CONDITION MONITORING AND ANALYSIS OF ADDITIVE MANUFACTURING MACHINE

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DECLARATION

I declare that this project entitled "Condition Monitoring and Analysis of Additive Manufacturing Machine" is the result of my own word except as cited in the references

Signature: ……………………

Name: MUHAMMAD HAFIZ BIN MOHD FADZIL

Date:……………………………

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering

Signature :

Supervisor's name : PROF MADYA IR. DR. MOHD RIZAL BIN ALKAHARI

Date :

DEDICATION

To my beloved mother and father.

ABSTRACT

3D printing is one of technology that help manufacturer to make an object without sacrifice a lot of material and time. The 3D printer comes in variety of makes and models as well as closed source or open-source system. The open-source system 3D printer is the viable option for others as the component and the software for the printer is readily available via online. This open-source 3D printer also needs testing to make sure the 3D printer did not causing any fault during printing which is the unwanted scenario for any people. The purpose of this study was to do a condition-based monitoring for the additive manufacturing machine. The machine that been used for this monitoring was the large 3D printer unit. The condition-based monitoring for this large 3D printer was focused on the nozzle and the transmission of every axis. The condition-based monitoring of the head extruder was based on the previous researcher. The first researchers done the nozzle tip from the normal diameter to the smallest diameter available, and the filament diameter and the feed rate is fixed. It was found that as the nozzle diameter reduced, the clogging of the melted filament was very visible, this suggested that the nozzle diameter is very important to avoid clogging during printing. The other nozzle condition-based monitoring focused on the feed rate of the filament. The extruder head is fitted with single torque motor with three filaments attached. The experiment showed that as the feed rate increased, the clogging rate of the nozzle also increased. Both finding will help future researcher of the large 3D printer to calibrate the large 3D printer extruder for smooth and long printing period. The transmission of the axis also helped to show the behaviour of the 3D printer in different design. The finding suggests that intricate design like gear caused vibration to the axis and the structure of the 3D printer. This finding also helps the other researchers of the large 3D printer to determine a suitable speed for each axis and reduced the need for finishing process of the printed object.

ABSTRAK

Percetakan 3D adalah salah satu teknologi yang membantu pengeluar membuat objek tanpa membazirkan banyak bahan dan masa. Pencetak 3D boleh didapati dalam pelbagai jenis dan model serta sistem sumber tertutup atau sumber terbuka. Pencetak 3D sistem sumber terbuka adalah pilihan yang sesuai untuk orang ramai kerana komponen dan perisian untuk pencetak tersedia dalam talian. Pencetak 3D sumber terbuka ini memerlukan ujian untuk memastikan pencetak 3D tidak mengalami masalah semasa mencetak yang merupakan senario yang tidak diingini bagi mana-mana orang. Tujuan kajian ini adalah untuk melakukan pemantauan berdasarkan keadaan untuk mesin pembuatan aditif. Mesin yang digunakan untuk pemantauan ini adalah unit pencetak 3D yang besar. Pemantauan berdasarkan keadaan untuk pencetak 3D besar ini difokuskan pada muncung dan transmisi setiap paksi. Pemantauan berdasarkan keadaan kepala *extruder* berdasarkan penyelidik sebelumnya. Penyelidik pertama menukarkan hujung muncung dari diameter normal hingga diameter terkecil yang terdapat di pasaran, dan diameter filamen dan kadar suapan adalah tetap. Didapati bahawa apabila diameter muncung berkurang, penyumbatan filamen cair semakin kerap berlaku, ini menunjukkan bahawa diameter muncung sangat penting untuk mengelakkan penyumbatan semasa mencetak. Pemantauan berdasarkan keadaan muncung yang lain tertumpu pada kadar suapan filamen. Kepala extruder dilengkapi dengan motor tork tunggal dengan tiga filamen terpasang. Eksperimen menunjukkan bahawa ketika kadar suapan meningkat, kadar penyumbatan muncung juga meningkat. Kedua-dua penemuan ini akan membantu pengkaji pencetak 3D besar pada masa depan untuk menentukur extruder pencetak 3D yang besar untuk tempoh percetakan yang lancar dan panjang. Transmisi paksi juga membantu memperlihatkan tingkah laku pencetak 3D dalam reka bentuk yang berbeza. Hasil kajian menunjukkan bahawa reka bentuk yang rumit seperti gear menyebabkan getaran pada sumbu dan struktur pencetak 3D. Penemuan ini juga membantu penyelidik lain dari pencetak 3D besar untuk menentukan kelajuan yang sesuai untuk setiap paksi dan mengurangkan keperluan proses menyelesaikan objek yang dicetak.

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LIST OF ABBREVIATIONS

3D	-	Three Dimensional
SLA	-	Stereolithograpgy
DLP	-	Digital Light Photography
MCO	-	Movement Control Order
ABS	-	Acrylonitrile Butadiene Styrene
PLA	-	Polylactic Acid
PET	-	Polyethylene Terephthalate
CAD	-	Computer Aided Diagram
FFF	-	Fused Filament Fabrication

CHAPTER 1

INTRODUCTION

1.1 Background

The three-dimensional printing method or as known by the masses as 3D printing, is a computer-aided manufacturing (CAM) device that creates three – dimensional objects out of custom material by using the digital data retrieved from the computer, which act as an input to the 3D printer. 3D printers, in general, used a process called additive manufacturing to form the layer of a physical object by layer until the model was completed. Additive manufacturing is different from subtractive manufacturing, in which the machine is only reducing or removing the material from the raw material.

3-Dimensional Printer has seven classifications: material extrusion, Vat photopolymerisation, powder bed fusion, material jetting, binder jetting, sheet lamination, and direct energy deposition. Every single classification used different material to execute the material. The commonly available material is ABS plastic, polyamide (nylon), stereolithography materials (epoxy resins), silver, titanium, steel, wax, photopolymers, and polycarbonates.

Figure 1.1: Example of 3D printer. (Source: https://www.makerbot.com/3D-printers/replicator/)

	ABS	Flexible	PLA	HIPS	PETG	Nylon	Carbon Fiber Filled
Ultimate Strength	40 MPa	26 - 43 MPa	65 MPa	32 MPa	53 MPa	40 - 85 MPa	45 - 48 MPa
Stiffness	5 / 10	1 / 10	7.5 / 10	10 / 10	5 / 10	5 / 10	10 / 10
Durability	8 / 10	9 / 10	4 / 10	7 / 10	8 / 10	10 / 10	3 / 10
Maximum Service Temperature	98 °C	60 - 74 °C	52 °C	100 °C	73 °C	80 - 95 °C	52 °C
Coefficient of Thermal Expansion	90 µm/m-°C	157 µm/m-°C	68 µm/m-°C	80 µm/m-°C	60 µm/m-°C	95 µm/m-°C	57.5 µm/m-°C
Density	1.04 g/cm³	1.19 - 1.23 g/cm³	1.24 g/cm³	1.03 - 1.04 g/cm³	1.23 g/cm³	1.06 - 1.14 g/cm³	1.3 g/cm³
Price (per kg)	$10 - $40	$30 - $70	$10 - $40	$24 - $32	$20 - $60	$25 - $65	$30 - $80
Printability	8 / 10	6 / 10	9 / 10	6 / 10	9 / 10	8 / 10	8 / 10
Extruder Temperature	220 - 250 °C	225 - 245 °C	190 - 220 °C	230 - 245 °C	230 - 250 °C	220 - 270 °C	200 - 230 °C
Bed temperature	95 - 110 °C	45 - 60 °C	45 - 60 °C	100 - 115 °C	75 - 90 °C	70 - 90 °C	45 - 60 °C
Heated Bed	Required	Optional	Optional	Required	Required	Required	Optional

	ASA	Polycarbonate	Polypropylene	Metal Filled	Wood Filled	PVA
Ultimate Strength	55 MPa	72 MPa	32 MPa	20 - 30 MPa	46 MPa	78 MPa
Stiffness	5 / 10	6 / 10	4 / 10	10 / 10	8 / 10	3 / 10
Durability	10 / 10	10 / 10	9 / 10	4 / 10	3 / 10	7 / 10
Maximum Service Temperature	95 °C	121 °C	100 °C	52 °C	52 °C	75 °C
Coefficient of Thermal Expansion	98 µm/m-°C	69 µm/m-°C	150 µm/m-°C	33.75 µm/m-°C	30.5 µm/m-°C	85 µm/m-°C
Density	1.07 g/cm³	1.2 g/cm³	0.9 g/cm³	2 - 4 g/cm³	1.15 - 1.25 g/cm³	1.23 g/cm³
Price (per kg)	$38 - $40	$40 - $75	$60 - $120	$50 - $120	$25 - $55	$40 - $110
Printability	7 / 10	6 / 10	4 / 10	7 / 10	8 / 10	5 / 10
Extruder Temperature	235 - 255 °C	260 - 310 °C	220 - 250 °C	190 - 220 °C	190 - 220 °C	185 - 200 °C
Bed temperature	90 - 110 °C	80 - 120 °C	85 - 100 °C	45 - 60 °C	45 - 60 °C	45 - 60 °C
Heated Bed	Required	Required	Required	Optional	Optional	Required

Figure 1.2: Material of 3D Printer and its properties. (Source: https://www.simplify3D.com/support/materials-guide/properties-table/

Condition monitoring to the 3D printer is crucial to reduce the material waste, and material waste can happen because the printer did not produce a good layer in every pass causing the product to be out from the spec thus rejected. This situation on a large scale can elevate the cost of the production and reduce the company productivity.

1.2 Problem Statement

This additive manufacturing machine, especially the newly developed and bigger scale, needed proper condition monitoring and analysis to ensure the machine can perform better than the smaller machine. The MACH 3 system used for this machine is different from Arduino based of 3D printer. All the moving parts, especially the one with the extruder head, need to be monitored due this part is crucial for the success of any printing object. The movement system also needs to be analysed for any irregularities to avoid the material shifting from the layer. The machine also tested for the time of operation behaviour to see any problem during running for a certain amount of time.

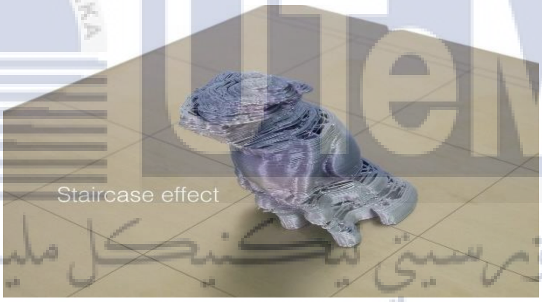

Figure 1.3: Staircase effect failure on the product. (Source: https://all3Dp.com/2/layer-shifting-3D-printing-tips-tricks-to-solve-it/)

With this monitoring and analysis, the proper correction or calibration to the machine. This modification will ensure the machine can print the project without any critical problem and smooth printing.

1.3 Objective

The main objectives for this project are:

1. To equip the temperature controller for the extruder of the filament.
2. To perform previous study for the additive manufacturing machine movement mechanisms.
3. To propose the condition-based monitoring requirements for the large 3D printer based on the previous study.

1.4 Scope

Scope for this project are:

1. Complete the necessary element for the 3D printer to print material like extruder and printing platform.
2. Monitor the additive manufacturing machine movement mechanisms.
3. Analysed the data from the monitoring of being retrieved from the machine.

1.5 Thesis Organisation

This report consists of five chapters. The introduction, which is chapter 1, is dedicated to the overview project, problem statements, objectives, and project scope. For the literature review, which is chapter 2, this chapter focused on scheming past research papers related to condition monitoring of a 3D printer machine. Chapter 3 is the methodology, which discusses the method that is involved in completing the analysis for the condition monitoring. The method that does be consider is to measure the vibration of the machine using the sensor. Chapter 4 is the results section. Discussion about the finding throughout the experiment and the result from the condition-based monitoring been made was discussed Chapter 5, which is the conclusion, discussed the overall of project and future recommendations for the next researchers to improve the machine performance and reduce the negative part of the machine.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The 3D printing process is an additive manufacturing process that constructs a product according to the input from the users in terms of G Code. This process generates less waste than the subtractive manufacturing process which produces product by reducing the material until dimension of the object achieved. The 3D printing process is used in the industry to make a prototype of the item with intricate design and high precision parameters. This process is widely used in aerospace, automotive, manufacturing, robotics, and education.

3D printing process generally starts with the material of choice for the object, and the material is heated either using a laser beam or heating element. The object is built layer by layer and is solidified as it is deposited and adhered to the previous layer.

2.2 Types of the additive manufacturing process.

As the technology progresses, additive manufacturing machine also face changes to accommodate the complexity of the design and the materials used. The additive manufacturing process that is being used in the industries are:

2.2.1 Material Extrusion

Material extrusion process, known as Fused Deposition Modelling (FDM) is the most common and popular type of 3D printing. The process started from the filament, which is come in a spool. The filament is deposited into the heated extruder. This extruder head can be either a single or dual setup nozzle. The nozzle will be travelled horizontal or vertical according to the coordinates set from the slicing software such as Slic3r and a layer will be created. The layer is bonded by either fan or room temperature cooling process after the filament exit to nozzle. The platform of the printer which is temperature-controlled, act as the support for the layer. This process in general taking some time as the geometry becomes more intricate and complex. Sometimes the adhesion in each layer have some issues due to the layer has gaping making it non-watertight.

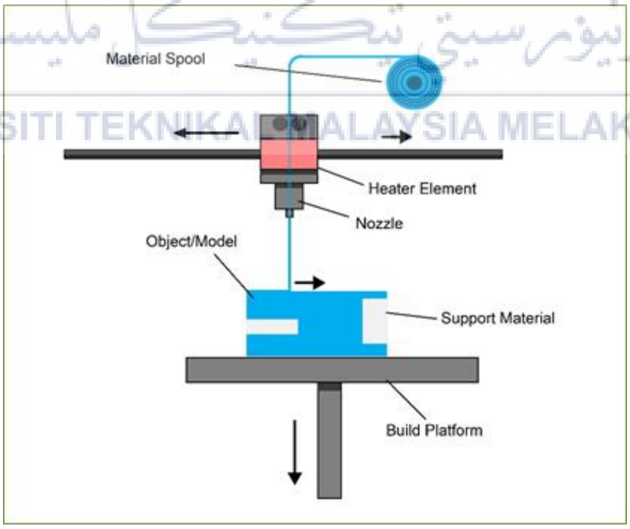

Figure 2.1: A representation of material extrusion machine. (Source: https://www.3dsourced.com/ .)

The filaments that are being used as 3D filaments is special types of plastics called thermoplastic. Thermoplastic is flexible yet pliable suitable for the 3D printer. The material used as the filament is ABS, PLA, PET, Nylon, and others. Every material has a different temperature to melt the filament. Filament also needs special care as not to expose the material to the open air as the filament absorbs moisture, making the filament brittle and cause the printing process need to be redone.

Figure 2.2: Improper storage of filament. (Source: https://3dprinting.com/.)

2.2.2 VAT photopolymerization

VAT photopolymerization is another process of 3D printing that using a light source that cures selective part of a photopolymer resin in a VAT. The most recognizable VAT photopolymerization in the industry are Stereolithography or SLA and Digital Light Processing or DLP. The advantage of using this method the surface of the product is very smooth, and the product came from this method have a better visual in the small details. The weakness for this method that the product that being made is brittle and not applicable to the mechanical application.

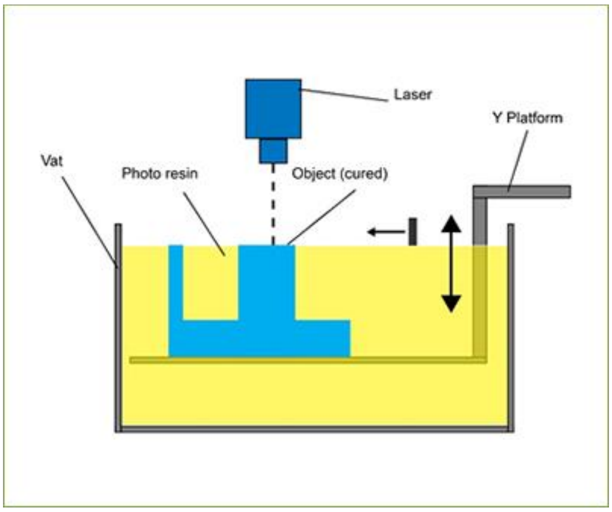

Figure 2.3: A representation of VAT photopolymerization machine. (Source: https://www.lboro.ac.uk/ .)

2.2.2.1 Stereolithography (SLA) technology

Stereolithography process or SLA terms being patented by the Chuck Hull back in 1984 under patent number US4375330A. the same patent for SLA also being filed by the French innovator Alain Le Méhauté, Olivier de Witte, and Jean Claude André to the French General Electric Company (Alcatel- Alsthom) and The Laser Consortium (CILAS) but their application was abandoned.

SLA is the process that is used for the project that need accuracy and precision. The process start with the plastic is heated until became a semi- liquid form. The printer then constructs the layers needed by ultraviolet laser directed by X and Y scanning mirror. Before the next layer started, a blade called "recoater" moves across the surface to give an even thin layer across the object. The print processes continue until the process finished. The platform will slowly descend in each layer. The finished product will have chemical bath to rinse the excess material and undergoes machining process when needed. This process widely used in automotive, medical, aerospace, entertainment, and household product.

2.2.2.2 Digital Light Processing (DLP) technology

Digital Light Processing DLP created by Larry Hornbeck back in 1987. This process has the same principle with SLA, with the difference in light sources. SLA uses ultraviolet light to solidify the photopolymer resin, DLP uses a traditional light source like arc lamp. With the light spreading wider than SLA printing process, the resin can harden faster thus contribute to the faster printing process.

2.2.3 Powder Bed Fusion

Powder Bed Fusion is a process when a thermal energy source pointed to the powder which induce fusion between the powder particles inside the designated printing area to provide with a solid product. The printer also came with mechanism which smooth the powder as the object being fabricated. The final item will be encased thus provide support to the object throughout the printing process.

The 3D printing technology that used the principle is Selective Laser Sintering (SLS). The SLS technology is developed and patented by Dr. Carl Deckard back in the mid-1980s. This printer relies on high power CO2 laser to fuse the powder particles together. The printing process started with the polymer powder is heated to a temperature just below the melting point of the polymer's melting point. The recoating blade or wiper deposits a thin layer of polymer powder on the building platform. The CO2 laser beam scan the powder layered surface and sintering the