Design and development of large scale FDM based 3D printer

Brathikan V M¹, Balasubramanian S², Kiranlal S³, Ravi Ragul R⁴

¹Research cell associate, Kumaraguru college of technology, Coimbatore-641049, India
²Assistant professor, Kumaraguru college of technology, Coimbatore-641049, India
³Assistant professor, Kumaraguru college of technology, Coimbatore-641049, India
⁴3rd year student, Kumaraguru college of technology, Coimbatore-641049, India

Abstract: Additive Layer Manufacturing (ALM) is one of the fabricating methods because it permits outrageous customization, quick prototyping of wanted designs and low volume creation of items. FDM printer goes under the material expulsion class. The filament is constrained into the hot extruder. The filament is warmed first and afterward stored, through the spout, onto a form stage layer-by-layer to frame the total 3D structure. A printer equipped for printing a 1.5-meter cubic-sized object was designed in SOLIDWORKS CAD software and manufactured into a functioning model. The Frame, Linear guide rail, and Z-axis rails were subjected to static structural, modal and harmonic response analysis with ANSYS Workbench. The designed parts were investigated by modal analysis to get the natural frequency. The effect on the guide rails and frame due to external forces, stepper motor, and extruder were examined with harmonic response analysis. The frequency at which the amplitude rises drastically from a phase angle of 0 degrees to 180 degrees was obtained using harmonic response analysis as well. The model was further subjected to motion analysis using ADAMS dynamic software.

Keywords: FDM printer; Additive manufacturing; Modal and Harmonic Response analysis; Dynamic analysis.

1. Introduction

In additive manufacturing, layers of materials are successively layered to create three-dimensional objects. It is for the most part utilized for prototyping and making complex mathematical designs with required materials. Initial attempts in 3D printing were done by Dr. Kodama in 1981 making headway in quick prototyping procedure. He was depicted a layer-by-layer approach for assembling, making a photosensitive gum that was polymerized by UV light. 3D printing is a profoundly viable added substance fabricating method. The process of additive layer manufacturing (ALM) involves computer control. It is ideal for rapid prototyping of very complex structures with little wastage of materials, resulting in reduced for high-value parts. Fused Deposition Modelling (FDM) printer is a universally used and practical 3D printing innovation. The material is imprinted on the bed by constraining liquid material out of a spout guided by a PC and built as organized layers. Plastics such as acrylic butadiene styrene (ABS), polylactic acid (PLA), metal powders, resins, and ceramics serve as the majority of 3D printed materials. The carriage structure for the expulsion arrangement of the 3D printer was analyzed considering force applied by the extruder on the carriage and without compromising the strength of the carriage. The determined forces were applied to the designed part with ANSYS software. The actuation of a stepper motor, the motion of the extruder, and material feed rate are controlled by Arduino Mega 2560 microcontroller. The paper discusses the kinematic configuration of the CoreXY 3D printer. It also discusses the issues (warping due to temperature differentials) caused by the surrounding temperature in the FDM printer. The print speed and print resolution are considerably increased by an optimized prototype extrusion system. The significance of various design methods like Filamentrics and MicroStrata are discussed here. These design methods reduce the differences in results between the simulation and fabrication process. They are used to achieve a higher level of resolution of the print. The printer operates as a system to organize material...
in response to specific concerns of structure, fabrication, and design. The static analysis of the nozzle system is carried out by dividing it into the melting and the feeding system. The fundamental goal of the paper is to examine the quality of the mechanical design of the printer and to outline the expected deformities in the construction of the printer. The modal analysis for the printer is completed to uncouple the normal recurrence with outside excitation. The modal frequency for different level shaft direction under various loading conditions has been considered. The methodology used in the construction of a 3D printer has been discussed. The significance of the electronic and mechanical components has also been discussed. The problem that often occurs due to the temperature difference that causes the edges of the print is illustrated. The main intention of the paper is to design and fabricate a composite frame for a 3D printer. The structural analysis of the frame has been carried out to examine the deformation and stresses of the frame, which have an impact on reliability and print quality. The paper analyses the attributes and uses of 3-D printing and contrasts it and mass customization and other assembling measures. The mechanical properties of 3D printed parts and the variety in the properties of the parts talked about. Testing of different examples comprised of various materials like PLA and ABS was completed. The elasticity versus strain for the two (PLA and ABS) was looked at and results show the mechanical properties of PLA and ABS. The paper outlines the practice of improving the strength of the 3D printed parts by filling them with high-strength tars that can further develop the solidness of the part from 25% to 45%. The strength of parts as printed and parts subsequent to application fillings has been elaborated. Filling the tar makes complex inner supporting constructions that give an expansion in strength and firmness. The vibration qualities of the FDM 3D printer were investigated and discussed. This provides a viable method for further developing the printing precision. The regular recurrence and dislodging were obtained from Modal investigation. The vibration qualities were improved by upgrading the mechanical design.

2. Modeling of CAD model

The series of Cartesian types of printers was selected design for construction. The indirect extrusion system or Bowden extrusion system has been used to reduce the weight in the guide rail. In Direct extrusion, drive gear, stepper motor and hot end are fixed as a single assembly. In Bowden extrusion, the hot end and drive gear that feeds filament are separated to reduce vibration in the guide rail. The complete design of the 3D printer was designed in SOLIDWORKS CAD software. The CAD model has been planned definitively with required measurements to acquire exact investigation results. The materials used in the leveller and linear guide rail is Aluminum 6063-T3. The mainframe has been fabricated with carbon steel and the slider support rod out of stainless steel.

![Fig. 1. CAD model of FDM 3D printer](image)

3. Finite element analysis

By using FEA (Finite Element Analysis), a product's reactions to real-world forces, vibrations, heat, fluid flow, and other factors can be modelled. The meshing of millions of smaller elements that combine to form a structure was performed to get accurate results.
### Table 1. Properties of materials used in fabrication

| Part                        | Material       | Density (g/cm³) | Poisson’s ratio | Modulus of elasticity (GPa) |
|-----------------------------|----------------|----------------|-----------------|-----------------------------|
| Outer frame                 | Carbon steel 1023 | 7.85           | 0.29            | 200                         |
| Leveller rail and linear rail | Aluminium 6063-T5 | 2.7            | 0.33            | 68.9                        |
| Screw rod and Slider rod    | Stainless steel AISI 316L | 8.0 | 0.265           | 193                         |
| Print bed                   | Glass          | 2.203          | 0.17            | 64                          |

3.1. Static analysis of leveler guide rail

The Linear guide rail was mounted on the leveler rail. A pair of NEMA 23HS7430 stepper motors drive the Y-axis motion at each end; a GT2 timing belt drives the X-axis movement. The forces acting on the guide were calculated and applied at a specific location on the rail. The face split was done in a design modular to split the faces and apply forces at the exact location. The fixed support was four sections of the rail where the Z-axis trapezoidal screw rod is mounted.
From the results of ANSYS, minimum stress of 366.96 Pa, maximum stress of 1.5023e7 Pa, maximum deformation of 0.00026513m, minimum equivalent elastic strain of 3.2791e-8 and maximum equivalent elastic strain of 0.00026404 were obtained.

3.2. Static analysis of linear guide rail

The extruder with the hot end was mounted on the center of the rail. It is driven by a NEMA 23HS7430 Stepper motor with a GT2 timing belt. The forces acting on the Linear rail were calculated and applied. Only the displacement along the Y and Z-axis were constrained.

From the results of ANSYS, minimum stress of 6006.9 Pa and maximum stress of 2.5732e6 Pa, maximum deformation is 0.0001621 m, minimum equivalent elastic strain of 1.1828e-7, the maximum equivalent elastic strain of 9.183e-5 were obtained.
3.3. Static analysis of Extruder mount plate

The material used in the mount plate is carbon steel. The holes where the plate is mounted in the linear rail with bolt and nut was considered as fixed support and force exerted on the plate by the extruder was calculated and applied.

From the results of ANSYS, minimum stress of 9.644 Pa and maximum stress of 39398 Pa, maximum deformation of $3.734 \times 10^{-9}$ m, the minimum equivalent elastic strain of $4.828 \times 10^{-11}$, and maximum equivalent elastic strain of $1.981 \times 10^{-8}$ were obtained.

Fig. 10. CAD model of extruder mount plate

Fig. 11. Stress analysis of extruder mount plate

Fig. 12. Deformation analysis of extruder mount plate

Fig. 13. Strain analysis of extruder mount plate
3.4. Static analysis of linear rail holder

Linear guide rail play a significant role in X and Y-axis movement. The total weight of the linear guide rail with extruder and the stepper motor was considered to be acting on the holder. The holes in which it is mounted were considered to be fixed support and the force acting on it was analyzed.

![Fig. 14. CAD model of linear rail holder](image1)

![Fig. 15. Stress analysis of linear rail holder](image2)

![Fig. 16. Deformation analysis of linear rail holder](image3)

![Fig. 17. Strain analysis of linear rail holder](image4)

From the results of ANSYS, minimum stress of 15.543 Pa and maximum stress of $1.4653 \times 10^6$ Pa, maximum deformation of $1.1802 \times 10^{-6}$ m, the minimum equivalent elastic strain of $6.5162 \times 10^{-10}$, and maximum equivalent elastic strain of $7.6963 \times 10^{-6}$ were obtained.

4. Modal analysis

Modal analysis is the process of analyzing the dynamic response of the structures during excitation. In mechanical construction, modal analysis utilizes the general mass and stiffness of a design to track down the different periods at which it will naturally resonate. Members should keep their natural frequency distinct from the frequency generated by the external forces to avoid resonance.
Table 2. Resonant frequencies of leveller guide rail

| Mode | Frequency [Hz] |
|------|----------------|
| 1    | 71.714         |
| 2    | 79.575         |
| 3    | 114.06         |
| 4    | 116.41         |
| 5    | 121.4          |
| 6    | 127.67         |
| 7    | 129.91         |
| 8    | 130.53         |
| 9    | 131.28         |
| 10   | 132.68         |

Table 3. Resonant frequencies of the linear guide rail

| Mode | Frequency [Hz] |
|------|----------------|
| 1    | 6.173e-3       |
| 2    | 24.759         |
| 3    | 88.22          |
| 4    | 108.91         |
| 5    | 261.9          |
| 6    | 277.81         |
| 7    | 386.72         |
| 8    | 530.76         |
| 9    | 548.21         |
| 10   | 821.73         |

Table 4. Resonant frequencies of the outer frame

| Mode | Frequency [Hz] |
|------|----------------|
| 2    | 5.3847e-3      |
| 3    | 3.2577         |
| 4    | 9.7956         |
| 5    | 9.8415         |
| 6    | 13.828         |

These were the resonant frequencies of linear guide rail obtained from the modal analysis. An operating frequency that does not match with these natural frequencies was chosen. The structures have been designed in such a way that the operational frequencies won’t affect the optimized running condition. Such conditions have been arrived at by selecting the effective stiffness for the structures.

5. Harmonic response analysis

Harmonic response analysis was used to simulate structural response during the repeated cycle of dynamic loading. When the structure begins to respond to the harmonic loads, it goes through an initial transient phase during which it moves irregularly. Displacement, speed, acceleration, and phase diagrams can be shown for any hubs in the construction. When the external harmonic frequency matches with the natural frequency of the structure, then
resonance occurs & the structure vibrates with maximum amplitude. This condition of resonance should be avoided because maximum vibration may lead to excessive stresses or in extreme cases failure of the structure.

5.1. Leveller guide rail

The fixed support was given at the location where the screw rod is mounted and only displacement along the X and Z-axis was constrained.

The external frequency created due to the external forces matches with the natural frequency at 72.974Hz and phase shift occurs with the amplitude of 4.5904e-7m. The results showed that the structure is capable of sustaining the harmonic load. Hence, the structure's design was predicted to be safe against cyclic loading.

5.2. Linear guide rail

In Linear rail, the displacement along the X-axis was assigned to be on free movement, and displacement along the Y-axis and Z-axis was restricted.

The notable frequencies where phase shift occurs are 90Hz, 270Hz, and 540Hz. The amplitude at which phase shift occurs were 2.9238e-6m, 3.9277e-7m, and 4.2319e-7m.
6. Dynamic analysis

The motion of linear rail along Y-axis and motion of extruder mount along X-axis was analyzed with ADAMS Dynamic analysis. The velocity at which the linear rail and extruder mount move was given as input and change in position was obtained as a result in the graph.

7. Conclusion

In this paper, the FDM-based printer that is capable of printing 1.5-meter cubic-sized objects has been designed and fabricated. The 3D CAD Model was created with SOLIDWORKS software and static, modal, and harmonic response analysis were done with ANSYS Workbench. This 3D printer uses only one extruder with a nozzle diameter of 0.2mm. The crucial parts like leveler guide rail, linear guide rail, extruder mount plate, and linear guide rail holder were analyzed by static structural analysis. The modal analysis for Outer frame, linear, and leveler guide rail was performed to obtain their natural frequency. To avoid resonance, a Harmonic analysis was completed using which structure’s response to repeated cycles of dynamic loading was examined. Additive manufacturing, can possibly democratize the creation of merchandise, from food to clinical supplies, to incredible coral reefs. Later on, 3D printing machines could advance into homes, organizations, and, surprisingly, space. With the right level of planning, engineering and material development, 3D-printed parts can flawlessly progress into rate production equipment, for example, Injection moulding.

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