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Araştırma Makalesi

Investigation the Effect of 3d Printer System Vibrations on Surface Roughness of the Printed Products

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ABSTRACT

Additive Manufacturing (AM), widely known as three-dimensional (3D) printing, is the process that a product is fabricated layer by layer in Cartesian coordinate system. Fused Deposition Modelling (FDM) is the most used AM process for functional rapid prototyping and products reduces the time and material involved in manufacturing. The purpose of this study is to investigate the effects of 3D printer system vibrations on the surface roughness of fabricated products. Polyethyletherphthalate Glycol (PET-G) is used as material for fabrication. Six different filling structures - Rectilinear, Grid, Triangular, Wiggle, Fast Honeycomb, and Full Honeycomb - were used and for each structure two different top - two and three - layers implemented. A total of 12 samples specimens were fabricated. The results showed that using Full Honeycomb filling structure with three top layers is more suitable for surface roughness compare to the others filling structure used. It can be concluded that the vibration of 3D printer system considering type of filling structure and number of top layers have a significant effect on surface quality of product.

Keywords: *3D Printer, Vibration, Surface Roughness, PET-G.*

3b Yazıcı Sistemi Titreşimlerinin Ürünlerin Yüzey Pürüzlülüğüne Etkisinin İncelenmesi

ÖZET

Yaygın olarak üç boyutlu (3D) baskı olarak bilinen Eklemeli Üretim (Additive Manufacturing - AM), bir ürünün Kartezyen koordinat sisteminde katmanla üretildiği süreçtir. Erişim Birikim Modelleme (Fused Deposition Modeling - FDM), fonksiyonel hızlı prototipleme ve ürün için en çok kullanılan AM sürecidir, üretimle ilgili zamanı ve malzemeyi azaltır. Bu çalışmanın amacı, 3D yazıcı sistem titreşimlerinin, imal edilen ürünlerin yüzey pürüzlülüğü üzerindeki etkilerini araştırmaktır. Üretim için malzeme olarak Polietileterftalat Glikol (PET-G) kullanılmıştır. Altı farklı dolgu şekli - Rectilinear, Grid, Triangular, Wiggle, Fast Honeycomb ve Full Honeycomb - kullanılmış ve her yapı için iki farklı üst katman - iki ve üç katman- uygulanarak toplam 12 test numunesi basılmıştır. Basılan ürünlerin yüzey pürüzlülüğü ölçümleri yapılarak elde edilen veriler üzerinden karşılaştırma yapılmış ve sonuçlar analiz edilmiştir. Sonuçlar, üç üst katmanlı ızgara (Grid) doldurma yapısının kullanılması, yüzey pürüzlülüğü için diğer doldurma yapılarına kıyasla daha uygun olduğunu göstermiştir. Dolgu

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şekli türüne ve üst katmanların sayısına bağlı olarak 3D yazıcı sisteminin titreşiminin ürünün yüzey kalitesi üzerinde önemli bir etkisi olduğu görülmüştür.

Anahtar Kelimeler: *3B Yazıcı, Titreşim, Yüzey Pürüzlülüğü, PET-G.*

I. INTRODUCTION

It is very important to use a proper process to achieve a better surface from a manufactured product. However, increasing demand for better surfaces makes the process a little bit complicated which many variables can deleterious the desired results. Additive Manufacturing (AM), widely known as three-dimensional (3D) printing, is the process that a product is fabricated layer by layer [1] in Cartesian coordinate system. One of the most used AM process is Fused Deposition Modelling (FDM). FDM is widely used for fabricating from medical equipment to industrial products. This process has gained significant interest due to its ability to fabricate complex geometries with optimal material. FDM is used in many areas such as household goods, toys, architecture, medical devices, aviation, automotive, and space crafts [2]. FDM fabricate products layer-by-layer by heating thermoplastic material to a semi solid state and extruding it according to information from computer aided design and control data. FDM will play a significant role in the future product design and manufacturing process. FDM is a widespread in various industries to fabricate complicated geometrical products without any shape constraints in short time [3-5]. A study [6] received a literature survey on the state of art of AM. Additional information on AM process can be found in overviews studies [7-10]. Considering the quality of fabricated products surface, most of the studies focus on mechanical properties of product and neglect the effects of vibration characteristics of the printer system. In general, the quality of a fabricated product's surface is mainly determined by the thickness of each fabricated layer [11]. Vibration from printer system also play a major role on surface quality of product because of vibration is inherent to the movement of printer system itself. The state of vibration is affected by the dynamic characteristics of the 3D printer system assemblies – table, extruder, etc. Studies relating to vibrations in printer system have been relatively few and that there is no study focusing on the effects of vibration on product surface roughness. Several studies [12-14] carried out on vibration analysis for quantifying the printing parameter effects on the structural characteristics of fabricated products. Also, a study [15] presents vibration data obtained from printer table in terms of impact of mechanical behaviors on fabrication quality. The objective of this study is to experimentally investigate the effects of system vibrations on the surface roughness of fabricated products.

II. MATERIAL AND METHOD

FDM based printer was used to fabricate the sample by varying its filling structures - Rectilinear, Grid, Triangular, Wiggle, Fast Honeycomb, and Full Honeycomb - and number of top layers. For each filling structure two different top (two and three) layers were implemented. So, a total of twelve samples were fabricated. Test samples were designed as 3D model using designing software and transferred to 3D slicing interface program to printer. A schematic drawing of 3D printer is shown in Figure 1.

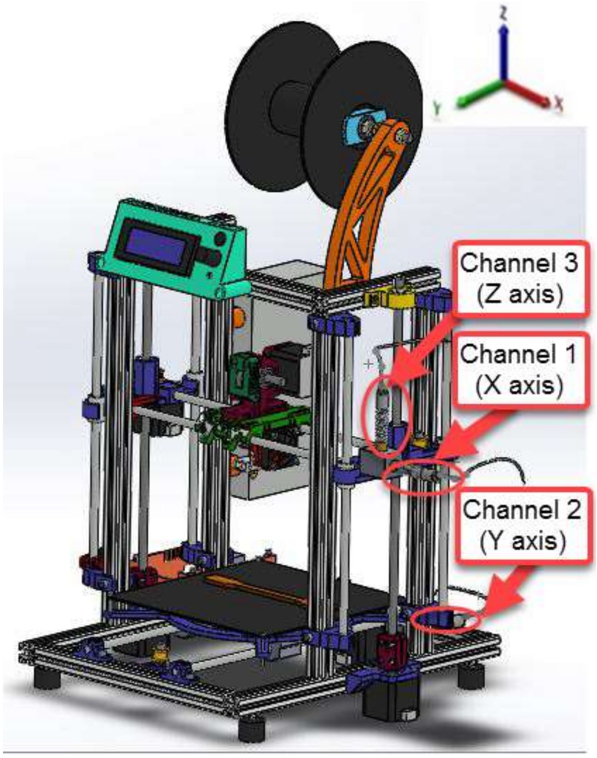


Figure 1. *A schematic drawing of 3D printer*

Polyethyletherphthalate Glycol (PET-G) is used as material for fabricating test sample because it is the most commonly used material in additive manufacturing. The properties of PET-G material are given in Table 1.

Table 1. *The properties of PET-G material [16]*

Material Properties	
Material	PET-G
Filament color	Orange
Filament diameter (mm)	1.75
Density (g / cm³)	1.27
Tensile strength at yield (MPa)	50
Tensile modulus (MPa)	2140
Elongation (%)	120
Melting point (ºC)	135
Heat deflection temp. (ºC)	70

The fabricating parameters such as occupancy rate, filling structure, layer thickness are defined as input in the program. Table 2 gives printing parameters [17].

Table 2. *Printing parameters*

Printing Parameters	
Filament diameter (mm)	1.75
Nozzle diameter (mm)	0.40
Extruder temperature (°C)	230
Table temperature (°C)	Built-in
Occupancy rate (%)	30
Extrude width (mm)	0.35
Layer thickness (mm)	0.20
Printing speed (mm/min)	4200
Speed for non-print moves (mm/min)	4800
Top Layer Number	2 – 3
Bottom Layer Number	3
Vertical Shell Number	2
Room Temperature (°C)	24 ± 1
Filling structure	1-Rectilinear 2-Grid 3-Triangular 4-Wiggle 5-Fast Honeycomb 6-Full Honeycomb

Sample for testing according ISO 527-2 standard was fabricated for surface roughness measurements. Picture of test sample with dimensions is given in Figure 2.

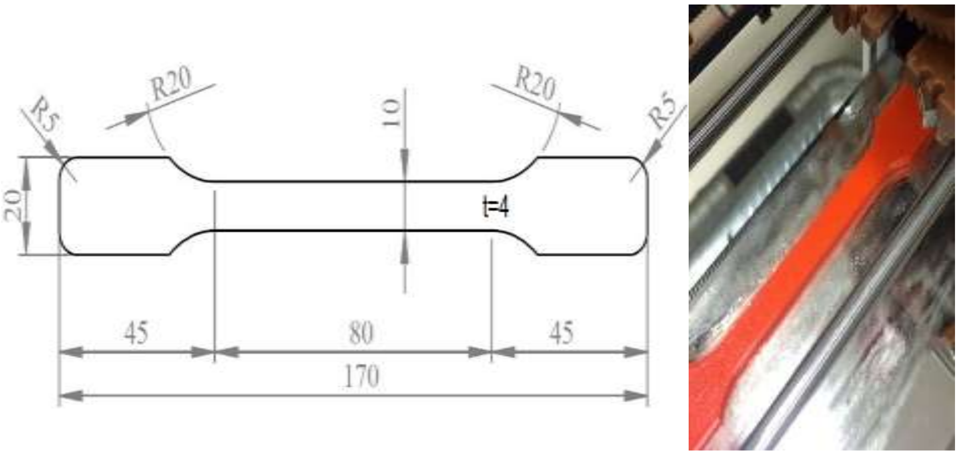


Figure 2. *Test sample dimensions (ISO 527 – 2 type 1A)*

An extruder nozzle E3D type with a 0.40 mm diameter was used for fabricating all test samples. The table has 200 mm width and 200 mm length.

The table moves in y-direction and the nozzle head moves in x and z direction which helps in fabricating the test sample in different filling structures with occupancy rate as 30 % as shown in Figure 3. The drive of each axis is performed by a stepper motor (NEMA 17 bipolar stepper). The stepper motor specifications include 200 steps per revolution (1.8° for each step), 4 voltages on phase, 1200 mA operational current (of one phase), 3.3-ohm phase resistance, 3.2 kg-cm holding torque.

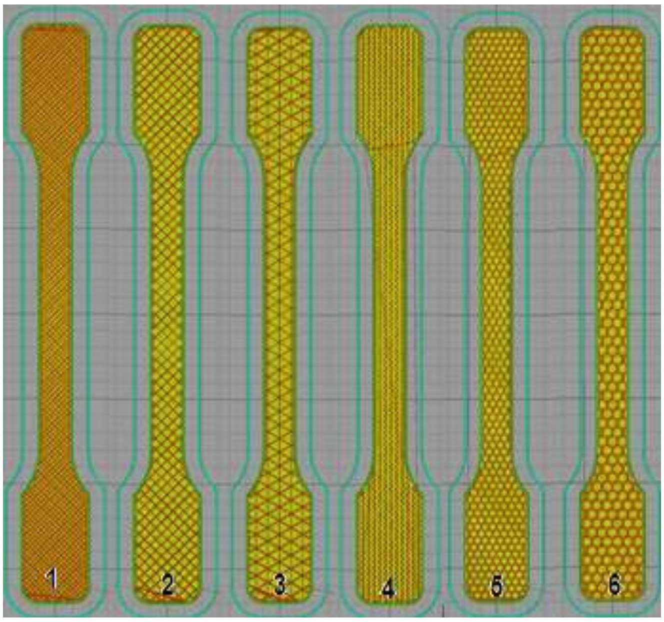


Figure 3. *Filling structures: 1-Rectilinear, 2-Grid, 3-Triangular, 4-Wiggle, 5-Fast Honeycomb, 6-Full Honeycomb*

Data Acquisition Unit (DAQ) from SpectraQuest were used to record vibration signals from accelerometer (608A11) sensor during experiments. Three accelerometers were set as Channel 1, Channel 2, and Channel 3 for x, y, and z axis respectively. The captured vibration signals have been analyzed in time domain.

All the surfaces of test samples were measured for surfaces roughness by a Taylor Hobson brand device. Surface roughness average (Ra) of the samples were measured for all test samples. Three measurement values were taken from each sample and averaged for both horizontal and vertical direction. Surface roughness was measured along 5 mm blue line from shaded area given in Figure 4.

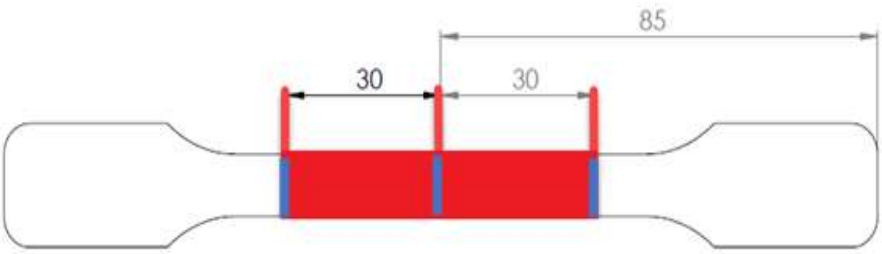


Figure 4. *Area of surface roughness taken*

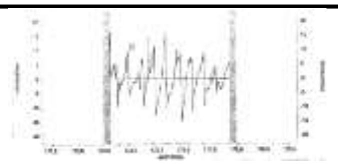
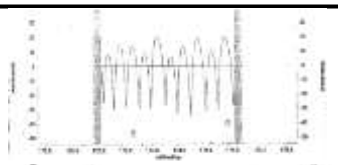
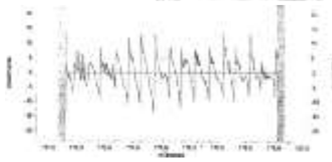
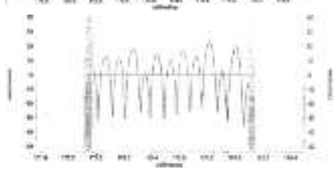
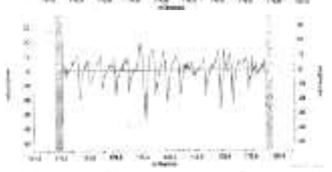
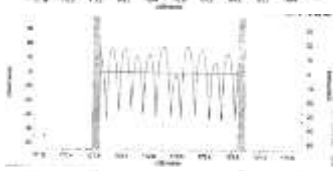
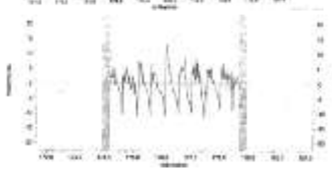
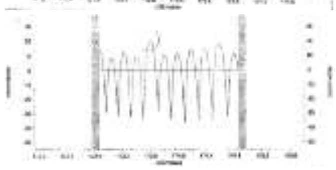
III. Results And Discussion

Table 3 gives the surface texture of fabricated test samples and Table 4 gives test samples surface roughness measured by a Taylor Hobson brand device. Also, we called the samples for clearance as SC means sample code, first number shows filling structures an in the Figure 3 and second number shows number of top layers.

Table 3. *Surface texture of fabricated test samples*

Sample	Two Top Layers	Three Top Layers
Rectilinear		
Grid		
Triangular		
Wiggle		
Fast Honeycomb		
Full Honeycomb		

Table 4. *Surface roughness averaged results*

Sample Code	Horizontal Measurement Plot	Vertical Measurement Plot
SC12		
SC13		
SC22		
SC23		

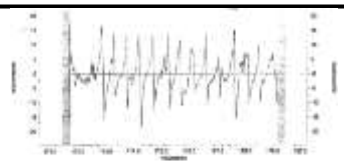
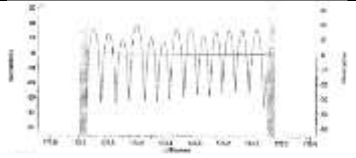
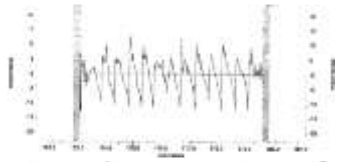
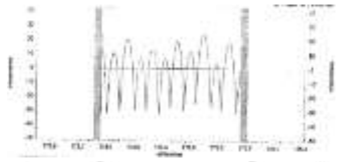
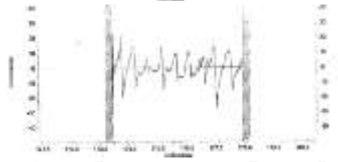
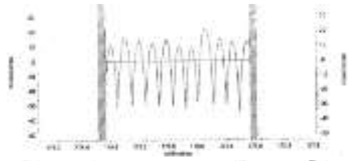
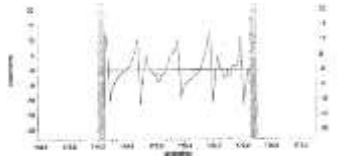
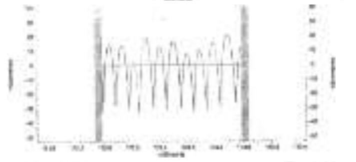
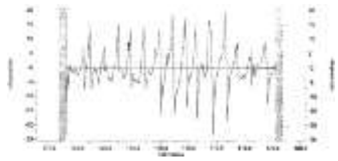
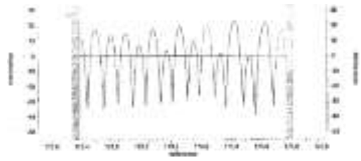
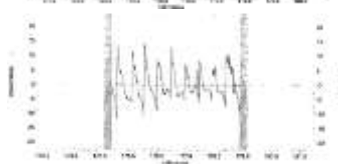
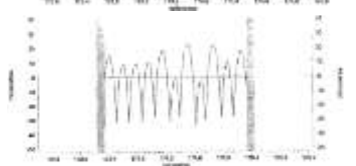
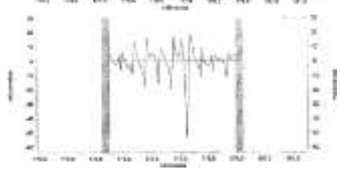
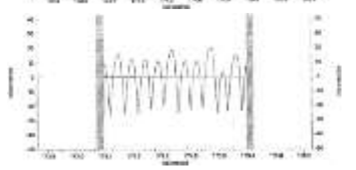
SC32		
SC33		
SC42		
SC43		
SC52		
SC53		
SC62		

Table 4.(continue). *Surface roughness averaged results*

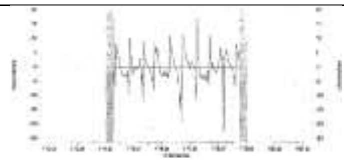
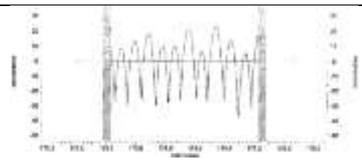
Sample Code	Horizontal Measurement Plot	Vertical Measurement Plot
SC63		

Table 5 and Figure 5 give Ra values for both horizontal and vertical direction for all test samples. Three measurement values were taken and averaged for each sample. A code is given for each sample. The first number in Sample Code (SC) indicates filling structure type and the second number indicates number of top layers. From the results obtained in surface roughness analysis shown in Figure 5, it is observed that filling structure has direct influence on surface roughness. In Table 5, the highest Ra value measured in horizontal direction is 5.79 µm (micrometer) for Grid filling structure with two top layers (SC 22) while the lowest Ra value measured in vertical direction is 3.5 µm for Full Honeycomb filling structure with three top layers (SC 63) and the highest Ra value measured is 12.50 µm for Fast honeycomb with two top layers (SC 52) while the lowest Ra value measured is 10.57 µm for Full

Honeycomb filling structure with two top layers (SC 62). It can be concluded that number of top layers can have a dramatic effect on the quality of surface roughness of fabricated products. In Figure 6, time domain data are presented with amplitude as the vertical axis and elapsed time as the horizontal axis for all test samples while fabricated. It can be seen that also vibration amplitude value for Full Honeycomb filling structure with three top layers is much lower compared to the others filling structures used. This is because of surface roughness measurement was taken from a narrow area. From the time waveform plots, it seems that vibration from the table (y-direction) has lower amplitude for Grid and Fat Honeycomb filling structures.

Table 5. *Measurements of surface roughness averaged results in horizontal and vertical direction.*

Sample Code	Horizontal Direction Ra (μm)	Vertical Direction Ra (μm)
SC 12	4.1914	11.5985
SC 13	3.7361	11.6880
SC 22	5.7946	11.8054
SC 23	3.6023	11.5875
SC 32	4.1466	11.7985
SC 33	3.9456	11.8376
SC 42	5.4288	11.3638
SC 43	3.7060	11.5165
SC 52	4.5909	12.5045
SC 53	4.1135	11.8857
SC 62	5.5201	10.5763
SC 63	3.5300	11.4328

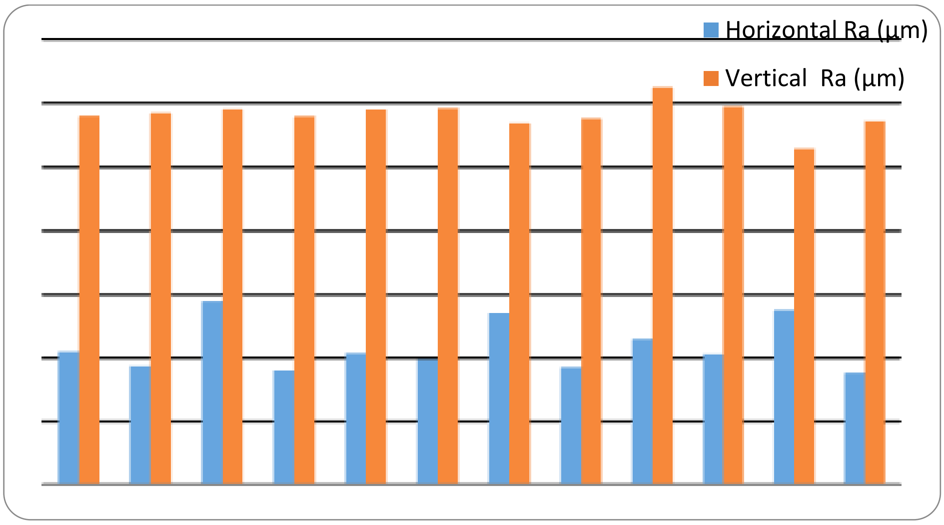


Figure 5. *Measurements of surface roughness averaged results in horizontal and vertical direction.*

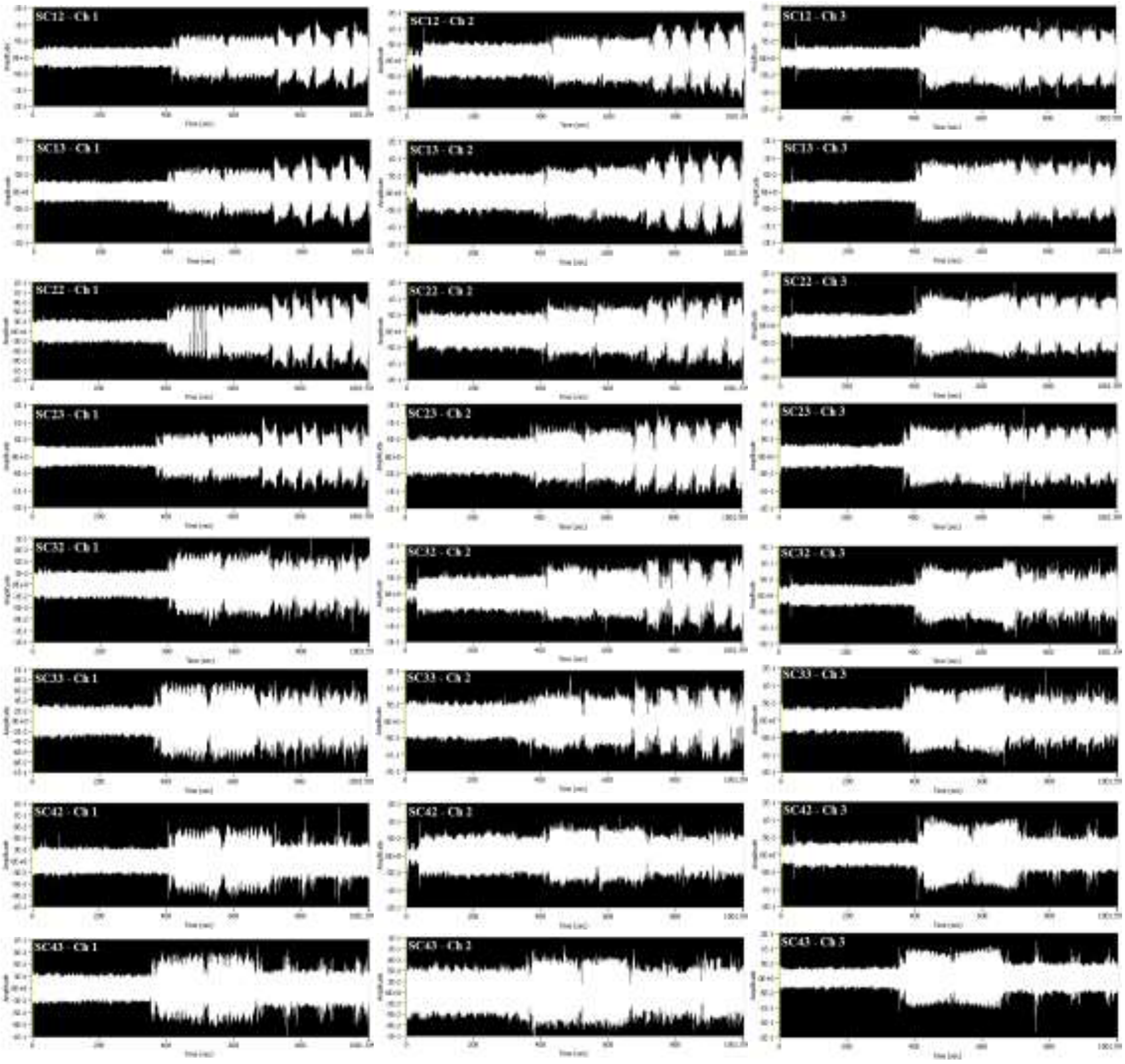


Figure 6. *Vibration amplitude values*

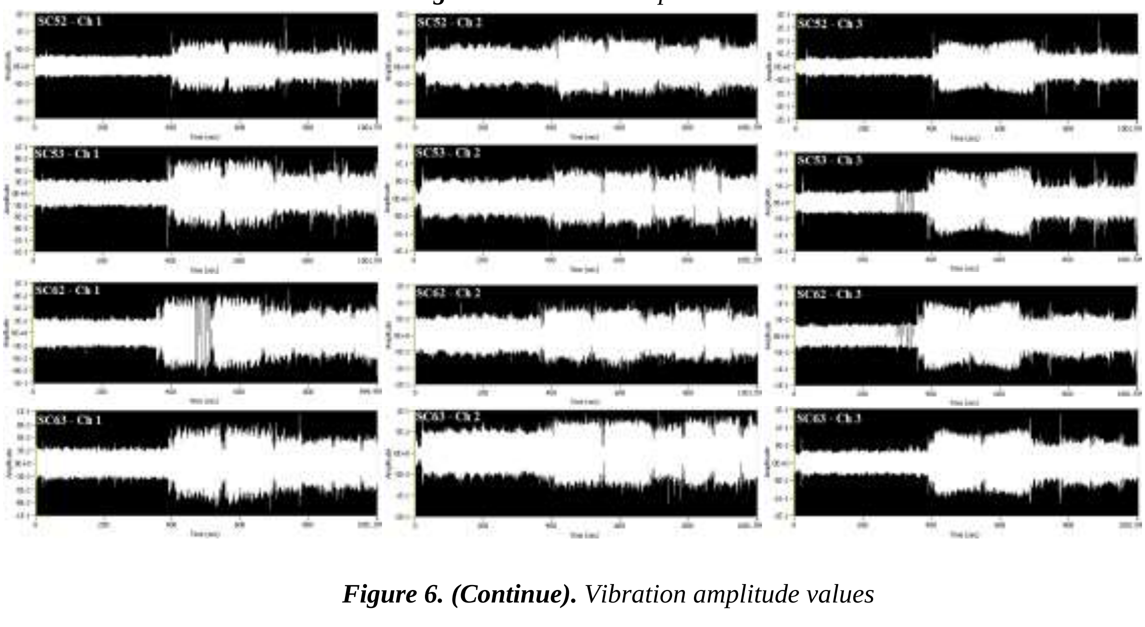


Figure 6. (Continue). *Vibration amplitude values*

IV. Conclusion

3D printer system vibrations have a significant influence on the surface roughness of fabricated products. Vibration in 3D printer system exist throughout the fabricating process while influenced by many sources such as 3D printer structure, nozzle type, filling structure type etc., the composition of the fabricating process is complicated. So, 3D printer system must be designed to operate without excessive vibration. The purpose of this study is to investigate the effects of 3D printer system vibrations on the surface roughness of fabricated products. Polyethyletherphthalate Glycol (PET-G) is used as material for fabrication. Six different filling structures - Rectilinear, Grid, Triangular, Wiggle, Fast Honeycomb, and Full Honeycomb - were used and for each structure two different top - two and three- layers implemented. It can be concluded that the surface roughness of Full Honeycomb filling structure with three top layers have been found to be superior to the others filling structures used and excessive levels of vibrations can have an imposing effect on the quality of surface roughness of fabricated products.

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