

Vibration Properties of 3D Printed/Rapid Prototype Parts

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ABSTRACT: Rapid Prototyping/3D printing technology is a fast growing prototyping technology in the manufacturing sector. For any engineering component, vibration also plays a major role. In practice, most of the 3D printer users focus on mechanical properties of components and neglect vibration characteristics which may lead to catastrophic failure. FDM (Fused Deposition Modeling) technology was used to print the parts for carrying out the study. ABS plastic is used as material for printing. A total of 27 samples specimens were printed. This paper makes an attempt to find the vibration properties of 3D printed rectangular beam under cantilever condition. An impact hammer modal analysis carried out on the beam to find the natural frequency, deflection and damping of beam and the results are compared with theoretical values.

KEYWORDS: Rapid prototyping, 3D printing, Fused Deposition Modelling, Vibration, Damping, Frequency.

I. INTRODUCTION

Rapid Prototyping (RP) is a combination of techniques which is used to prototype parts using a three-dimensional computer-aided data. There are various RP technologies widely used for prototyping such as Stereo Lithography Apparatus (SLA), Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), Laminated Object Manufacturing (LOM) etc [6, 12]. Rapid prototyping reduces the time and material involved in manufacturing which results in reduction of the cost involved compared to conventional manufacturing techniques [7]. RP is used in many areas such as automobiles, consumer products, business machines, medical, academic, aerospace and military [15]. RP is extended to many applications which include product development tool, direct part manufacturing and rapid tooling [2]. Among these RP techniques, FDM has advantages of chemical free process and no build material storage problem which makes FDM is widely used to prototype parts.

FDM builds parts layer-by-layer by heating thermoplastic material to a semi-solid state and extruding it according to computer controlled path. Two materials namely build material and support materials are used for this process. Build material is used to build the main component and support material is used to create the support structure needed to hold the main component. The build material is supplied in the form of spools and is fed into the extrusion head where the material is heated just above melting point so that it solidifies easily after extrusion. The build platform moves in z-direction and the nozzle moves in x and y direction which helps in printing the parts in different orientations as shown in Fig 1. Once the required part is printed completely, it is removed from the printer and the part is separated from its support structure [11, 14]. The finished product exhibits different properties based on its printing orientation and layer thickness [5, 3].

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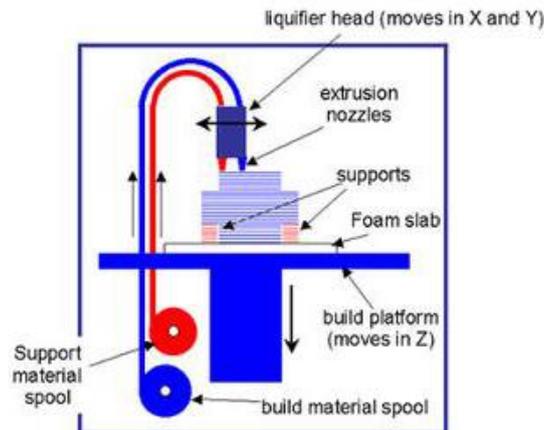


Fig. 1. FDM Process

Vibration plays an important role in engineering components. When the excited frequency of component matches with its natural frequency, resonance condition occurs which leads to failure of component. Hence, it is necessary to find the natural frequency of the component. In this paper, an effort is made to find the vibration properties such as frequency, deflection and damping of the FDM printed part.

II. DESIGN AND MANUFACTURING OF SPECIMENS

The material used to print the rectangular beam is ABS (Acrylonitrile butadiene styrene) plastic. FDM based printer was used to print the beam by varying its printing orientation (namely flat, side and vertical) and layer thickness. For each orientation, different layer thickness of 0.1mm, 0.2mm and 0.3mm was implemented and for each layer thickness three samples were printed. So, nine samples were printed for each orientation. A total of 27 samples were build for all three orientations. Figure 2 indicates the different orientations and isometric view of rectangular beam.

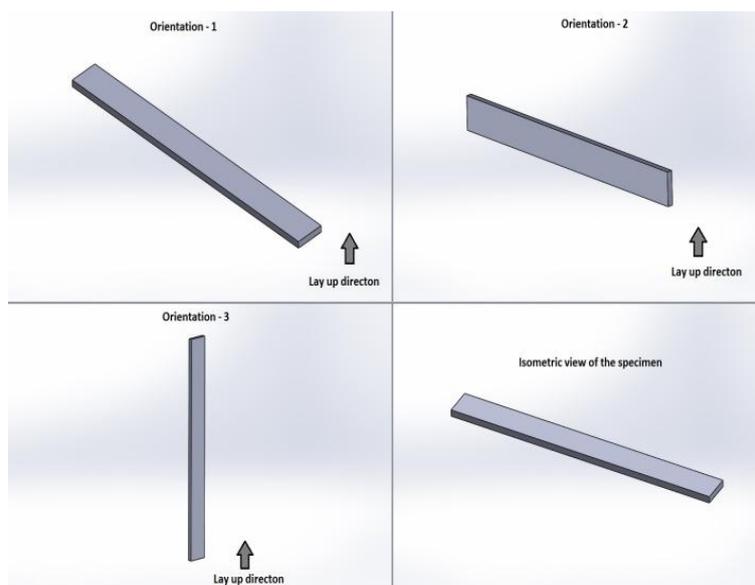


Fig. 2. Three Different Orientations

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The detailed breakup of the number of specimens manufactured for each orientation and layer thickness are given in Table I.

TABLE I
NUMBER OF BEAM SAMPLES

Layer Thickness(mm)	Orientation		
	Flat	Side	Vertical
0.1	3	3	3
0.2	3	3	3
0.3	3	3	3

Mechanical properties of ABS filament used for manufacturing of the specimens are as follows:

TABLE II
MECHANICAL PROPERTIES OF ABS PLASTIC

Yield Stress (MPa)	Poisson Modulus	Density (Kg/m ³)	Young Modulus (GPa)
45	0.4	1040	2.3

III. EXPERIMENTAL MODAL ANALYSIS

Modal analysis is used to identify the dynamic behaviour of structure. Here, an impact hammer modal analysis was selected for experimenting as it is a less cost procedure. In this, an impact hammer as shown in Fig. 3 was used to excite the beam and the response was noted by using Dewetron 7.0.6 software. This impact hammer was designed and manufactured by DYTRAN INSTRUMENTS, INC, CHATSWORTH, CA.



Fig. 3. Impact Hammer

The Fig. 4 shows the experimental setup for modal analysis. The specimen having dimensions 250mm x 25mm x 5mm is clamped as a cantilever beam support upto a length of 5mm and the accelerometer is attached to the cantilever beam with the help of wax. An impact hammer was used to hit the beam at fifteen places on it to obtain frequencies. The data is directly transferred to computer through data acquisition system where FFT (Fast Fourier Transform) and FRF (Frequency Response Function) graphs were obtained using Dewesoft 7.06 software. Damping value ($\zeta = 1/2Q$) was calculated from Q factor which was obtained from FRF graphs. The results obtained are shown in below tables from III to VI.

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Fig. 4. Experiment Setup

The first three natural frequencies for the cantilever beam were observed as shown in Table III to Table V.

TABLE III
FREQUENCY AND DEFLECTION AT MODE1

Thickness (mm)	Orientation	Frequency (Hz)	Deflection (mm)
0.1	FLAT	35.11	0.1448
	SIDE	32.55	0.2370
	VERTICAL	33.56	0.2129
0.2	FLAT	35.40	0.1942
	SIDE	33.16	0.2406
	VERTICAL	33.16	0.1969
0.3	FLAT	34.38	0.1773
	SIDE	33.13	0.2122
	VERTICAL	31.74	0.2286

TABLE IV
FREQUENCY AND DEFLECTION AT MODE2

Thickness (mm)	Orientation	Frequency (Hz)	Deflection (mm)
0.1	FLAT	176.80	0.0040
	SIDE	166.62	0.0048
	VERTICAL	500.08	0.0022
0.2	FLAT	789.38	0.0009
	SIDE	432.53	0.0019
	VERTICAL	166.42	0.0038
0.3	FLAT	171.30	0.0043
	SIDE	429.49	0.0027
	VERTICAL	167.23	0.0036

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TABLE V
FREQUENCY AND DEFLECTION AT MODE3

Thickness (mm)	Orientation	Frequency (Hz)	Deflection (mm)
0.1	FLAT	502.01	0.0022
	SIDE	793.46	0.0023
	VERTICAL	528.36	0.0023
0.2	FLAT	1089.88	0.0008
	SIDE	971.68	0.0001
	VERTICAL	461.02	0.0031
0.3	FLAT	783.49	0.0016
	SIDE	470.25	0.0012
	VERTICAL	464.07	0.0032

The damping value for cantilever beam is as shown Table VI. These damping values were obtained from FRF graphs using Dewetron 7.0.6 software.

TABLE VI
DAMPING VALUE OF 3D PRINTED CANTILEVER BEAM

Layer Thickness (mm)	Orientation	Damping
0.1	FLAT	0.18354
	SIDE	0.06981
	VERTICAL	0.32842
0.2	FLAT	0.25383
	SIDE	0.31634
	VERTICAL	0.29652
0.3	FLAT	0.13591
	SIDE	0.31424
	VERTICAL	0.16241

The outcome of the results are briefly discussed in the results and discussion.

IV. THEORETICAL CALCULATIONS

All the calculations used to find the natural frequency is as follows:
Stiffness of cantilever beam,

$$K = \frac{3EI}{L^3}$$

Where,

$$I = \frac{b * d^3}{12}$$

$$I = \frac{25 * 5^3}{12} = 260.416 \text{ mm}^4$$

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$$K = \frac{3 * 2.3 * 10^9 * 260.416}{200^3 * 10^6} = 0.2246088 \text{ N/mm}$$

Measured value of the mass of beam, m= 0.013 kg
Natural frequency is calculated as,

$$f_n = \frac{1}{2\pi} * \sqrt{\frac{k}{m}} \text{ Hz}$$

$$f_n = \frac{1}{2\pi} * \sqrt{\frac{0.2246088}{0.013}} = 20.91 \text{ Hz or Cycles/sec}$$

V. RESULTS AND DISCUSSION

The natural frequency obtained from the experimental modal analysis excited using an impact hammer deviates much when compared with the theoretical natural frequency. From Table III to Table V shows that natural frequency is high for the specimens with flat orientation and the order frequency changes with respect to orientation decreases from flat, side and vertical. Also with increase in the layer thickness the natural frequency reduces. The Table VII shows the comparison of natural frequency obtained from experiment and theoretical calculations. Higher difference in the theoretical and experimental values is found, this is may be due to lumped mass analysis in the theoretical evaluation.

TABLE VII
COMPARISON OF NATURAL FREQUENCY

Layer Thickness (mm)	Orientation	Natural Frequency (Hz)	
		Experiment	Theoretical
0.1	FLAT	35.11	20.91
	SIDE	32.55	
	VERTICAL	33.56	
0.2	FLAT	35.40	
	SIDE	33.16	
	VERTICAL	33.16	
0.3	FLAT	34.38	
	SIDE	33.13	
	VERTICAL	31.74	

VI. CONCLUSION

This paper explains the experimental modal analysis done to find the vibration properties of 3D printed cantilever beam. The results obtained from experiment vary much from the theoretical calculation. The natural frequency of the beam obtained from experiment on keep observation indicates the fact that the value changes when the layer orientation and layer thickness of the beam changes. This indicates that catastrophic failures may occur if proper layer orientation and layer thickness is not selected in real life situations. Further experiments are needed to verify the vibration properties of the RP made components. Continuous mass analysis and numerical analysis could to be carried out to cross verify the experimental values. Also numerical analysis may suggest the best orientation and thickness of layup for prototyping the parts.

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