DEVELOPMENT OF LOW COST FUSED DEPOSITION MODELING (FDM) 3D PRINTER

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Abstract : 3D printing technology, also known as Additive Manufacturing (AM) is a manufacturing process in which a three dimensional object is built by laying down successive layers of material. At the core of AM is the Fused Deposition Modeling (FDM) technology where objects are created by extruding and depositing thermoplastic material in layers. The 3D printer works on the Cartesian independent drive system which has better aesthetic features and larger build volume of the print part. The E3D Hot end, which is used to melt and deposit material has a nozzle that heats up in less than two minutes which saves time and also provides excellent print quality. A material cartridge supplies a plastic filament to the extrusion head where material melts and the head, controlled by a stepper motor, moves along X and Z-axes while liquefying and depositing material. The bed of the machine moves along the Y-axis to give the part the third dimension. 3D printing is not yet a standardized practice and a major reason is that cost of printers are very high. In order to build a cost effective, ergonomic and lighter 3D printer cast acrylic plates were used for the structure, the inner parts of the machine like the motor holders, guide rod holders were 3D printed using Poly Lactic Acid (PLA) which has significantly reduced the weight and cost of the machine while retaining its rigidity.

IndexTerms **- Additive Manufacturing, Fused Deposition Modeling, Cartesian Independent Drive System, Poly-Lactic Acid.**

I. INTRODUCTION

3D printing also known as "Additive Manufacturing" (AM) was first used in rapid prototyping during the end of the 1980s and beginning of the 1990s. The initiation of 3D printing took place at Massachusetts Institute of Technology (MIT) and Chuck Hull of 3D systems Corporation, created the first working 3D printer in 1984.

3D printing systems have introduced a number of 3D techniques since it was settled in 1986. ASTM recognizes seven methods of AM, with a wide range of products available on the market based on these types. Some of the most widely adopted 3D printing technologies include Fused Deposition Modelling (FDM), Stereolithography (SLA), Selective Laser Sintering (SLS), Selective Laser Melting (SLM), and Digital Light Processing (DLP), but new additive processes continue to be developed and commercialized [7].

The technology used by most 3D printers to date especially hobbyist and consumer-oriented models is Fused Deposition Modeling. 3D printers that run on FDM technology soften thermoplastic filament by heat and extrude the softened filament according to pre-set coordinates, to build parts layer-by-layer from the bottom. The 3 main parts are a printing plate on which the part is printed a filament coil that serves as printing material, and an extrusion head, called an extruder. The filament is melted by the extruder of the printer, which deposits the material layer-by-layer on the plate. **Figure 1.** shows the working of FDM additive manufacturing [6].

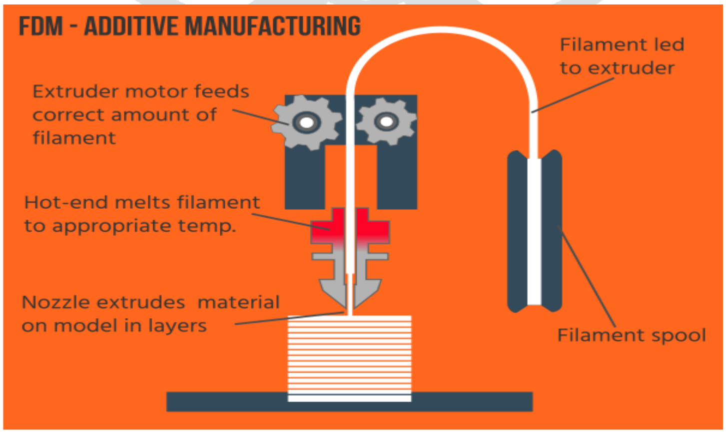


Fig. 1. FDM 3D printing process

FDM begins with a software process which processes an STL file (Stereolithography file format), mathematically slicing and orienting the model for the build process. The 3D printer will begin printing when the machine has reached the temperature needed to melt the material, usually around 200°C (392°F). Once hot enough, filament is extruded onto the platform. This moves through a nozzle on the X, Y, and Z axes printing the object layer-by-layer [5].

Fawaz Alabdullah [1] proposed the mechanism of fused deposition modeling mechanism. In his research he studied the foundation, mechanism, filament material, speed and the economy efficiency of Fused Deposition Modeling (FDM).

Agnes Bagsik and Volker Schöppner [2] in their research paper, studied the mechanical properties of FDM samples built up with FDM process were analysed depending on the build direction. Therefore, the samples were generated with different parameters for the toolpath generation and the mechanical tests conducted were the tensile test. The results show that the mechanical strength properties depend on the given inner part structure as a result from the build direction and the toolpath generation. If required, support structures may be generated. The machine may dispense multiple materials to achieve desired model or part.

A Myriad of materials are available, such as Acrylonitrile Butadiene Styrene (ABS), Polylactic acid (PLA), Polycarbonate (PC), Polyamide (PA), Polystyrene (PS), lignin, rubber, among many others, with different trade-offs between strength and temperature properties. There is a growing number of 3DP organizations that are providing educational support [3].

II. IDENTIFICATION OF THE PROBLEM

Customer driven product customization, demand for cost and time savings and speed of delivery are the major challenges faced by manufacturing industries. Yet this immediacy- right here, right now is not economical in traditional manufacturing processes. Traditional manufacturing is only optimized for large volumes of consistent output, while for low volumes 3D printing provides a significant value because 3D printing enables precise control of the material being used, the designer can recreate the internal structure of a product for optimal effect. The 3D printers available in the market are expensive and not many industries have taken initiatives to use this technology. Hence there is a need for FDM technology to reach wider audience, and adoption rate must also increase. Therefore, there is a need to make printers affordable and compact without sacrificing the quality of the print.
The main objectives are :

- To reduce the cost of the various parts.
- To make rigid structures so that system does not fail due to different load conditions.
- To reduce the manufacturing cost.
- To reduce the overall weight of the machine.
- To compete with the other 3D printers in the market.
- Improve customer satisfaction.

III. CONCEPTUALIZING

Two concepts [4] were considered to develop the machine that fulfills the above objectives:

3.1 Concept 1

Figure 2. shows the initial concept and design work of the low cost FDM 3D printer which is a Cartesian type 3D printer. The concept 1 machine works on the Core XY mechanism. Incorporating Core XY system keeps the motor stationary. It is compact, precise, repeatable and linear and also it is easy to understand the mechanical reasons for this. Although it has many benefits it is not easy to calibrate the machine to produce high accuracy products. **Figure 3.** shows the bed mechanism and Core XY mechanism. Some of the difficulties in incorporating this system are :

- Not easy to calibrate the machine to produce accurate print products.
- Difficulty in assembling the parts.
- It increases the cost of the machine.
- Not suitable for larger build volumes.

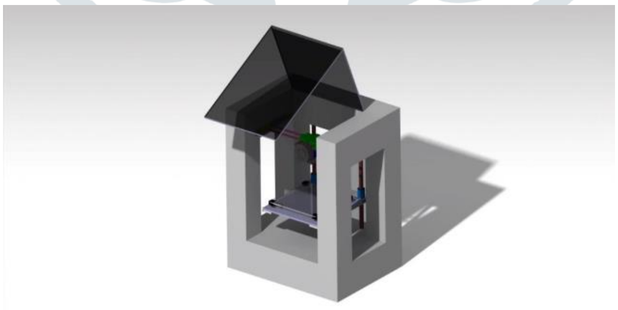


Fig. 2. Assembly of the 3D printing machine

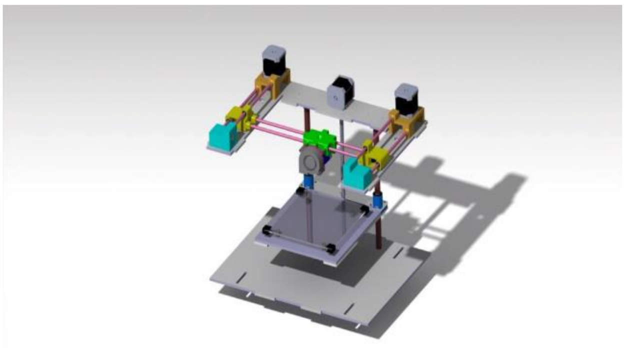


Fig. 3. Core XY mechanism and bed mechanism

3.2 Concept 2

To overcome the challenges posed by the initial design it was decided to go about independent drive single extruder 3D printer. Here each stepper motor is used for movement of extruder. Unlike CORE XY mechanism, this mechanism is very simple.

- Easy to troubleshoot problems and gives a very good finish at the end of the print.
- It is easier to find parts and to repair Cartesian printers.
- Cartesian printers have more rigid axes, which allow less room for error when the print head moves within the 3D space.
- Also, the major development was increase in the build volume. Therefore, this concept design helped in development of larger build volume 3D printer.
- The other advantages are that it requires less time to assemble the machine and number of parts used is reduced. **Figure 4.** shows Concept 2 , the final design, that was developed after Concept 1.

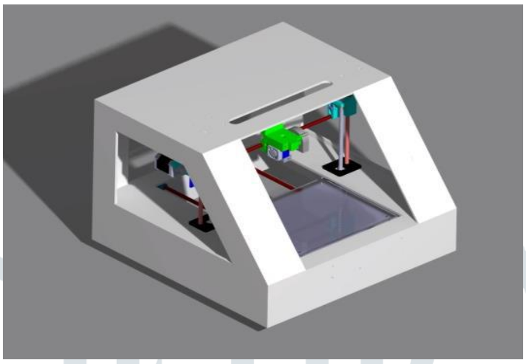


Fig 4. Final Design

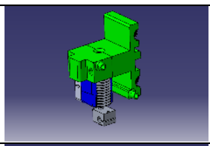
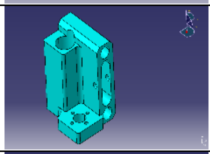
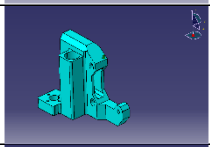
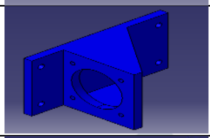
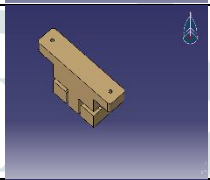
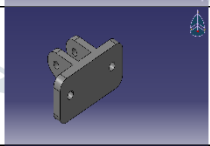
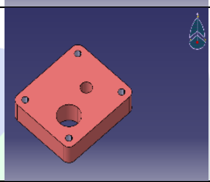
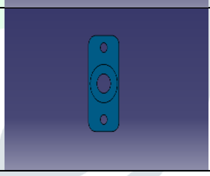
IV. Manufacturing of Acrylic Plates

In order to design and develop the FDM 3D printer, CATIA V5 design software was used for the model development. Also, the parts that were to be machined needed to be drafted in the CATIA software so as to effectively communicate the needs to be met in the manufacturing stage. The structure of the machine is made up of Cast acrylic material which is light in weight and brittle. The cast acrylic was cut to dimensions with help of laser cutting technology. **Figure. 5** shows the laser cutting of acrylic plates.

Fig. 5. Laser Cutting of Acrylic Plates

Acrylics are cut by vaporizing the solid material. The laser is absorbed by the material causing it to change from a solid to a liquid then to a vapour. This is done with a very low level of chemical degradation. To help combat the copious amounts of vapour created by laser cutting, it is important to have a high quality, strong vacuum system to remove the vapour. The vapour that is emitted from the laser cutting process is highly flammable, hence the laser system should never be left unattended while acrylics are being cut. Table 1. gives the list of all the parts involved in building the structure of the 3D printer.

Table 1. Parts of the structure of the 3D Printer

PART NAME	QUANTITY	DESIGN
Print Head Assembly	**1**	
XZ motor mount left side	1	
XZ motor mount right side	1	
Y motor mount	1	
Y bed mount	1	
Y pulley holder	1	
Top Z motor mount holder	2	
Z guide top holder	2	

V. ASSEMBLY AND PRINTING OF A COMPONENT

After successful manufacturing of the parts, the final assembly was carried out. The machine was painted black using spray paint and was fitted with LED lights for better aesthetics. The printer was named “Neo” means new. **Figure 6** shows the final assembly of the machine, **Fig. 7** shows the machine with lightings, **Fig. 8** shows the printing of the part model on the bed of the machine.

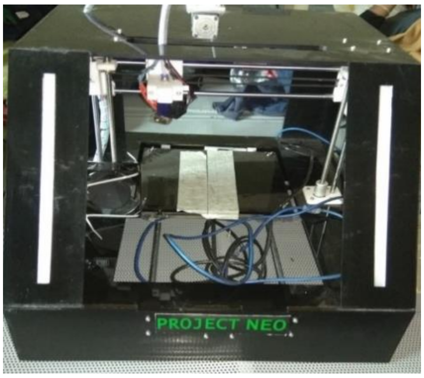


Fig. 6. The final assembly of the machine

Fig. 7. The final assembly with lightings

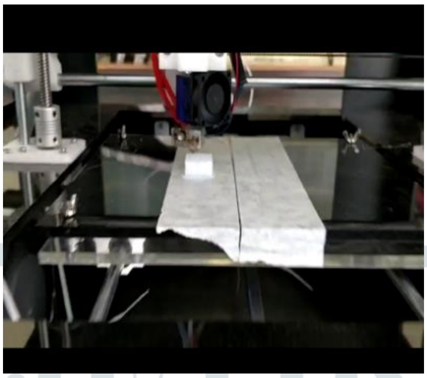
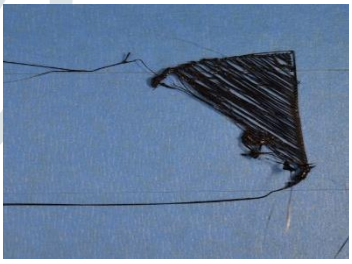
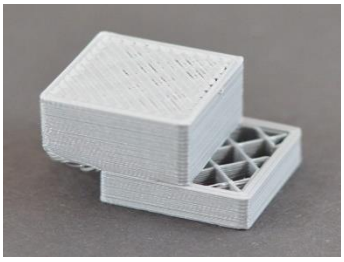
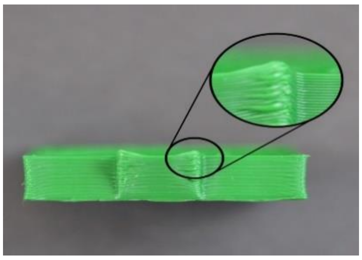
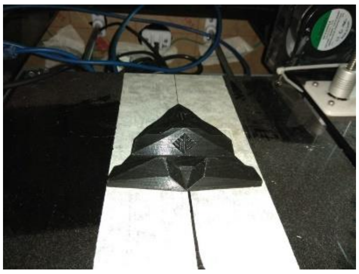


Fig. 8. Printing of a part on the bed

This was followed by trial printing of a component. Table 2. shows the problems faced while printing and the reasons for it.

Table 2. Printing of Component

Trial No.	Problem faced	Reasons	Illustration
1.	The first layer of your print is strongly connected to the printer's build platform so that the remainder of your part can be built on this foundation. This was not taking place.	• Build platform not in level • Nozzle starts too far away from the bed • First layer is printing too fast.	
2.	Sometimes due to a wrong process and the extruder is no longer able to push plastic through the nozzle.	These jams or clogs are usually due to something inside the nozzle that is blocking the plastic from freely extruding. Filament can be reloaded or nozzle can be cleaned to rectify this,	
3.	Layer shifting, where one layer is displaced by a certain distance with respect to the preceding layer.	• Mechanical, electrical issues • Tool head moving too fast	

4.	Curling or rough corners.	• Hot extruded material does not cool quickly. Corrected by using a cooling fan to rapidly cool each layer.	
5.	Phone Stand successfully 3D printed.	All problems were rectified and the component had a good surface finish.	

VI. Cost Analysis And Comparison

Since the objective of the project is to reduce cost it is necessary to conduct the cost analysis. As an engineer it is important to understand the economics involved in the entire development process. The total cost of the machine including labor and other miscellaneous was **Rs. 20470**. Table 3 shows the cost of all the parts involved in building the machine. This also includes the labour cost and other miscellaneous items.

Table 3. Cost Analysis

Sl. No	NAME	QUANTITY	COST
1	Front Slant Plates	2	4000
2	Top and Back Plate	2	
3	Side Plates	2	
4	Acrylic bed Plate	1	
5	Mid Plate	1	
6	Bed Mounting Plate	1	
7	X carriage holder	2	200
8	Z motor holder	2	400
9	Y motor holder	1	200
10	Print head	1	300
11	Screw Rod	2	200
12	Linear bearing	6	120
13	Pillow bearing	3	360
14	Nut	2	100
15	Coupling	2	200
16	Guide Rod	6	250
17	E3D V6 hot end	1	1000
18	Limit Switch	4	30
19	Stepper motor	5	9750
20	Microcontroller	1	1000
21	SMPS	1	1800
22	Stepper motor drive board	4	160
23	RAMP 1.4	1	450
TOTAL COST		**20470**	

A cost comparison with other 3D printers in the market was also carried out as given in Table 4.

Table 4. Cost Comparison

Product	Build Volume (mm^3)	Price (Rupees)
LuLzbot 3D mini	152x152x158	82000
Flashforge 3D Finder	140x140x140	43000
Makerbot mini+	101x126x126	62000
NEO	**200x200x200**	**20470**

VII. CONCLUSION

As the limits on object size and printing speed decrease and the price of printing materials falls, the economics of manufacturing will change dramatically in favour of 3D printing. The 3D printer developed met the objectives set as the total cost of the machine was Rs 20,470. It is a highly competitive price in the market as the printer is capable of producing good surface finish and can produce complex structures that can be used for various applications. The focus in the future would be to reduce the gap between Additive Manufacturing and its practical use in industries.

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