Condition Monitoring of 3D Printer Using Micro Accelerometer

K.Gomathi¹*, T.Ganesh², J.Bharanidharan³, A.P. Arvindh Prajathkar⁴, R.Aravinthan⁵

¹Associate Professor, Department of Mechatronics Engineering, Kongu Engineering College, Erode - 638060. Tamilnadu, India.
²,³,⁴,⁵ UG Scholars, Department of Mechatronics Engineering, Kongu Engineering College, Erode - 638060. Tamilnadu, India.

*Email : gomathik@kongu.ac.in

Abstract: The unwanted disturbance in the form of vibration causes damages to the components produced and reduces the efficiency of the machine. Analysing and controlling the vibration is very important for moving machines. The working principle of 3D printer is Additive Manufacturing Technique. Thus, for a minute vibration the observable defects are produced. So, it is necessary to analyse the vibrations of the 3D printer. To analyse a machine, it is important to know about the motions produced by the machine, then suitable sensors must be chosen to measure those motions. The condition of the machine can be found using sensor measurement values. A 3D printer produces three types of motions such as point to point motion, zigzag motion and continuous motion. The vibration produced during each of these motions is monitored using the conventional accelerometer, micro accelerometer and the micro flown sensor. The values of micro accelerometer are acquired using Arduino and NI – cDAQ9174. The results from each of these sensors are analysed and compared. From the results, it is clear that during the continuous motion the vibration is very less since it is observed during the soft edges of the components. The vibration is maximum and rhythmic during the zigzag motion due to sudden acceleration and deceleration. The point to point motion is produced while using the support material.

Keywords: 3D printer, Vibration MEMS accelerometer, Microflown Meter.

1. Introduction
Three dimensional solid objects are made from a CAD file by using 3D printing or additive manufacturing. An object is created in an additive process by laying down consecutive layers of material before the object is created. Any of these layers can be viewed as a finely sliced horizontal cross-section of the final material. 3D printing is the reversal of subtractive production, such as a milling machine, which cuts out a piece of metal or plastic. Complex pattern can be created in 3D printing by using less material. 3D printing is considered to be an industrial production technology due to high precision, range of material and repeatability. Micro-Electro-Mechanical Systems is simply known as MEMS. In Europe, it is also called Micro Systems Technology (MST) [1]. In a nutshell, a micro device is created by combining electrical and mechanical concepts on a single chip. The systems are usually made at micro scale, with even decreasing feature sizes. The MEMS technology is in rapid development and has expanded into many fields in the last decades. Micro flown sensors determines...
the velocity of sound particles as well sound pressure, hence high accuracy can be achieved. A Micro flown utilises two extreme sensitive heat platinum wires with low thermal resistance. Vibration plays a vital role while working with an instrument or machine. Vibration can cause machinery to consume excessive power and may damage product quality [2].

The undamped vibration produces harmonics which cause damages to the working of machine and the tool components. Hence, analysis of vibration is very important in the field of manufacturing and measuring. Since 3D printing uses additive manufacturing technique even a small vibration can cause the adverse effect on the outcome [3]. 3D printer operates with high speed which will create a light, flexible and inexpensive material. These vibrations provide a demerit to create a printing job.

More researchers tested the handle vibration of a vertical disc stump grinder and estimate the permissible years of operating the vertical disc stump grinder according to the standard ISO 5349 format. With this International Organization for Standards allows to measure hand arm vibration [4]. Finite element model have been developed for the vibration of disc grinder. Random vibration analysis is done for the input excitation of the engine and cutting disc by using the analysis module of the ANSYS Workbench to obtain the vertical acceleration power spectral density of the handle. Most of the manufacturing industries focusing on the use of vibration monitoring techniques to monitor the condition of the machine tools’ spindle units [5]. Mostly condition monitoring data is analysed by trend analysis, which compares measured results with the machine data [6].

Accelerometers are used to measure the damping values of the offshore wind turbines [7]. The planned automated procedure is validated by real time vibration measurements of an offshore wind turbine in non-operating conditions from a 24hours monitoring period. Electrical fault and mechanical vibration fault are deducted by using the big data analysis [8]. The integrating FFT and radial-based CRA have been presented for mechanical vibration fault detection in turbine generators.

A data collection system supported by LabVIEW software captures cutting tool vibration signals. A complete factorial laboratory architecture was used to improve the buoyancy and durability of the experiments. In CNC machining procedures, cutting tool vibration in tangential and axial direction was measured based on the vibration signal obtained through a LabVIEW data acquisition system and managed using neoprene viscoelastic material (VEM) [9].

Improving the gear configuration and enclosure of gearbox is favoured to protect against noise. With regard to the issue of gearbox noise, it can be inferred that a low noise gearbox needs adequate rigid housing, shafts and gears, as well as the HCR gears and the adjustment of the tooth surface for construction load[3]. In general two methods of fault diagnosis are preferred such as Vibration analysis and Current signature analysis which was analysed on their ability to detect induction motor operation abnormalities. The vibration analysis using MEMS transducers may also be used to fine mechanical faults in stator and electrical faults in rotors [10].

The mathematical modelling of 3D structure of Micro accelerometers have been designed [2]. This paper proposed a new flexible sensing micro accelerometer, which measures its individual 3D configuration. Random vibrations of full aircraft with active and passive landing gears have been done by numerical simulations on random runway profile. The analysis was done using Mat lab /Simulink.

Industrial sewing machine vibrations are monitored using multimode optical fiber sensors [6]. The cable fibers are used to monitor the vibrations [11]. Three phase induction motor vibration was measurement. In addition, biaxial optical fiber micro accelerometer was calibrated and tested [12]. Finally the measure result of optical accelerometer were compared with the capacitive micro accelerometer [13]. These enhanced vibrations produce harmonics, thus increases the temperature of the 3D printer. The defects are visibly produced at the sharp edges of components and the point of contact i.e., point at which starting and ending meets [11].

2. Methodology
The Proposed Methodology shown in Figure1 which implies that the vibration of the 3D Printer is analysed by using two types of accelerometers and with Microflown Sensor.

- Conventional Accelerometer
- Micro Accelerometer

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Initially the sensors are placed at the base of the printer and the vibrations are noted, and later were placed in the vertical column shown in Figure 2 of the 3D printer and vibration values are taken. Both the values are compared and analysed. It is found that vibrations were high and accurate when the sensors mounted at the vertical column (pillar). Hence the further analyses are taken by placing the sensors at the vertical column. The 3D printer monitored by accelerometer plotting graph between frequency and acceleration printer vibration is analysed. The results were drawn from the values and the motion analysis of 3D printer was done.

From the literature survey it is clear that the unwanted vibrations cause severe damages to the work piece and to the tool or machine components. Therefore analysing of machine is very important. The machines were analysed before and after construction, and in different working conditions. From the results suitable damping were provided to arrest those unwanted vibrations. So, it is necessary to analyse 3D printer at different working conditions. The method of 3D printing transforms an entire piece into thousands of small slices and renders it slice by slice from bottom to top. Slid objects are made with a tiny layers.3D printers can produce moving parts such as hinges and wheels.
The most common and universal file formats for 3D printing are STL shown in Figure 2. STL is known as “stereo lithography”. It is a 3D model containing a single colour only. Usually, this is the file format used for 3D desktop printers. This file provides specific instructions for each slice to be followed by a 3D printer, such as the starting point of each sheet follows the nozzle when laying the flat material. In addition to this, manufactures of 3D printers has its own proprietary input file format which contains unique instructions to the product technique. 3D printer manufacturers use their own tools to generate a file to make it readable form. The 3D printer is manufactured by the Cube Pro the software they provided is Cube-Pro. The product designed was processed by this software and then printed by the 3D printer.

Three different components were chosen for the analysis of motion. The first component, cylindrical ring shown in Figure 4 (a) is very small and has soft edges and there is no need of support material, only the continuous motion was observed. The second component, blade shown in Figure 4 (b) is very complex and has sharp edges at the corners. The support material had been provided. The vibrations due to both the point to point motion and the rapid zigzag motion were observed in this component. The third component, gear shown in Figure 4 (c) is larger in size and has pointed corners, but there is no need for the support material. This produces the point to point motion during injection process.
2.1 Program and Setup

Figure 5 represents the block diagram of the LabVIEW program to acquire signal from the triaxial accelerometer and front panel. The data from the accelerometer is acquired by the NI cDAQ-9174. This compact signal conditioning unit was manufactured by National Instruments. It features four 32-bit general-purpose counters/timers. Both the analog and digital signals can be processed using it. The micro accelerometer readings are acquired using the Arduino controller. The programming is done using the Arduino (IDE) software. The Values of the three axis is produced in acceleration so there is no need for further conversion of values.

3. Results and Discussion

3.1. Cylindrical Ring

The Figure 6(a) represents the vibration reading taken from the conventional accelerometer. Micro accelerometer is fixed at the stake of 3D printer to observe the maximum vibrations. Figure 5(a) and 6(b) represents the conventional accelerometer and micro accelerometer graph for cylindrical ring. The responses from these sensors are noted and those values are analysed. The results were interpreted and by plotting graph. After the readings were taken by using both the accelerometer, it was confirmed that the vibrations at the Z-axis increases due to the movement of the injector. From the values of both the sensors it is clear that the negative acceleration acts on the X-axis. Since the vertical column is fixed at the bottom the vibration on the Y-axis were controlled maximum only a small amount of vibrations were observed. On the z-axis the column is free to move hence maximum vibrations were observed in that axis.

3.2. Blade

Figure 7(a) and 7(b) represents the conventional accelerometer and micro accelerometer graph for blade. The responses from these sensors are noted and those values are analysed. The results were interpreted and by plotting graph.
From the Figure 6 (b) it is clearly seen that there is sudden negative g-force acts on the column. It is happened due to the rapid zigzag movement produced by the printer for printing the sharp edges in the component. For injecting the support material the 3D printer produce sudden acceleration and the deceleration. These sudden movements cause the 3D printer to vibrate. From the graph it is shown that the Z-axis has the negative g-force, this shows that the Z-axis have more deceleration.

3.3. Gear

Figure 8 (a) and 8 (b) represents the acceleration reading taken by the conventional accelerometer and the micro accelerometer respectively. From the result it is clearly seen that there is more vibration in the Z-axis this due to the point to point movement produced by the printer for printing the tooth in the gear. For injecting the support material the 3D printer produce sudden acceleration and the deceleration. This produces more vibrations leading to uneven distribution of the support these sudden movements causes the 3D printer to vibrate.
3.4. Micro flow Sensor

The only transducer that can precisely calculate the velocity of acoustic particle mechanically is a Microflown sensor. Two complementary acoustic properties are characterized such as the acoustic particle velocity vector and the scalar sound pressure. Microflown sensor identifies velocity vector of a one-dimensional particle. 3D printer produces three types of motion.

- Continuous motion
- Rapid zigzag motion
- Point to point motion

3.4.1. Continuous Motion

This motion is due to the injection in the soft corners and the rounded edges of the product. During this motion the vibration of the printer is very minimum and produces good surface finish.

![Graph](image-url)
3.4.2. Rapid Zig-Zag Motion

This movement is due to the injection of the material in the sharp edges of the product. For injecting in the sharp corners the motor has to suddenly accelerate and decelerate. This sudden acceleration and the deceleration cause the 3D printer to vibrate thereby reducing the surface finish and edge accuracy of the product.

3.4.3. Point to Point Motion

This motion is produced for providing the support material. Support material is not continuously, the support is given point by point thus forming a support. Hence this produces more vibrations leading to uneven distribution of the support there by affecting the product.

The vibration shown in Figure 9(a) is due to point to point motion. The vibration produced during the zigzag motion and the continuous motion is shown in the Figure 9(b). By analysing the result the conclusion were provided relating the vibration produced and the motion which causes the vibration.

![Figure 9(a) Microflown Graph - Point to point](image)

![Figure 9(b) Microflown Graph - Continuous](image)

Static analysis result shows the measured acceleration. Also cross axis sensitivity are measured for all the designs. Table 1 shows the cross axis sensitivity values.

Cross axis sensitivity = \( \frac{\text{Acceleration in y axis} \times 100}{\text{Acceleration in x axis}} \)

### Table 1. Cross Axis Sensitivity

| Components   | Conventional Accelerometer (%) | Micro Accelerometer (%) |
|--------------|--------------------------------|-------------------------|
| Cylindrical Ring | 0.18                           | 0.039                   |
| Blade        | 0.039                          | 0.029                   |
| Gear         | 0.19                           | 0.037                   |
Cross axis sensitivity is the highest sensitivity of the plane perpendicular to the direction of measurement equal to the sensitivity of the direction of measurement. It is measured in two perpendicular directions (Sx and Sy) in this plane as the geometric sum of the sensitivities. Z axis acceleration range is 50 times higher than other two axis. Therefore ±2g acceleration range is selected for X and Y axis and single axis ±100g accelerometer for the Z axis.

4. Conclusion and Future Scope

4.1 Conclusion
The vertical column of the 3D printer is placed without any support at the top and there was no damping provided to it. Hence this structure produces more vibrations. By providing suitable support at the top and a damping circuit with the piezoelectric patches to the vertical columns of 3D printer, the vibrations can be controlled thereby increasing the accuracy. The comparative vibration result between conventional accelerometer and Micro accelerometer for cylindrical ring, Blade and Gear is shown in Table 2.

| Parameter       | Cylindrical Ring | Blade | Gear          |
|-----------------|------------------|-------|---------------|
|                  | Conventional     | Micro | Conventional  | Micro | Conventional | Micro |
|                  | Accelerometer    | Accelerometer | Accelerometer | Accelerometer | Accelerometer | Accelerometer |
| Maximum Vibration| 0.00030          | 17.670 | 0.0010        | 17.520 | 0.00024      | 17.862 |
| Frequency (Hz)   | 0.15             | 0.02   | 0.02          | 0.012  | 0.04         | 0.03   |

4.2. Future Scope
Vibrations may not be arrested completely. In Future, it can be minimised by providing the vertical column of the 3D printer with a support. It absorbs the vibration produced by the 3D printer. Another method is to use the piezoelectric patches. The piezoelectric patches will absorb the vibration produced on the 3D printer during the injection process.

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