Design of A 3d-Printer

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Abstract : - This paper describes the project based on 3-D printing technology. A 3-D printer is a machine which uses additive manufacturing process to create a 3-dimensional object using digital data. This 3-D printer uses the FDM technology and has 3-axis arrangement with inbuilt heating platform. The heating platform can be finely tuned for precise levelling. This 3-D printer can print things right from microns to 180mm. It is compatible with various materials having melting temperature up to 300°C. The materials like PLA, ABS, HIP, etc can be used. The structure of the 3-D printer is rigid cuboidal frame of 6065 Aluminum having a printing volume of $180x180x180mm^{3}$. The main objective of the project is to create a reliable and most cost efficient 3-D printer. This project also emphasizes on design of such machines, various types of extruding materials and its application in some of the core engineering, architecture and medical fields.

Keywords: - Additive manufacturing, Design, FDM ,3D printer, Rapid Prototyping.

I. INTRODUCTION

3D printing uses the technique of additive manufacturing where an object which is required is made by adding successive layer of materials. This technique is also known as Rapid Prototyping. This is a time saving activity where we can complete a object in a single process. The object formed by this technique can be used to test the functionality and assembly of the object in its real material, which cost more in time and raw material. It also helps in validating the products designs and identify the error which otherwise would not have been noticed in virtual simulation and analysis. 3D printing technology finds its application in various industries such as Shelter, Food, Bio-organ, Dental Implants, Education etc.

II. 3D PRINTING TECHNOLOGIES

2.1 **Stereolithography (SLA) Technology:** SLA is a fast prototyping process and is popular for its fine details and accuracy. In this process the liquid polymers are converted in solid 3D objects, one layer at a time. The plastic is first heated to turn it into semi liquid form and then it hardens on contact by means of ultra violet laser directed by X and Y scanning mirrors.

2.2 **Fused Deposition Modelling (FDM) Technology:** This technique is popular for producing functional prototypes, concept models and manufacturing aids. It uses production grade thermal plastic to print its 3D object. Before the FDM printing process begins, the user has to slice the 3D CAD data (the 3D model) into multiple layers using special software. The sliced CAD data goes to the printer which then builds the object layer at a time on the build platform. It does this simply by heating and then extruding the thermoplastic filament through the nozzle and onto the base. The printer can also extrude various support materials as well as the thermoplastic. For example, as a way to support upper layers, the printer can add special support material underneath, which then dissolves after the printing process. As with all 3D printers, the time it takes to print all depends on the objects size and its complexity.
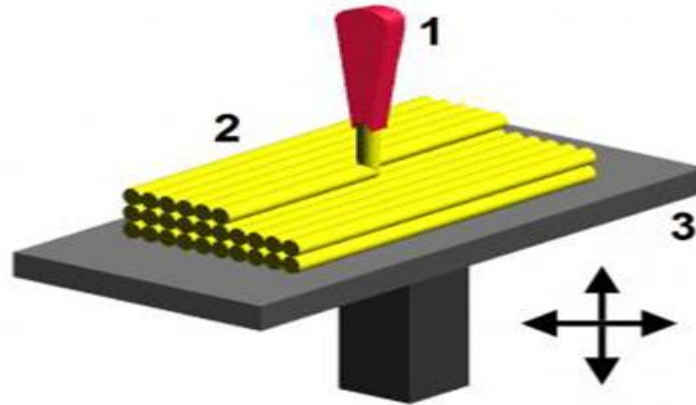
Fig 1 : Fused Depostion Modelling (FDM) Technology [1].

2.3 **Selective Laser Sintering (SLS) Technology :** This technology uses high power CO_2 lasers to fuse particles together. The laser sinters powdered materials. It's a perfect technology for fully functional, end use parts and prototypes. SLS is quite similar to SLA process as far as speed and accuracy is concerned, the main difference is the material SLS uses powdered substances while SLA uses liquid resins.
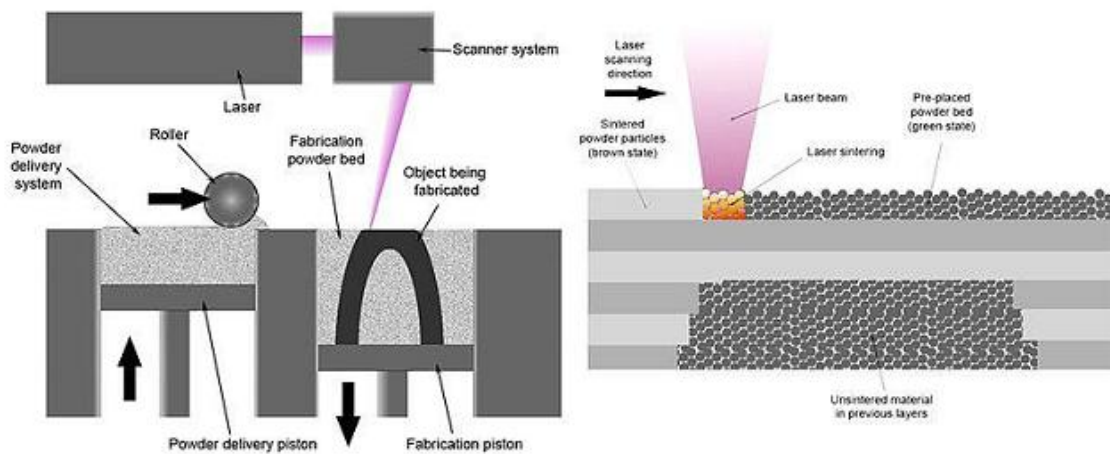

Fig 2 : Selective Laser Sintering (SLA) Technology[1].

2.4 **Laminated Object Manufacturing (LOM) Technology :** LOM is a rapid prototyping system that works by fusing or laminating layers of plastic or paper using both heat and pressure. A computer-controlled blade or laser cuts the object to the desired shape. Once each printed layer is complete, the platform moves down by about 1/16th of an inch, ready for the next layer. The printer then pulls a new sheet of material across the substrate where it's adhered by a heated roller. This basic process continues over and over until the 3D part is complete.
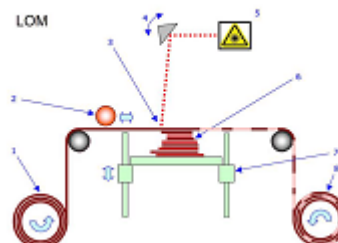

Fig 3 : Laminated Object Manufacturing (LOM) Technology[1].

III. 3D MODEL DESIGNING PROCESS

3.1 Design: Users first design their model using CAD tools. There is a diverse array of available CAD tools including freely available options such as OpenScad or SketchUp or any other tool such as SolidWorks, Creo, Inventor etc.

3.2 Slicing : Slicing means to divide the entire 3d geometry into a sequence of 2D slices parallel to x-y plane at for a regular interval of height. If the entire object of height H is sliced into i intervals of slices having height h than the ith slice represents the perimeters of the object to be printed at height i. To generate G-code, the slicer computes tool paths to trace the perimeters at each height, the space between the perimeters are filled with a regular pattern or a pattern defined by the user. Within these layers, the slicer inserts G-codes to start and stop extrusion during movements along perimeters and over fill areas. The slicer then inserts additional G-code between the instructions for each layer to increment the printer's z axis by h. Finally, the slicer inserts sets the basic parameters such as fan speeds as well as build plate and extruder temperatures to appropriate values for the material being printed. Throughout the slicing process, the compiler performs optimizations to minimize the travel time of the print head.

3.3 Compilation: Compilation happens in two steps, Firstly a CAD model is converted in Stereolithography(STL) format. This format represents the surface mesh in the form of polygons in a 3D coordinate system. In Second step STL is "sliced" to obtain G-code. The G-code is a sequence of imperative commands that control extrusion, movement and temperature. The slicer determines the tool path which refers to the path the print head should follow while printing.

3.4 Print: The printer runs firmware that interprets the G-code and sends control signals to motors, heating elements, and cooling fans. An extruder melts printing material and pushes it through a nozzle which builds the part layer by layer on the build plate. There are many physical parameters involved in this step that affect the print quality i.e the inertia on the print head, thermal expansion of the print material, the temperature and humidity of the environment, speed for flow of material etc.

3.5 Iterate: This is a implicit step in which the parameters affecting the quality of the print are set until we get the 3D object as per the desired output.

IV. SPECIFICATIONS OF THE PRINTER

Before actually starting with the designing process we need to have some basic output requirements and specifications. Specifications of 3D printer are as follows.

Table 4.1 Specifications of 3D printer

1. Build	Volume	180mm X 180mm X 180mm
	Environment	Room temperature
	Built surface	Aluminum bed
2. Temperature	Bed temperature	30-80 ^{o}C
	Nozzle temperature	30-300 ^{o}C
3. Print Accuracy/Resolution	Layer resolution	50 microns to 600 microns
	3d printer part accuracy	+/-0.5mm
	Wall thickness	Depends upon nozzle diameter
4. Machine accuracy	XY positioning accuracy	Within 100 microns
	Z positioning accuracy	Within 50 microns
	Repeatability accuracy	Within 100 microns
5. Nozzle supported	Nozzle diameter	0.1mm,0.2mm,0.35mm,0.4mm,0.6mm
	Head and extrusion	Single head single extrusion
	Printing mode	Single colour & single material
6. Material	Filament diameter	1.75mm
	Material supported	PLA, ABS, HIPS, PVA, NYLON
7. Bed levelling	No. of adjuster	4 screws at each corner
8. Command	Computer	Directly from cura or proterface
	Graphical controller	From memory card

V. DESIGN PROCEDURE

After deciding on the specifications and features next step is to design individual components of the printer.

5.1 Feeding Mechanism and Hot End: Feeding mechanism is called as extruder, which extrude the filament into the hot end in desired rate. Based on requirement MK8 extruder assembly is available in market. Components of extruder assembly is given as follow:

5.1.1 Frame: Frame is supporting part which supports other accessories and it gets mounted on motor.it is made up of aluminum or brass.

5.1.2 Driving Gear: It is used to push the filament or retract the filament. It have 20 V-shaped teeth.it is mounted on motor shaft & driven by motor.

5.1.3 Idler Pulley: It is used to provide support to the filament and to maintain filament wire align with gear teeth. It is fitted on roller bearing and these bearing and pulley arrangement is mounted on the pivoted lever through a screw which can be tighten or loosen based on requirement.

5.1.4 Pivoted lever: This lever is pivoted at one corner of the frame and the idler pulley is mounted over it from one side and on other side it is fixed with spring arrangement for adjustment of gap between gear & pulley and also to maintain filament in contact with gear teeth and idler pulley.
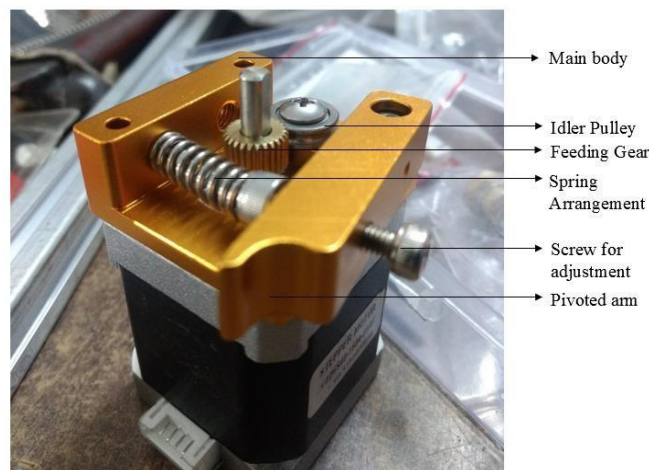
5.1.5

Fig 4 Extruder assembly mounted on motor

5.1.6 Spring Arrangement: These arrangement is used to maintain proper gap between the idler pulley and driving gear and to maintain force on filament.

5.1.7 Motor for extruder : NEMA-17 with torque 4.7 kg-cm is selected as per the manufacturers catalogue.

5.1.8 Hot end: MK3 V6 is the most advanced hot end available in the market. It can reach up to the temperature 300^0 C. It comes with 0.4mm nozzle diameter and does not have jamming problem. Because of all these advantages the we are selected MK3 V6 hot end.

5.2 Selection of driving mechanism:

5.2.1. For X & Y Axis: X & Y axis drives the hot end and print the actual cross section of the object. It has to move rapidly from one point to another. It experiences jerks during sudden change in direction.it have to carry small load i.e. of around 300 grams. Belt drive is selected for X & Y axis drive because

1. No backlash problem
2. Sudden change in direction is efficient
3. Can be driven at high speed
4. No lubrication required
5. Sufficient breaking strength.

5.2.2. For Z Axis: Z axis moves the platform on which object is made. It should have fine movement of around 10 microns. It does not have to move rapidly like X & Y axis. But load on platform increases as the object building starts. Lead screw drive is selected for the Z axis because

1. High load carrying capacity
2. Provides fine movement
3. Long rated life
4. Tensioning *is not required*

5.3   Bed Arrangement & Design of Platform Elements:

5.3.1 Bed Arrangement: The arrangement of heating bed as as shown in Fig 5.

→ Wing Nut
→ Spring
→ MK3B Heat Bed
→ L-section Frame
→ Brass Nut
→ Linear Motion bearing
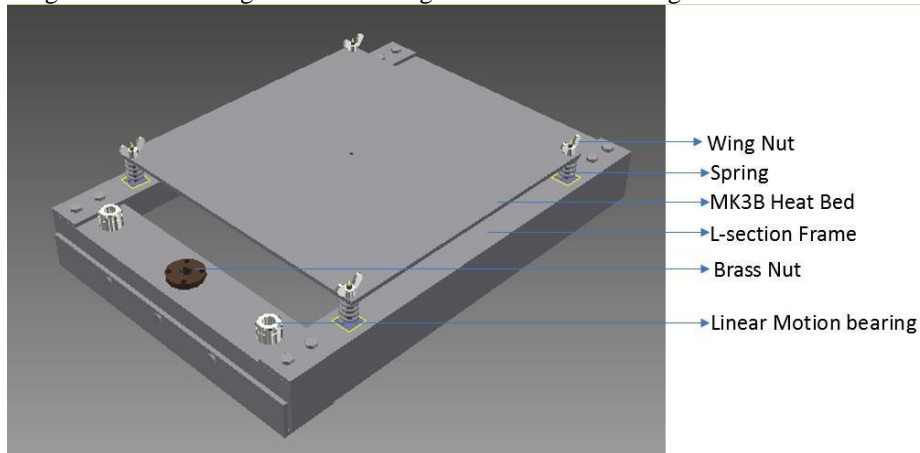
Fig 5 Bed arrangement

5.3.2   Design:
A.   Maximum Printing Volume
 Length: 180mm , Width: 180mm , Height: 180mm
 Volume =180*180*180 = 583200 mm^2
 $\qquad\qquad\qquad\qquad$ = 5.832*10-3m^2
B.   Max. weight of printed object:
 Weight = density * volume
 $\qquad\qquad$ =1250 * 5.72 * 10^{-3}
 $\qquad$ =7.29 kg = 72.9 N ≈ 73 N

5.3.2.1 Design of MK3b heat Bed:
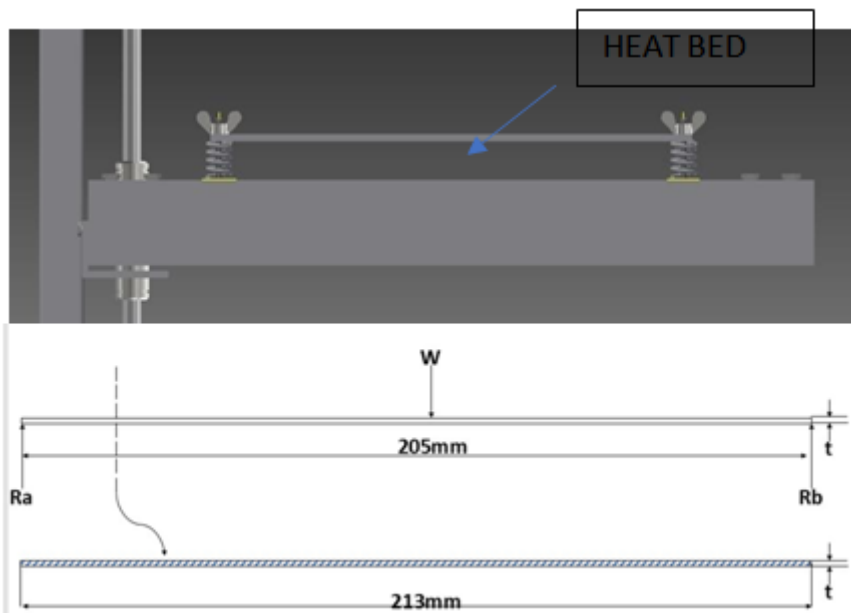
W= 73 N

$M_A = M_B = 73 * (205/2) = 7380$ N-mm

By flexural formula:

$M/I = [\sigma_b]/y$ (1)

For Aluminium 6065 : $\sigma u = 310$MPa $\sigma y = 276$MPa $\rho = 2700$Kg/m^3 $\sigma_b = 0.72$ $\sigma_y = 98.72$MPa

Taking FOS = 3

$[\sigma_b] = 66.24$MPa

$[\tau_s] = 46$MPa

$7380 / (bt^3 / 12) = 66.24 / (t/2)$

b= 213 mm

$(7380 * 12) /213 = t^2 * 2 * 66.24$ t = 1.77mm we have available thickness of 3mm.

5.3.2.2 Design of Spring:

Material: Alloy Steel 37Mn2

$\sigma_y = 700$MPa

FOS =4

$[\sigma_y] = 175$MPa

$\tau_s = 7$MPa

Now taking c= 6 and $K_s = 1.2525$

$\tau s = ks8PC / \pi d^2$ (2)

$= (1.2525 * 8 * 36.5 * 6) / \pi d^2 = 87.5$.

D = 1.826 ≈ 2 mm

Stiffness = 50 N/mm

$q = Gd/8C^3n$ (3)

$50 = 210*10^3*2 / 8*6^3*n$ n

$= 7.298 ≈ 7$

For square & ground end n'= 9

Solid length = n'*d = 9 * 2 = 18 mm

Free length = 30 mm

$L_f = P_n + 2d$

30= P * 7 + 2 * 2

P = 3.71 mm

5.4 Calculation of motor torque (for Z- axis)

Reaction force in L – section = 73 N

Taking lead screw of diameter 8 mm

& $D_m = 7.183$, P = 1.5

$\Phi = \tan^{-1} (p/\pi Dm)$ (4)

$= \tan^{-1} (2/ \pi * 7.183) = 5.1^o$

$\Phi = \tan^{-1} \mu = \tan^{-1}(0.25) = 14.03^o$

Torque required to raise the load $T_{raise} = (FD_m / 2) \tan (d+\varphi)$ (5)

$= [(73 * 7.183) / 2] * \tan (5.1 + 14.03)$

$= 90.94$ N/mm

$= 0.09094$ Nm

$= 0.9094$ kg.cm

There are some extra load acting on the motor due to the machining error or misalignment by considering all these aspects

We are selecting NEMA–17 motor with holding torque of 4.7 kg-cm.
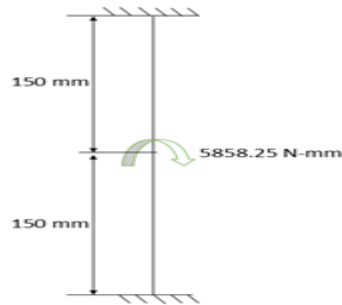
5.4 Design of chrome platted hardened shaft (for Z-axis)

Fig 6 : Chrome Plated Shaft

σy= 700MPa
FOS = 2
$[\sigma t]$ = 0.72,
$[\sigma t]$= 252MPa
$M/I = \sigma b/y$
$(11716.5/2)/(\pi/64) * d4 = 252/(d/2)$
$d3 = 236.79$
$d= 6.186$ mm $\approx$ 8mm

5.5 Design for Belt and Pulley:
As per application GT2 pulley and belt are suitable for application.
Specification:
Number of teeth=20
Pitch=2mm
Pulley Material: aluminium
Belt Material: Composite of Polyurethane and Rubber

5.6 Design of aluminium t slot section for frame

Fig 7 : T slot Aluminium section

Aluminium 6065
σyt = 380MPa
N= 2
$[\sigma yt]$ = 190MPa
$[\sigma b]$ =0.72$[\sigma yt]$ =136.8MPa
Checking of bending strength
$M/I = \delta b/y$
$BM_{max} = (11716.5/2) + 5 * 200 +(11716.5/2)$
$\qquad = 2.5 * 400$
$R_{HA}=R_{HV}= 2.5N$
$BM_{MAX}=13716.5$ N-mm
y= 10mm I=6227.25mm4
$13716.5/6227.25 = \sigma b/10$
$\sigma b = 22.02MPa < [\sigma b]$

V. COST REPORT

Sr. No.	COMPONENTS OR PARTS	AMOUNT
1.	5x NEMA17 Stepper motor 0.4 Nm 1.7A	2500
2.	Arduino Mega 2560 or compatible	1000
3.	10x 6mm GT2 belt pulley 20 teeth 8mm bore	1360
4.	2x 6mm GT2 belt pulley 20 teeth 5mm bore + 2m belt	440
5.	3x 6mm GT2 belt pulley 20 teeth 5mm bore	480
6.	20x Linear Bearings 8mm	800
7.	10x Hard coated linear rods 8mm x 500mm	2500
8.	2x M12x500mm Threaded rods (All Thread), or alternative	400
9.	Aluminium extrusion and its accessories	4000
10.	2x M8 Nuts "for extending All thread"	320
11.	5 meters 6mm GT2 belt	800
12.	10x 100k high temp NTC thermistors	360
13.	RAMPS 1.4+ Stepper drivers	1600
14.	5x End stops on PCB	460
15.	Graphical LCD / control for RAMPS	1000
16.	Nozzle 0.4mm	240
17.	2x Pneumatic quick release fittings 4mm OD (1/8" or 5mm thread)	160
18.	Braided cable sleeving 18mm flat	1280
19.	2x 25x10mm fan	160
20.	Cartridge heater 6x20mm 12v 40w	120
21.	2m PTFE tubing ID=2mm OD=4mm	260
22.	4x 158 teeth closed loop 6mm GT2 belts	320
23.	4m PTFE tubing ID=0.3mm OD=0.6mm (20 cm needed)	240
24.	4x M4x20 Bolts or Allen screws	80
25.	M4 Nuts	400
26.	M6 Nuts	400
27.	20x M3x20 Bolts or Allen screws (Some may have to be longer)	340
28.	25x M4x5mm set screws	80
29.	3D Printer filament ColorFabb XT	1500
30.	Spring OD=8mm T=0.9mm L=300mm	400
31.	Aluminium for extruder and brackets	240
32	Miscellaneous cost	3000
	TOTAL	**32740**

VI. CONCLUSION

The above paper highlights all the technical and non-technical information about the 3D Printing technology which is based on method called Fused deposition modelling (FDM) or Fused filament fabrication (FFF). As we know the 3D printing machine has high cost in the market, so we tried to optimize its cost in every possible manner and made a 3D printer which cost around Rs. 32,000/- which is much lower than market price. Our 3D printer has accuracy of up to 100 microns. This optimization will be helpful in society and in the field of manufacturing. In future it may be possible that the 3d printer can be easily installed in household at cheaper cost. Since this technology growing day by day, it creates great impact in today's world and their might be huge scope in this field.

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