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DESIGN OF FUSED DEPOSITION BASED 3D PRINTER

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ABSTRACT- 3D printing is an additive manufacturing technique in which 3D objects are printed with the help of Computer-Aided Design software. There are various processes which are available in 3D printing technology such as (1) FDM (Fused Deposition Method), (2) SLS (Selective Laser Sintering), (3) EBM (Electron Beam Machining), (4) LOM (Laminated Object Manufacturing), (5) DLP (Digital Light Processing),etc. In this paper, we have focused on the design of a 3D printer of build volume which can be constructed economically. We are using 3 axis mechanisms where 3 axes are x-y-z. The modeling technology adopted by us is FDM, in which different the materials like PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), HIPS (high impact polystyrene), etc. By heating any of the filament material to its melting point and it is deposited layer by layer. Combination of many layers of such type will give us a final 3D model. The 3D model is stored in as a STL format and after that forwarded to a 3D printer. The 3D printer prints the CAD design layer by layer forming a real object.

1. INTRODUCTION

A 3d printer is an additive manufacturing device where 3D objects and components are made by the adding multiple layers of material. It is an automated process where 3D objects are quickly manufactured as per the required size. The device is connected to a computer containing 3D model/design of the object. 3D printers are used in many industries such as aerospace, automobile, medical, construction and in manufacturing of different household products.

The 3D design is stored in computer as STL format which is forwarded to the 3D printer. We can use various materials such as ABS (Acrylonitrile Butadiene Styrene), PLA (Polylactic Acid), and composites to build an object.3D printing process are derived from inkjet desktop printers [2].

1.1. HISTORY

3D printing technologies first became visible in the 1980'sduring that period they were called Rapid Prototyping (RP) technologies. The first patent for RP technology was filed by Dr. Kodama in 1985.

Hideo Kodama of Nagoya Municipal Industrial Research Institute is generally regarded to have printed the first solid object from a digital design.

Charles Hull is the co-founder of the 3D corporations which is one of the largest and most major companies in the field of 3D printing and rapid prototyping. He was a pioneer of the solid imaging process known as stereo lithography and the STL file format which is still the most widely used format used today in 3D printing. He is also regarded to have started commercial rapid prototyping.

Since 1984, the technology has advanced and 3d printers have become more and more effective and useful, while their price is lowered, which makes them more affordable.

In 1990, the plastic extrusion technology most widely associated with the term "3D printing" was invented by Stratasys by the name Fused Deposition Modeling (FDM).

From 1993-1999, the 3D printing sector had emerged with different techniques. The Sanders prototype and Z Corporation were set up in 1996 to operate commercially, and Arcam was established in the year 1997.

These 3D printers have been focusing on overall development and improvement of their functioning in prototyping that were being developed specially for offices, user friendly and the cost-effective systems. So, these systems have been very much vital in industrial applications.

During that time when the 3D printing sector had started, they were of high-end 3D printing and are very expensive which have geared up towards the par production for high quality and complex objects. These are growing rapidly and ongoing but the results are now visible in production applications such as the automotive, aerospace, medical and also in jewelry sectors.

After the beginning of the 21st century, there has been a large growth in the sales of 3D printers and their price has been decreased gradually.

In the year 2004 the RepRap project had begun which consisted of a self-replicating 3D printer. This RepRap project had caused in spreading of FDM 3D desktop, 3D printers and 3D printers started getting popular.

By the early 2010s, the terms 3D printing and additive manufacturing evolved senses in which they were an alternate term for AM technologies.

Both terms reflect the same principle that the technologies all share the common process of layer-by-layer material addition throughout the 3D work process under automated control [2].

2.1 DIFFERENT TYPES OF 3D PRINTING TECHNOLOGIES

There are various methods of 3d printing, each of these methods differs in the way the layer is built to create the final component or object. The most common methods are as follows:

2.1.1. Fused Deposition Modeling (FDM)

2.1.2. Stereo lithography (SLA)

2.1.3. Selective laser sintering (SLS)

2.1.4. Digital Light Processing (DLP)

2.1.1. FUSED DEPOSITION MODELING(FDM)

It was developed by Stratasys of Eden prairie in the early 1990's. It is one of the most common methods .It forms the required parts by extruding the raw material on a surface.

The raw materials used in general are thermo plastic material such as Poly Lactic Acid (PLA), Acrylonitrile butadiene styrene (ABS), Wood material, Nylon and Resin, etc. The raw material is extruded through a small nozzle to form a thin bead that is deposited in a predetermined manner.

These raw materials have different melting point temperatures, which is used to determine a working temperature for the extruder and the surface on which the extrusion is carried out.

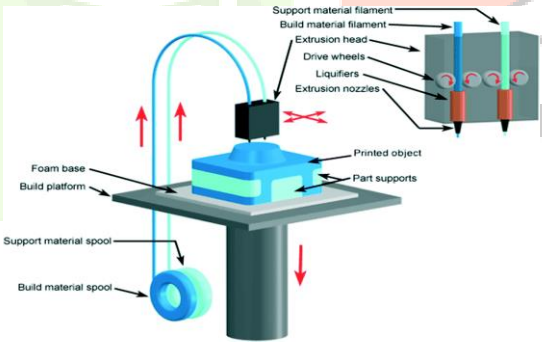

Figure 3: Fused Deposition Modeling [1]

2.1.2. STEREO LITHOGRAPHY APPARTUS (SLA)

It is a Rapid prototyping method for making solid component or object out of a photosensitive liquid polymer using a directed laser beam to solidify the polymer.

The component or object is made from a series of layers. Each layer is added onto the previous layer to gradually build the 3D geometry.

It is a very fast and very expensive method and it requires the more post processing as the cleaning of liquid resin on the solid object needs to be done and also there are support structures used which is to be detached.

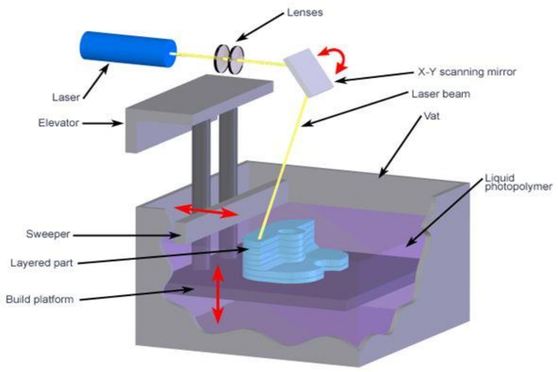

Figure 4: Stereo lithography [1]

2.1.3. SELECTIVE LASER SINTERING (SLS)

It is an additive manufacturing method which uses laser as the power source to sinter powdered material like nylon and polyamide.

It aims the laser directly at points in space given by the 3D model and binds the material together to form a solid structure.

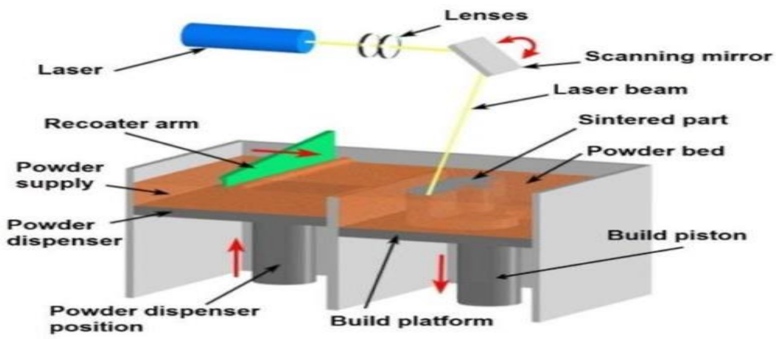

Figure 5: Selective Laser Sintering [1]

2.1.4. DIGITAL LIGHT PROCESS (DLP)

DLP (Digital Light Processing) is a similar method to stereo lithography method in which the 3d printing process works with photopolymers. DLP uses liquid photopolymers resins to make objects. The resin is hardened by reflecting a patterned light by using a reflecting mirror and this is continued for every layer which has been sliced. Faster speeds can be achieved irrespective of the complexity of layer.

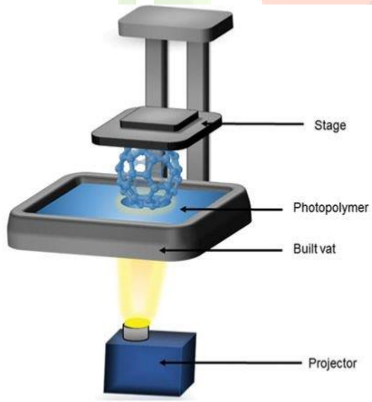

Figure 6: Digital Light Process [3]

2.2. WHY CHOOSING FDM PRINTERS OVER OTHERS?

In this project, the major focus is on designing a 3D printer which gives a better-quality output at a reasonable cost. The FDM technology consists of less expensive hardware and many open source software's which are very helpful.
The raw materials used in FDM process are easily available and eco-friendly. There will not be any time consuming post processing required after the object is printed unless the design given by the user is a customized one.
The power consumption in this method is comparatively less than other methods. The build volume of the object can be increased easily depending on the application. Printing can be done at higher speeds which limits the quality. For a greater quality output, the printing has to be done at a low speed.
The software's are readily available for the users with license at a minimal cost and some are for free.

So, by choosing FDM method of 3D printing we can complete key aspects of the project.

2.3. COMPONENTS

3D printer has a collection of components that work simultaneously to provide the manufacturer the required output using the input digital STL file; the basic components are listed below:

2.3.1. Frame: It is the main component of the 3D printer. Its main function is to support the components (Both Mechanical and Electrical) which carry out the printing process. It also depicts the build volume of the 3D printer.

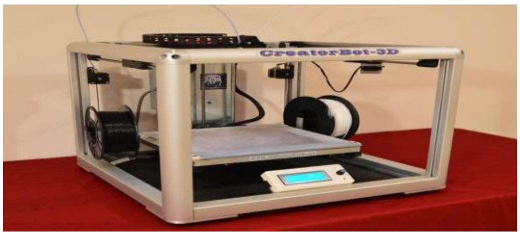

Figure 7: Frame (1) [4]

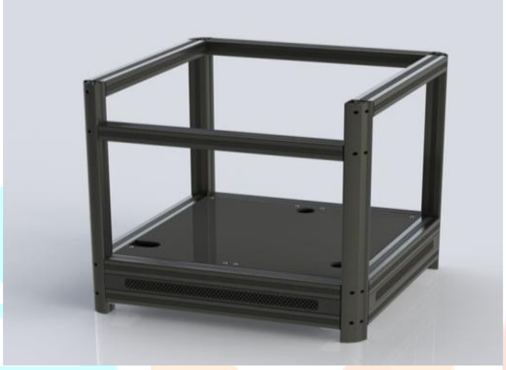

Figure 8: Frame (2) [5]

2.3.2. Print Bed: It is a flat surface on which the printing or manufacturing of components or parts takes place layer by layer. It is used at temperature as per the need of filament used for printing. The print bed is maintained at a high temperature nearly 180°c and more. The heat bed is used to maintain the temperature of the printed section for layering of the next layer.

Figure 9: Print bed (1) [6]

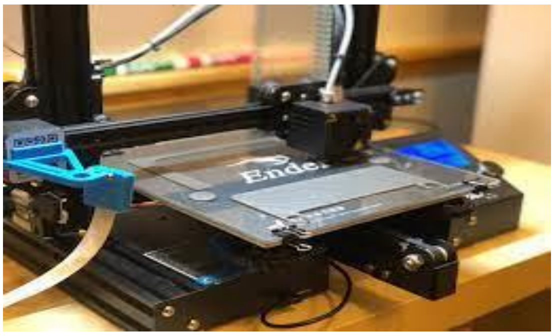

Figure 10: Print bed (2) [7]

2.3.3. Extruder: It is the component that releases and supplies the suitable filament into the hot-end. Extruders are basically fixed into the hot-end, which sends the filament inside a tube, into the hot-end by using a simple two gear mechanism. Some of the times we use a dual extruder when there is necessity to print two different materials simultaneously.

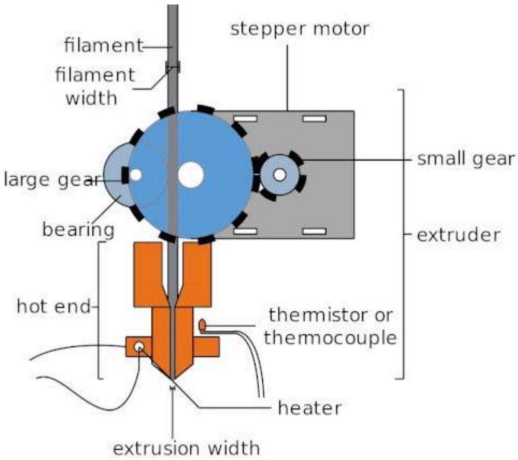

Figure11: Extruder (1) [8]

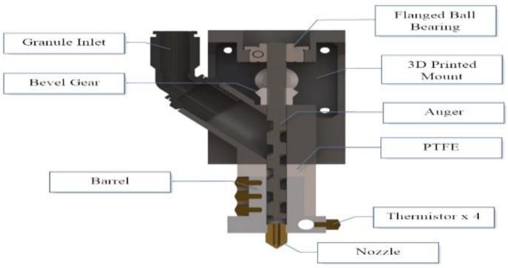

Figure 12: Extruder (2) [9]

2.3.4. **Hot-end:** A hot-end comprises of a device like Thermistor or any other device which senses or detects temperature, heat source and an extrusion tip where filament is fed through to deposit molten material. The size of hole varies between 0.2mm to 0.8mm. Small size hole increases the time of printing.

Figure 13: Hot end [10]

2.3.5. **Filament:** It is the material to which heat is supplied and melted in order to print 3D solid object. Nozzle releases this melted filament in the form of semi-solid.

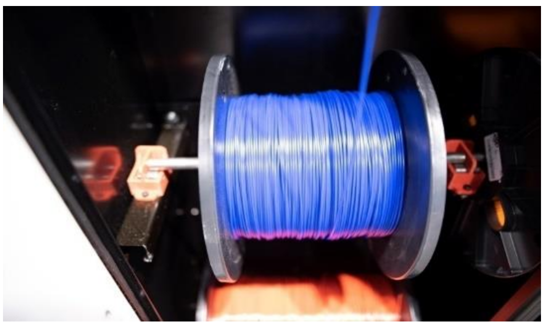

Figure 14: Filament (1) [11]

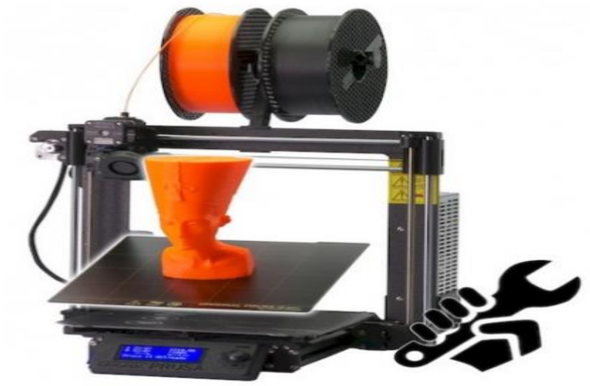

Figure 15: Filament (2) [12]

2.4. MATERIALS USED IN 3D PRINTING

1) PLA

PLA (Polylactic Acid) is one of the regularly used desktop 3D printing materials. The reason is that PLA is useful in a broad range of printing applications, has the virtue of both odorless and low warp and it will not require a heated bed. PLA plastic is also one of the eco-friendly 3D printer materials; it is made from renewable resources (corn-starch) and requires less energy to process compared traditional (petroleum-based) plastics.
The Printing Temperature is in the range of 180 - 220°C.The Bed Temperature is in the range of 20 - 55°C.

2) PET (Polyethylene Terephthalate)

PET is an industrial strength filament with several features. Its strength is higher than PLA, it is FDA approved for food containers and tools used for food consumption, it barely warps, and produces no odors or fumes when printed. PET filament is not biodegradable, but it is 100% reclaimable. The Printing Temperature is in the range of 230-255 °C.
The Bed Temperature is in the range of 55-70 °C.

3) TPE

TPE filament is a flexible 3D printing material that feels and acts much like flexible rubber. TPE filament can be used to make parts that can bend or must flex to fit their environment - stoppers, belts, springs, phone cases and more. The Printing Temperature is in the range of 210-225 °C. The Bed Temperature is in the range of 20-55 °C

4) LAYBRICK

LAYBRICK is a material that gives parts the look and feel of grey stone while retaining the resiliency of plastic, making it ideal for landscape and architectural designs. Which is made up of the LAYBRICK can be painted and sanded. In the lower range of 165°C to 190°C, the print will come out mostly smooth, whereas with higher temperatures it will begin to have a more pitted, sandstone-like texture. The Printing Temperature is in the range of 180 - 200 °C. The Bed Temperature is in the range of 20 - 55 °C.

5) ABS

ABS (Acrylonitrile Butadiene Styrene) is another commonly used 3D printer material. Best used for making durable parts that needs to withstand higher temperature. In differentiating to PLA, ABS plastic is less brittle. It can also be post-processed with acetone to provide a glossy finish.
The Printing Temperature is in the range of 220 – 235°C 80 - 110 °C

6) LAYWOO-D3

LAYWOO-D3 is a wood-like material that gives 3D printed objects the look and feel of fibreboard. It also imbues parts with other wood-like attributes, such as the ability be cut, painted, and sanded. LAYWOO-D3 which will be created from the combination of recycled wood combined with polymer binders that are allowing it to be melted and extruded through your extruder on to the heated bed. The Printing Temperature is in the range of 175-250 °C. The Bed Temperature is 30 °C.

7) Gel-Lay

Gel-Lay is a jelly-like material that is very porous. This material is made from a rubber-elastomeric polymer and a PVA-component. Once you rinse this material in water, the PVA component disappears and the rubber polymer remains as micro-porous object. Gel-Lay is ideal for creating artificial limbs or body parts, marine animals (like an octopus) or floatables. There are several great applications which will very much include objects in water marine organism flow simulation and bio mechanics. The Printing Temperature is in the range of 225-235 °C. The Bed Temperature is in the range of 20-55 °C.

8) Nylon (Polyamide)

Nylon is an incredibly strong, durable, and versatile 3D printing material. It is very Flexible when it is thin but it is high inter layer adhesion and the nylon lends itself well to things like the living hinges and the different functional parts. Nylon filament prints as a bright natural to white with a translucent surface and can absorb color added post process with most common, acid-based clothing dyes. Nylon filament is very sensitive towards the presence of moisture so taking drying measures during storage and immediately prior to printing is highly recommended for best results. The Printing Temperature is in the range of 235-270 °C. The Bed Temperature is in the range of 60-80 °C.

9) TPU (Thermoplastic Polyurethane)

TPU is an elastic grease resistant and abrasion resistant material with a Shore Hardness of 95A. TPU has various applications that are used inside automotive instrument panels, caster wheels, power tools, sporting goods, medical devices, drive belts, footwear, inflatable rafts, and a variety of extruded film, sheet and profile applications. It is also commonly used in mobile phone cases. The Printing Temperature is in the range of 240-260 °C. The Bed Temperature is in the range of 40-60 °C.

2.6 WORKING PRINCIPLE OF FDM 3D PRINTER

The FDM based 3D printers work by melting and extruding the raw material through an extruder in a thin form of layer by layer in the desired shape till it completes the CAD model and completes the object.

The linear motion of extruder is controlled by stepper motors. These linear motions are required to make the extruder or the surface or both to move in a particular direction simultaneously.

3. METHODOLOGY

3.1. Problem statement

To develop a 3d printer, it is necessary to create a complex design and to analyse the mechanism of the extruder and to find out a working temperature for the extruder and for the print bed.3d printers have long passed the point of being used only for prototyping. Many Companies are trying to create new designs of 3d printers to incorporate them in their production, with applications ranging from tooling to spare/replacement parts and some end-use components. In spite of high cost and limited material options, the objects or components which are of high complexity can be manufactured by fabricating the objects within less time when compared to the traditional manufacturing, and also it reduces the material wastage which is observed in traditional process. So, there needs to be a cost-effective 3d printer which prints medium-sized to large-size objects with a desired level of quality within a specific time. For this quality of functioning, we have chosen to design a 3d printer which serves the purpose of printing 3d objects which may vary from medium to large sized objects, and where the final object is having a desired level of texture, and also at a reasonable cost.

3.2. Objectives

The objective of this project is given below:

- To design a 3d printer having an increase in its build volume.

4.DESIGN AND ANALYSIS

4.1 DESIGN

The design of the 3D printer has to be done in a 3D CAD software where a model is to be created according to the design specifications. The design process has to be started by considering the build volume of the basic parameter. The objective of the project is to design a 3D printer with an increase in its build volume which is suitable to build Medium sized to large sized products. The build volume of the 3D printer in this project is of the volume 600*600*600mm3. The design of the 3D printer has been created in a design software.

4.2 MODELLING PROCEDURE:

1) Open Creo parametric3.0 software

2) Click on new file option.

3) Click on part under the category of type and click ok.

4) Select the front plane and select the Sketch tool option under Model tab.

5) Draw the cross-sectional diagram of the component.

6) Click on Extrude option under the Model tab and enter the extrude length.

7) Go to File menu and click on Save. Follow the same steps for modelling remaining components.

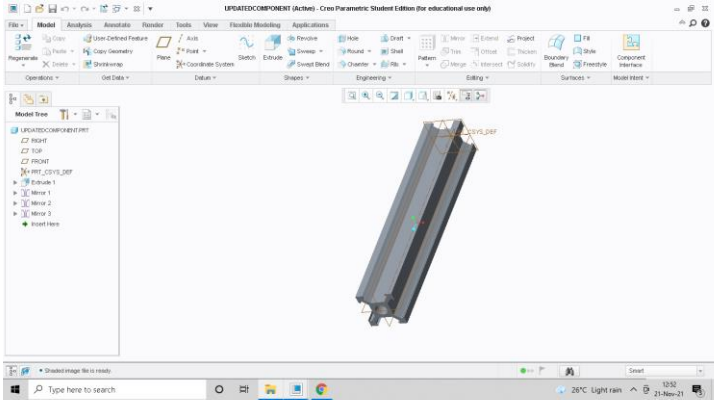

Figure 21: Rod

4.3 ASSEMBLING OF THE COMPONENTS:

1) Open Creo Parametric 3.0 software.

2) Click on file and click on new.

3) Select Assembly option under the category of type.

4) Select the front plane and click on Assemble option under the model Tab.

5) Now Select the previously created Model and Click on open

6) Under the component Placement Tab Click on the tick Mark Option.

7) Now import all the components in the similar way.

8) Now Select the surfaces of the components in such way that the required surfaces are coincident to each other.

9) Similarly follow the same steps for remaining imported components.

10) After the Assembling is done Select Save option from File Menu and check the working Directory and Click on Ok.

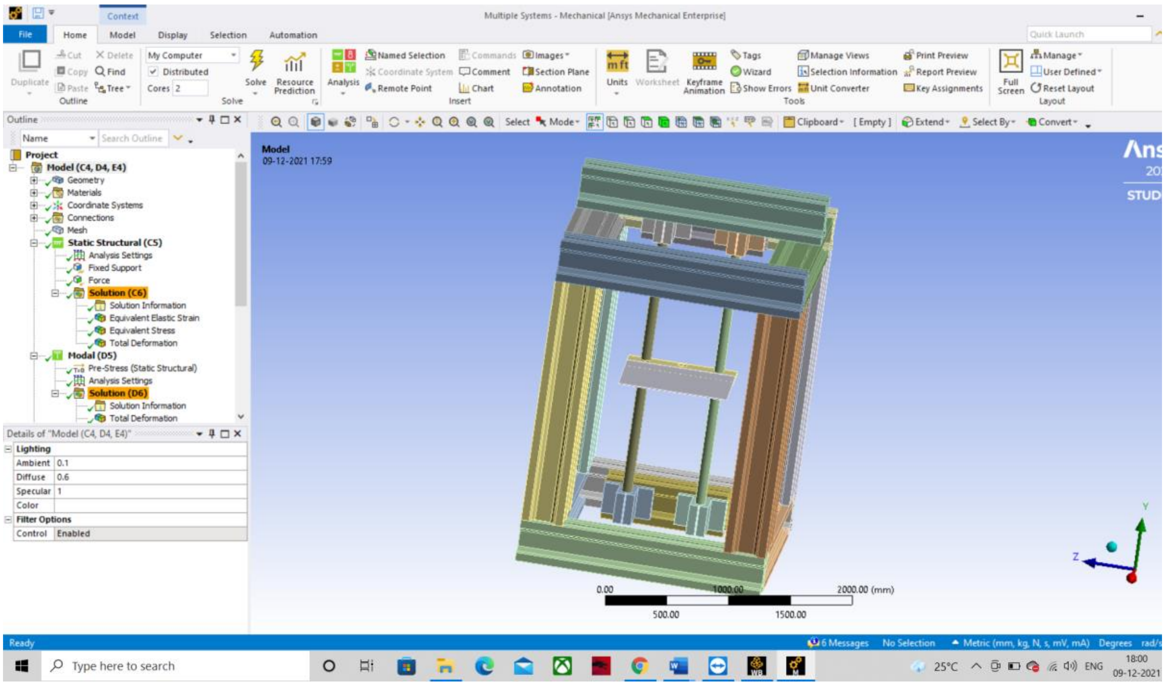

Figure 22: Frame

4.4 ANALYSIS

The Model Analysis is used to Calculate stresses, strains and deformation of a given structure or a machine. In this project the analysis is done on the designed 3D Printer in order to determine the best optimum size of the 3D printer under the workable conditions of stresses, strains and deformation.

4.4.1 STATIC STRUCTURAL ANALYSIS PROCEDURE:

1) Open the Ansys Workbench 2021 R2 software.

2) Select the Static Structural under the tool box Menu.

3) Click on Engineering Data and Select the Material (Aluminium Alloy) and check the box for other default Materials in order to suppress.

4) Click on the project tab and right click on the Geometry and Select import Geometry and Click on browse and click on open.

5) Click on Model and new window (Mechanical Window) opens where we have pre-processing and post processing operations are present.

6) Under the Model Category Click on the geometry and under assignment click on the required material for all the components of the assemble structure.

7) Click on Mesh and check the required parameters according to the quality of mesh required.

8) Right Click on Mesh and Click on generate Mesh.

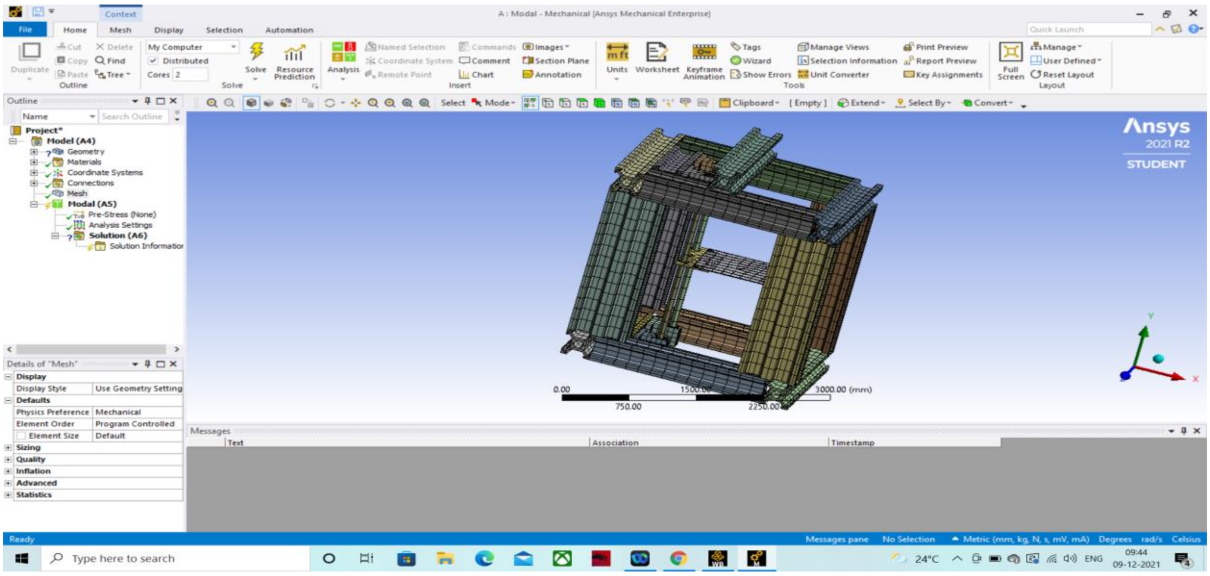

Figure 23: Meshing

9) Right Click on Static Structural and Click on insert and Select the Fixed Support.

10) Now Select the Geometry of the Components which are to be fixed and click on apply.

11) Right Click on Static Structural and Click on insert and Select force.

12) Now Select the Geometry of the Component on which force has to be applied and also give the magnitude and direction of the force.

13) Right Click on solution and click on insert and under deformation Select Total. Right Click on solution Click on Insert and under strain Select Equivalent (Von-Mises) and follow the same for stress.

14) Click on Solve and wait till it Evaluates the results and we get the stresses, strains and deformations corresponding to the load applied.

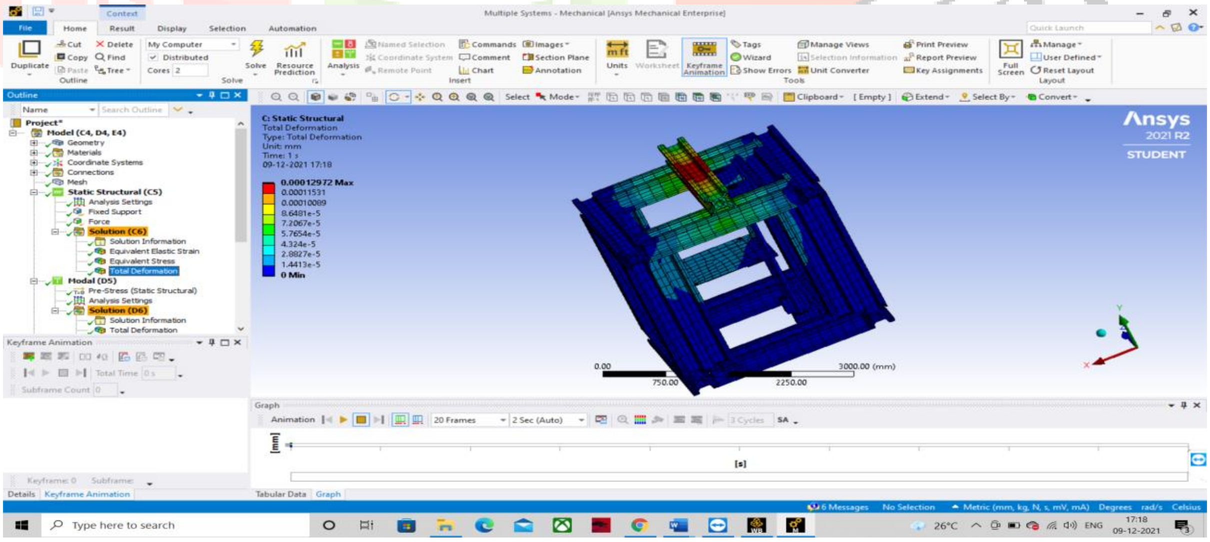

Figure 24: Total Deformation

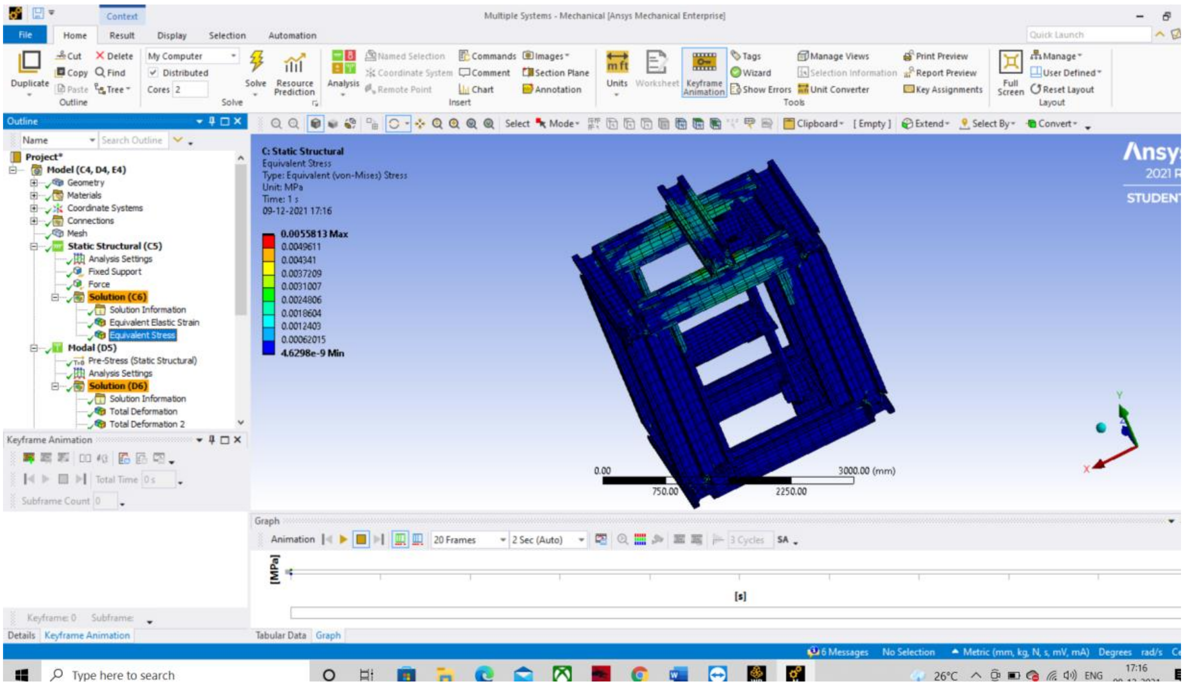

Figure 25: Total Stress

4.4.2 MODAL ANALYSIS PROCEDURE:

1) Open the Ansys Workbench 2021 R2 software.

2) Select the Modal under the tool box Menu.

3) Click on Engineering Data and Select the Material (Aluminium Alloy) and check the box for other default Materials in order to suppress.

4) Click on the project tab and right click on the Geometry and Select import Geometry and Click on browse and click on open.

5) Click on Model and new window (Mechanical Window) opens where we have pre-processing and post processing operations are present.

6) Under the Model Category Click on the geometry and under assignment click on the required material for all the components of the assemble structure.

7) Click on Mesh and check the required parameters according to the quality of mesh required.

8) Right Click on Mesh and Click on generate Mesh.

9) Right Click on Static Structural and Click on insert and Select the Fixed Support.

10) Now Select the Geometry of the Components which are to be fixed and click on apply.

11) Right Click on Modal and click on insert and select fixed support.

12) Now Select the Geometry of the Component where the component has to be fixed.

13) Click on Solve and wait till it Evaluates the results and we get the frequencies to the load applied and also click on create mode shapes by selecting all frequencies under graph tab.

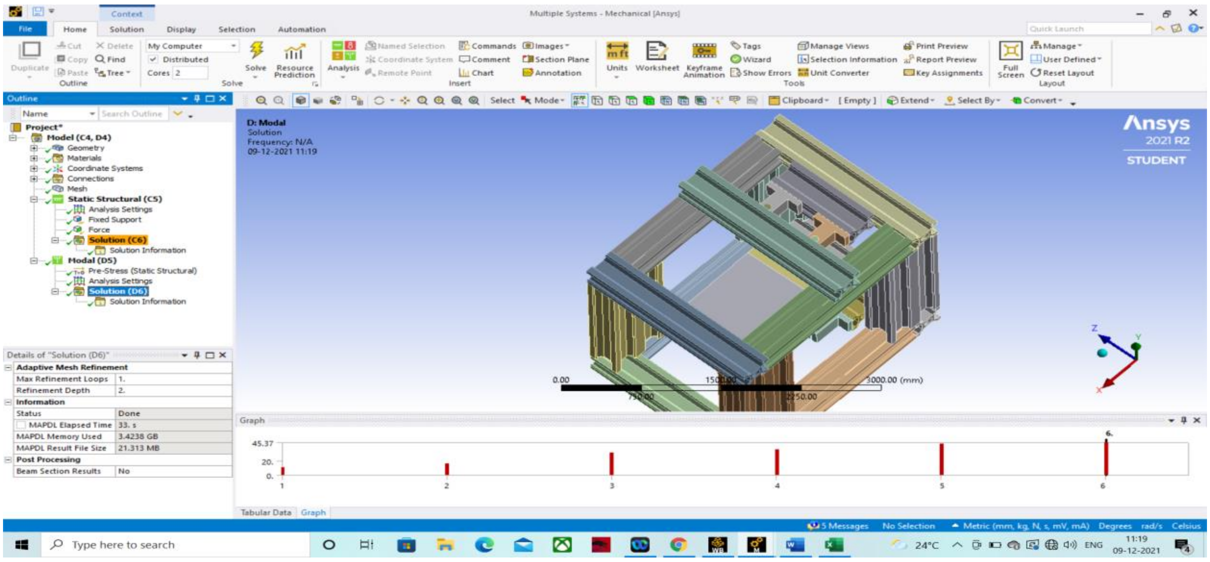

Figure 26: Frequencies and Displacement

4.4.3 RANDOM VIBRATION ANALYSIS:

1) Open the Ansys Workbench 2021 R2 software.

2) Select the Random Vibration under the tool box Menu.

3) Click on Engineering Data and Select the Material (Aluminium Alloy) and check the box for other default Materials in order to suppress.

4) Click on the project tab and right click on the Geometry and Select import Geometry and Click on browse and click on open.

5) Click on Model and new window (Mechanical Window) opens where we have pre-processing and post processing operations are present.

6) Under the random vibration category Click on the PSD displacement and give the boundary conditions and tabular data and give the direction as Y-axis.

7) Now Select the Geometry of the Components which are to be fixed and click on apply.

8) Click on Solve and wait till it Evaluates the results and we get the frequencies and displacement due to the load applied.

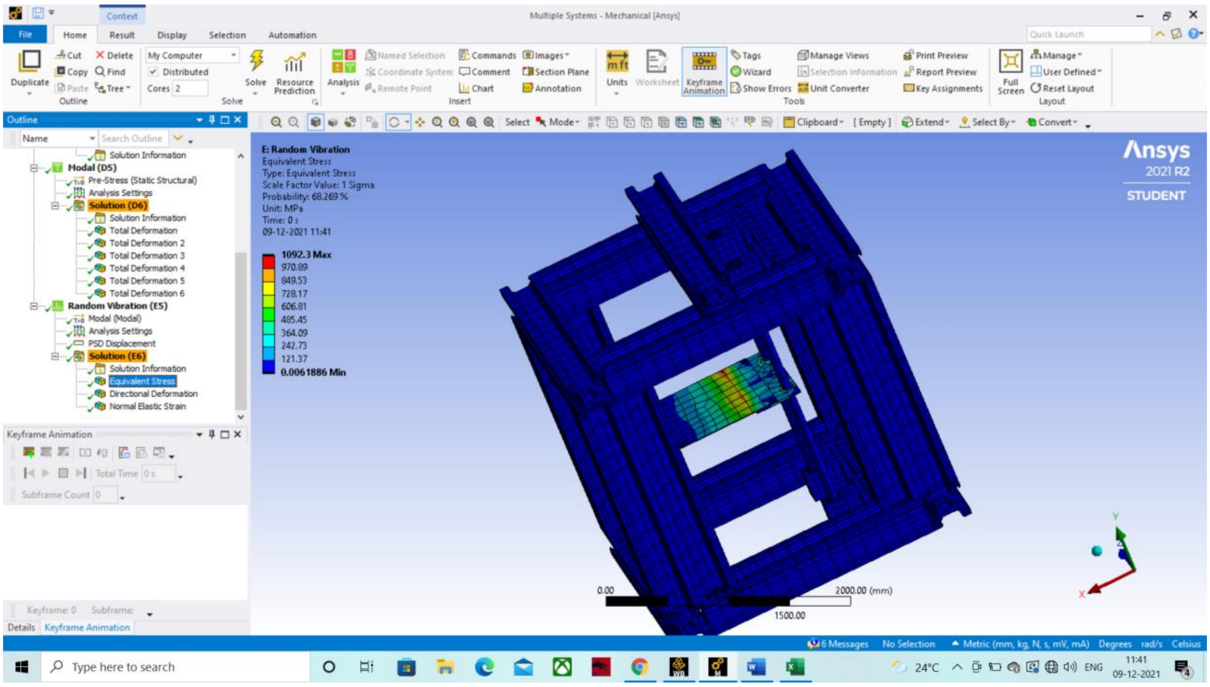

Figure 27: Equivalent Stress due to Vibration

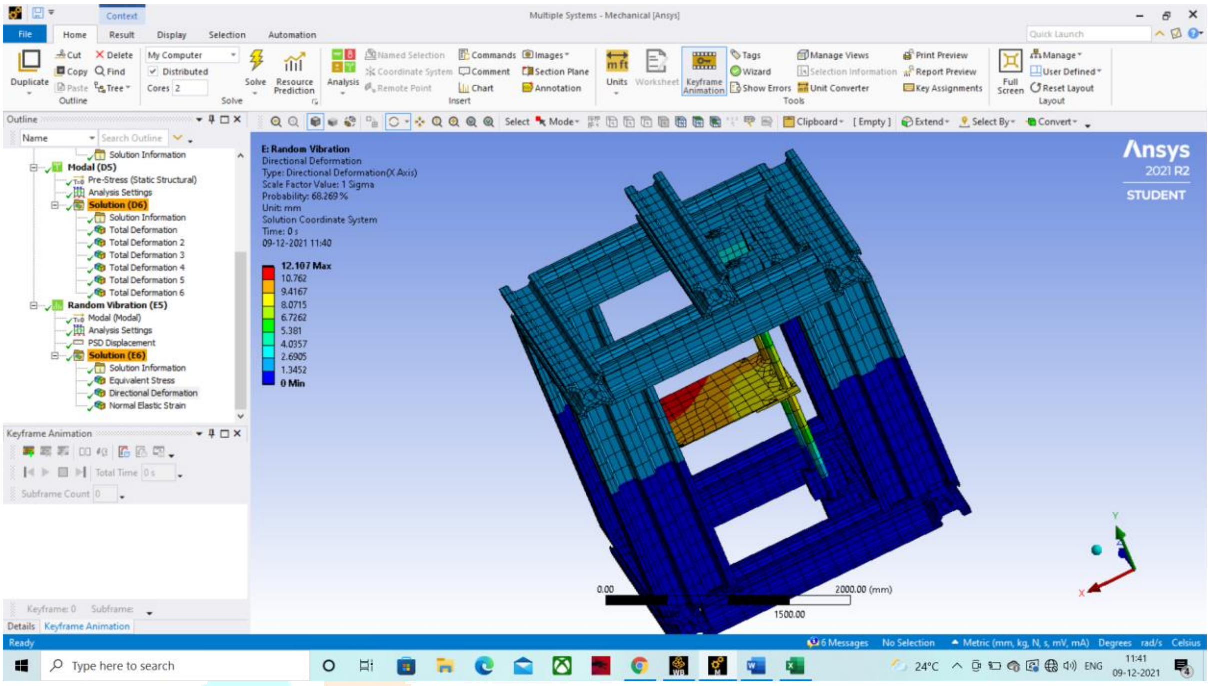

Figure 28: Deformation due to Vibration

5. RESULT AND DISCUSSIONS:

Table-5.1: Result for Vibrational Analysis

FREQUENCY(Hertz)	DEFORMATION (mm)	DISPLACEMENT (mm^2/Hz)
11.098	21.929	480.881041
16.448	32.242	1039.546564
31.473	1.1641	1.35512881
35.198	31.564	996.286096
43.202	8.1091	65.75750281
45.37	2.6542	7.04477764

Table 5.1 Displays frequency, Deformation and Displacement. The results obtained during the evaluation from Vibrational and Modal Analysis are shown above. From this result it can be analysed that the given set of boundary conditions are suitable for this frame of specified Build Volume and hence the design is found to be safe under the operating conditions. We have considered the design parameters such as boundary conditions which include fixed supports and force induced due to the extruder on the print bed and also the PSD displacement and its corresponding induced vibrations. The analysis is done based on the static structural analysis where the load of the extruder exerts a load on the components of the 3D printer and the mode shapes at different points on the 3D printer is found and its corresponding vibrations are evaluated.

6. CONCLUSION:

3D printers nowadays are limited to build upto small sized components limiting them to domestic usage. Our main objective is to overcome this limitation. This machine is intended to increase the volume of the production ranging from medium sized objects to Large sized objects and we have created the basic design in this paper and its continuation concludes about the various analysis and real model of the 3D printer and we are going to do further analysis on the 3D printer and create an economical design according to our design specifications.

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