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A Study of Availability of Bambu Lab X1 Carbon FDM 3D Printer Machine Based on Maintenance Schedule

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Abstract:

In modern times, where Industry 4.0 takes precedence, additive manufacturing has become an innovation in the acceleration of production process. In different 3D printing techniques, Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) is considered one of the simplest, cheapest, and easy to maintain. FDM provides faster and more flexible creation of products in comparison with other techniques; therefore, FDM technique is suitable for industrial uses. One of the key aspects affecting efficiency of such devices is maintenance, which is connected with the machine availability and general productivity. Machine availability implies the possibility of work without any breaks and downtime of the device, and it results in higher production rates. Therefore, the purpose of this research paper is the investigation of downtime of FDM 3D printers and maintenance activities. Through the assessment of downtime and its connection with maintenance activities, the importance of maintenance for keeping high availability is underlined in this research paper.

Keywords - **3D Printer, FDM, Maintenance, Availability, Down time**

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I. INTRODUCTION

Of all the manufacturing technologies, Additive Manufacturing is the most versatile and fast. Fused Deposition Modeling (FDM) is one of the popular additive manufacturing technologies that produces three-dimensional objects by extruding molten thermoplastics layer by layer [1]. The principle of operation of this technology is very simple and at the same time very efficient. A spool of filament feeds thermoplastic into an extruder that melts it and pushes it through a thin nozzle. Nozzle moves along X and Y axes to form the shape of the layer, and the platform (or nozzle) moves up along Z axis to add new layers, creating the whole object eventually [2].

The secret of precise functioning of FDM is in its extrusion and movement system. While the molten filament is being extruded, it hardens very quickly, sticking with the previous layer and thus forming a durable structure. For complex geometric shapes, additional supports can be added during the printing process and later removed either mechanically or chemically, depending on the material used [3].

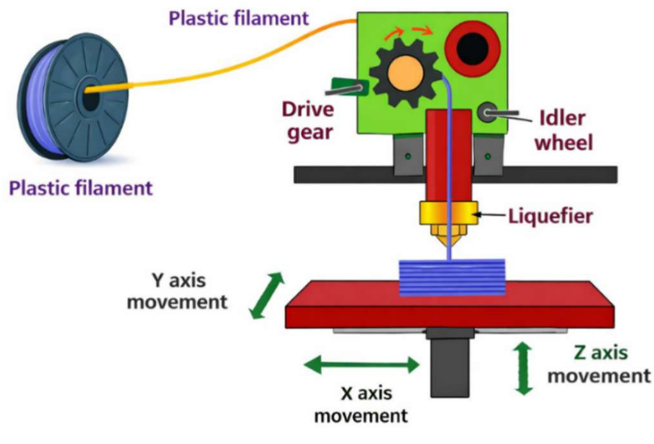

Fig. 1 FDM 3D printer working methodology

II. MAJOR COMPONENTS

A. *Nozzle*

In an FDM 3D printer, the nozzle is very important as it is responsible for controlling the dispensing of melted filament on the building platform one layer at a time. It does this by controlling the layer height and hence the resolution, finish, and accuracy of each layer [4]. The diameter of the nozzle impacts the speed and detail of each layer while the type of material used (brass, steel, ruby tipped) guarantees compatibility with certain filament materials. Temperature stability, cleaning and timely replacement are key aspects in avoiding clogs and wear and tear [5].

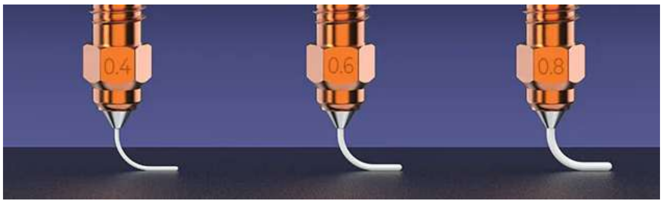

Fig. 2 Layer thickness with different nozzle

The FDM printer nozzles normally vary in diameter between 0.4 mm and 1.0 mm in order to achieve balance between detail and speed. Nozzles usually consist of brass with stainless steel tips that can withstand high temperatures, and M6 threads allow easy integration into FDM hot ends [6].

Fig. 3 Various size of nozzle diameter

B. Build Plate

The build platform, more often referred to as the build plate in 3D printing technology, is an essential part of a 3D printer. This component serves as the surface where the print is built layer by layer. The selection of the material for the build plate and its surface finish plays a critical role in the quality of the print and adhesion of the object to the build plate [7]. Some common types of build plates are mentioned below:

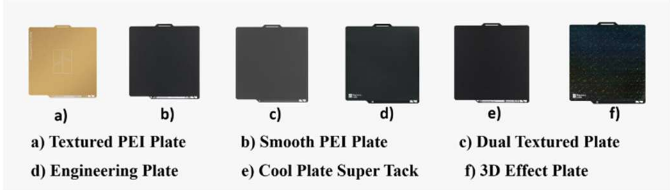

Fig. 4 Types of build plate

The build plate in FDM 3D printers comes in different sizes such as 180 × 180 mm, 256 × 256 mm, 330 × 320 mm, and 350 × 320 mm, among others. The particular size is determined by the compatibility of the model used for the printer since different printers have build plates that can be used to achieve particular print sizes [8].

C. Filament and Filament Material

The filament utilized by FDM 3D printers is a thermoplastic material that is available in the form of thin, continuous strands wound on spools. The filament is then fed to the printer's extruder and goes through the heater before melting and being laid on the bed of the printer [9]. Apart from being the material to be used in printing, the filament is very important in determining the properties and performance of the printed item [10].

Fig. 5 Various colours of filament in spool

The FDM 3D printer filament is typically available in two sizes: 1.75mm and 2.85mm depending on the printer's specifications. In choosing the filament to use, some considerations should be made including the material, its printing temperature, adhesion to build plate, post processing requirements, cost, and eco-friendliness.

The filament that is frequently used includes PLA, ABS, PETG, Nylon, PC and PEEK. Among these, the most common type of filament is PLA because of its low cost and favourable material properties [11].

D. Extrusion System

The extruder assembly of the FDM 3D printer consists of several main components: the filament feed system, the heating system, the nozzle, and the hot end cooling fan.

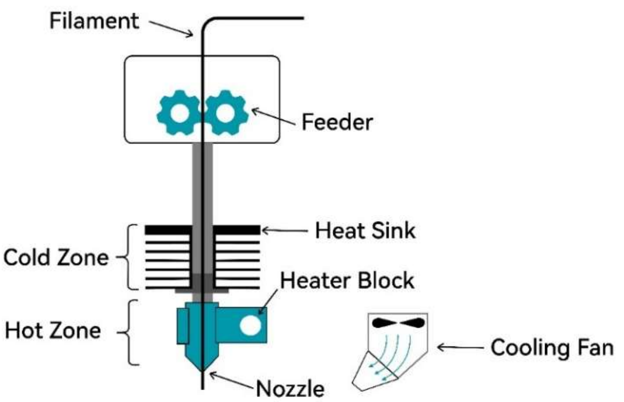

Fig. 6 Working of extrusion system

The filament feed system (cold zone) pushes the solid filament into the hot end by a steady and regulated process, which involves components such as the stepper motor, drive gear, idler gear, and the system for tension regulation [12].

The heating system (hot zone) melts the filament so that it becomes flexible enough to be pushed through the nozzle while bonding well with the neighbouring layers; it includes the components like the heater block, heater cartridge, temperature sensor, and heat break.

The hot end cooling fan is placed on the heatsink at the cold end of the extrusion system and serves as a continuously working device for active cooling. Its function is to keep the filament solid and rigid before entering the hot end by stopping any potential heat creep that may affect the state of the filament before the melting point is reached and, therefore, ensures the proper extrusion process. The fan operates at full capacity constantly when the machine is turned on [13].

III. MAINTENANCE

A maintenance management system refers to a planned approach that involves extending the life span of equipment, minimizing downtime and reducing costs [14]. In FDM 3D printing, maintenance is an important factor since it ensures good performance of the machine and avoids any product defects. This type of maintenance includes reactive, preventive, predictive and reliability-centered maintenance, all of which are scheduled based on machine function and components [15].

The Bambu X1 Carbon printer has its maintenance schedule recorded within several years. This consists of daily, weekly, monthly and yearly maintenance schedules. Taking into account the fact that the printer runs 10 hours per day, six days a week, four weeks per month, all the scheduled maintenance times are converted into weekly units.

A. Daily maintenance

TABLE I
DAILY MAINTENANCE

S.No	Activity	Time (min)	Avg. Time (min)
1	Cleaning the build plate	2-3	2.5
2	Inspect and cleaning the nozzle condition	2-4	3
3	Checking the filament and change the filament	3-5	4
4	Cleaning the machine parts	1-2	1.5
5	Build platform height inspection	1-2	1.5
6	First layer calibration	1-2	1.5
	Total time		14

Total daily maintenance time in a week
= 14 x 6 = 84 minutes.

B. Weekly maintenance

TABLE III
WEEKLY MAINTENANCE

S.No	Activity	Time (min)	Avg. Time (min)
1	Clean and wash the build plate	3-5	4
2	Clear unwanted chips from the machine	3-4	3.5
3	Remove the nozzle and clean it properly	3-5	4
4	Inspection of feeding mechanism	4-5	4.5
5	Calibration of print	6-8	7
	Total time		23

Total weekly maintenance time in a week
= 23 minutes.

C. Monthly maintenance

TABLE IIIII
MONTHLY MAINTENANCE

S.No	Activity	Time (min)	Avg. Time (min)
1	Lubricating the gear, rail and rods	4-6	5
2	Adjust the belt tension	3-5	4
3	Dusting the fan and electronics parts	8-10	9
4	Clean the extruder	8-10	9
5	Check Frame, Screws, and Cables	5-7	6
6	Inspection of vibration and motor	6-8	7
7	Build plate level inspection and calibration	3-4	4
	Total time		44

Total monthly maintenance time in a week
= 44 / 4 = 11 minutes.

D. Yearly maintenance

TABLE IVV
YEARLY MAINTENANCE

S.No	Activity	Time (min)	Avg. Time (min)
1	Replacement of nozzle	3-4	3.5
2	Replacement of timing belt drive	10-15	12.5
3	Replacement of built plate if scratches & burned	5-10	7.5
4	Dusting the entire extrusion mechanism	15-20	17.5
5	Replacement bearing of all the drives	20-30	25
6	Deep clean motion system	20-30	25
7	Electrical inspection	2-25	22.5
8	Software update and installation	15-20	17.5
9	Stepper motor speed verification and motion inspection	20-30	25
	Total time		156

Total daily maintenance time in a week
= 156/ 52 = 3 minutes

IV. DOWN TIME

Down time is defined as any period when a machine or system is non-operational and unable to perform its intended function, resulting in a halt in production activities [16]. To minimize such interruptions and extend the overall lifespan of equipment, maintenance activities are systematically carried out. While the maintenance schedule is planned and predictable, all other causes of downtime such as failure time, administrative delays and external factors are uncertain and vary depending on the nature of the problem [17].

Down time = Failure time + Maintenance schedule + Administrative delay + External factors

Except for the maintenance planning, the rest of the causes of the downtime are unpredictable in nature. The amount of time spent on such interruptions will vary each time according to the particular case of the problem. In actual analysis, this time period is calculated based on the number of weeks, taking into account only the major problems affecting the machine's performance [18].

A. Failure time

TABLE VV
FAILURE TIME

S.No	Activity	Time (min)	Avg. Time (min)
1	Filament failure due to environmental condition	5-10	7.5
2	Improper input and temperature setting	10-15	12.5
3	Clogging issue in the nozzle due to temperature	5-10	7.5
4	Post processing cleaning defects	5-10	7.5
5	Improper heat dissipation	6-8	7
	Total time		42

B. Maintenance schedule

TABLE VIV
MAINTENANCE SCHEDULE

S.No	Activity	Time (min)	Avg. Time (min)
1	Daily maintenance	84	84
2	Weekly maintenance	23	23
3	Monthly maintenance	11	11
4	Yearly maintenance	3	3
	Total time		121

C. Administrative delay

TABLE VIIV
ADMINISTRATIVE DELAY

S.No	Activity	Time (min)	Avg. Time (min)
1	Electricity issue	2-4	3
2	Spart parts delay	2-4	3
3	Lack of scheduling and demand	5-10	7.5
4	Lack of experienced technicians	3-5	4
5	Inconsistent production method	5-10	7.5
	Total time		25

D. External factors

TABLE VIIIV
EXTERNAL FACTORS

S.No	Activity	Time (min)	Avg. Time (min)
1	Environmental temperature and pressure	2-4	3
2	Software issue	5-10	7.5
3	Network failure	1-2	1.5
	Total time		12

V. CONCLUSIONS

Machine availability is one of the critical performance measures, which reveals how efficiently the equipment has been used during the entire time it has been working. This factor includes both planned outages like scheduled maintenance and unplanned ones due to malfunctioning or outside factors.

By calculating availability, companies will be able to understand how efficiently their machinery works, what its productivity is throughout the time. In other words, this measure shows what percentage of time the machine has been effectively functioning in comparison with all the time available.

$$Availability = \frac{Actual\ operation\ time}{Planned\ production\ time}\ x\ 100$$

or

$$Availability = \frac{Up\ time}{Total\ time}\ x\ 100$$

Total time = 1 week = 6 days = 6 * 8 Hours
= 6 * 8 * 60 min
= 2880 min

Down time = Failure time + Maintenance schedule + Administrative delay + External factors
= 42 + 121 + 25 + 12
= 200 min

Up time = Total time – Down time
= 2880 – 90
= 2680 min

$$Availability = \frac{2790}{2880}\ x\ 100 = 93.05\ \%$$

Failure time, administrative delays, and external factors make their own contribution to downtime, contributing 1.45%, 0.86%, and 0.42%, respectively. Thus, all of them together provide for a 2.74% impact on the total amount of downtime. This fact has a direct negative influence on the efficiency of production processes, since it is important to decrease unpredictable downtimes and keep machines in proper condition.

The Bambu Lab X1 Carbon has the level of weekly machine availability at 93.05%, which means that it functions in a good condition. This availability proves the effective use of equipment within its operating schedule. The planned maintenance of the machine plays an essential role in providing the mentioned result, because not only does it increase the longevity of the machine, but it also allows decreasing its failure rate.

VI. FUTURE WORK

Machine availability could also be increased through efficient reduction of downtime due to various causes. Some of the important factors like failure time, administrative delays, and external factors need to be reduced to increase efficiency. The problem areas of failure activities have to be given special attention, since they constitute the major part of the unplanned downtime [19]. Advanced maintenance methods can play an important role in minimizing the problem of failure time. This includes prediction and preventive maintenance that anticipates problems and takes preventive actions, thus ensuring smooth functioning of the machines [20].

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