

**FABRICATION AND FUNCTIONING OF
FUSION DEPOSITION MODELLING MACHINE**

**A PROJECT REPORT
SUBMITTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE
AWARD OF THE DEGREE OF
“BACHELOR OF TECHNOLOGY”
IN
MECHANICAL ENGINEERING (MECHATRONICS)**

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CERTIFICATE

This is to certify that the project report entitled
Fabrication and Functioning of Fusion Deposition Modelling Machine
submitted by

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In partial fulfillment for the award of the Degree of Bachelor of Technology in Mechanical Engineering (Mechatronics) is a record of bonafide work carried out by him under my guidance and supervision during the academic year 2010 – 12. The results embodied in this project report have not been submitted to any other University or Institute for the award of any Degree or Diploma.

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ABSTRACT

Plastic fusion deposition is an additive machining process where an object is created by laying down successive layers of material, in this project ABS plastic is the material used. The term additive manufacturing describes technologies that create objects through a sequential layering process. This process, commonly called 3D printing is considered distinct from traditional machining techniques (subtractive processes) which mostly rely on the removal of material by methods such as cutting and drilling. This project is the fabrication and functioning of a Plastic Fusion Deposition CNC Machine.

Objects that are manufactured additively can be used anywhere throughout the product life cycle, from pre-production, i.e. rapid prototyping to full-scale production, i.e. rapid manufacturing, in addition to tooling applications and post-production customization.

The CNC Machine consists of a thermoplastic extruder mounted on a computer-controlled Cartesian XYZ platform. All three axes are driven by stepper motors, in X and Y via a timing belt and in Z by a lead screw mechanism. At the heart of the 3D printed is the thermoplastic extruder. These extruders use stepper motors (sometimes geared) to drive the filament, pinching the filament between a splined or knurled shaft and a ball bearing.

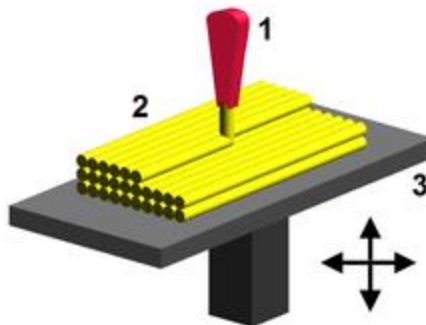


Fig. Fused deposition modeling: 1 - nozzle ejecting molten plastic, 2 - deposited material (modeled part), 3 - controlled movable table

CONTENTS

CHAPTER 1	INTRODUCTION	
1.1	A BRIEF HISTORY	1
1.2	RAPID PROTOTYPING	2
1.3	FUSION DEPOSITION MODELLING	3
CHAPTER 2	MECHANICAL BUILD	
2.1	FRAME	4
2.2	X-AXIS	4
2.3	Y-AXIS	5
2.4	Z-AXIS	6
2.5	EXTRUDER	6
2.6	ACTUATION	8
2.6.1	BIPOLAR STEPPER MOTORS	8
2.6.2	TIMING BELT	9
2.6.3	LEAD SCREW	9
CHAPTER 3	ELECTRONICS	
3.1	OVERVIEW	11
3.2	M/C MOTHERBOARD – ARDUINO	11
3.2.1	ARDUINO IDE	12
3.3	STEPPER DRIVER	12
3.4	POWER RESISTORS	13
3.5	POWER SUPPLY	14
CHAPTER 4	SOFTWARE	
4.1	OVERVIEW	15
4.2	MODELLING	SOLIDWORK 15
4.3	SLICING AND G-CODE GENERATION	SLIC3R 16
4.4	CAM SOFTWARE	PRONTERFACE 17
4.5	CAM SETTING SOFTWARE	SKEINFORGE 19
4.6	MICROCONTROLLER FIRMWARE	TEACUP 19
CHAPTER 5	FUNCTIONING	
5.1	HOW PRINTING TAKES PLACE	21
5.1.1	BOUNDARIES	21
5.1.2	FIRST LAYER – PERIMETER	21
5.1.3	FIRST LAYER – INFILL	22
5.1.4	SECOND LAYER AND SUBSEQUENT LAYERS	23
5.2	POST PRINTING OPERATIONS	25

CHAPTER 6	CONCLUSIONS, FUTURE SCOPE AND APPLICATIONS	
6.1	CONCLUSIONS	26
6.2	FUTURE SCOPE	26
6.3	APPICATIONS	26
CHAPTER 7	REFERENCES	27

CHAPTER 1

INTRODUCTION

1.1.BRIEF HISTORY

Additive manufacturing or 3D printing is a process of making three dimensional solid objects from a digital model. 3D printing is achieved using additive processes, where an object is created by laying down successive layers of material. 3D printing is considered distinct from traditional machining techniques (subtractive processes) which mostly rely on the removal of material by methods such as cutting and drilling.

3D printing is usually performed by a materials printer using digital technology. Since the start of the twenty-first century there has been a large growth in the sales of these machines, and their price has dropped substantially. The technology is used in jewellery, footwear, industrial design, architecture, engineering and construction (AEC), automotive, aerospace, dental and medical industries, education, geographic information systems, civil engineering, and many other fields.

Early examples of 3D printing occurred in the 1980s, though the printers then were large, expensive and highly limited in what they could produce.

The term "3D printing" was coined at MIT in 1995 when then graduate students Jim Brett and Tim Anderson modified an inkjet printer to extrude a binding solution onto a bed of powder, rather than ink onto paper.

The term additive manufacturing describes technologies that create objects through a sequential layering process. Objects that are manufactured additively can be used anywhere throughout the product life cycle, from pre-production (i.e. rapid prototyping) to full-scale production (i.e. rapid manufacturing), in addition to tooling applications and post-production customisation.

In manufacturing, and machining in particular, subtractive methods are typically coined as traditional methods. The very term subtractive manufacturing is a retronym developed in recent years to distinguish it from newer additive manufacturing techniques. Although fabrication has included methods that are essentially "additive" for centuries (such as joining plates, sheets, forgings, and rolled work via riveting, screwing, forge welding, or newer kinds of welding), it did not include the information technology component of model-based definition. Machining (generating exact shapes with high precision) has typically been subtractive, from filing and turning to milling and grinding.

Types of 3D printing

Various technologies have been used for 3D printing. The various techniques and the materials they use are mentioned below.

Extrusion	Fused deposition modelling (FDM)	Thermoplastics (e.g. PLA, ABS, eutectic metals, edible materials)
Granular	Direct metal laser sintering (DMLS)	Almost any metal alloy
	Electron beam melting (EBM)	Titanium alloys
	Selective heat sintering (SHS)	Thermoplastic powder
	Selective laser sintering (SLS)	Thermoplastics, metal powders, ceramic powders
	Powder bed and inkjet head 3d printing, Plaster-based 3D printing (PP)	Plaster
Laminated	Laminated object manufacturing (LOM)	Paper, metal foil, plastic film

In this project we are using the technique of fused deposition modelling.

1.2. RAPID REPROTOTYPING

Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. What is commonly considered to be the first RP technique, Stereolithography, was developed by 3D Systems of Valencia, CA, USA. The company was founded in 1986, and since then, a number of different RP techniques have become available.

Rapid Prototyping has also been referred to as solid free-form manufacturing, computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create male models for tooling, such as silicone rubber molds and investment casts. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of RP.

There is a multitude of experimental RP methodologies either in development or used by small groups of individuals. This section will focus on RP techniques that are currently commercially available, including Stereolithography (SLA), Selective Laser Sintering (SLS[®]), Laminated Object Manufacturing (LOM[™]), Fused Deposition Modeling (FDM), Solid Ground Curing (SGC), and Ink Jet printing techniques.

1.3. Fused Deposition Modelling

Fused Deposition Modeling (FDM) is an additive manufacturing technology commonly used for modeling, prototyping, and production applications.

FDM works on an "additive" principle by laying down material in layers. A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The model or part is produced by extruding small beads of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle. Stepper motors or servo motors are typically employed to move the extrusion head.

The technology was developed by S. Scott Crump in the late 1980s and was commercialized in 1990.

FDM begins with a software process, developed by Stratasys, which processes an STL file (stereolithography file format) in minutes, mathematically slicing and orienting the model for the build process. If required, support structures are automatically generated. The machine dispenses two materials – one for the model and one for a disposable support structure.

The thermoplastics are liquefied and deposited by an extrusion head, which follows a tool-path defined by the CAD file. The materials are deposited in layers as fine as 0.04 mm (0.0016") thick, and the part is built from the bottom up – one layer at a time.

FDM works on an "additive" principle by laying down material in layers. A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The model or part is produced by extruding small beads of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle. Stepper motors or servo motors are typically employed to move the extrusion head.

Although as a printing technology FDM is very flexible, and it is capable of dealing with small overhangs by the support from lower layers, FDM generally has some restrictions on the slope of the overhang.

Several materials are available, such as acrylonitrile butadiene styrene (ABS) polymer, polycarbonates, polycaprolactone, polyphenylsulfones and waxes, with different trade-offs between strength and temperature properties.

A water-soluble material (such as PVA) can be used for making temporary supports while manufacturing is in progress, this soluble support material is quickly dissolved with specialized mechanical agitation equipment utilizing a precisely heated sodium hydroxide solution.

CHAPTER 2

MECHANICAL BUILD

2.1. FRAME

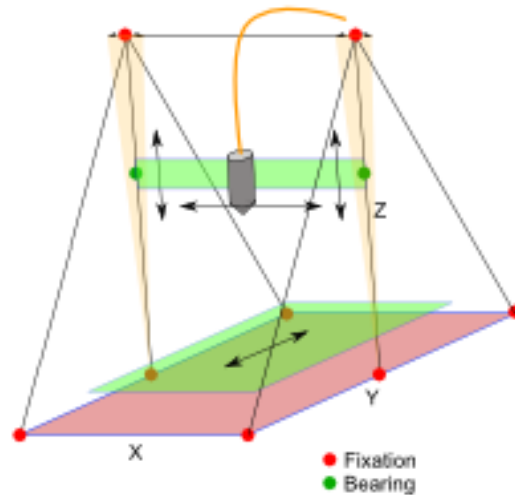


Fig 2.1: Frame and the 3 axes.

It offers more stability than cubical or any other frame, as it is more rigid, yet very light and decent in construction. The truss has been fabricated using threaded rods (M8) and wooden blocks at the vertices.

The X-axis and the Print bed are mounted on the lower two horizontal cross bars, with channels that allow uni-directional motion. That is considered the X-axis motion. This motion is actuated by a stepper motor, which transmits power to a timing belt to move the bed.

The Z-axis is suspended from the upper cross bar. It is suspended on threaded rods that act as lead screws and, they are coupled to a stepper motor shaft individually. The two stepper motors rotate simultaneously, to produce the vertical movement, which we consider to be Z-axis motion.

The Y-axis is mounted on the Z-axis carriage. A pair of linear bearings provides the required horizontal motion over a pair of smooth rods. The actuation is provided by a stepper motor which transmits motion to a timing belt to move the Extruder, which is mounted onto the Y-axis. This horizontal motion is what we consider as Y-axis.

The extruder is the main important component of the machine. Apart from its function of extruding the plastic, it even has two axis motions, one along the Y-axis and another along Z-axis. The bed has the X-axis motion. Hence, The Extruder has 3 Dimensional motions with respect to the bed.

2.2. X-AXIS

X-axis is the horizontal motion of the bed. The bed is mounted on two parallel channels, which are mounted on to the two horizontal cross bars of the frame. The bed is free to move along the channels. One stepper motor provides the necessary actuation, and the timing belt transmits the power to the Bed.

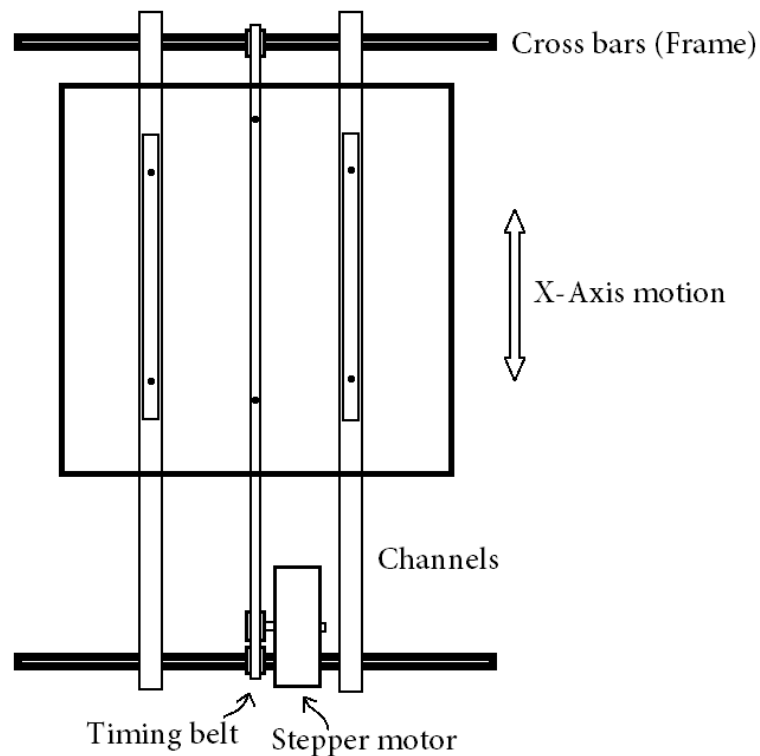


Fig 2.2: X-axis motion setup (Top view).

The above illustrated diagram explains the setup. The timing belt runs over a gear on the stepper motor shaft and over two free pulleys on the cross bars. The timing belt is attached to the bed by two screws.

The Maximum movement of the X-axis is 20cms.

Here, the channels act as linear bearings, to provide smooth motion to the bed. They consist of ball bearings arranged in between two sets of guide ways, to provide smooth linear motion for a particular length.

2.3 Y-AXIS

Y-axis is the horizontal motion of the Extruder over Z axis carriage. The extruder unit is mounted over two linear bearings that move along two parallel smooth rods. This motion is considered to be the Y-axis motion. One stepper motor provides the necessary actuation, and the timing belt transmits the power to the Bed.

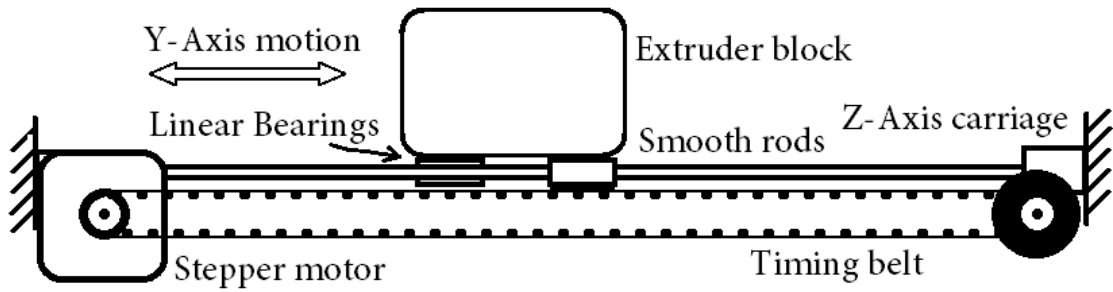


Fig 2.3: Y-Axis motion setup (Front view).

The above illustrated diagram explains the Y-axis setup. The timing belt runs over a gear on the stepper motor shaft and over a free pulley fixed onto the fixed Z-Axis carriage. The timing belt is attached to the extruder unit.

The Maximum movement of the Y-axis is 20cms.

Here, the linear bearings provide smooth motion to the bed.

2.4 Z-AXIS

Z-axis is the vertical motion of the Extruder along with the carriage. The carriage consists of the smooth rods, Extruder, Y-Axis motor and timing belt. The vertical motion of the whole carriage is considered to be the Z-axis motion. Two stepper motors provide the necessary actuation, and the power is transmitted along the M8 threaded rods, that act as a lead screw and convert the rotational motion of the stepper motor shaft into linear motion of the carriage.

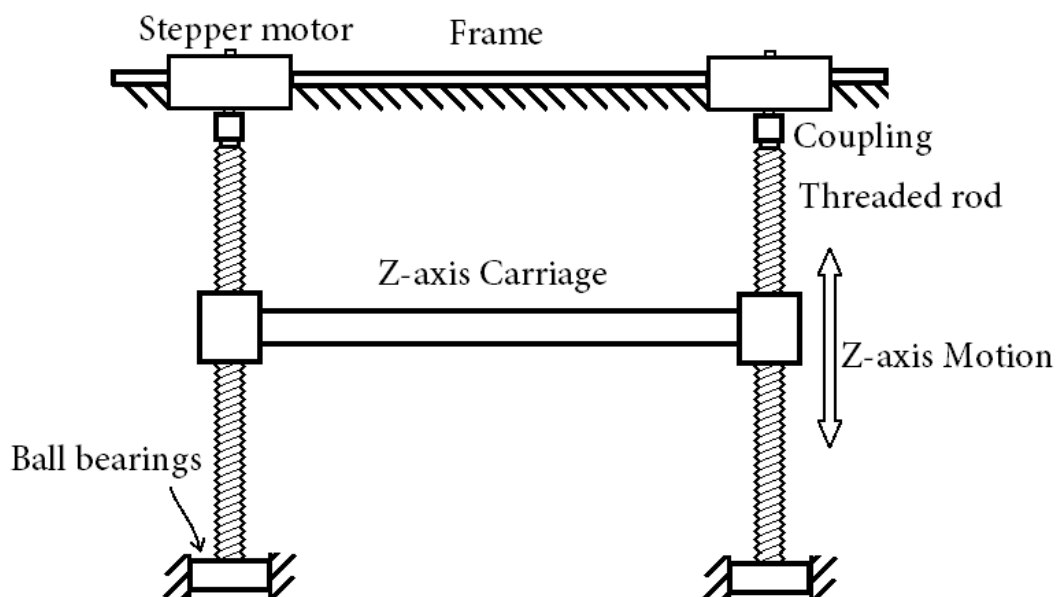


Fig 2.4: Z-Axis motion setup (Front view).

The above illustrated diagram explains the Y-axis setup.

The Maximum movement of the Y-axis is 20cms.

Here, the ball bearings are used to constrain the threaded rod in all other degrees other than rotation about its own axis. It is very much required, for proper functioning of the machine.

2.5 EXTRUDER

Extruder forms the most important component of the FDM machine. It is responsible for the melting of the raw material, to start and stop extruding whenever necessary and extruding it at a particular required rate. The proper functioning of this component is the utmost priority.

The following is the internal block diagram of the Extruder.

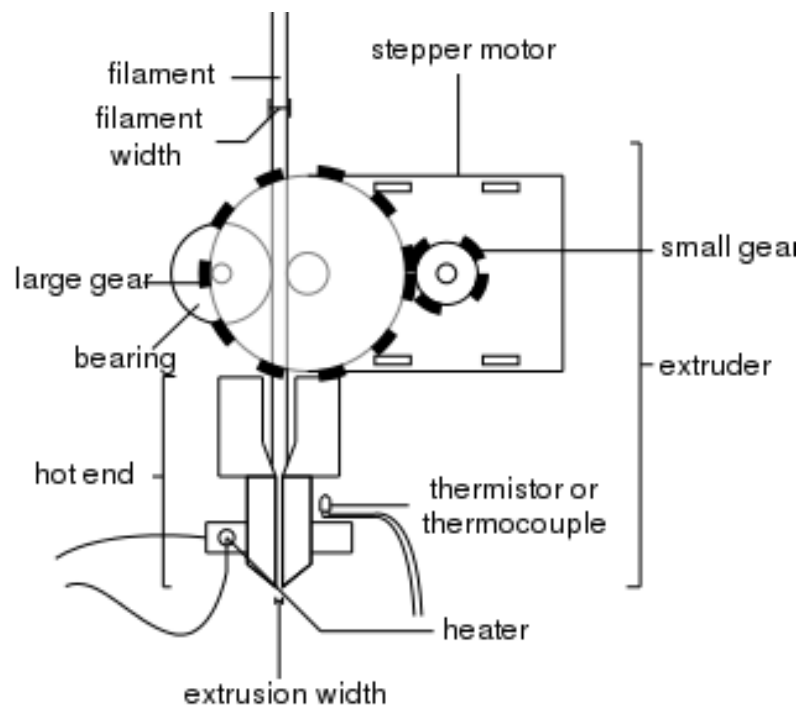


Fig 2.5: Internal block diagram of Extruder.

The extruder can be divided into two parts, hot end and cold end. Hot end is responsible for heating the raw material, while cold end controls its feed rate. The filament is gripped and pushed into the extruder in the cold end, and gets melted at the hot end and is extruded from the nozzle.

A small gear is mounted onto the stepper motor shaft, which is in constant mesh with a larger gear, which is mounted on a splined shaft. A ball bearing is placed at a distance less than the filament diameter from the splined shaft. The filament is fed into this gap, and the splines pierce into the filament and grip it. Proper gripping is essential as the feed rate would vary greatly with a minor slip of the filament.

After the filament is properly gripped, it is pushed by the splined shaft into the hot end. Hot end consists of many small parts. They are illustrated in the following cross sectional view.

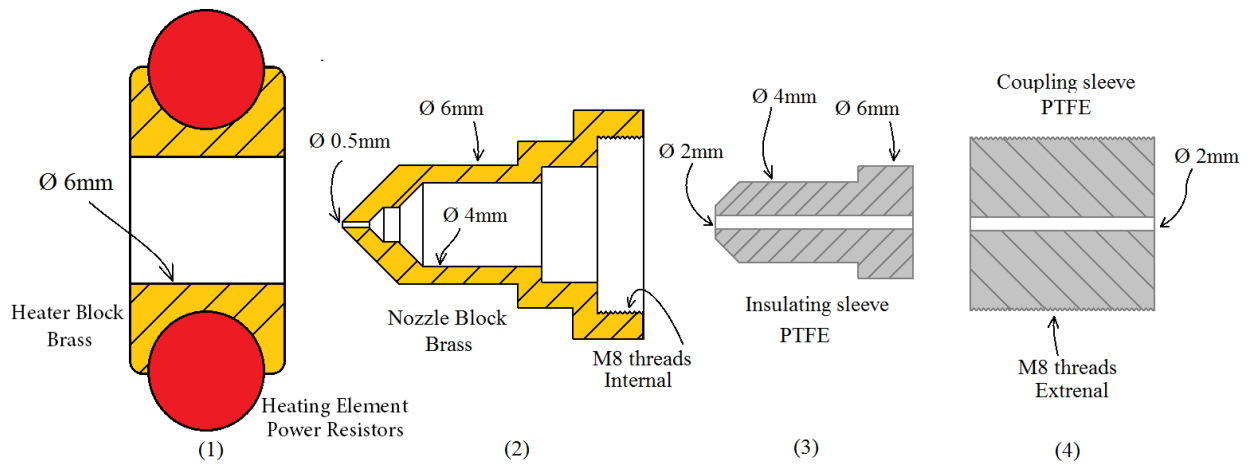


Fig 2.6: Cross sectional view of the Hot End

1. Heater Block (Brass)
2. Nozzle Block (Brass)
3. Insulating Sleeve (PTFE)
4. Coupling Sleeve (PTFE)

2.6 ACTUATION

Any machine requires actuations to perform its function. True to this machine as well, Five Bipolar Stepper motors have been used to provide the actuation. Power transmission was achieved by Timing belts and Threaded rod acting as Lead screw.

In this machine, the three axis motion has to be very accurate and smooth. The reason for using stepper motors is that, they rotate in number of steps, which could be easily controlled. And, hence the number of steps required for moving a part by a particular distance could be easily calculated and precise distance can be moved. This isn't possible with DC motors and Servo motors. A costlier alternative would be linear servo motors, but, they are manufactured for a particular length which can't be adjusted if in case required.

Timing belt was used for power transmission in both horizontal dimensions. Timing belt doesn't offer any backlash, In comparison to gear and lead screw. Backlash could not be avoided as the machine required precise motion up to a first degree of a millimeter. This was the main reason why timing belts were used. They run over a gear mounted on motor shaft and on free pulleys.

Threaded rod that acted as a lead screw was used for the Vertical movement. The backlash in lead screw here is minimized because, weight of the Z-Axis carriage would always keep it at the lowermost position possible.

2.6.1 BIPOLAR STEPPER MOTORS

A stepper motor is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller), as long as the motor is carefully sized to the application.

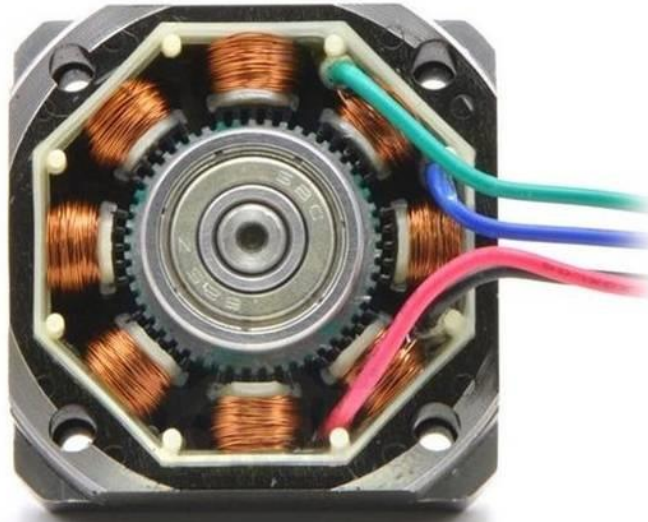


Fig 2.7: Internal Windings of a Bipolar Stepper Motor

Stepper motors effectively have multiple toothed electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by an external control circuit, such as a stepper driver. To make the motor shaft turn, first, one electromagnet is given power, which makes the gear's teeth magnetically attracted to the electromagnet's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. So when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one, and from there the process is repeated. Each of those slight rotations is called a "step", with an integer number of steps making a full rotation. In that way, the motor can be turned by a precise angle.

Bipolar motors have a single winding per phase. The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement. There are two leads per phase, none are common.

Because windings are better utilized, they are more powerful than a unipolar motor of the same weight. This is due to the physical space occupied by the windings. A unipolar motor has twice the amount of wire in the same space, but only half used at any point in time, hence is 50% efficient (or approximately 70% of the torque output available). Though a bipolar stepper motor is more complicated to drive, the abundance of driver chips means this is much less difficult to achieve.

2.6.2 TIMING BELT

Timing belts are reinforced bands of rubber used to coordinate the turnings of the driver gear and driven gears in various machines. The inner surface of most timing belts has teeth which correspond precisely to the gears of a specific design.

As they effectively coordinate the movement of driver and driven, they have been used in various industries. Their main advantage over other power transmitting media is the negligible backlash.

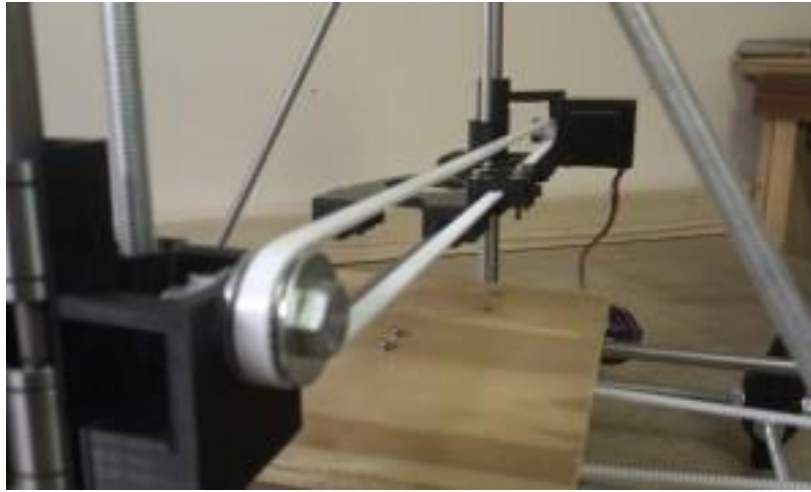


Fig 2.8: Y-Axis Timing belt running over an idle pulley on left and a Stepper motor on right

Timing belt has been used to move the X and Y axes in this machine.

2.6.3 THREADED ROD - LEAD SCREW

A lead screw, also known as a power screw or translation screw, is a screw designed to translate turning motion into linear motion. In this project we have used lead screw mechanism to move the Z-Axis carriage in the vertical plane.

The two threaded rods that function as lead screws are coupled to the two stepper motor shafts with couplers. Both the stepper motors rotation is synchronized by providing the same input to both the stepper drivers.

Fig 2.9 shows the Lead Screw mechanism on the FDM machine. The rotational motion of the stepper motor is converted into the translations motion of the Z-axis carriage along the threaded rod.



Fig 2.9: Z-Axis Lead screw assembly on the FDM machine

CHAPTER 3

ELECTRONICS

3.1 A BRIEF OVERVIEW

Electronics is the neural network of any modern day machine. It forms an integral part of modern CNC machines as well. It is responsible for the actuation, sensing and the functioning of the machine as a whole. Its efficient performance is immensely essential in a FDM machine. In this chapter, the electronics that were used in this project have been explained.

Briefly dividing, the electronics on the FDM could be classified into

- Motherboard Microcontroller
- Stepper Drivers
- Power Supply
- Power Resistors

3.2 MOTHER BOARD MICROCONTROLLER – ARDUINO

Arduino is a single-board microcontroller designed to make the process of using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open source hardware board designed around an 16-bit Atmel AVR microcontroller, though a new model has been designed around a 32-bit Atmel ARM. The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller.

An Arduino board consists of an Atmel 16-bit AVR microcontroller with complementary components to facilitate programming and incorporation into other circuits. An important aspect of the Arduino is the standard way that connectors are exposed, allowing the CPU board to be connected to a variety of interchangeable add-on modules known as shields.

Official Arduinos have used the megaAVR series of chips, specifically the ATmega8, ATmega168, ATmega328, ATmega1280, and ATmega2560. Atmega 168 chip has been used in this project.

Most boards include a 5 volt linear regulator and a 16 MHz crystal oscillator. An Arduino's microcontroller is also pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory, compared with other devices that typically need an external programmer.

At a conceptual level, when using the Arduino software stack, all boards are programmed over an RS-232 serial connection, but the way this is implemented varies by hardware version. Serial Arduino boards contain a simple level shifter circuit to convert between RS-232-level and TTL-level signals. Current Arduino boards are programmed via USB, implemented using USB-to-serial adapter chips such as the FTDI FT232.



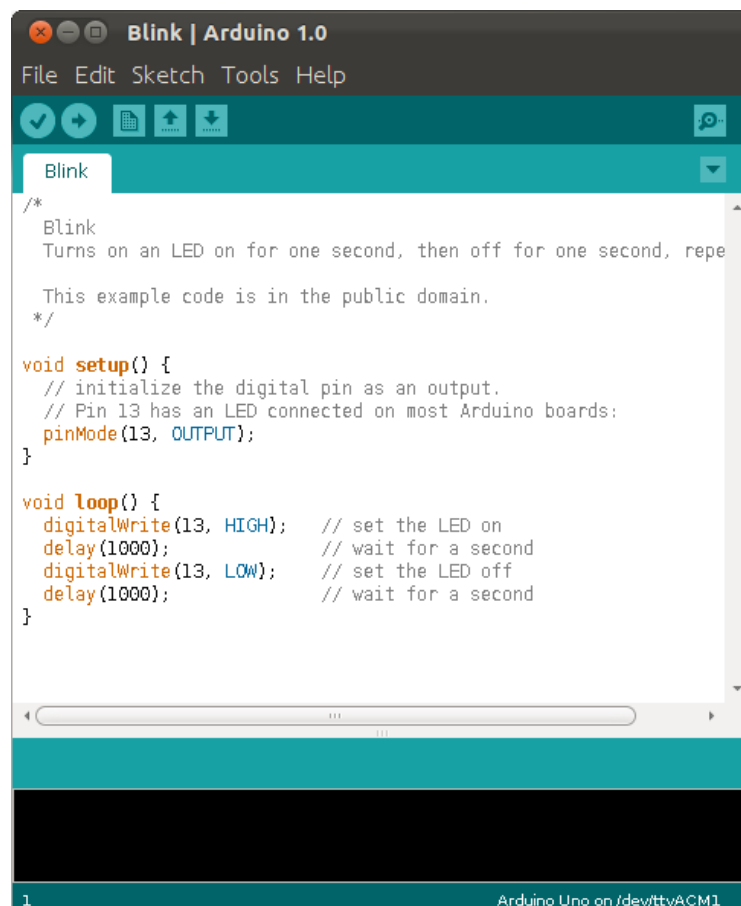
Fig 3.1: Arduino Duemilanove – Motherboard.

The Arduino board exposes most of the microcontroller's I/O pins for use by other circuits. The Diecimila, Duemilanove, and current Uno provide 14 digital I/O pins, six of which can produce pulse-width modulated signals, and six analog inputs. Pulse width modulated signals are required to precisely control the stepper motors. Each Stepper requires one PWM and one Digital signal. Thermistors provide analog output, which is read by the ADC inbuilt into the chip. Six analog inputs can be given to Arduino Duemilanove.

3.2.1 ARDUINO 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. A program or code written for Arduino is called a sketch.

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/output operations much easier. As the Arduino platform uses Atmel microcontrollers, Atmel's development environment, AVR Studio or the newer Atmel Studio, may also be used to develop software for the Arduino.

A screenshot of the Arduino 1.0 IDE. The window title is "Blink | Arduino 1.0". The menu bar includes "File", "Edit", "Sketch", "Tools", and "Help". Below the menu bar is a toolbar with icons for opening files, saving, uploading, and downloading. The main text area shows the code for the "Blink" sketch. The code includes a comment block, a setup function that initializes pin 13 as an output, and a loop function that toggles the LED on and off with 1000ms delays. The status bar at the bottom shows "1" on the left and "Arduino Uno on /dev/ttyACM1" on the right.

```
/*
 * Blink
 * Turns on an LED on for one second, then off for one second, repeatedly.
 *
 * This example code is in the public domain.
 */

void setup() {
  // initialize the digital pin as an output.
  // Pin 13 has an LED connected on most Arduino boards:
  pinMode(13, OUTPUT);
}

void loop() {
  digitalWrite(13, HIGH); // set the LED on
  delay(1000);           // wait for a second
  digitalWrite(13, LOW); // set the LED off
  delay(1000);           // wait for a second
}
```

Fig 3.2: Arduino 1.0 IDE Screenshot

All through the project, Arduino IDE has been used to flash the firmware onto the board.

3.3 STEPPER DRIVER

FDM requires stepper motors for precise actuation of its axes and extruder. However, the bipolar stepper motors that are used in this project are not directly drivable by the microcontroller. Each motor required an Amp of DC through each coil. Arduino motorboard cannot source such high currents through it. And hence a H-Bridge is required.

An H bridge is an electronic circuit that enables a voltage to be applied across a load in either direction. The most commonly used H-bridge to drive stepper motors is the combination of L297 and L298 IC's. However, these IC's are very fragile and cannot operate under enduring conditions that a FDM has to work. Hence, the usage of these IC's isn't considered a logic option. An another IC breakout board, a costlier option to the previous pair of IC's is used in this project.

The EasyDriver is a stepper motor driver, manufactured by Sparkfun corp. and it incorporates a A3967 chip which is compatible with a digital 0 to 5V pulse. EasyDriver requires a 7V to 30V supply to power the motor, and has an on board voltage regulator for the digital interface. EasyDriver drives bi-polar motors, and motors wired as bi-polar. I.e. 4,6, or 8 wire stepper motors. This project uses 4 wired motors only.

EasyDriver V4 is used to drive the stepper motors in the project. It provides much more flexibility and control over your stepper motor, when compared to L297&L298 IC pair. The microstep select (MS1 and MS2) pins of the A3967 are broken out allowing adjustments to the microstepping resolution. The sleep and enable pins are also broken out for further control. However, only the Motor coils out, step input and Direction input have been given in this project.

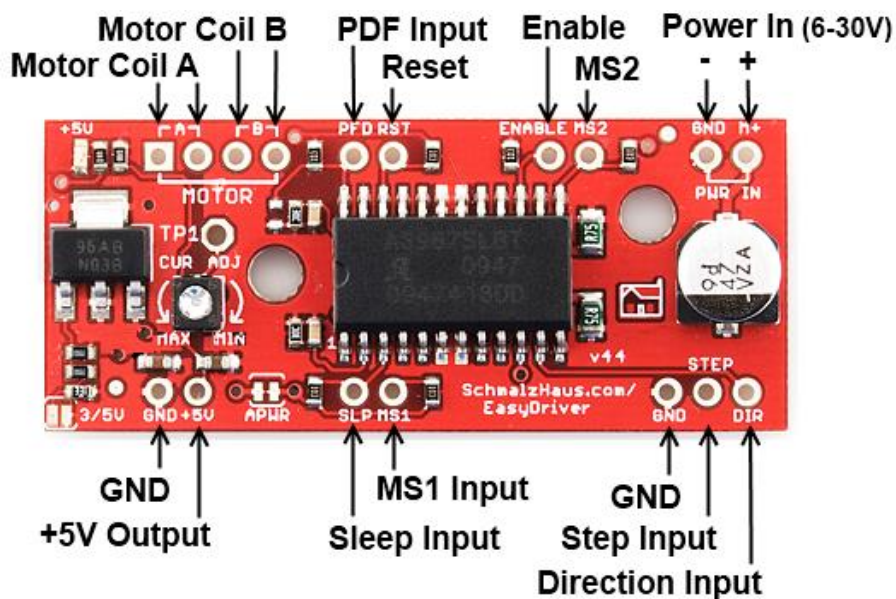


Fig 3.3: EasyDriver v4, Top view.

3.4 POWER RESISTORS

Power resistor is a electric device that offers a particular resistance to current and converts electrical energy into Heat. It is one of the most important components of the whole setup as, without the hot end being as hot as required, extrusion cannot take place.



Fig 3.4: Ceramic Power Resistors

These power resistors have a ceramic coating all around the resistive element, usually Nichrome, to insulate it electrically, but, conduct the produced heat to the environment.

These power resistors are capable of reaching temperatures upto 350°C.

Two 5Ω, 10W power resistors are connected in parallel, on either side of the heater block. The heater block is required to keep some buffer heat in case of a power loss. The same heat is transferred to the nozzle, as they both have a transition fit.

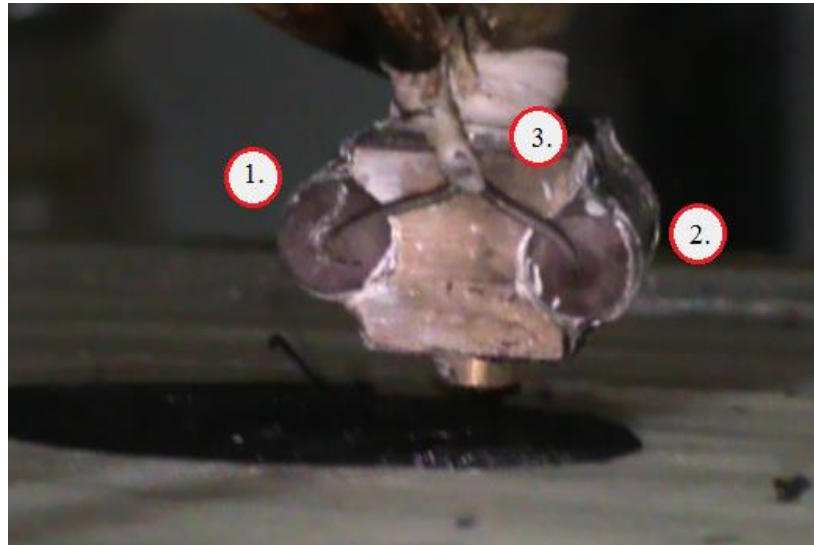


Fig 3.5: Hot End. (1) and (2) are power resistors.
(3) is the heater block.

3.5 POWER SUPPLY

The power supply used to power the machine is a SMPS, or generally called a Computer Power supply Unit. A power supply unit (PSU) converts mains AC to low-voltage regulated DC power for the internal components of a computer. Modern PSU's universally use a switched-mode power supply. Some power supplies have a manual selector for input voltage, while others automatically adapt to the supply voltage.

This power supply unit is rated to provide 15amps of 12V DC and 5V DC to run the various electronic components of the FDM.

Stepper motors drivers and Power resistors require a 12V supply, while the Mother board works at 5V.Both these voltages are generated by the SMPS power unit.

CHAPTER 4

SOFTWARE

4.1 A BRIEF OVERVIEW

Software forms an integral part of any CNC machine. It is responsible for the proper control of all the components to produce the product as per the given input. To understand the function of each of the software's, first let us see the steps involved in 3D printing.

Steps involved in 3D printing:

- **Modelling** – CAD design of the required object is modelled in a CAD software (eg. SolidWorks, AutoCAD). This software produces .stl files.
- **Slicing** – Slicing is the process of dividing the solid CAD object into layers for the ease of converting to G-Codes. A Software (eg. Slic3er) is used to slice the CAD object and convert the object into G-codes. It takes .stl files as input and produces .gcode file as output.
- **CAM software** – This software runs on a PC connected to the printer. It is a typical CAM software that communicates with the printer to produce the required object. This software (eg. PronterFace) takes .gcode as the input and communicates with the Printer via USB serial Interface.
- **Firmware** – Firmware is the code that is being run on the Printer's controller unit. In this project, a Arduino Duemilanove microcontroller is used and the printer controller. The firmware used in this project is Teacup Firmware.

This Firmware controls the stepper motors and Extruder in the printer, as per the instructions given by the CAM software, to print the required object.

Hence a set of software's are used for different operations, each serving a particular purpose. The software's used are:

- **Modelling** - .stl file generation using CAD software's like *SolidWorks, AutoCAD* etc.
- **Slicing** - G-Code generation using *Slic3r*.
- **CAM Software** - Machine Client that runs on the PC, *Printer Interface (Pronterface)*.
- **CAM Settings** - Machine parameter setting software, *Skeinforge*.
- **Firmware** - *Teacup Firmware*.

Detailed Explanation of each of the software's is explained in the following sections.

4.2 MODELLING

Modelling forms the First step of FDM or 3D printing. Any of the available software's can be used to Model the part to be printed. Any software that could export the file as a .stl file could be used. The most frequently used software's are Solidworks, AutoCAD etc.

Once the part is modeled as required, it is exported as a .stl file. STL is the abbreviation for Stereo-Lithographic File.

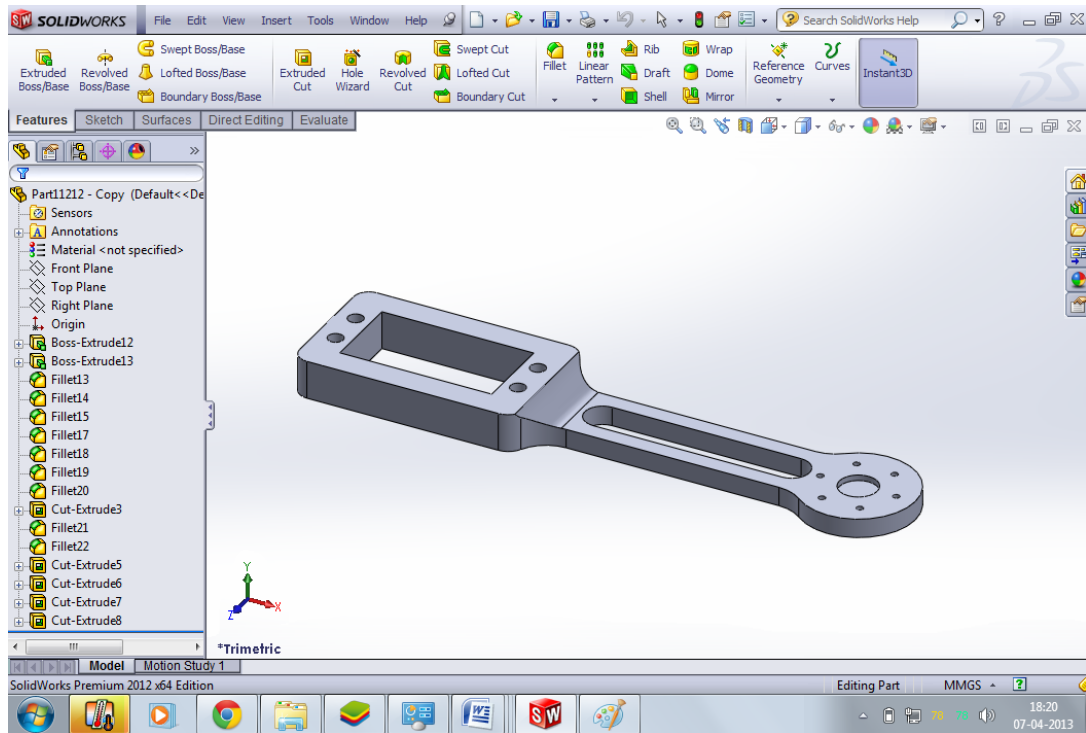


Fig 4.1: Screen shot of SolidWorks, With a Servo Link arm after Modelling.

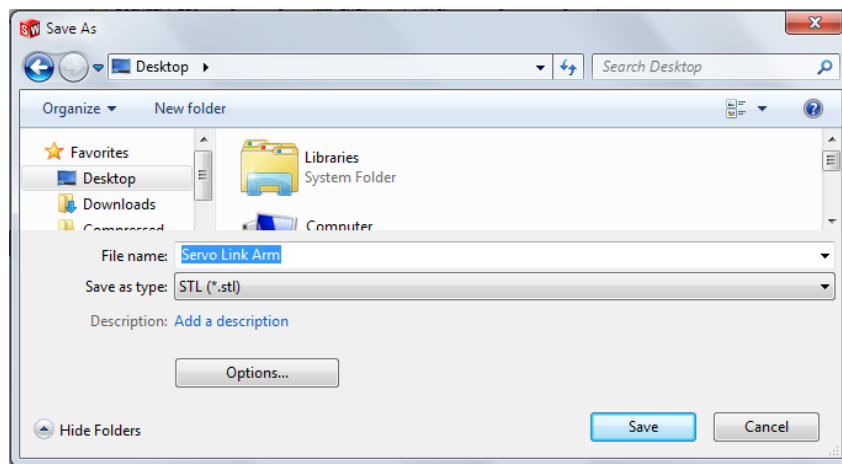


Fig 4.2: Screen shot of SolidWorks, Exporting Servo Link arm as .STL file.

4.3 SLICING AND G-CODE GENERATION

Slicing is the process of dividing the solid CAD object that is exported as .stl file, into layers for the ease of converting to G-Codes. Slic3er is the software used to slice the CAD object and convert the object into G-codes.

Slicer is the software that generates the G-Code for the Machine to perform. It is the most important software of all. It consists of various settings. All the parameters of the machine have to be input, e.g., Perimeters required, Nozzle Diameter, Layer height, Input filament dia, Feed rates for various situations, print bed settings etc. All the parameters have to be measured and the software performs all the required calculations and outputs the G-Code. A typical G-Code is in thousands of lines. The G-Code for the above Servo Link Arm is 8490 lines.

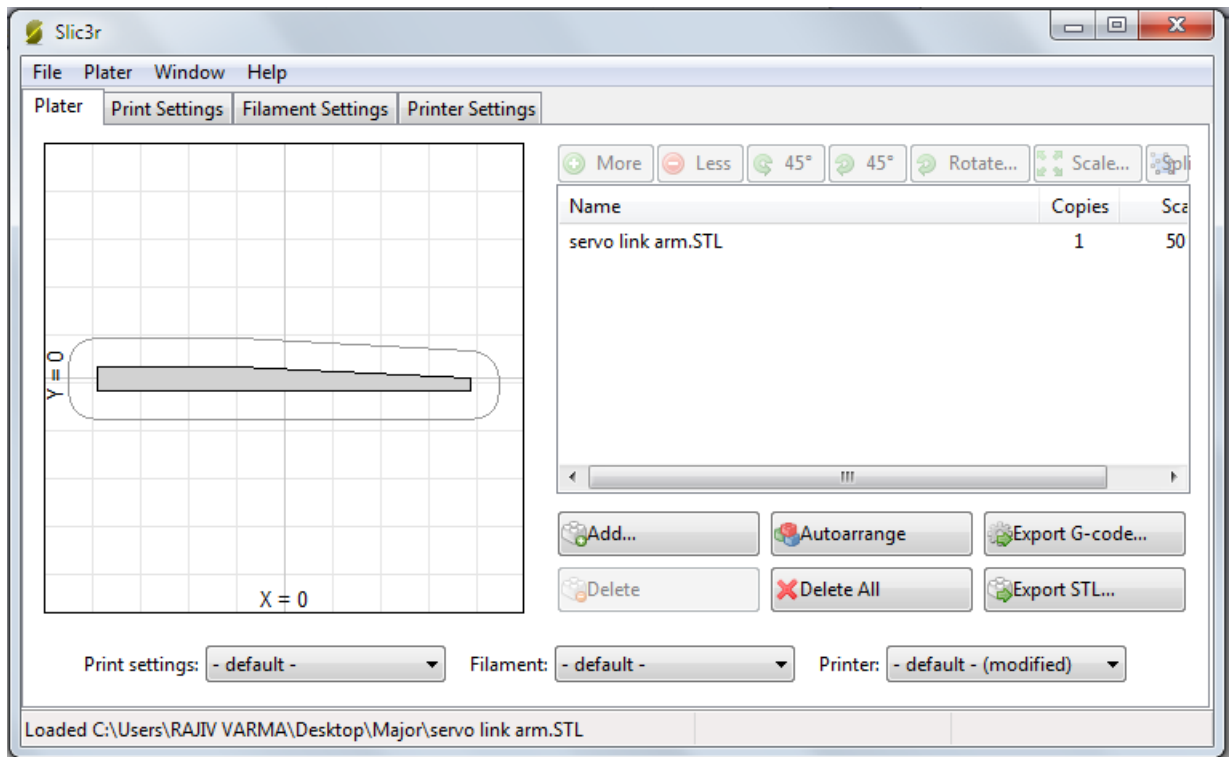


Fig 4.3: Screen shot of Slic3r, an open-source slicing software.

The G-code that is exported by Slic3r is the input for Pronterface.

4.4 CAM SOFTWARE

A CNC machine requires a PC client to convert the G-code into instructions that the Microcontroller can understand. That function is fulfilled by Pronterface.

Pronterface is a Python script application that functions as PC client for Teacup firmware. It takes the G-code file as input and gives commands to the Microcontroller via USB Serial Communication. The Teacup firmware on the microcontroller receives these commands and controls the motors and extruder.

Pronterface console consists of a lot of parameters that have to be set and calibrated before functioning of the machine. Fig 3.4 shows the console and the various manual override options available for the user. Right from Manual Override to Heater and Extruder setting, all the parameters can be calibrated and changed based on the print and the machine. Proper calibration is very important to obtain decent prints.

The screenshot displays the Printrouter software interface. At the top, the 'Printer Interface' title bar includes standard window controls. Below this, the 'File Settings' menu is visible. The main control area features a 'Port' dropdown set to 'COM4' and a 'Load file' button. A 'Meters off' status is shown. The central part of the interface contains a 3D model of a gear on a yellow grid, with a red circle '3' around it. To the right of the model is a 'Monitor Printer' checkbox and a 'Mini mode' button. Below the model are various control buttons: '+X', '-X', '+Y', '-Y', '+Z', and '-Z', along with a 'Check temp' button. A 'Set' button is also present. The bottom section shows printer status: 'Heater: Off', 'Bed: Off', 'Extrude: 5 mm/min', and 'Reverse: 50 mm/min'. A '6' is circled around the 'Set' button. The console window at the bottom right shows a series of status messages, with a '4' circled around the 'T:225.8 E:0 W:8' line. A '5' is circled around the 'T:225.2 E:0 W:0' line. The status bar at the bottom indicates 'Printer is online. Loaded DrivenGear.gcode Hotend:224.3 /225.0 Bed:103.8 /105.0 @:75 Printing:87.71 % | Line# 274781 of 313270'.

Fig 4.4 Prnterface Console screenshot

- 1.Import options
- 2.Manual Override settings
- 3.Graphical Progress Display
- 4.Status bar
- 5.Progress bar
- 6.Heater and Extruder options

4.5 SKEINFORGE

Skeinforge is the software that runs alongside Pronterface, and functions as the secondary settings application. A lot of parameters have to be calibrated in skeinforge as well.

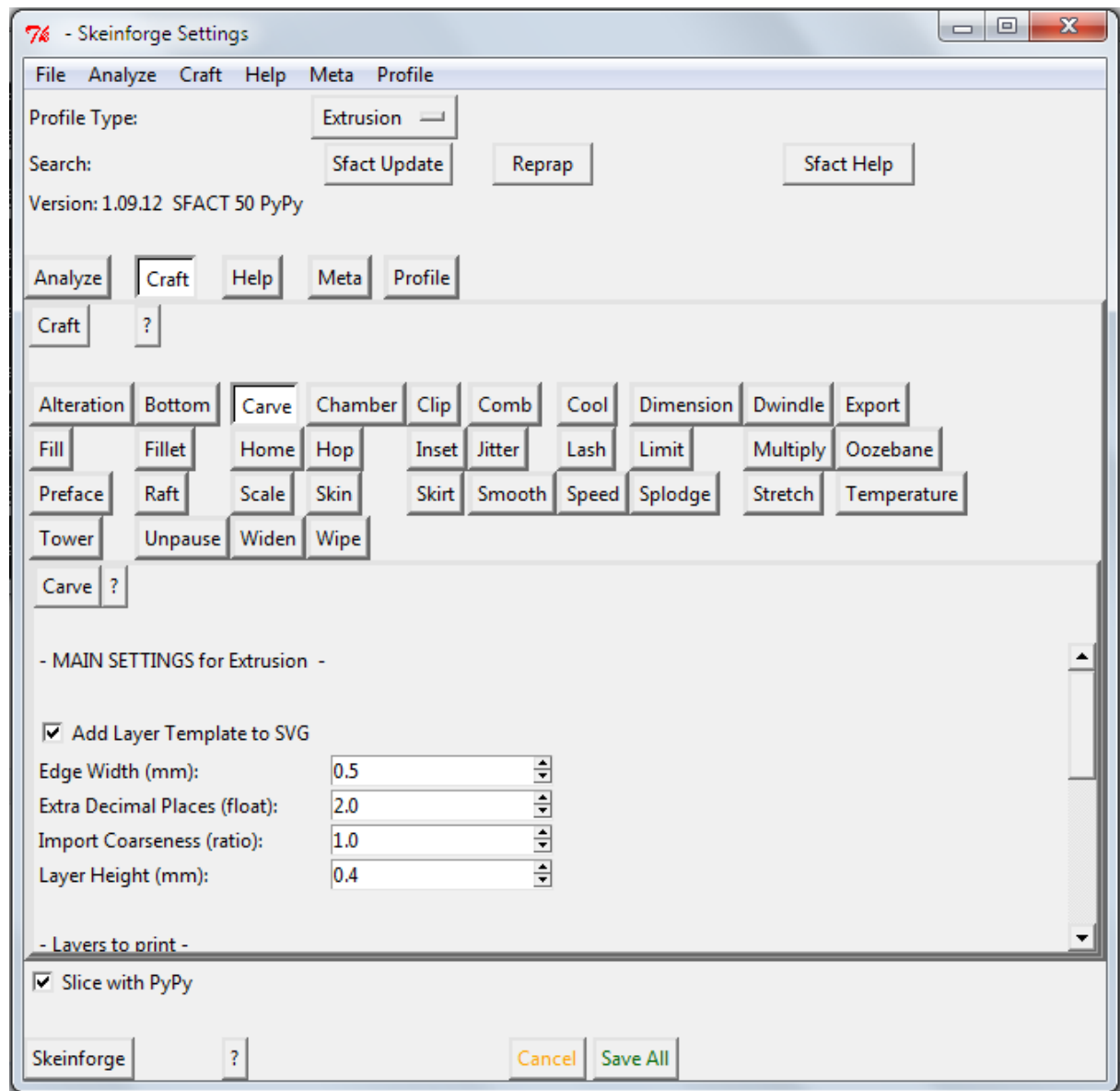


Fig 4.5: Skeinforge Console screenshot.

Various variables like feed rates, Layer height, Scaling etc. have to be saved and this python application modifies the g-code accordingly.

4.6 TEACUP FIRMWARE

Teacup firmware is the C code that is flashed onto the Atmega168 microcontroller on the Arduino motherboard. It is one of the smallest and the most efficient firmware's available. It uses plain C instead of C++ and is small enough to run on small boards like the Atmega168.

It consists of various C files. Config.h is the file in which the calibrated values are to be saved. Other parameters include federate, Steps/mm, Temperature settings etc.

The following shows some of the functions in Config.h.


```

/** \def STEPS_PER_M
    steps per meter ( = steps per mm * 1000 )
    calculate these values appropriate for your machine
    for threaded rods, this is
        (steps motor per turn) / (pitch of the thread) * 1000
    for belts, this is
        (steps per motor turn) / (number of gear teeth) / (belt module) *
1000
    half-stepping doubles the number, quarter stepping requires * 4, etc.
    valid range = 20 to 4'0960'000 (0.02 to 40960 steps/mm)
*/
#define STEPS_PER_M_X          320000
#define STEPS_PER_M_Y          320000
#define STEPS_PER_M_Z          320000
#define STEPS_PER_M_E          320000

```

The above functions are regarding the calibration of X, Y, Z axes and Extruder motor. The steps required for the motor to move it by 1mm is to be calculated and feed into this functions.

```

/// used for G0 rapid moves and as a cap for all other feedrates
#define MAXIMUM_FEEDRATE_X    200
#define MAXIMUM_FEEDRATE_Y    200
#define MAXIMUM_FEEDRATE_Z    100
#define MAXIMUM_FEEDRATE_E    200

/// used when searching endstops and as default feedrate
#define SEARCH_FEEDRATE_X     50
#define SEARCH_FEEDRATE_Y     50
#define SEARCH_FEEDRATE_Z     50
// no SEARCH_FEEDRATE_E, as E can't be searched

```

The above functions are regarding the various feed rates of all the different axes and extruder. All the units are in mm/min.

```

#define          TEMP_THERMISTOR
//              name          type          pin          additional
DEFINE_TEMP_SENSOR(extruder,          TT_THERMISTOR,          AIO0,
THERMISTOR_EXTRUDER)
//              name          port          pwm
DEFINE_HEATER(extruder, PB3,          1)
#define          HEATER_EXTRUDER HEATER_extruder

```

The above functions are regarding the Extruder temperature settings. A thermistor is used to record the temperature readings of the extruder end.

Some other functions regarding enabling and disabling various features like limit switches, thermistors etc.

CHAPTER 5

FUNCTIONING

5.1 HOW PRINTING TAKES PLACE

5.1.1 BOUNDARIES

Once the G-code is loaded into Pronterface, and the print is initiated, first a boundary is printed. It helps in clearly mentioning the print extremities and only to prune the extruder if there is any delay.



Fig 5.1: Boundary printing

In Fig 5.1, the boundary isn't a complete ellipse because of the delay in the extruder. The presence of delay is quite common, and has to be compensated in the beginning.

5.1.2 FIRST LAYER – PERIMETER



Fig 5.2: The first layer begins with the inner perimeter and extends outward. Here you can see the first perimeter completed.

After the boundary, the first one to be printed is the perimeter. 3 perimeters are printed in very close to each other to fuse everything together.



Fig 5.3: After the final perimeter is completed.

5.1.3 FIRST LAYER – INFILL

After the perimeters are printed, then infill is printed. Infill is printed diagonally at 45degrees. Infill for the first three layers is 100%. Parallel lines are printed close to each other similar to the perimeters to aid in faster fusing. In the subsequent layers, the infill is reduced, ranging from 30% to 60%, and then the distance between the parallel extrusions increases.



Fig 5.4: Beginning of 100% Infill



Fig 5.5: Almost complete Infill

After the infill, the first layer is complete. The Z-Axis moves up and the second layer printing is initiated. Second layer also is printed in a similar way, expect that the infill is perpendicular to the infill on the previous layer. It enhances the strength of the product.

5.1.4 SECOND LAYER AND SUBSEQUENT LAYERS



Fig 5.6: First layer completed. Second layer perimeter Initiated.

After the first layer is complete, the second layer perimeter is initiated and the same repeats until the last layer. The first three and the last three layers how ever get a 100% infill compared to the 30-60% infill in all the other layers, to reduce weight and material.



Fig: 5.7: After a 3 layers.

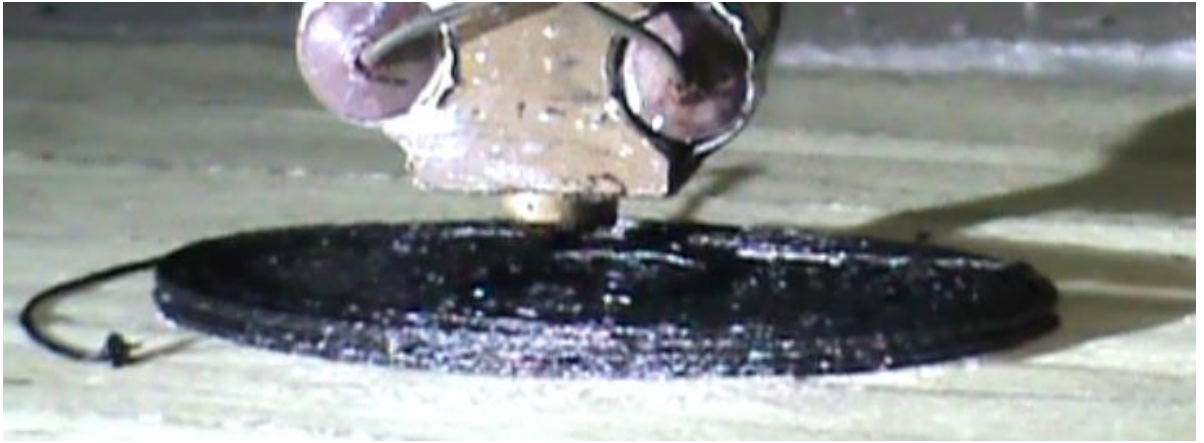


Fig 5.8: After 5 layers



Fig 5.9: 8th layer Infill

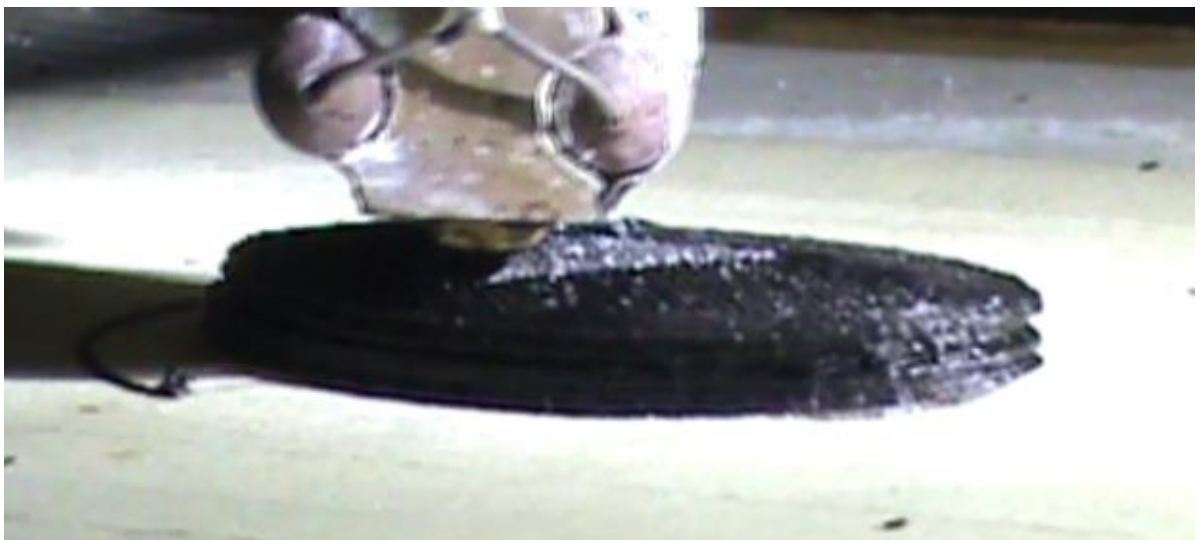


Fig 5.10: 9th layer infill.
Notice the infill being perpendicular to 8th layer infill

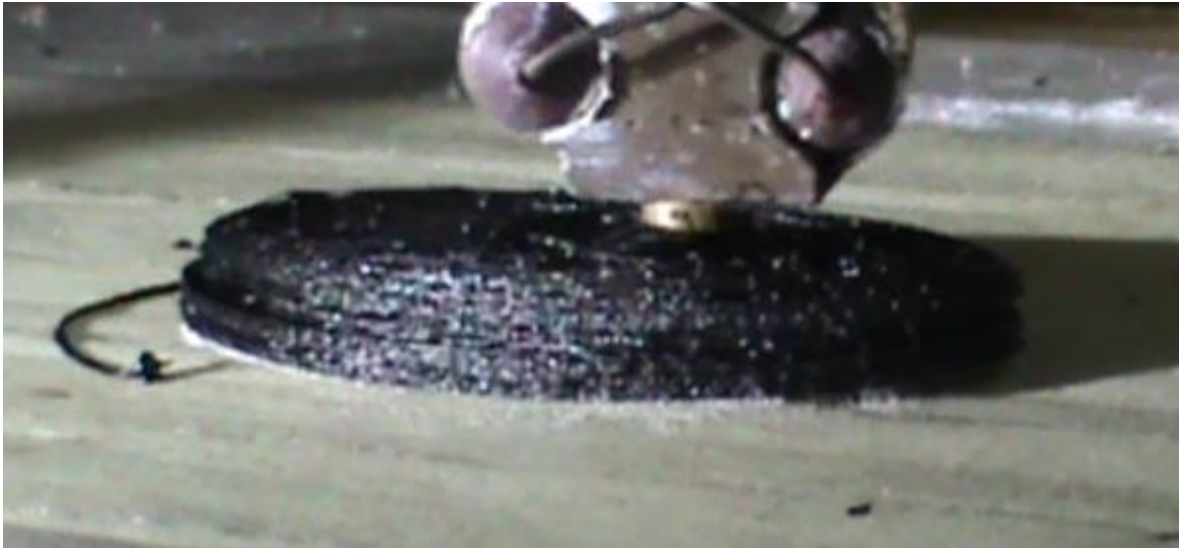


Fig 5.11: Last layer Infill. Notice the Curved edges that were produced as per the design.



Fig 5.12: The final product.

5.1 POST PRINTING OPERATIONS

After the product is obtained from the FDM machine, the surface finish is not as often as desirable. Its surface finish is smoothed by using Acetone. Acetone, systematically named propanone, is the organic compound with the formula $(\text{CH}_3)_2\text{CO}$. It is a colorless, mobile, flammable liquid, and is the simplest ketone. The interesting property of Acetone is it could dissolve ABS plastic, the raw material used in FDM. Heating Acetone and subjecting the products to the acetone vapours would highly increase the surface finish.



Fig 5.13: Acetone polishing. Notice the difference in surface finish of the two products.

1. Unprocessed product

2. Processed Product

CHAPTER 6

CONCLUSION, FUTURE SCOPE AND APPLICATIONS

6.1 CONCLUSION

A Fusion Deposition Modelling Machine has been fabricated and proper functioning of the machine has been achieved. Throughout the project, various open-source software's have been used, that were released under GNU General Public License. GNU General Public License guarantees that end users (individuals, organizations, companies) of the software have the freedoms to use, study, share (copy), and modify the software.

Specifications of the FDM machine fabricated:

- The diameter of the extrusion nozzle used in this project is 0.5mm.
- Raw material used is ABS (Acrylonitrile butadiene styrene).
- The layer height that could be achieved is 0.6mm.
- Maximum print volume is 200*200*120mm.
- Optimal feed rate is calibrated to be 35-40mm/sec during operation.
- No. of filaments required is 1.
- Filament Dia. is 1.75mm
- Temperature of the Extruder Block is 290-320° C.

6.2 FUTURE SCOPE

Further development could be performed on the FDM machine to increase its reliability and efficiency of production. Quite a number of changes have to be made to achieve that. Some of the few modifications that could be beneficiary in effective production would be:

- Reducing the diameter of the extruder nozzle from 0.5 to 0.3mm.
This reduction in nozzle diameter would increase the surface finish and the intricacy of FDM machine
- Increase in bed size.
The size of the bed could be increased to match the industrial FDM machines of 400*400*200mm build volume.
- Installing a heated bed.
Heating the print bed to about 100° C would improve proper adhesive properties between the print and the bed. It would reduce the chances of Warping.
- Installing Multiple Extruders would be useful to produce multi colored products.

6.3 APPLICATIONS

Major applications of FDM machines are in rapid reprototyping where a CAD file can be built into a 3D object within a few minutes. However, FDM nowadays is used in customisable consumer products ranging from Spectacles to Machine components. The only limit for FDM to produce is only the lack of creativity. It could produce virtually any shaped object. In recent days there has been a huge rise in the applications of FDM. FDM is now used to produce custom toys, spectacles, automobile components, Bicycles, scale RF aircrafts and even in medicine. 3D printed parts can now be used as replacement to bones. Recent breakthrough has been achieved after a human jaw has been 3D printed as replacement for a natural jaw.

CHAPTER 7

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