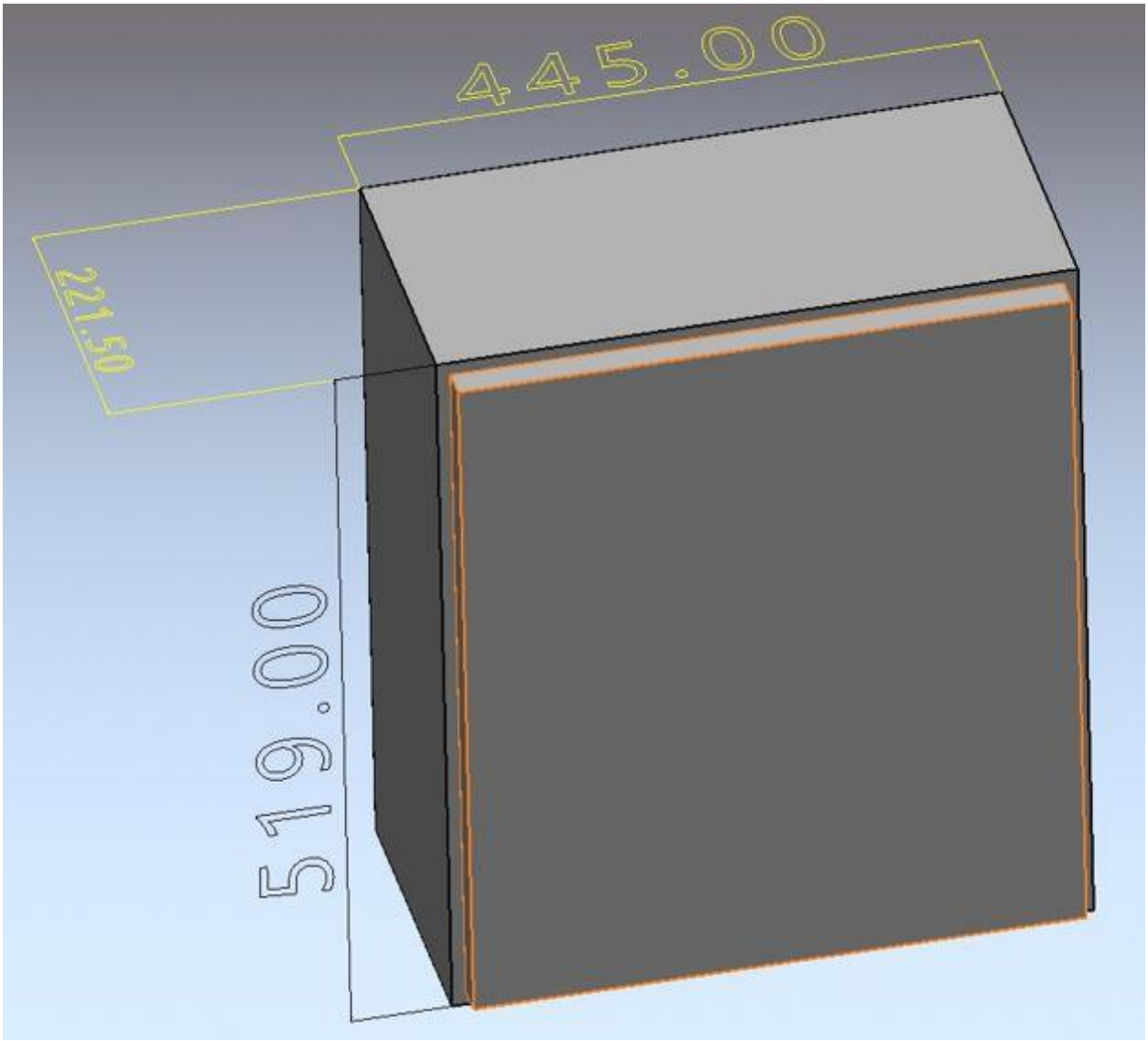


Figure 13 *Distribution Box 3D Model*

The components that are installed in the distribution box are listed below:

1) **Switching Power Supply**

A power supply's primary function is to transform the current coming from a source into the proper voltage, current, and frequency needed to drive a load. Consequently, power converters is another name for power supply.

The power supply's technical specs that we employed are as follows:

Model:	S-120-24	
Brand:	MEAN WELL [20]	
Input:	115 VAC	2.6 A
	230 VAC	1.3 A
	50/60 HZ	
Output:	+24 VDC	5.0 A

Figure 14 *Switching Power Supply*

2) **Single Pole Circuit Breaker**

Miniature circuit breakers are designed to protect electrical circuits from damage caused by excessive current. Its function is to safeguard the loads and the entire circuit from damage that may arise from electrical faults. A single-pole circuit breaker is used in our machine to switch on and off the heater.

Figure 15 *Single Pole Circuit Breaker*

3) **Two - Pole Circuit Breaker**

For heavy-current appliances, a two-pole circuit breaker can serve as the main switch or as a protective device. Double pole breakers generally provide electricity for large 240 volt equipment while protecting two lines. A two-pole circuit breaker is used in our machine to switch on and off the main power.

Figure 16 *Two-Pole Circuit Breaker*

4) **Timer**

Electrical timers called "on-delay timers" are used to delay the activation of a circuit or process after receiving a trigger signal. They are frequently employed to control the timing of operations in industrial automation and control systems. It provides flexibility in setting the delay duration and allows users to set the desired delay time within a specific range. The specifications of the on-delay timer are as follows [21]:

Input Voltage:	DC24V
Contact:	5A 250VAC Resistive Load
Type:	MS4SA-AP (Super Timer)
Number of Poles:	8 pin plug-in with a DPDT contact output
Brand:	Fuji Electric
Application:	On - Delay Timer
Timing Range:	0.6 S – 60 H

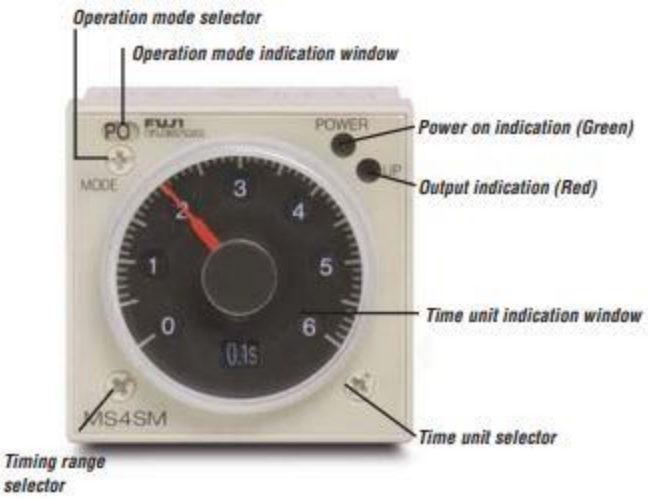


Figure 17 *On-Delay Timer* [4]

5) **Relays**

Relay is basically a simple electromechanical switch. A normal switch is used to manually open or close a circuit, but a relay is also a switch that connects or disconnects two circuits. However, a relay makes use of an electrical signal to control an electromagnet, which in turn connects or disconnects another circuit, as opposed to a manual process [22].

One 220 VAC relay was used to turn on and off the heater, and four 24 VDC relays were used to operate the pneumatic valves.

Figure 18 *General Purpose Relay* [5]

6) **Control Panel LED Indicators**

Control panel indicators are optoelectronic devices that emit light to display a machine's or appliance's operational state. Red indicates that the heater is on or off, whereas green indicates that the machine is on or off.

Figure 19 *Control Panel LED Indicators*

7) **Temperature Controller**

When a sensor signal is compared to a set point and calculations are made based on the difference between the two values, a temperature controller is used to regulate a heater or other type of equipment [23].

The following diagram shows the temperature control process:

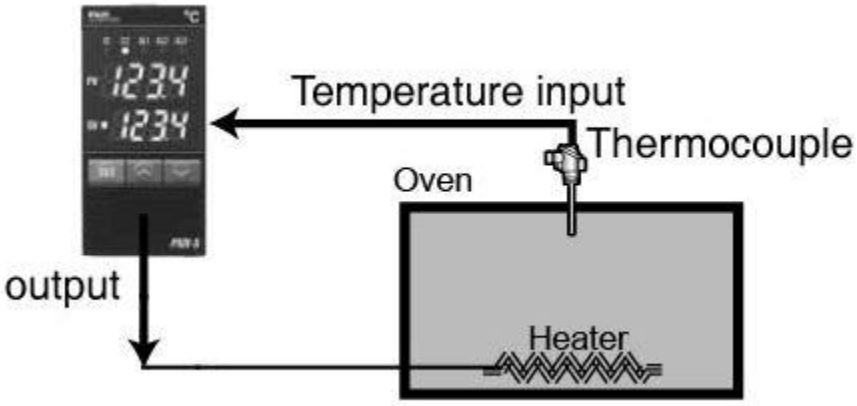


Figure 20 *Temperature Control Process*

The thermocouple temperature is measured by the temperature controller, which then compares it to the set point to determine how long the heater has to be on to maintain the desired temperature.

The technical specifications of the temperature controller that we used are as follows [24]:

Product Name:	Digital Temperature Controller
Model:	REX-C900FK07-M*AN
Control Mode:	PID (For Heating)
Measurement Range:	0 – 1300 Degree Centigrade
Supply:	AC (220V), 50/60HZ
Input Type:	K Type
Output Type:	Electromagnetic Relay

Figure 21 *Temperature Controller*

8) **Start Switch**

An electrical circuit is controlled mechanically by a push-button switch, which requires human button pressing to activate the internal switching mechanism. Depending on the requirements of the design, they are available in numerous shapes, sizes, and configurations. We used this push-to-on switch in our machine in order to initiate the pipe bending process.

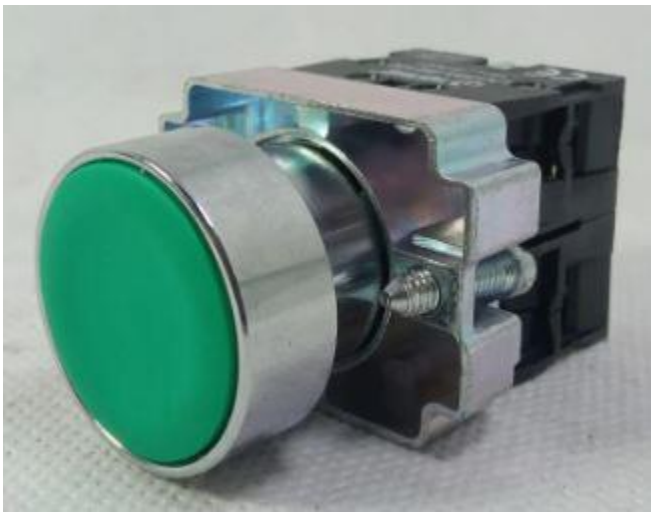


Figure 22 *Start Switch*

9) **Emergency Stop Switch**

Push-button emergency stop switches are mostly employed as a preventative measure to lower the risk of workplace accidents for operators. Physical injuries produced by machinery, which are frequently fatal, are one of the main risks present in industrial sectors. Heavy-duty machinery is equipped with a safety feature called the emergency stop push button. To be easily seen in an emergency, the emergency stop push-button switches are typically painted red. They are connected to the machinery's control circuit via wiring. When the emergency stop push button is pressed, the control circuit breaks and the electrical connection is disrupted. When activated, the emergency stop push button will quickly cease the flow of electricity to the equipment, ensuring both operator and equipment safety in the event of an emergency shutdown. Pushing the twist release button will turn off the electricity to the linked industrial machinery. Twisting the button will turn it back on.

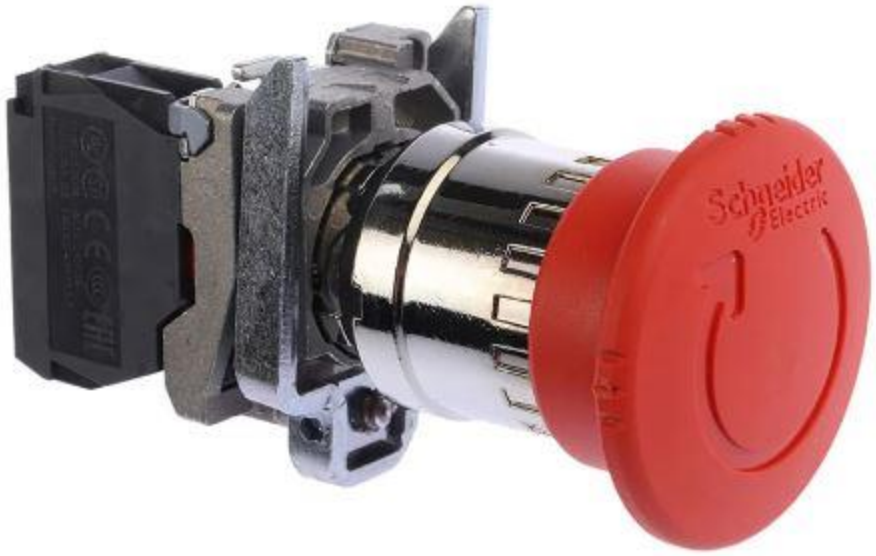


Figure 23 *Emergency Stop Switch*

10) **PVC Electrical Strip Connector**

In many electrical applications, PVC electrical cable connectors are employed. It is used to join electrical cables and join the wires together. Polyethene, which is not flammable, is the material used to create each strip. Connections between the panel's internal and external peripherals are made possible via the terminal strip. Therefore, all of the connections between the equipment and the central panel must be made by the strip. The terminal strip simplifies switchboard installation and connection. In practise, it is claimed to organise wiring and ensure the mechanical and electrical safety of the panel. The terminal strip also makes it simpler to measure tension, current, resistance, and to connect and disconnect wires.

Figure 24 *PVC Electrical Strip Connector*

11) **Contactor**

An electrical device called a contactor is used to turn on or off electrical circuits. It is regarded as a unique kind of relay. The relay is utilised in applications where a lower current is required, whereas the contactor is employed in cases where a higher current carrying capacity is required. This is the fundamental distinction between the relay and the contactor. These electrical devices typically have many contacts. When the contactor coil is energised, these contacts, which are often normally open, provide operating power to the load. Contactors are intended to be directly linked to high-current load devices, in contrast to general-purpose relays. In our machine, we employed a contactor for wiring joints and distribution in addition to automatically turning on and off the heater. The specifications of the contactor that we employed are as follows [25]:

Model: MC-40a

Number of Poles: 3 Poles

Operational Current: 40 Ampere

Manufacturer: LS Electric

Figure 25 *Contactor*

3.2.11 3D CAD Model of Machine

The developed machine has consistent superior quality, a pipe heating system, socket pins, sliding guides, pneumatic cylinders, a die, linear bearings, plates, a distribution panel, and a simple user interface. These small components were integrated to make a fully functioning, stand-alone, cost-effective PVC pipe bending machine. The machine was designed with the objective that it should be easy to operate by a common, unskilled operator.

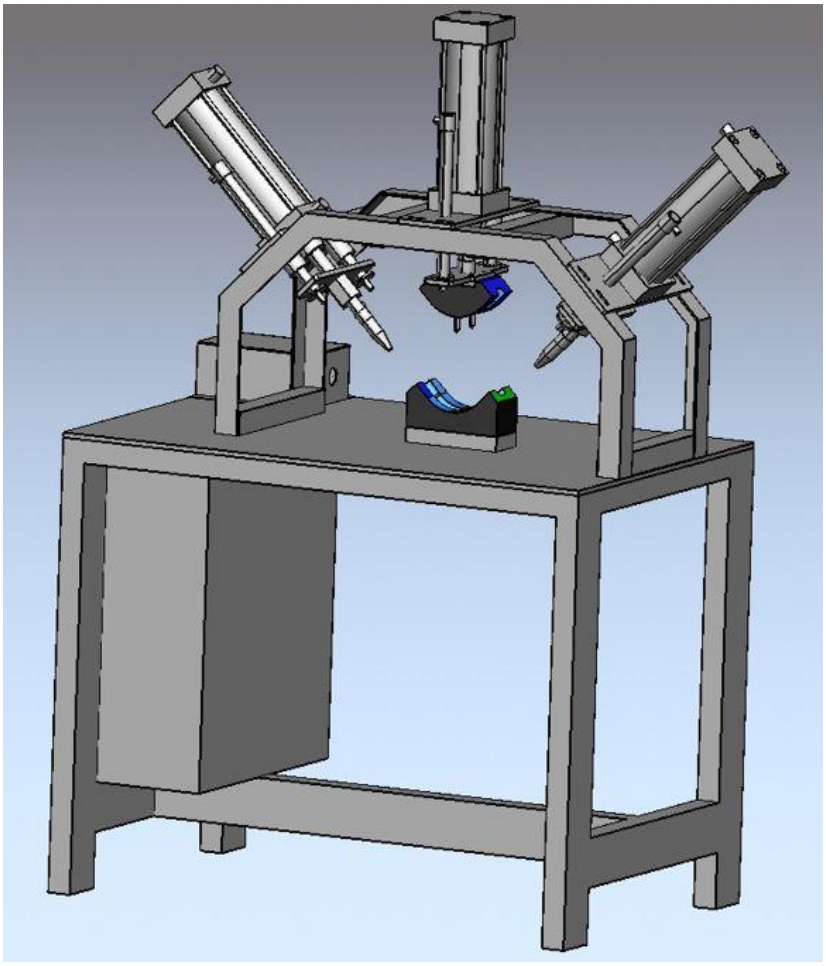


Figure 26 *3D CAD Model of Machine*

3.2.12 Heating Element

A quite common type of heating source was used, which is often called a heating element or cartridge heater. You can insert a cartridge heater, an industrial heating element with a tube shape, into pre-drilled holes. Cartridge heaters are extensively used in the heating process industry because they provide precise and localised heating. Cartridge heaters are usually manufactured to a specified watt density dependent on the demands of the application in order to heat a metal block from the inside. To heat metal objects, cartridge heaters are often placed into pre-drilled holes. The heaters are somewhat undersized compared to their nominal diameter for simple installation.

A resistance coil is twisted around a ceramic core, which is covered in a metal sheath and surrounded by dielectric in a cartridge heater. The heat that is transferred to the sheath from the coil causes it to warm up. The interior metal portion that needs heat then receives this heat transfer [26].

Figure 27 *Heating Element*

Cartridge heaters are designed to be installed inside a heater block, allowing heat to be transferred indirectly to the material being processed. They are made up of S.S (Stainless Steel) material.

3.2.13 Heating Capacity

To finalize the heating capacity, we used a clamp multimeter in order to find the resistance of the heating element. According to Ohm's law:

Voltage (**V**) = Current (**I**) × Resistance(**R**)

Power (**P**) = Current (**I**) × Voltage (**V**)

V = 220 Volts

V = **I** ×**R** **Eq. 1**

P = **I** × **V** **Eq. 2**

By using Eq. 1, Eq. 2 becomes:

P = $\boldsymbol{I^2}$ × **R**

P = 300 Watts

By using a clamp multimeter, we found that

Resistance = 162 Ohm, and we get:

V = **I** ×**R**

I = $\frac{V}{R}$ = $\frac{220}{162}$ **= 1.36 Ampere**

Now,

P = $\boldsymbol{I^2}$ × **R**

= $\mathbf{1.36^2}$ × **162**

3.2.14 Heater Design

To begin, a simple metal block was manufactured using aluminum alloy AL6061-T6 material with the help of CNC machining. Then we drilled two through holes in it, i.e., one for the insertion of the cartridge heater and the other for the placement of PVC pipe in order to heat it. In order to mount the K-Type temperature sensor, we additionally drilled a threaded hole in one side of the metal block. The metal block heats up as the temperature of the heating element rises, and indirect heat is then transferred to PVC pipe, which is placed inside a metal block. For one minute, we want to heat the PVC pipe to a temperature of 100 degrees. For this purpose, we continuously monitored the temperature via a K-Type temperature sensor, which is mounted on the surface of the metal block via a threaded bolt. We continuously monitored and controlled the temperature using a temperature controller. A K-Type temperature sensor is connected to the input of the temperature controller. The hit-and-trial method was used to find the temperature controller's set point, which came out to be 100 degrees. When the temperature falls below this set point, the heater will turn on automatically to achieve this set value.

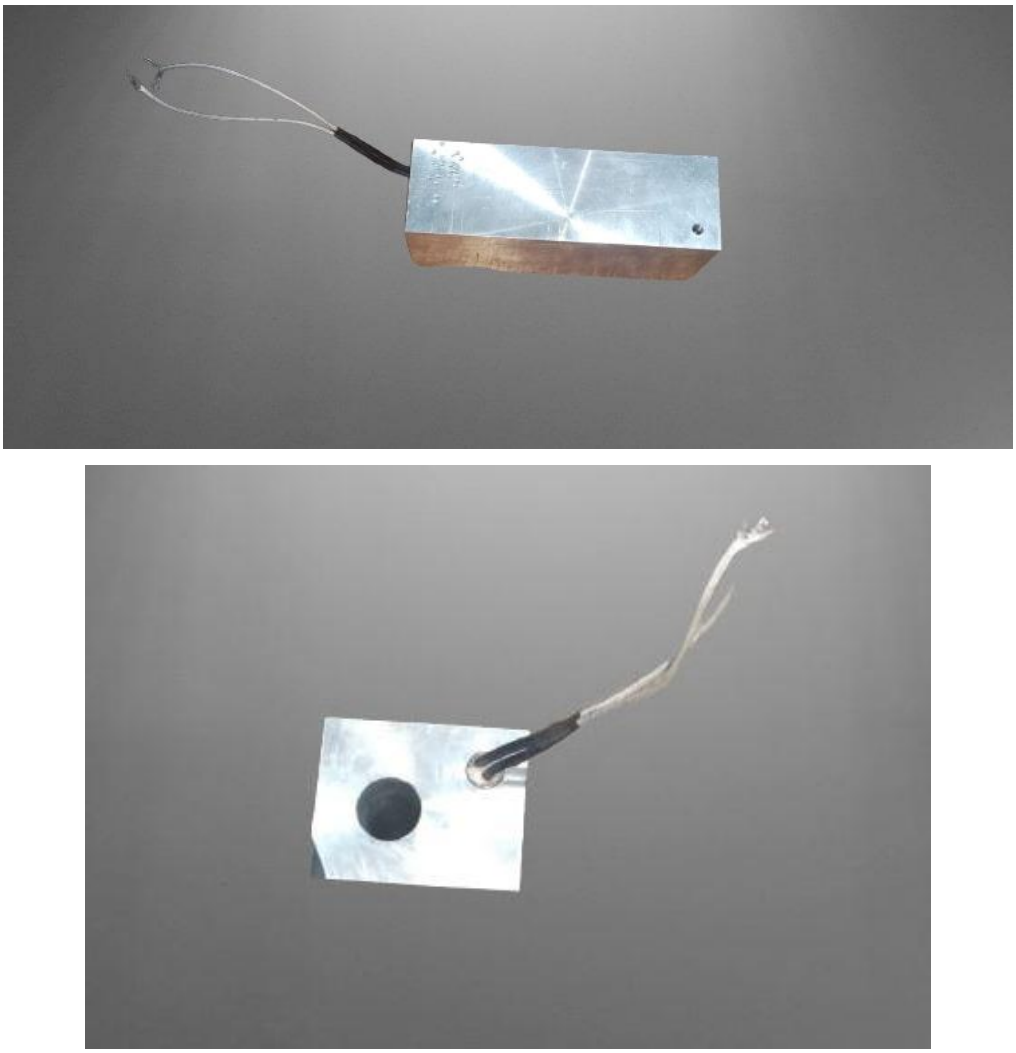


Figure 28 *Heater Design*

3.2.15 Heater Outer Casing Design

The heater's outer casing was designed and manufactured using M.S (Mild Steel) material. We used CNC machining for the manufacturing of the outer casing. The heating element is fixed inside the metal block, and the metal block is placed inside the outer casing. Basically, this outer casing was made for the protection and safety of the heater as well as the machine operator. We used glass wool insulation in between the metal block and the outer casing in order to reduce the effect of heat on the outer casing and to avoid heat loss. Because air is a poor conductor of heat, the glass fibres form pockets of air that serve as barriers to stop heat loss. We made a hole in the design of the outer casing in order to place pipe, and a metal block was placed inside the outer casing that is perfectly aligned with the hole. The heater is placed and mounted on the base table on one side using L-Key bolts.

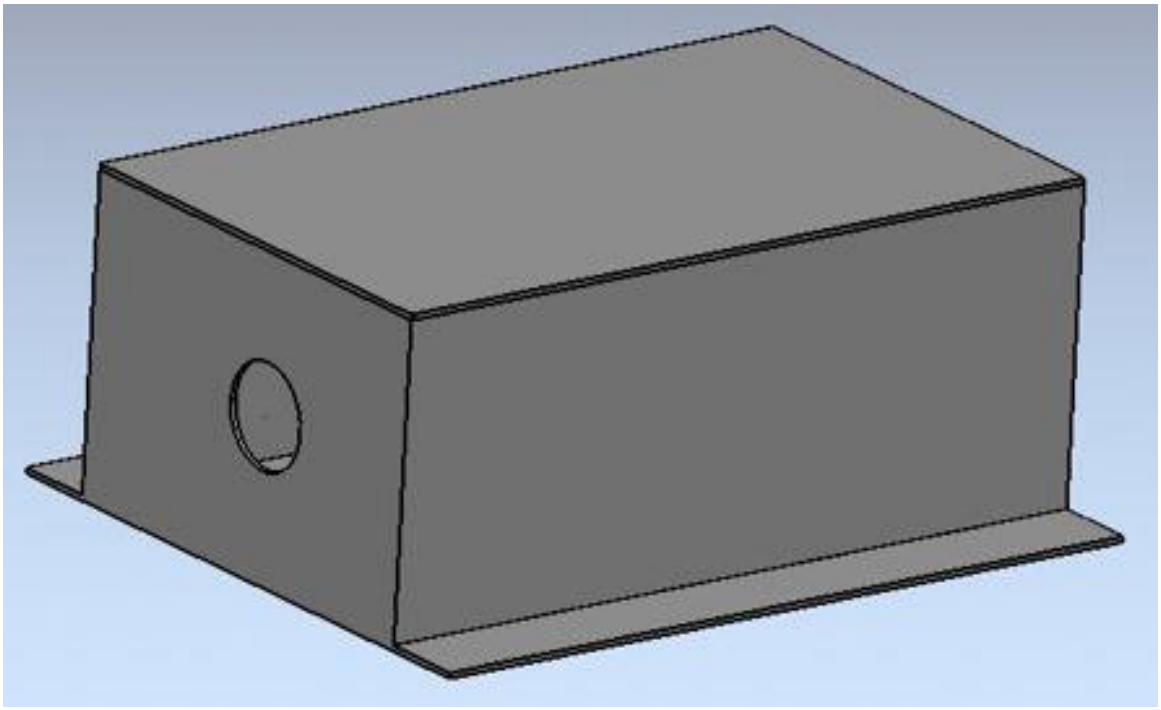


Figure 29 *Heater Outer Casing 3D Model*

3.3 Wiring Diagram

A wiring diagram displays the relative layout of the components and the wire connections between them. Essentially, a wiring diagram is a visual representation of each of the electrical connections on a given circuit. Different shapes and symbols used in the wiring diagram are used to represent the various circuit components. These illustrations are a useful approach to demonstrate how wires are linked to various system components. The primary use of a wiring diagram is to demonstrate the connectivity of a circuit. The wiring diagram of our machine's control panel is as follows:

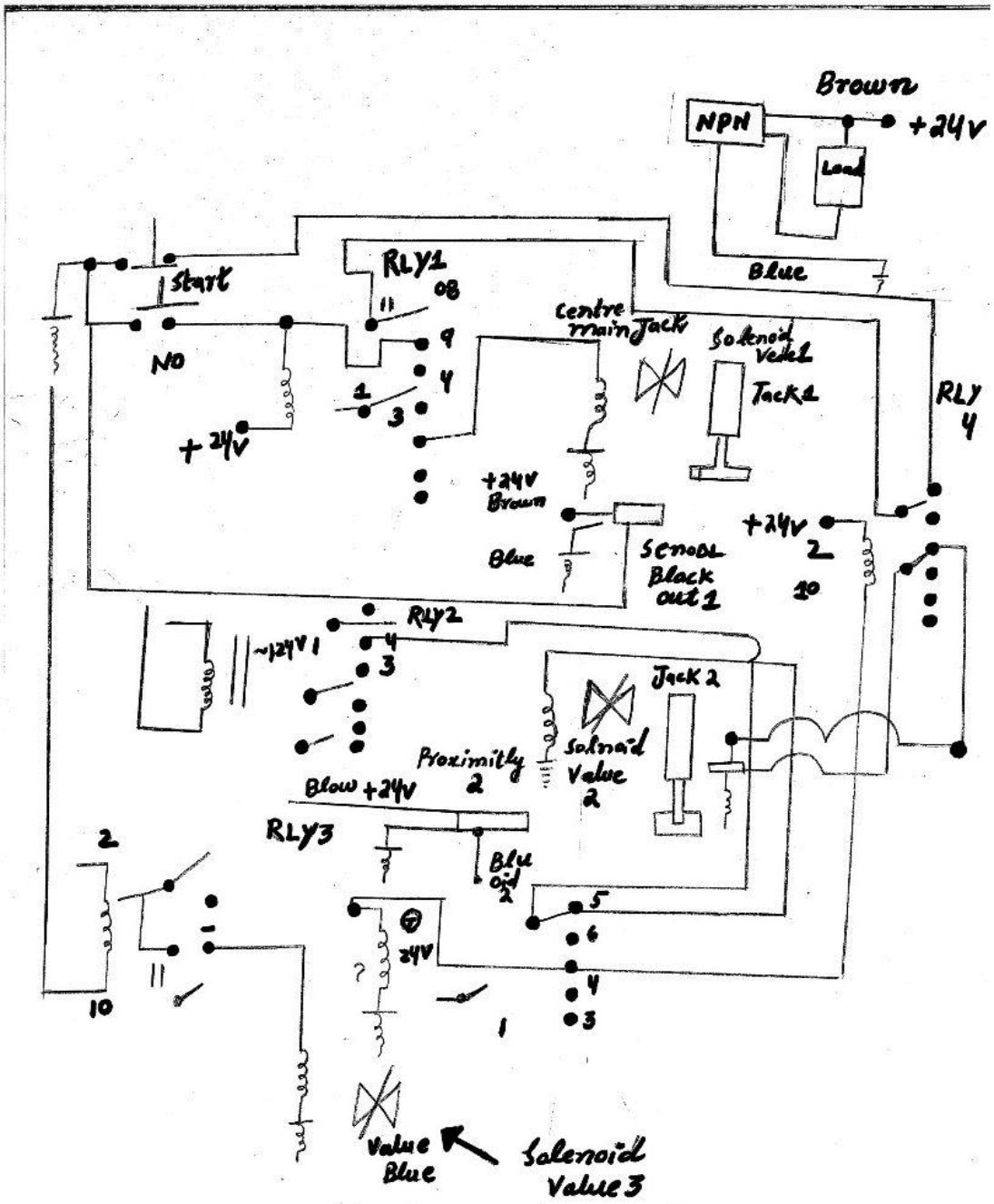


Figure 30 *Wiring Diagram*

3.3.1 Elaboration of Wiring Diagram

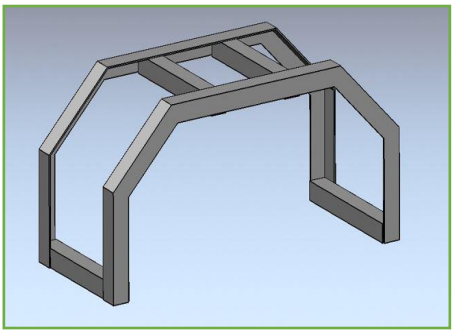
First, we press the start button, which turns on relay 1, which is interlocked with relay 4, so relay 1 stays on until relay 4 turns on. Then, relay 1 activates valve 1, causing jack 1 (the top cylinder) to travel downward. As Jack 1 went down, proximity 1 activated, which activated relay 2. Relay 2 is also interlocked with timer 1, i.e., when timer 1 is up, relay 2 will be turned off. Relay 2 activates valve 2, causing jack 2 (side cylinders) to slide down, and as jack 2 hits proximity 2, proximity 2 activates relay 3. Relay 3 performed two actions: the first was to turn on valve 3, which started the air blow, and the second was to turn on the timer. Relay 2 will be off when timer 1 is up, as it was previously known that timer 1 and relay 2 were interlocked. Jack 2 (side cylinders) begin to move upward as soon as relay 2 is switched off, and air blow is cut off when jack 2 moves away from proximity sensor 2. When jack 2 reaches the top, proximity 3 is activated, which causes relay 4 to activate, which switches off relay 1 because relay 1 is interlocked with relay 4. The machine is right now in a zero state and is prepared for the next cycle.

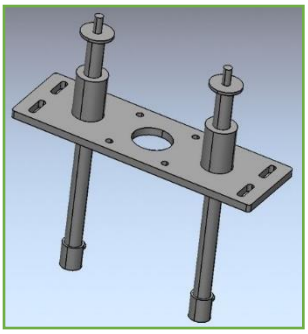
Chapter 04: Results and Conclusion

4.1 Manufacturing

A rigid M.S (Mild Steel) base table was designed and fabricated using flat rectangular bars and sheets of different dimensions, and supports were given where required to increase the strength and stiffness of the base table during the process.

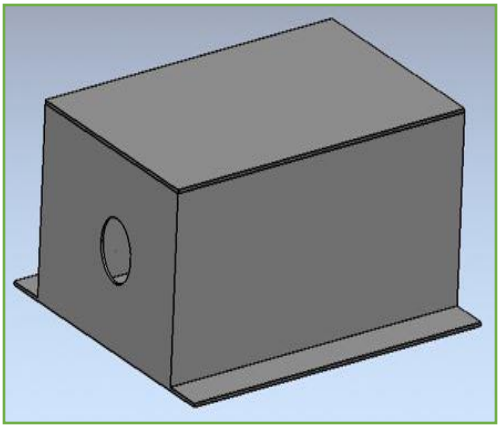
A rigid M.S (Mild Steel) main frame was designed and fabricated using angle iron of 1.5 × 1.5 inches with a thickness of 4.8 mm. Different lengths of angle iron were joined together through welding in order to make a strong main frame on which all three cylinders are mounted via cylinder plates.



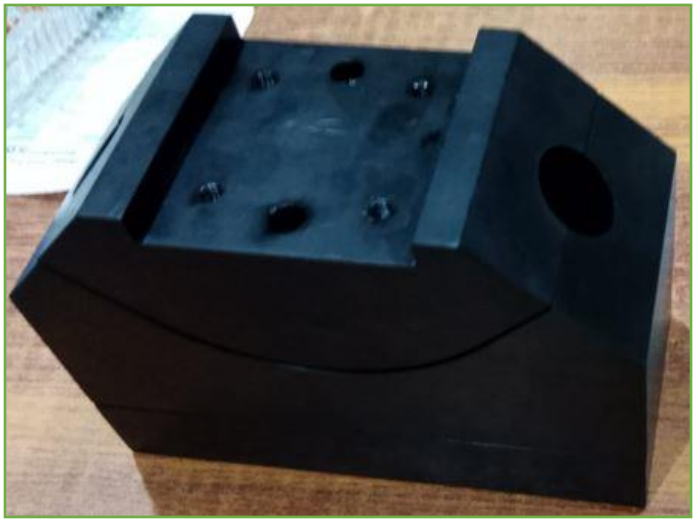


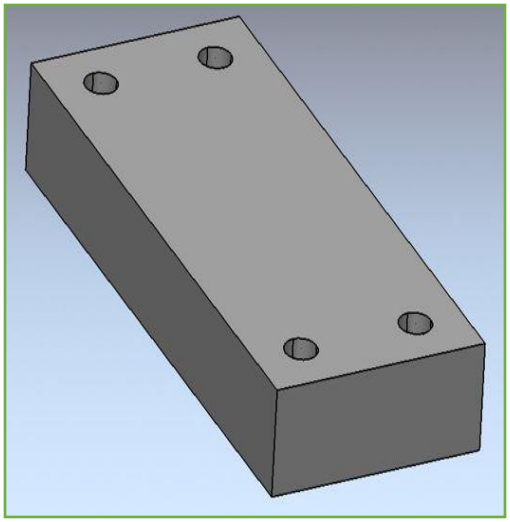
Distribution panel can be considered a controller for our machine as all the controls and power distribution is provided to components with the help of this box. The material used to manufacture the DB box is galvanized sheet of SWG18. The thickness of the 18 gauge galvanized sheet is 0.048 inches or 1.219 mm.

Figure 31 *Manufactured Pipe Bending Machine 1*



A simple metal block was manufactured using aluminum alloy AL6061-T6 material with the help of CNC machining. Then we drilled two through holes in it, i.e., one for the insertion of the cartridge heater and the other for the placement of PVC pipe in order to heat it. Metal block is placed inside the outer casing.





The die is made up of aluminum alloy 6061-T6, which has relatively high strength, good workability and high resistance to corrosion. It consists of an upper die (a punch) and a lower die, both of which are machined using CNC. The purpose of electroplating a die was to enhance its thickness while also increasing its wear resistance, corrosion protection, and aesthetic appeal. Guide pins are used to align both the upper die (Punch) and lower die. The lower portion of the die rests on the base plate.

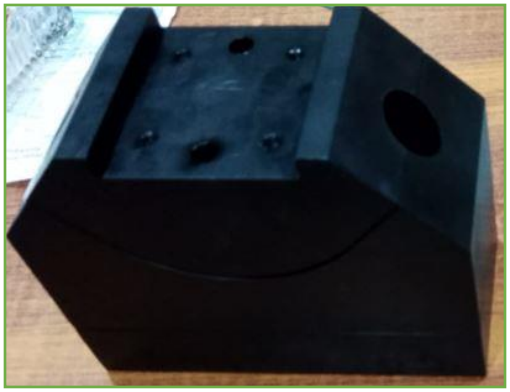


Figure 32 *Manufactured Pipe Bending Machine 2*

Figure 33 *Manufactured Pipe Bending Machine 3*

Figure 34 *Manufactured Pipe Bending Machine 4*

4.2 MANUFACTURING ASSISTANCE

There were three manufacturing facilities available that we used for manufacturing that are:

- MRC
- Tribology Lab
- Local Vendors in Market

4.2.1 MRC

Manufacturing Resource Center (MRC) has been established in the School of Mechanical and Manufacturing Engineering Sector H-12 Campus, Islamabad.

MRC plays a vital role of backbone for manufacturing of parts and products in NUST (National University of Sciences and Technology). It has provided support to local industry according to their requirements apart from supporting student projects at under and post graduate level. Many projects are on the pipeline.

Figure 35 *MRC NUST*

4.2.2 Tribology Lab

It is a Lab in DME (Design and Manufacturing Engineering) Department at SMME (School of Mechanical and Manufacturing Engineering), NUST. It has basic manufacturing facilities such as:

- Welding
- Cutting
- Drilling
- Tapping
- Grinding etc.

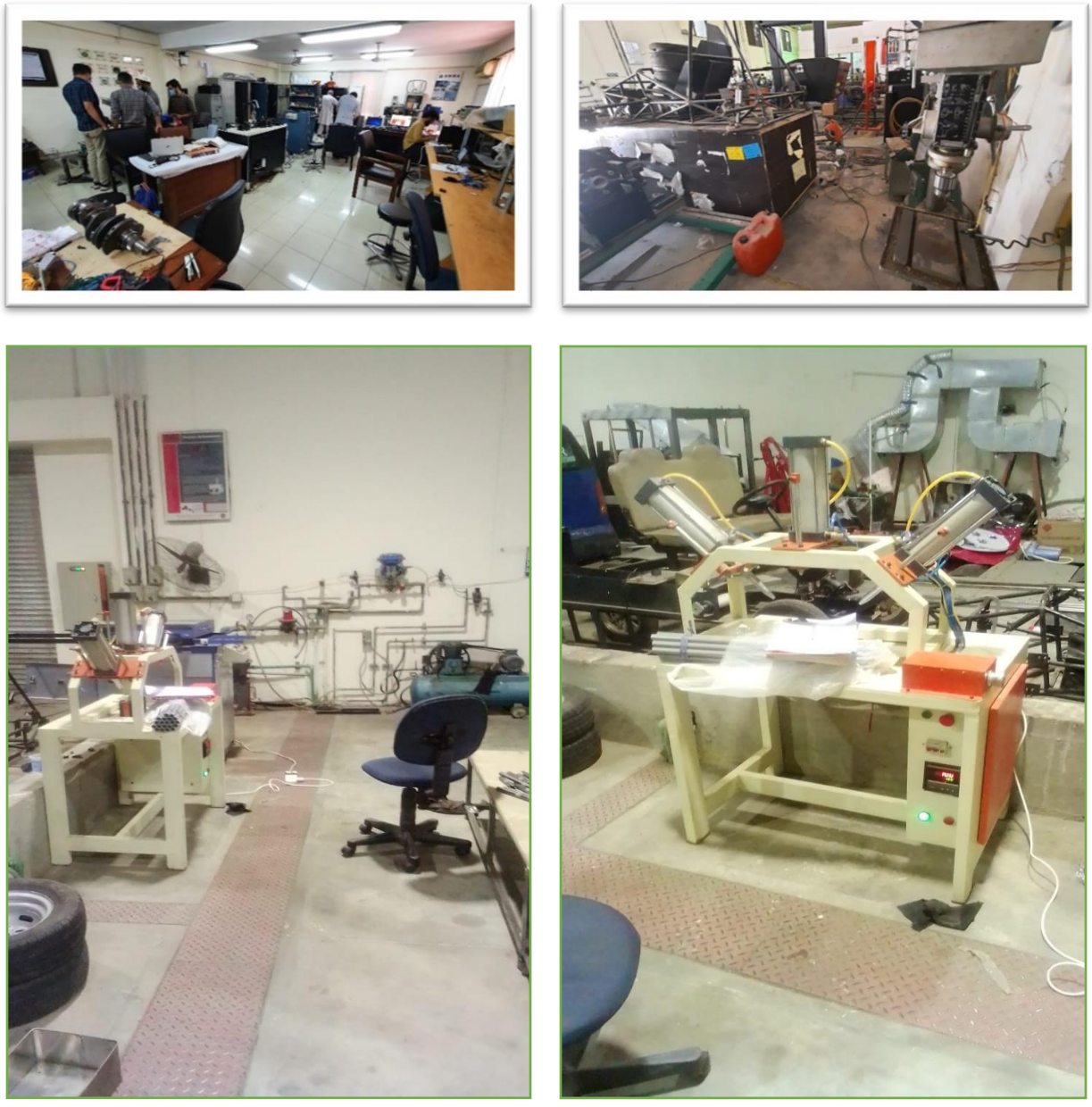


Figure 48 *Tribology Lab*

4.2.3 Local Market Vendors

There are a lot of manufacturing facilities in the local market that offer various types of services. They were used whenever required for manufacturing and purchasing as well.

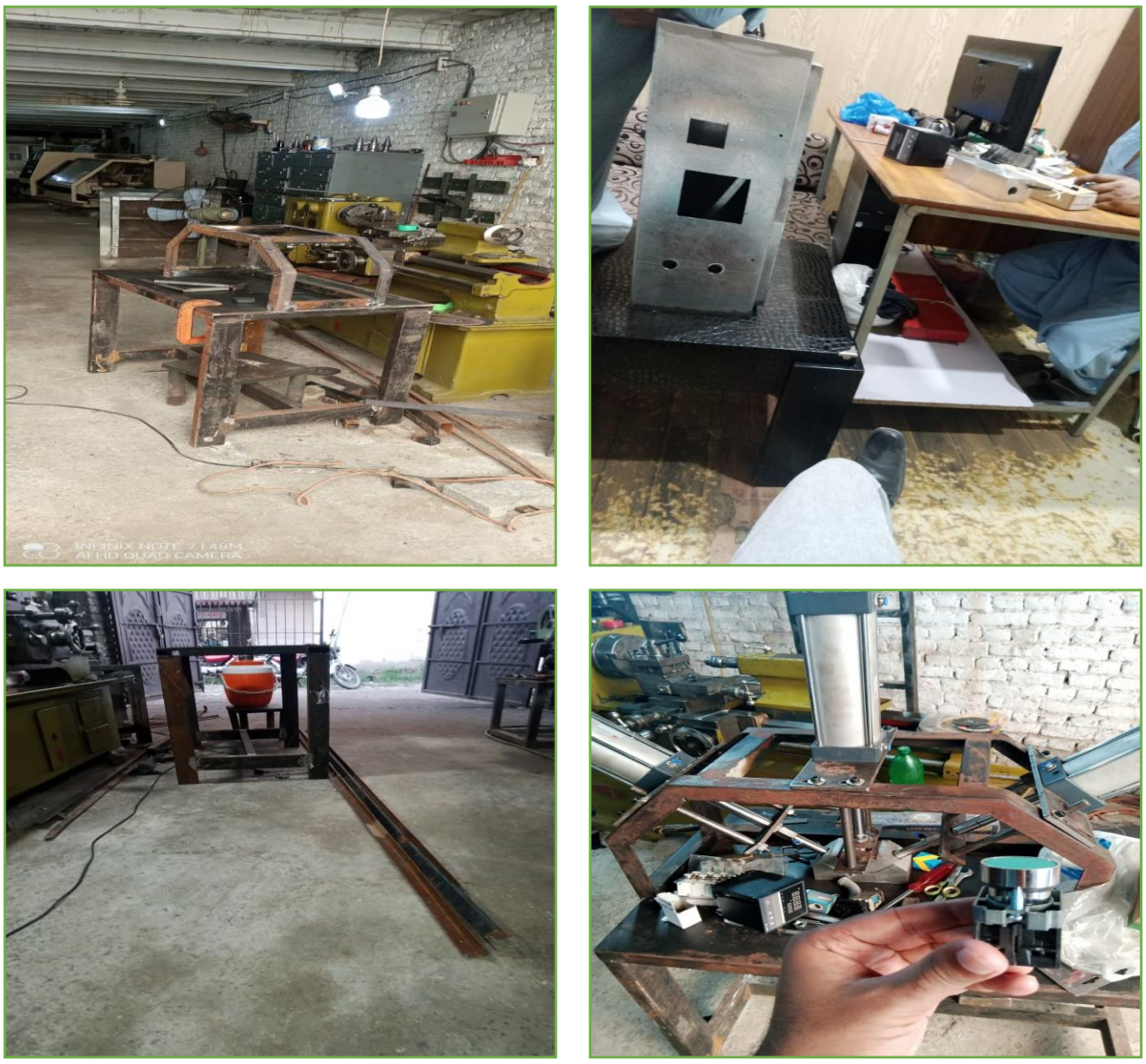


Figure 49 *Local Vendors*

4.3 Energy Consumption for Heater

How many units of electricity does a 300-watt heater consume that is operated on 220V?

R = 162.5 Ohm

V = 220 V

$$\boldsymbol{V = I \times R}$$

$$\mathbf{I = \frac{V}{R} = \frac{220}{162.5}}$$

I = 1.35 A

P = 300 W

$$\mathbf{KWh = \frac{(Watts \times Hours)}{1000}}$$

t = 1 hour

$$\mathbf{Energy\ in\ KWh = \frac{300 \times 1}{1000}}$$

Energy in KWh = 0.3 KWh

So, it draws 0.3 units of electricity per hour. If you pay 13 Rupees per KWh, then it will cost you 3.9 rupees per hour to run.

4.4 Production and Testing

Initially, testing was carried out on 10 pieces, and results were presented. The heater was on for one hour, so the energy meter showed 0.5 units of electricity consumption. Then we produced 10 pieces, and the energy meter displayed that the production of 10 pieces consumed 0.1 units of electricity. This means that the machine produces 100 pieces and consumes only one unit of electricity, which is a very cost-effective solution. Below are the tested samples that were produced on the machine, and the results were higher than expected, as we can see.

Figure 50 *Testing Results*

Through continuous testing of the machine, we studied defects that occurred during the process and are working on and analyzing their remedies. Without the air blowing, quality gets compromised, and pipes have poor quality, meaning they puncture and can't keep their original round shape. Air blowing is therefore required via socket pins.

Figure 51 *Poor Quality Pipe Samples without Air Blow*

4.5 Conclusion

The output of this thesis is a cost-effective PVC pipe bending machine. This is a standalone solution which is easy in terms of operation and maintenance. This machine is used to bend a 7-inch length of PVC pipe into a curved shape and to perform socketing operation at both ends of a PVC pipe for joining purposes. It is a semi-automatic machine to be manually controlled using the required user interface tailored for our local market.

There is no company in Pakistan that is making such machines; hence, locally, there is no competition. However, there are a few companies that have imported such machines from China, Malaysia, and Korea. The competitors are imported machines, which are more expensive and not tailored to our local requirements in terms of simplicity and operation. The imported machine also suffers from the problem of after-sales service. A locally developed machine, on the other hand, can be serviced and maintained with much ease.

There is a lot more to do in terms of research and development in Pakistan. The development of this machine is surely a proof that local development and production of these types of machines can also be done with the resources we have in our country. This will not only create more job opportunities but will also have a great impact on reducing import bills.

In future, this transfer of technology can be used to create more pipe bending machines, considering local requirements and tailored accordingly. We designed and developed a customized solution in the form of a PVC pipe bending machine that is not only beneficial for our local industry but also has potential for export to other countries. The size of the machine is very convenient for portable work. This machine can be improved with the passage of time. This prototype is the first step in exploring this massive field, and product development and machine durability can be improved with time.

References

[1] 9 th Nov 2021, (2021).

[2] M.K. V, Design and Fabrication of Pneumatic Sheet Metal Cutting and Bending Machine, 9 (2016) 564–572.

[3] 201404290147275006.PDF, (n.d.).

[4] U. To, G Uide To S Uper T Uesday, (1970).

[5] S. Hoists, General purpose relays, (n.d.).

[6] K. Choudhary, P. Rane, V. Inamdar, D.A. Wagholikar, Department of Mechanical Engineering , Pimpri Chinchwad College of Engineering , Pune University , 6 (2015) 4472–4476.

[7] M. Jiménez, E. Kurmyshev, C.E. Castañeda, Experimental Study of Double-Acting Pneumatic Cylinder, Exp. Tech. 44 (2020) 355–367. https://doi.org/10.1007/s40799-020-00359-8.

[8] I. Gallego, Pneumatic cylinders., Fluidos Hidraul. Neumatica Lubr. 14 (1985) 586–602.

[9] P. Muroni, M SC PL O E – C EO PL O E –, (n.d.).

[10] 4V200-201909160942009636.PDF, (n.d.).

[11] A.W. Pope, Air compressors., (1979) 1–10.

[12] F. Wikipedia, Thermocouple, (2016) 1–23.

[13] J.W. Gooch, Type K Thermocouple, Encycl. Dict. Polym. 12 (2011) 776–776. https://doi.org/10.1007/978-1-4419-6247-8_12272.

[14] Y.X. Guo, C. Lai, Z.B. Shao, K.L. Xu, T. Li, Differential structure of inductive proximity sensor, Sensors (Switzerland). 19 (2019) 10–12. https://doi.org/10.3390/s19092210.

[15] Galvanized Sheet Thickness Tolerances Thickness In Inches Continuous Sheet Galvanized Coating Specifications, (n.d.) 1100.

[16] Fluid Automation Systems, (n.d.). http://fas.ch/.

[17] G. Singh, A review on effect of heat treatment on the properties of mild steel, Mater. Today Proc. 37 (2020) 2266–2268. https://doi.org/10.1016/j.matpr.2020.07.702.

[18] TE_EDPTeacherMaterials_8.5x11.pdf, (n.d.).

[19] . A.K.K., Design and Analysis of Punching Die, Int. J. Res. Eng. Technol. 05 (2016) 249–255. https://doi.org/10.15623/ijret.2016.0504048.

[20] Mean Well Enterprises, Switching Power Supply Technical Manual, (2003). https://www.adminstrumentengineering.com.au/files/mean-well-user-technical-manual.pdf.

[21] S. Timer, Time Delay Relays Super Timers compact body Time Delay Relays, (n.d.) 52–59.

[22] V. Gurevich, Electric Relays, 2018. https://doi.org/10.1201/9781315221168.

[23] OMRON, Technical Explanation for Temperature Controllers, (2016).

[24] C.W.W. Ng, Q. Shi, C. W. W. Ng & Q. Shi reply:, Q. J. Eng. Geol. 32 (1999) 303. https://doi.org/10.1144/GSL.QJEG.1999.032.P3.08.

[25] M.C. Tor, Mc/ tor, (n.d.).

[26] U. Five, U. Wl, U.W. Titanium, CARTRIDGE カートリッジヒーター, (n.d.).

Design and Development of Pneumatic Based PVC Pipe Bending Machine

ORIGINALITY REPORT

8%	8%	0%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	researchblog.nust.edu.pk Internet Source	3%
2	prr.hec.gov.pk Internet Source	3%
3	mce.nust.edu.pk Internet Source	2%
4	ijariie.com Internet Source	2%

Exclude quotes	On	Exclude matches	< 2%
Exclude bibliography	On		

Design and Development of Pneumatic Based PVC Pipe Bending Machine

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32

PAGE 33

PAGE 34

PAGE 35

PAGE 36

PAGE 37

PAGE 38

PAGE 39

PAGE 40

PAGE 41

PAGE 42

PAGE 43

PAGE 44

PAGE 45

PAGE 46

PAGE 47

PAGE 48

PAGE 49

PAGE 50

PAGE 51

PAGE 52

PAGE 53

PAGE 54

PAGE 55

PAGE 56

PAGE 57

PAGE 58

PAGE 59

PAGE 60

PAGE 61

PAGE 62

PAGE 63

PAGE 64

PAGE 65

PAGE 66

PAGE 67

PAGE 68

PAGE 69

PAGE 70