Design and Development of Layer by Layer Deposition Mechanism for Selective Laser Melting Process

Author
HAMZA NAWAZ
Registration Number
00000274089

Supervisor
Dr. Mushtaq Khan

DESIGN AND MANUFACTURING DEPARTMENT
SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY
ISLAMABAD

July,2021

Design and Development of Layer by Layer Deposition Mechanism for Selective Laser Melting Process

Author

HAMZA NAWAZ

Registration Number

00000274089

A thesis submitted in partial fulfillment of the requirements for the degree of

MS Design & Manufacturing Engineering

Thesis Supervisor:

Dr. Mushtaq Khan

Thesis Supervisor's Signature: ____

DESIGN AND MANUFACTURING DEPARTMENT

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY,

ISLAMABAD

July, 2021

Thesis Acceptance Certificate

It is certified that the final copy of MS Thesis written by **Hamza Nawaz** (Registration No. **00000274089**) of Department of **Design and Manufacturing Engineering (SMME)** has been vetted by undersigned, found complete in all respects as per NUST statutes / regulations, is free from plagiarism, errors and mistakes and is accepted as a partial fulfilment for award of MS Degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in this dissertation.

Signature: ____________________

Date: ____________________

Dr. Mushtaq Khan (Supervisor)

Signature HOD: ____________________

Date: ____________________

Signature Principal: ____________________

Date: ______________

FORM TH-4

NATIONAL UNIVERSITY OF SCIENCES & TECHNOLOGY

MASTER THESIS WORK

We hereby recommend that the dissertation prepared under our supervision by: Hamza Nawaz having Registration # 00000274089 Titled: Design & Development of Layer by Layer Deposition Mechanism for Selective Laser Melting Process be accepted in partial fulfillment of the requirements for the award of MS degree.

Examination Committee Members

1. Name: Dr. Syed Hussain Imran   Signature:_______________
2. Name: Dr. Shamraiz Ahmad   Signature:_______________
3. Name: Dr. Ashfaq Khan   Signature:_______________

Supervisor's name: Dr. Mushtaq Khan   Signature:_______________

Date:___________________

___________   _______________________
Date   Head of Department

COUNTERSINGED

___________   _______________________
Date   Dean/Principal

Declaration

I certify that this research work titled "*Design and Development of Layer by Layer Deposition Mechanism for Selective Laser Melting Process"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student

Hamza Nawaz

2021-NUST-MS-DME(2018)

Plagiarism Certificate (Turnitin Report)

This thesis has been checked for Plagiarism. Turnitin report endorsed by Supervisor is attached.

Signature of Student

Hamza Nawaz

Registration No. 00000274089

Signature of Supervisor

Dr. Mushtaq Khan

Copyright Statement

Acknowledgements

I am thankful to my Creator Allah Subhana-Watala to have guided me throughout this work at every step and for every new thought which You setup in my mind to improve it. Indeed I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

I am profusely thankful to my beloved parents who raised me when I was not capable of walking and continued to support me throughout in every department of my life.

I would also like to express special thanks to my supervisor Dr Mushtaq Khan for his help throughout my thesis. I can safely say that I haven't learned any other engineering subject in such depth than the ones which he has taught.

I would also like to pay special thanks to Dr. Hussain Imran and Dr. Shamraiz Ahmad for their support and cooperation. Also, I would like to pay thanks to CNC Lab Operators Waseem and Akseer for their support and cooperation. Each time I got stuck in something, they came up with the solution. Without their help I would not have been able to complete my thesis. I appreciate their patience and guidance throughout the whole thesis.

Finally, I would like to express my gratitude to all the individuals who have rendered valuable assistance to my study.

Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment

Abstract

Selective Laser Melting is a process which comes under the field of additive manufacturing in which a high-power density laser is used to melt and fuse the metallic powders together. This project is about modifying a laser marking machine's design application from its two-dimensional marking application to a three-dimensional layer by layer additive manufacturing application. An experimental scale lab setup was developed which makes the 3D metallic parts from the powder. Process starts by the deposition of the layer of powder onto the surface which is followed by the melting of powder done by the laser machine on the specified area. Again, the powder layer will be deposited, and the powder will be melted. This process is repeated until the 3D part is built up completely. Product finish will be dependent upon the powder size being used and the size of the layer deposited. Layer deposition is controlled by the designed z-axis mechanism which is controlled with the help of stepper motors according to the required layer size.

Key Words

Additive Manufacturing, Selective Laser Melting(SLM), Layer Deposition Mechanism, Metallic 3D Printer

Table of Contents

Thesis Acceptance Certificate i
MASTER THESIS WORK ii
Declaration iii
Plagiarism Certificate (Turnitin Report) iv
Copyright Statement v
Acknowledgements vi
Abstract viii
Key Words viii
Table of Contents ix
List of Figures xii
List of Tables xiii
Abbreviations xiii
Chapter 1: Introduction 1
1.1 Introduction to Additive Manufacturing 1
1.1.1 VAT Photopolymerisation 1
1.1.2 Material Jetting 1
1.1.3 Binder Jetting 2
1.1.4 Material Extrusion 2
1.1.5 Sheet Lamination 2
1.1.6 Direct Energy Deposition (DED) 3
1.1.7 Powder Bed Fusion 3
1.2 Objectives 4
1.3 Breakdown of Thesis Report 4

Chapter 2: Literature Review **5**

2.1 Introduction 5

2.2 Steps Involved in Additive Manufacturing 6

2.2.1 Computer Aided Design 6

2.2.2 Model to STL Conversion 7

2.2.3 File Transfer to Machine 7

2.2.4 Machine Settings 7

2.2.5 Part Buildup 7

2.2.6 Removal 7

2.2.7 Post Processing 7

2.2.8 Application 8

2.3 Benefits of Additive Manufacturing 8

2.4 Powder Based Systems in Additive Manufacturing 9

2.4.1 Introduction to Powder Bed Fusion 9

2.5 Process Parameters 12

2.6 Applied Energy Correlations & Scan Patterns 13

2.7 Challenges in Powder Handling 15

2.8 Laser 17

2.8.1 Optical Properties of Laser 18

2.8.2 Laser Power 20

2.8.3 Laser Pulse Characteristics 20

2.8.4 Continuous-Wave Laser Emission 21

2.8.5 Lasers Pulsed by Power Sources 21

2.8.6 Fiber Lasers 21

Chapter 3: Design and Methodology 25
3.1 Complete Model & Actual Product 26
3.2 Chamber 28
3.3 Hopper Arm Assembly 29
3.4 Hopper 30
3.5 Arm 31
3.6 Shaft 32
3.7 Z Axis Mechanism 33
3.8 Z-Axis Mechanism Components 34
3.8.1 Cylinder 34
3.8.2 Piston 35
3.8.3 Lead Screw 36
3.8.4 Brass Nut 37
3.8.5 Guide Rods 38
3.8.6 Moving Plate 39
3.8.7 Top Plate 40
3.8.8 Base Plate 40
3.8.9 Side Plate 41
Chapter 4: Conclusion and Future Work Recommendations 42
4.1 Conclusion 42
4.2 Recommendations for the Future Work 42
References 43

List of Figures

Figure 1: Balling Phenomenon 15
Figure 2: Basics of Fiber Laser 22
Figure 3 : Complete CAD Model (mm) 26
Figure 4 : Complete Actual Product 27
Figure 5: Chamber Top View CAD Model (mm) 28
Figure 6: Fabricated Chamber Top View 28
Figure 7: Hopper Arm Assembly CAD Model (mm) 29
Figure 8: Fabricated Hopper Arm Assembly 29
Figure 9: Hopper arm side view 30
Figure 10: Hopper top view 31
Figure 11: O Ring on Hopper 31
Figure 12: Arm CAD Model Top View (mm) 32
Figure 13: Fabricated Arm 32
Figure 14: Shaft CAD Model (mm) 33
Figure 15: Axis Mechanism CAD Model Front View (mm) 33
Figure 16: Fabricated z-axis mechanism 34
Figure 17: Cylinder Top View CAD Model(mm) 34
Figure 18: Cylinder Front View CAD Model(mm) 35
Figure 19: Fabricated Cylinder 35
Figure 20: Piston Front View CAD Model(mm) 36
Figure 21: Piston Bottom View CAD Model(mm) 36
Figure 22: Lead Screw 37
Figure 23: Brass Nut Side View CAD Model(mm) 37
Figure 24: Brass Nut top view CAD Model(mm) 38
Figure 25: Guide Rod CAD Model(mm) 38
Figure 26: Fabricated Guide Rods 39
Figure 27: Moving Plate CAD Model(mm) 39
Figure 28: Z-axis mechanism top plate CAD Model (mm) 40
Figure 29: Z-axis mechanism Base Plate CAD Model(mm) 41
Figure 30: Side Plate CAD Model(mm) 41

List of Tables

Table 1 Laser Machine Parameters 18

Abbreviations

AM	Additive Manufacturing
PBF	Powder Bed Fusion
SLM	Selective Laser Melting
CAD	Computer Aided Design
ABS	Acrylonitrile butadiene styrene
UAM	Ultrasonic Additive Manufacturing
LOM	Laminated Object Manufacturing
STL	Standard Tessellation Language
OEM	Original Equipment Manufacturer

Chapter 1: Introduction

1.1 Introduction to Additive Manufacturing

Additive Manufacturing or Rapid Prototyping is gaining traction these days due to high and precise performance demands with multiple functionalities and complexities in the computer aided designs. Products of Additive Manufacturing are of near net shaped dimensions which are given in CAD models. There is very minimum or no post processing requirement in the products. With these kind of advantages Additive Manufacturing processes are being used in applications covering aerospace, defense, oil and gas, medical and various other sectors and there is no need of tooling in this type of manufacturing.

There are many types of processes available for the parts fabrication in Additive Manufacturing. The processes are as follows.

1.1.1 VAT Photopolymerisation

VAT polymerization uses photopolymer resin from which the part is created by layer deposition mechanism. Ultraviolet light is used to cure the resin based on the given CAD model and platforms moves accordingly.

This process products are of high-level accuracy but is relatively expensive, it has very long post processing time and photo resins type materials have very limited use/applications.

1.1.2 Material Jetting

This process is same in nature to 2-dimensional ink jet printers where material is jetted onto the build platform with either of the Drop or continuous on Demand Approach. Material is deposited on the build platform using layer deposition mechanism where it solidifies and is then cured by ultraviolet light.

This process products are of high accuracy but require support material and is generally limited to waxes and polymers in terms of material.

1.1.3 Binder Jetting

This process makes use of two materials one is powder form and the other one is binder which is for the adhesion between powder layers. Material is in powder form and binder is in liquid form usually. The binder is deposited by the print head and material powder platform is deposited over the platform which is lowered according to the required layer height.

Binder jetting method products have the advantage of using wide variety of materials like polymers, ceramics and metals. Also the two-material method allows different combination of materials having different mechanical properties. But this process is not always recommended for the structural parts because of the material of the binder. And significant time delay can happen to overall process during additional post processing.

1.1.4 Material Extrusion

Material is drawn through the heated nozzles and layers are deposited through the assigned mechanism. It is also known as fused deposition modelling. It is similar to other deposition mechanisms with additional controls of material pressure and temperature in the nozzle head.

It is a inexpensive process in which Acrylonitrile butadiene styrene (ABS) plastic is used which is easily accessible and has good structural properties. Its nozzle radius determines the final product quality and constant pressure is needed to increase the quality of final product.

1.1.5 Sheet Lamination

This process has further two types which are:

1. Ultrasonic Additive Manufacturing (UAM)
2. Laminated Object Manufacturing (LOM)

In Ultrasonic Additive Manufacturing ultrasonic welding is used to join metal sheets. It requires additional post processing which includes removal of unbound metal and CNC machining.

LOM uses layer deposition mechanism similar to other processes and the only difference is in material which is paper and binder. This process is used for visual modelling and is not suitable for structural use.

Its advantages include the ease of material handling, low cost but model integrity is dependent on the type of adhesive used. Disadvantages include the finish quality which is dependent on the plastic or paper material.

1.1.6 Direct Energy Deposition (DED)

DED is also known as 3D Laser Cladding, Direct Metal Deposition and it consists of nozzle attached to a multi axis arm which deposits melted material on the specified area. Upon deposition, material is melted by the heat source which is usually the Laser Beam or Plasma Arc.It is mostly used in repairing high quality functional parts.

1.1.7 Powder Bed Fusion

Powder bed Fusion also works on the principle of addition of layers sequentially. It starts with the making of CAD model which is then sliced in several 2D layers by a software. Each layer is bonded sequence wise. A heat source is used to melt the powder on a single layer which is then moved down by the help of stepper motors, the stepping down of platform is in accordance with the layer thickness which basically determines the finish of the product. Next layer is deposited on the prescribed area which is then melted according to the input given to the heat source. And the sequence continues similarly. The layer thickness depends on the type and size of material being used and the processing conditions.

This project is under the powder bed fusion process in which layer deposition mechanism was to be designed according to the laser machine. Layer deposition mechanism involves box containing the hopper which will deposit the powder on a specified area and arm connected to the stepper motor which controls the motion of the hopper. Under the box is a Z axis motion mechanism of piston which determines the layer thickness of the powder being deposited.

1.2 Objectives

Main aim of this research was to design and develop the layer deposition mechanism for the Selective Laser Melting Process. Following objectives of research are covered in this thesis:

- To study the procedures already present for layer deposition.
- To review the literature available on the designs mechanisms and Heat sources being used.
- To design the Hopper mechanism for the deposition of powder.
- To design the Z axis platform which will be responsible for layer thickness.
- To determine and recommend future work.

1.3 Breakdown of Thesis Report

This thesis report consists of Four Chapters. Chapter 1 includes General introduction of types of Additive Manufacturing processes and which process is used in this project and Objectives of the project. Chapter 2 includes the literature which was reviewed during the research. Chapter 3 consists of the Design and Actual Development of the project. Chapter 4 concludes the research and includes the future work recommendations.

Chapter 2: Literature Review

2.1 Introduction

Additive manufacturing which is also known by the name of 3D printing is a type of manufacturing process in which parts are made by joining materials from the provided 3D model data and are joined by layer deposition mechanism. It is also known as tool less manufacturing approach because it almost gives the finished products and is flexible, reduces energy and reduces the time to market. Rapid Tooling, Rapid Prototyping, direct part production and repair of some parts of metal, plastic. Recent trend has shifted the additive manufacturing processes from rapid prototyping to direct metal parts production.

Two parameters which are most important in additive manufacturing are:

1. Energy Source.
2. Raw Material being used to form the product.

For energy source Laser Beams are used and metallic powders/wires are used as Raw Materials. Additive Manufacturing machines reads only STL file format so CAD model of the part is converted in STL file format. The model is then sliced in 2D layers. The process builds the layers sequentially to build a complete product. Layer thickness depends on the type of material being used and many other factors like shape, size, compaction etc. of the powder particles and the additive manufacturing process used to fabricate the parts.

Metallic Additive Manufacturing can be classified in two broad groups which are as follows:

1. Powder Bed Fusion.
2. Direct Energy Deposition.

Further classification of these technologies can be done based on the energy source being used. In Powder bed Fusion the energy source selectively fuses the regions of powder bed. Selective Laser Sintering, Selective Laser Melting and Electron beam melting are main processes of Powder Bed Fusion based techniques.

In Direct Energy Deposition thermal energy is used to bond the materials by melting them as they are being laid down on the surface. Electron beam Free Form Fabrication, Direct Energy Deposition and Laser Engineered Net Shaping are the main techniques known under Direct Energy Deposition Based techniques.

This process needs to be carried out in inert atmosphere to provide shielding of molten metal. Powder is spread across the surface and energy source is used to scan each layer and selectively melt the material to fuse them together as given in the sliced model 2D shape. Same process is repeated powder layer is deposited, scanned (melted to fuse the powder) and next layer is deposited. The z axis mechanism determines the layer thickness. The end product is in powder and powder is removed to see the finished product. Complex geometries with good surface finish can be made in Powder Bed Fusion Process but part build time is more in powder bed fusion technique. Some components require supports for their overhanging surfaces to prevent distortion and dislocation between layers. Once generated supports can be easily removed via mechanical treatment while post processing. For more better finish after supports removal some parts may undergo processes like machining, heat treatment, shot peening or surface polishing. For better part density some parts may require Hot Isostatic Pressing to ensure required part density.

2.2 Steps Involved in Additive Manufacturing

Additive Manufacturing includes many steps that start from the Computer Aided Design and results in a physical product. Every Additive manufacturing process involves these steps but manufacturing method can vary. The number of stages through which a product goes through may vary depending on the complexity of the product. Some of the generic processes are mentioned below:

1. Computer Aided Design
2. Model to Standard Tessellation Language Conversion
3. File Transfer to Machine
4. Machine Settings
5. Part Build Up
6. Removal
7. Post Processing
8. Application

2.2.1 Computer Aided Design

Initially the design is made on a software which describes the complete physical attributes of the product. Softwares are of different categories depending on the type of detailing required. Sometimes a product model is created from a physical product using the optical scanning technology and further processing is done to finalize the model.

2.2.2 Model to STL Conversion

Additive Manufacturing machines accept the file format of STL. STL means Standard Tessellation Language which can be generated from any CAD software. It is in machine readable format so all the model slicing information is stored in it.

2.2.3 File Transfer to Machine

The file is transferred to the machine through different means. Some machines have the facility of connecting wire. Some machines have the option of USB. So file is transferred to machine via any means given by the manufacturer.

2.2.4 Machine Settings

Machine should be properly calibrated according the manual given by OEM (Original Equipment Manufacturer). Some Additive Manufacturing processes require support structure to be built by the machine so that the model layers are no distorted or broken. That support structure is either manually drawn in the machine model or on auto option machines builds up the necessary supports itself.

2.2.5 Part Buildup

This process is automated so generally there is no need of supervision required. Only monitoring is done to ensure that there are no software glitches or machine does not run out of material or pawer etc.

2.2.6 Removal

After completing the process of fabrication product is detached or removed from the build platform. This process may vary from machine to machine depending on the type of manufacturing process and the type of material being used.

2.2.7 Post Processing

Once removed some parts require additional cleaning or tooling. Supports are removed in this stage if there is any.

2.2.8 Application

Mostly the parts at this stage are finished usable products. But they may require further treatment before they are put to use. For example, for a good surface finish and texture they may require priming and painting. They may also need to be integrated with other mechanical or electrical components to create a finished product.

Materials, in addition to machines, may need cautious management. Some of the raw ingredients used in additive manufacturing processes have a short shelf life and may need to be stored in special conditions to avoid undesired chemical reactions. Moisture, excessive light, and other pollutants should be avoided as well. The majority of the procedures employ materials that may be reused for several builds. However, repeated reuse may deteriorate the characteristics, thus a method for ensuring constant material quality via recycling should be followed.

2.3 Benefits of Additive Manufacturing

This technique has been described as changing product development and production by many individuals. AM is now widely regarded as one of the fast developing technologies that are altering the way we develop goods and launch new ventures.

Fast nature of this technology means that the time it takes to produce pieces isn't the only benefit in terms of speed. The use of computers throughout the product development process aids in the speeding up of the entire process. Now the machine interface concern is very less because of the modern softwares in which files are built automatically by selecting the required CAD model and then converting it into our required file format. The seamlessness may also be noticed in the reduced number of phases in the process.

Building a product in additive manufacturing is usually a single stage process regardless of the intricacy of the pieces to be manufactured. The majority of alternative production methods would need several, iterative steps. The number of phases in a design may drastically rise as more features are added. One of the benefits of these machines is also that it calculates the manufacturing time before hand so even a little modification in the part design might result in a substantial increase in the amount of time it takes to construct using traditional methods.

Similarly, AM may dramatically minimize the number of procedures and resources required. If a competent artisan is asked to create a prototype from CAD designs, he may discover that the item must be manufactured in several phases. This might be due to the fact that he has to use a range of building processes, from hand carving to moulding and shaping techniques to

CNC machining. Carving by hand is time-consuming, complex, and prone to mistakes. Molding is a messy process that necessitates the creation of one or more moulds. CNC machining necessitates meticulous planning and a sequential process, which may include the creation of fixtures before the component can be manufactured. Many of these multistage procedures may be eliminated or simplified using AM. With the inclusion of several supporting technologies such as silicone-rubber moulding, drills, polishers, grinders, and so on, a wide range of diverse components with various characteristics may be manufactured.

2.4 Powder Based Systems in Additive Manufacturing

One of the benefits as compared to other processes in powder based systems is that no supports are needed as the powder is melted layer by layer and the remaining powder acts as a kind of support. Except some of the cases with metals. Because of this no support system in powder based Additive Manufacturing these machines are not very complex. Colored products can be made easily by using a colored binder material in binder jetting. Sometimes it takes longer to code for the colored products as the Standard Tessellation Language does not includes color in standard style. Every product that has been subjected to some amount of heat contains a considerable amount of wasted powder in powder bed fusion operations. The powder properties may vary because of its temperature history. So it is important to keep that in mind while designing such systems. Powder feed chambers are of different styles. There are mainly two types of feed chambers. One type is in which feed chamber is on one side of the build platform so problem may arise in its density due to powder weight as it causes the powder in the bottom to be compacted. So material deposition layers might vary and in result affect the product properties. This project however uses the second type of feed chamber in which a hopper is used to spread powder layer and is not on that much large scale where the powder weight might impact its density in different layers. Instead an O ring is also used on the bottom of hopper to spread layers evenly across the build platform.

2.4.1 Introduction to Powder Bed Fusion

Powder Bed Fusion (PBF) process is an old process under the category of Additive Manufacturing. Commercially the first of the processes of powder bed fusion was selective laser sintering. All powder bed fusion processes have same basic approach with some necessary modifications according to the material and the products. All powder bed fusion processes include a thermal source or heating element for the particle fusion of powder, controlled atmosphere, controlled bed layer thickness and powder deposition mechanisms. Laser is one of the most common sources of thermal energy in powder bed fusion processes. Machines used for these processes are Laser Sintering machines. Metal and polymer sintering/melting machines are different from each other. Many of the early Laser Sintering processes were developed for the plastics prototypes and Later on this approach was experimented on the ceramic and metallic powder. One of the methods of powder deposition mechanism is powder leveling roller which is counter rotating, and the product is made inside a closed chamber filled with any inert gas argon or usually nitrogen which is used to prevent oxidation and hence the decay of powder. Temperature is a very important component and powder is preheated to a certain temperature before the exposure to the heat source. Powder spreading the layers is also preheated and the chamber temperature is also maintained using infrared heaters above the platform. This heating of the chamber and powder bed is done so that the thermal energy required to melt the powder will be less used and lower laser power will also do the work. It also prevents degradation of the part due to uneven contraction and expansion. Once the powder layer is laid a Laser is used as a heat source to join the powder material together and is controlled by using galvanometers. The laser is directed on the specific area as specified in its software and the remaining powder acts as the support to main product. The process of layer deposition and laser is repeated till the build up of part. The temperature of the chamber as well as the powder bed needs to be near ambient temperature so that the powder does not degrade in the presence of Oxygen. Final step is to remove the part, clean it and further process it if needed.

2.4.1.1 Selective Laser Melting (SLM)

Selective Laser Melting comes under the category of Powder Bed Fusion processes in which Laser is used to melt and join the metallic powder layers. SLM is also known as DMLM which stands for Direct Metal Laser Melting and LPBF which stands for Laser Powder Bed Fusion. It is based on the application of thin metallic powder layers to a platform which are then melted by the heat source which in this case in Laser. The powder layer is selectively melted and then resolidified. The build platform is lowered according to layer thickness and then re coater deposits another layer. Carefully built scanner optics can channel and refocus laser beams through a pattern drawn on the computer software. As a consequence, the powder is melted according to the pattern given in the CAD model forming the melted/fused layers and thus making a 3D part (Rashed et al., 2016). Copper, aluminum, chromium, titanium, stainless steel, cobalt chromium, super alloys and tool steel, are just a few of the metal powders that have been used in the SLM process. Although most leftover powders may be reused for other additive manufacturing processes, the requirement of fulfilling the volume in the Selective Laser Melting working chamber is cumbersome and unproductive, particularly when big products are created. Loss of material occur, when powders are oxidized or contaminated during the melting process consequently becoming non-recyclable. The SLM technique has several limitations which include some arbitrary shapes or forms.

Producing overhanging horizontal or geometries struts is presently difficult because of the poor heat transfer through conduction in the powder bed directly below the newly build exposed powders layers. (Rashed et al., 2016).

Most of the SLM systems for commercially use powders with diameter ranging between 20 to 50 microns and an average layer thickness of 20–100 microns. For high resolution of the product of SLM some of the parameters like Powder size, Laser Beam and Layer thickness are the three primary variables that have been studied in order to scale down the traditional SLM for higher feature resolution. In micro SLM systems both continuous and pulsed type lasers are being used.

For micro SLM systems, the spot size of the laser of 20 to 30 microns has been used, and the associated feature resolution might be lowered to the same level as the spot size. (Nagarajan et al., 2019).

Micro SLM has a number of advantages over direct writing methods that are more often employed for micro applications, including a simpler process setup, quicker cycle time, and more material variety. (Nagarajan et al., 2019). Micro SLM is increasingly being used in the manufacture of precision components and lattice structures in a variety of disciplines, including microfluidic devices, MEMS, dentistry, and so on. The strut build angle determines the characteristics of metallic micro lattice, and micro SLM has so far been unable to build horizontal struts. Even though it is rather costly, it has shown to be a speedier procedure for avoiding material waste. Current micro selective laser melting systems have achieved the part density of more than 99 percent with a minimum surface roughness of 1 micron and a minimum feature resolution of 15 microns.

2.5 Process Parameters

Process parameters in PBF can be divided into four categories:

1. Laser-related parameters (laser power, pulse duration, pulse frequency)
2. Scan-related parameters (scan pattern, scan speed, and scan spacing)
3. Powder-related parameters (powder bed density, layer thickness, material properties (particle shape, distribution, size).
4. Tunable parameters (those parameters that can be changed)

All of these variables are interconnected with each other. Laser power needs to be changed for every other material because of absorptivity of materials which will be different for every material because of material's size, density, powder shape, powder compaction, materials melting point, powder bed temperature.

A typical powder bed fusion machine consists of 2 axes (X&Y). Scanning is done in 2 modes which are fill mode and contour mode similar to stereolithography. Contour feature is used to scan the outline of any layer of part cross section. Around the perimeter, this is usually done for accuracy and surface polish purposes.

For a laser based scanning one of the axis is moved forward and backwards continuously over the part and the other one scans the width increasing stepwise as per required accuracy. Basic raster pattern is used in case of polymers scanning. Sometimes the fill area seems like strips or squares so randomized scanning is used to ensure that the residual stresses created by scanning do not have a preferred orientation.

Residual stresses on a part depend on melt pool features as well as the scanning approach and pattern of scan. By changing the location of the part even within a machine the pathways of laser might change. The part may distort more in one region than another as a result of these laser path modifications. As a result, due to differences in how the scan method is implemented in different areas, a part may build correctly in one location but not in another in the same machine.

Powder shape, size, distribution, powder bed density, thermal conductivity, and powder spreading are all influenced by powder shape, size, and distribution. Because of the larger surface area coarser particles absorb laser energy more efficiently than finer particles. Laser power, scan spacing, scan speed, powder bed temperature needs to be adjusted to have better results in surface finish, dimensional accuracy, build rate and the melt pool size. By ensuring that the powder bed temperature is same reproducible results might be obtained.

With high laser power and high bed temperature dense parts can be obtained but that leads to poor recyclability, cleaning and poor growth issues. Whereas the low laser power and low bed temperature leads to high dimensional accuracy of the product but density of parts is less and is on the risk of layer delamination. Keeping the powder bed temperature low and laser power high the shrinkage tends to occur and part curling results from the residual stresses. Scan Speed, Powder bed temperature, spot size and laser power combined determine the energy that needs to be given to the powder layers to fuse together. More time on the powder by laser means deeper fusion and larger melt area of the pool. Thickness of the layer typically ranges from 20-150 microns. For better fusion lower scan speeds and lower laser strengths are better. Melt pool is dependent on the powder bed temperature ,scan speed ,spot size and laser power settings.

Powder bed density which is dependent on the powder shape, distribution, spreading process and powder size has a significant impact on component quality. Powder bed densities for most commercially available powders are normally between 50 and 60%, however irregular ceramic powders can be as low as 30%. Better mechanical properties of the product are also dependent on the powder compaction and the thermal conductivity of the bed.

Continuous-wave (CW) lasers are used in the majority of marketed PBF procedures. However, research revealed number of advantage of pulsed laser as compared to continuous one. These days machines with dual system both pulsed and continuous is being used. Pulsed laser is used because it prevents the balling effect and creates a flat molten zone on the surface.

The amount of energy required to fuse powder into a usable component is determined by scanning speed, spot size, powder bed temperature and laser power. The fusion depth will increase and diameter of the melt pool widens with the longer the laser stay in a specific spot.

2.6 Applied Energy Correlations & Scan Patterns

PBF methods are applicable to a wide range of physics, thermodynamics, and heat transport models. Powder bed fusion processes can benefit from solidification. A simplified model for estimating Input energy characteristics is to assume that the entire energy applied gets absorbed by the powder bed as laser passes by and it also determines the melt pools creation and geometry. Absorbed energy density determines the actual size and depth of the melt pool.

For connecting density and strength of the product to the process parameters a simple energy density equation is used.

The applied energy density E_A (also known as the Andrews number) may be calculated using their simple approach.

$$E_A = \frac{P}{U \times SP}$$

Where,

P stands for laser power

U stands for scan velocity

SP stands for scan spacing between parallel scan lines.

This relation shows that the laser input energy is dependent on three main factors which are laser scan velocity, scan spacing and laser power. Applied input energy is directly proportional to the laser power and inversely proportional to scan spacing and velocity. Scanning spacing for pLS is typically 100 µm whereas laser spot sizes are typically 300 µm. As a result, every spot is generally scanned many times by the laser beam. Although above mentioned equation does not take into account powder absorption, powder bed temperature, heat of fusion or laser spot size, it is the most straightforward mathematical technique for optimizing machine performance for a given material.

For PBF of polymer materials build speed optimization by applied energy is pretty successful. When molten metal is on the powder bed surface a process known as balling frequently happens. The molten metal will form a ball when surface tension forces overcome a combination of dynamic fluid, gravitational, and adhesion forces. Because the surface energy driving force for metal powders to restrict their surface area to volume ratio (which is minimized as a sphere) is considerably larger than for polymers, this phenomenon is insignificant for polymers but important in metals.

The following diagram illustrates the balling propensity for various power, P, and scan speed, U, combinations.

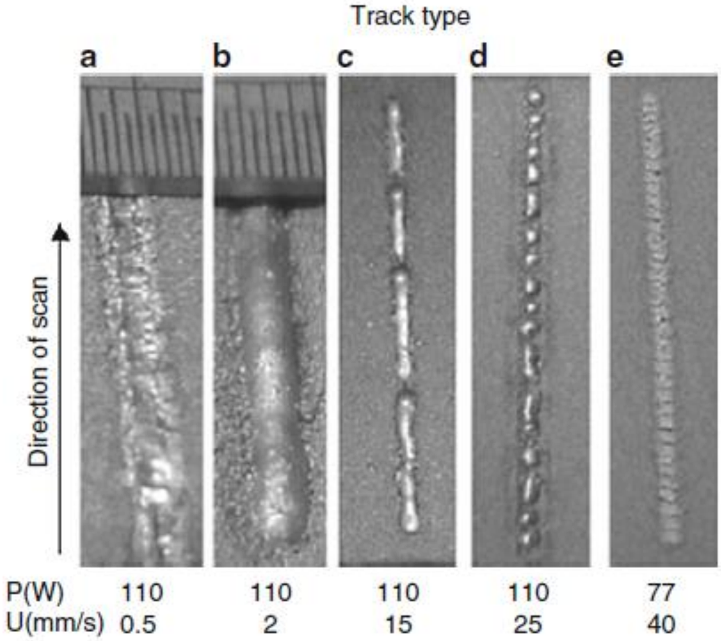

Figure 1 : Balling Phenomenon

(© Professional Engineering Publishing, reproduced from T H C Childs, C Hauser, and M Badrossamay, Proceedings of the Institution of
Mechanical Engineers, Part B: Journal of Engineering Manufacture 219 (4), 2005)

2.7 Challenges in Powder Handling

Powder delivery systems for PBF operations have been developed in a variety of ways. Lack of a single powder distribution method extends beyond merely eliminating proprietary counter-rotating roller embodiments.

At least four features must be present in every powder delivery method for PBF.

1. Powder carrier or powder reservoir should be large enough to provide complete required powder for the product.
2. Powder other than depositing a layer should not be wasted by depositing extra powder.
3. Powder should be smooth and thin coating.
4. Excessive shear pressures from the powder spreading must not disrupt the previously treated layers.

Furthermore, Powder delivery system should be capable of dealing with these universal powder feeding features.

1. Interparticle friction and electrostatic forces rise as particle size decreases.

As a result, the powder's flowability may be compromised. For example, compare the flow properties of a spoonful of granulated sugar with a spoonful of fine flour to demonstrate this lack of flowability. The sugar will flow out of the spoon at a shallow angle, but the flour will stay in the spoon until it is tipped at a big angle, at which point it will fall out in a huge clump unless some disturbance (vibration, tapping, etc.) forces it to come out a tiny quantity at a time. As a result, any successful powder delivery system must make the powder flowable in order to achieve effective distribution.

2. Certain powders must be handled in an inert environment, and powder handling must not result in the formation of sparks. As a particle's surface area to volume ratio grows, its surface energy rises, making it more reactive. This indicates that in the presence of oxygen, the powder turns explosive, or that it will ignite if a spark is present.

3. Powder distribution system should be designed to reduce the amount of airborne particles produced because when tiny particles are handled, they tend to become airborne and float in a cloud. Airborne particles collect on surrounding surfaces in PBF devices, clouding lenses, reducing sensor sensitivity, deflecting laser beams, and damaging moving components. Furthermore, airborne particles have a larger effective surface area than packed powders, making them more likely to explode or burn.

4. Small powder particle provide a better surface finish, more precision, and thinner layers. But small powder particles are very difficult to handle so powder delivery system should be designed such that above mentioned issues of small particle size should be taken care of.

2.8 Laser

A Laser as an energy source is one of the most popular powder bed fusion processes e.g. Selective Laser Melting, Selective Laser Sintering or Direct Metal Sintering. Laser stands for Light Amplification by Stimulated Emission of Radiation. In lasers lights get emitted through a process of optical amplification that is based on stimulated emission of electromagnetic radiations. Laser emits light which coherent and that is the main difference between laser and other lights. This spatial coherence is the reason for its applications in laser cutting, lithography due to its ability to be focused in tight spots. Spatial coherence means the output of laser is narrow beam which is diffraction limited.

Laser technology was used in many of the first AM systems. The reason behind it is that lasers' ability to generate highly collimated energy beam which has high intensity as well as it can be moved quickly and precisely using directional mirrors. Because AM involves selective solidification or joining of the material in each layer, lasers are reasonable option for application, provision of energy is consistent with the material mechanisms of transformation. In relation to lasers two types of processing related to lasers is used in Additive Manufacturing One is Curing and the other one is heating. Photopolymer resins require a specific frequency of the laser energy which will solidify or cure that resin. The range in which photopolymer resins solidify generally falls in range of ultraviolet but others may be used on occasion. During heating the laser is required to provide enough thermal energy so that it can cut through a layer or melt a layer of powder and fuses the sheets of metals. For powder processes the powder needs to be melted in controlled manner such that the metal in molten state hardens when the laser is withdrawn with creating too much built of heat. In cutting of material through laser early technologies utilized tube lasers in order to deliver that much energy but recent trend is towards the solid state technology due to superior reliability, efficiency and life.

The Laser used for this project is a Yb Laser and the software used for the interface of machine is EZCAD 2.0 version. 2D section can be drawn on the software or can be imported. Machine is equipped with the function of both continuous and pulse mode. It is equipped with the ability to control frequency, speed, power. The frequency range is from 20KHz to 100 KHz whereas the maximum marking speed goes to 9000 millimeters per second and its power can be controlled by putting required percentage. Summary of the laser parameters is given in the table below.

MODEL	KT LF Desktop
Laser Type	Fiber Laser
Power Output	20 watts
Marking Area	175 mm x 175mm
Wavelength	1064 ±10 nm
Cooling	Air Cooled
Marking Speed	Less than or Equals to 9000 mm/s
Frequency	20 KHz to 100 KHz
Marking Depth	Less than or Equals to 0.1 mm
Operation Temperature	10-35°C
System Compatible File Format	Windows Xp or 7 32bit/PLT

Table 1 : Laser Machine Parameters

2.8.1 Optical Properties of Laser

Applications of Lasers are limitless due to its optical properties ranging from sheet cutting to sensitive and accurate measurements for research.

Some of the significant optical properties of Laser are as follows:

1. Beam Energy and Power
2. Pulse Duration (Variation of beam power with time)
3. Wavelength
4. Coherence
5. Beam Divergence and size
6. Efficiency

1. Energy, Intensity & Beam Power

For laser beams, power is a critical number that can be quantified in three various different ways, each of which yields different results.

Power is the rate at which energy is delivered by a laser beam. Formula of power is given by

Power = Change in energy/change in time

One watt of the laser power means its energy is equal to one joule per second. Power differs with respect to time for pulsed lasers and for continuous lasers is normally same. If series of pulses are emitted by laser its power can be calculated by calculating the totaling of pulse energies by the total time of pulses. Peak power refers to the highest rate of power's delivery through a laser pulse, and it might be quite high.

The total quantity of energy transported in an interval is measured in joules. It usually calculates the amount of delivered energy by a single laser pulse. The higher the peak power, the quicker the time it takes the laser to transfer a specific amount of energy.

The power deposited per unit area is measured by intensity. The larger the intensity and the more it impacts on what is being illuminated, the narrower the laser spot. Consider how intense sunshine may increase temperature of a sheet of paper, however focusing sunlight via a magnifier can cause the paper to heat up to the point where it burns in a small area.

2. Pulse Duration

Because of their inherent features, some lasers can only emit pulses, whereas others can create continuous beams. By regulating the output of continuous lasers, they may be turned on and off. Some inherently pulsed lasers only fire a shot of single laser at an instance, while others shoot a series of pulses over period of regular intervals.

Laser pulses can range from milliseconds to femtoseconds in length. The operator can vary the pulse time and spacing, which are dependent on the inherent properties of the laser. One method is to vary the power of input so that the laser turns on and off, similar to how a laser pointer works.

3. Wavelength

Most lasers are monochromatic, which means they have just one wavelength. However, dependent upon the laser's material of light-emitting and optics, that single wavelength can be changed little or significantly. Material of the laser decides the range of output wavelengths and the optics used determines the laser wavelength which to be emitted. Lasers are most commonly used in the spectrum of visible, ultraviolet, and infrared portions.

4. Coherence

Laser light having photons of the same wavelength makes it coherent. Output photons of laser that have the same wavelength as that of input photons makes laser light coherent in stimulated emission. Coherent light waves' highs and lows are all of the same length and have aligned highs and lows. Incoherent light waves' highs and lows do not line up. Majority of the thermal sources produce incoherent emission like the bulbs, flames etc. The degree of coherence is determined by the wavelength range emitted, which varies amongst lasers. Coherence is not related to light being monochromatic but it is a fact that lights having wider spectrum cannot remain coherent for longer distances. Lasers are the only light sources that can reliably generate coherent light over distances of a few centimeters or more.

5. Beam Size & Divergence

Laser Beam in the air cannot be generally seen until it is reflected back from something like the particles in the air. Diameter of the beam varies according to the types of optics used in the laser. And due to these optics beams spread at a slight angle which generally cannot be picked by human naked eye. This divergence depends on the laser type and the type of the optics used. Unit of divergence is milliradians.

6. Energy Conversion Efficiency

For some laser applications, conversion efficiency is critical, and many advancements in recent years have resulted from efficiency improvements. Currently maximum 70 percent of the input energy is converted to laser light by lasers. This conversion efficiency is important is applications like fusing or cutting of metals. The laser's beam was valuable because it was finely focused, coherent, and monochromatic. Semiconductor diode lasers have the ability to convert up to 70 percent of the energy that passes through them into light. Solid-state fibre lasers can convert more than 70% of the light energy they receive into a high-quality laser beam, making them ideal for industrial machining applications.

2.8.2 Laser Power

Power of a laser is an important factor in Selective Laser Melting. Laser power added with scan speed, scan direction greatly effects the mechanical properties of the product. Depending on the type of use lasers these days are generally equipped with the continuous as well as pulse mode.

2.8.3 Laser Pulse Characteristics

One of the most important characteristics of a laser is its output power, which humans practically intuitively recognize. Another important aspect of lasers is the duration of emission. This is less visible. Continuous beams are ideal for tasks that demand constant lighting for example in construction projects establishing a straight line or in sheet metal welding. Beams with pulse characteristics are generally suitable for applications that need quick but strong pulses, such as laser radar distance measurement or drilling holes.

How long is the pulse and how many times it repeats can differ according to the application it is being used in. A sequence of small yet strong pulses may drill holes and the spacing between pulses is such that the plasma of one pulse should not block the light of the next. Pulses may pull off the upper layer of material so quickly that their heat does not harm the layer underneath it, making them suitable for glass cutting applications.

2.8.4 Continuous-Wave Laser Emission

On atomic time scale a continuous-wave laser produces a beam indefinitely which implies that the laser might emit for a very short span of time which is in seconds but in this time the output stabilizes at constant level. This time varies from laser to laser specially for metal vapor lasers. Continuous wave lasers depending on the type may even emit for days without break. Many lasers can emit constantly, however due to intrinsic physics, others cannot. Nitrogen and excimer gas lasers are two examples.

2.8.5 Lasers Pulsed by Power Sources

The power source of certain lasers controls their pulsing. One example is s semi-conductor diode laser being driven by the electrical pulses in sequence and sending a digital signal via a fiber optic data link. Pulsed lamps or pulsed lasers are applied to pump other lasers optically. Flashlamps, which shoot millisecond-long pulses, are used to power many solid-state lasers. Because of the time delay of laser getting to threshold from pump energy, the solid-state laser would shoot millisecond pulses that were somewhat shorter than the lamp pulses if there were no additional controls.

A powerful pulse of pump energy can be used to improve gain within the laser cavity. Laser output pulses which are shorter than the pump pulses can be created by rapid amplification inside the laser medium of semiconductor diode, gas or pumped solid state lasers.

2.8.6 Fiber Lasers

Fiber laser is a type of solid-state lasers which use optical fiber for their laser medium. Light in this type of laser is transported through a central core which is surrounded by an outer layer of low refractive index. The phenomenon of total internal reflection takes place inside the core cladding interface in which light is trapped in a high index core thus allowing it to transit to the length of the fiber.

2.8.6.1 Fiber Laser Basics

The primary concept behind this laser is that the light emitting device is placed inside the core which allows complete internal reflection making it travel along the fiber's length. The fibre core, which contains the active laser species, is faintly tinted. All directions are open to spontaneous emission.

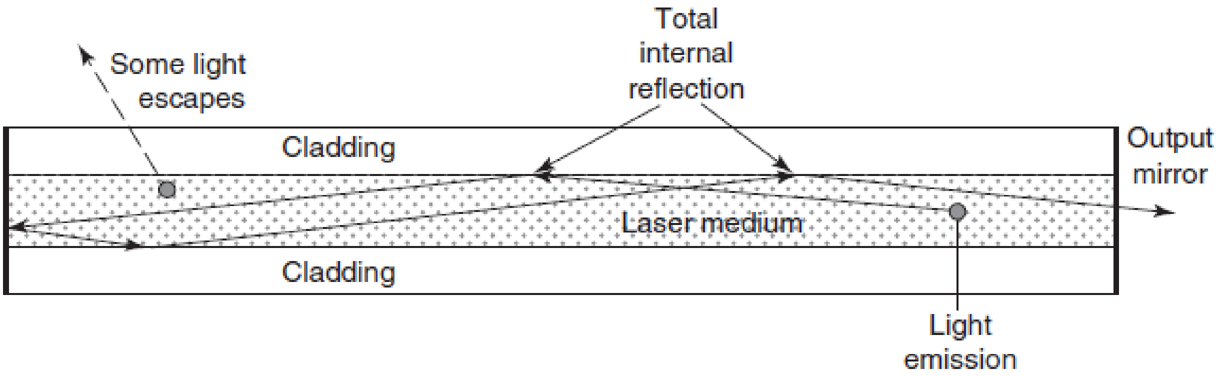

Figure 2: Basics of Fiber Laser

As depicted in the top left of the Figure 2, some of the light escapes midway from the sides of the fiber. The remaining emissions through total internal reflection travel through the cavity mirrors to the output mirror.

This initial spontaneous emission prompts further emission, accumulating intracavity power in the fibre core. One of the advantages of fiber laser is that even it is bent or rolled because it is based on the total internal reflection the light still passes through the glass fibers which are thin and flexible.

A fiber laser's whole resonant cavity is included within the fibre in which the cavity mirrors are also included which are often layers in sequence created in between particular fiber segments. Optical fibers are commonly used to provide pump light, and the light created within the fibre is frequently used in fiber laser output by coupling the light created to the beam delivery fiber. Doing this reduces the path of light and less optical equipment is used so less equipment means less operation and maintenance requirement and it avoids intracavity contamination.

2.8.6.2 Ytterbium-Doped Fiber Lasers

Ytterbium doped fiber lasers are one of the most powerful lasers which generate both continuous as well as pulsed waves in the range of 1015 to 1120 nm. Wavelength is dependent on many factors like the length of the laser cavity or optics of the cavity or how the laser is being stimulated. Along the length of the fiber the single semiconductor lasers typically pump in either directions.

Germanate silicate glasses are among the most used glasses and the strongest pump bands are at the range of 975 nm with slight peaks of greater absorption. Ytterbium doped lasers have very tiny quantum defect of light which is lost in the output photon which results in efficient optical to optical conversion of pump diode light into ytterbium laser. One of the additional qualities of Ytterbium doped fiber lasers is its no self-quenching effects which can take down neodymium's efficiency and so these ytterbium doper fiber lasers can be used for larger concentrations thus increasing power. Another advantage of Yb-fiber lasers over diode lasers is that these lasers reach up to the efficiency of 50 percent. Better efficiency means less heat waste. That is why the commercial Yb lasers are able to produce power of more than 10 KW and in multi-mode the power generation is about 100 KW. To attain such high performance, careful design is necessary.

This factor of good conversion rate and better efficiency has resulted in growth of Laser based applications.

2.8.6.3 Advantages of Fiber Lasers

Some of the advantages of fiber lasers include the conversion of input power into light in fiber lasers. Bad conversion results in significant energy expenditures and the need for cooling. Commercial fibre lasers with the highest efficiency convert only 50 percent of the input power into light but that leads to lower equipment running cost and a good laser strength, low heat generation within the laser optics hence air cooling which is a passive cooling method is good enough for most of the fiber lasers, compact design with more power, lesser exposure of parts to dirt hence preventing surface damage and decreasing maintenance demands and one of the best power conversion efficiency means that it converts maximum input power to light.

2.8.6.4 Fiber Laser Disadvantages

Concentration of power which helps fiber lasers pump more efficiently can be problematic in terms of non linear phenomena that causes limitations to the laser power and laser's performance. Non linearity of glass is low by nature, yet nonlinear effects accumulate with time and increase with distance. Non linear effects are proportional to the intensity of light within the glass so smaller fiber core will have more nonlinear effects. Due to the scattering of atoms in glass due to photons by lowering the frequency and transferring that energy to glass vibrations. Photons bounce back and deplete the laser's energy. Peak power determines the limiting effects. As a result, they're best for brief laser pulses with the highest peak powers. Continuous lasers cannot reach such high power levels as compared to pulsed lasers so they are less susceptible to these kind of damages.

Chapter 3: Design and Methodology

Design is basically of two types. One type is Design for Manufacturing and the other one is Design for Assembly. The purpose of both the types is to make part manufacturing and assembly easy and economical depending on the application the product.

Design for Manufacturing focuses on the elimination of unnecessary, complex features to reduce manufacturing time and cost. In design for manufacturing the part features and tolerances are focused. Tolerancing is very important in the manufacturing designs because tight tolerances or wrong tolerance designs make the part nonfunctional. Material availability is checked first. Extra and expensive tooling is avoided.

Design for Assembly process focuses on the assembly perspective of the product like which parts to assemble, what will be the sequence to assemble, ease of assembly, assembly time and to minimize the total parts inside assembly. Ease of disassembly for repair and maintenance, interconnected parts motion is kept in mind.

This project is assembly-based design because it's for lab experimentation and during the experiments parts are required to be disassembled. The complete chamber box is made up of Aluminium plates and all plates are then assembled to complete chamber box. This is done so because additional parts are mounted on each plate individually so extra work could not be done if the box was made as a single part. For example, the bottom plate consists of two holes. One is of powder bed surface and the other one is for the shaft to go through. In addition to that shaft bearing housing is made on the base plate. Z-axis mechanism is also based on the design for assembly. Below the box is z-axis mechanism which contains a piston inside a cylinder in which the piston surface is our concerned area on which the powder layers will be deposited. The z-axis mechanism consists of 5 plates which include top plate, base plate ,2 side plates and the moving plate and two guide rods which will keep the mechanism straight. The piston is fixed on the moving plate using M4 x 35 screws. Brass nut is assembled on the bottom side of moving plate whose threads bear the piston and moving plate load. Below this z axis mechanism and the box base plate are two stepper motors in which one motor is responsible for the rotation of hopper which will deposit layers of powder and the second motor is responsible for the motion of z axis mechanism which will be responsible for the movement of powder layers sequentially. 2 mm pitch lead screw is used in this mechanism which is connected through coupler to stepper motor. Stepper motors are coded such that minimum step size of the z-axis mechanism is 10 microns. And the hopper stepper motor is controlled through limit switches which will change direction of the hopper rotation once it completes layer deposition coming from one side to the other. Hopper movement speed is controlled by a potentiometer so that the powder deposition speed can be adjusted according to the laser setting.

3.1 Complete Model & Actual Product

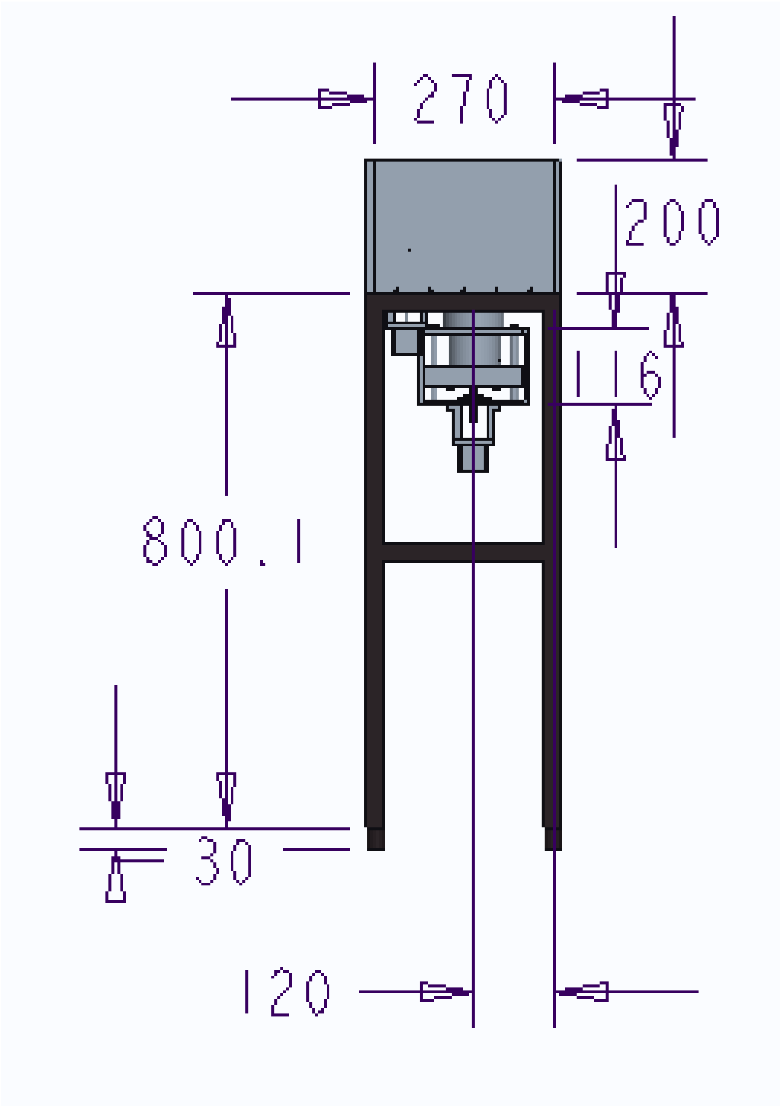

Figure 3 : Complete CAD Model (mm)

Figure 4 : Complete Actual Product

Individual Components of the product are as follows:

3.2 Chamber

Chamber Box is made of Aluminium plates and the size of the box is 320x290x200 mm. Base plate of the box contains a hole for the piston and the bearing. Bearing housing is also made in the base plate. All the plates are assembled by M5 x 20 mm Allen bolts. The cylinder of the z axis mechanism is being carried by 4 M5 x10 mm set screws.

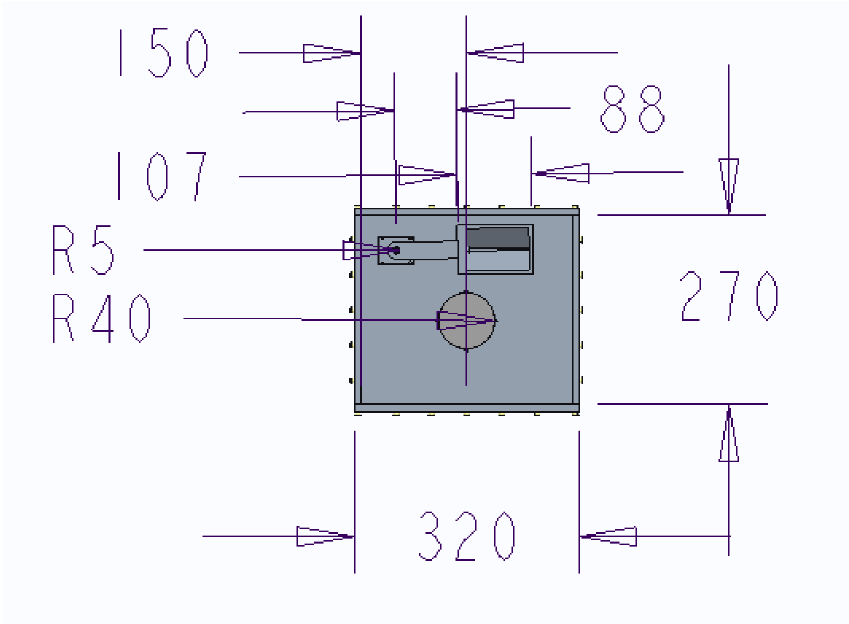

Figure 5: Chamber Top View CAD Model (mm)

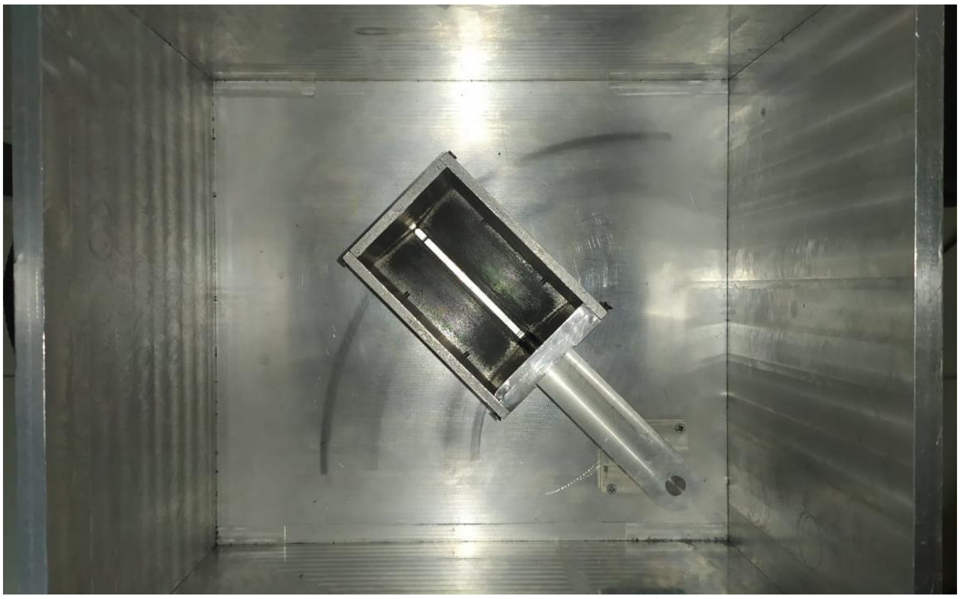

Figure 6: Fabricated Chamber Top View

3.3 Hopper Arm Assembly

This assembly coupled with the stepper motor will be responsible for depositing the powder layers across the desired surface. This assembly movement will be controlled by a stepper motor which will be operated through limit switches.

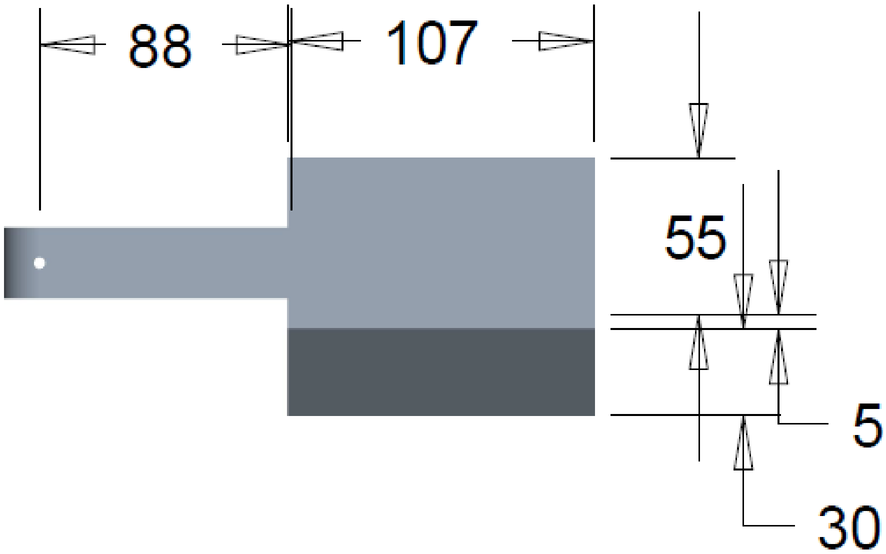

Figure 7: Hopper Arm Assembly CAD Model (mm)

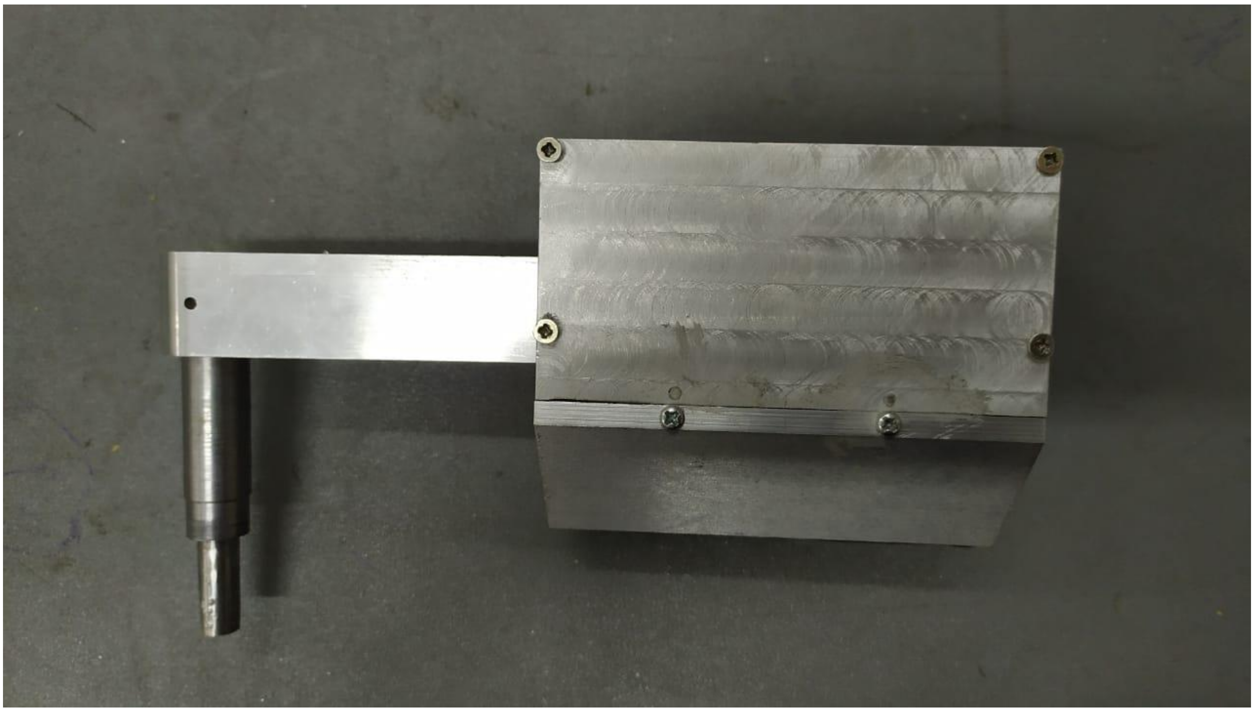

Figure 8: Fabricated Hopper Arm Assembly

3.4 Hopper

Hopper was first 3D printed with resin in Rapid Prototyping Lab. It was light weight but its accuracy and finish was not up to mark so then it was made from the Aluminium plates and assembled together by M3 x 12 mm screws. The front side of the hopper in Figure 9 has a vertical slot of 25 mm width which is for the arm vertical alignment so that it does not slips or changes its position during the operation. The slots in the Figure 9 are for M5 allen bolts and these slots are also made larger in length so that the hopper placement from the layer surface can be easily adjusted by adjusting allen bolt's height. The clearance from the ground is 0.035 mm and is checked by placing a shim under the hopper after fixing this assembly in the box.

Bottom Side of the hopper contains a 2 mm thick silicon O ring which is placed to smooth out the powder surface as well as to prevent the powder from getting out of the hopper body from the bottom side.

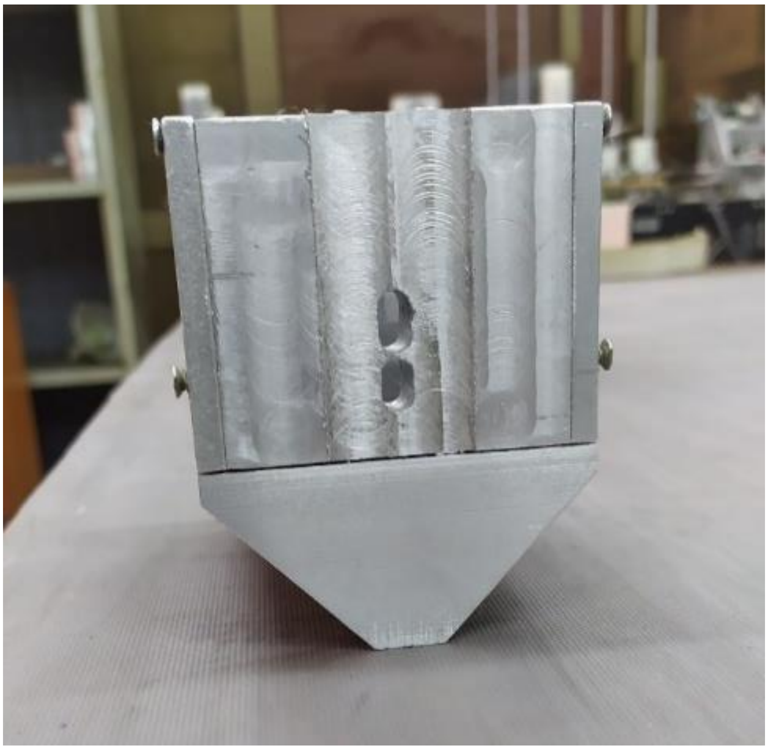

Figure 9: Hopper arm side view

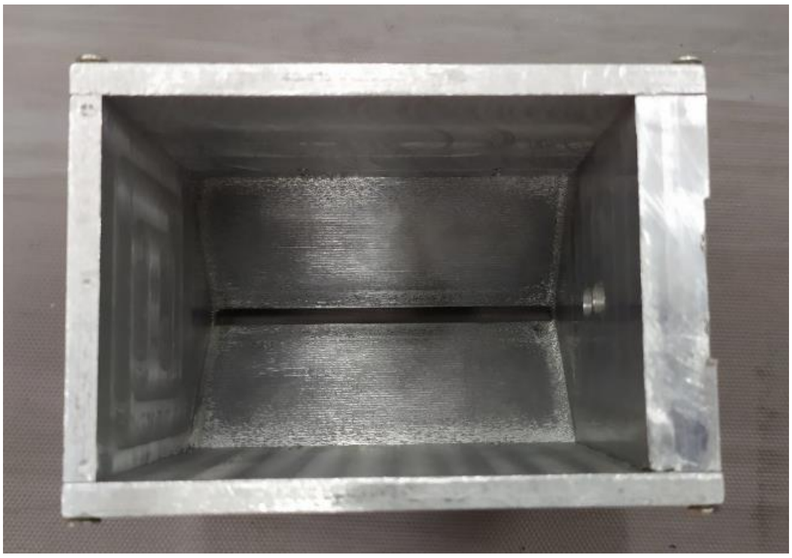

Figure 10: Hopper top view

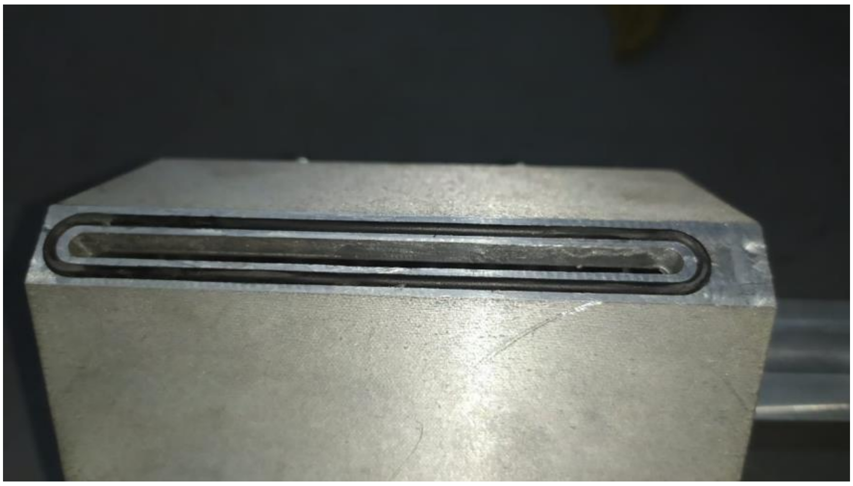

Figure 11: O Ring on Hopper

3.5 Arm

Arm is designed to connect the hopper body with the shaft. Arm is made of Aluminium and its height and width is 25mm each. Two M5 x 20 mm Allen bolts which are put from inside of the hopper to keep the arm in place and these two bolts are also responsible for the option of choosing the height of the hopper from the powder bed surface.

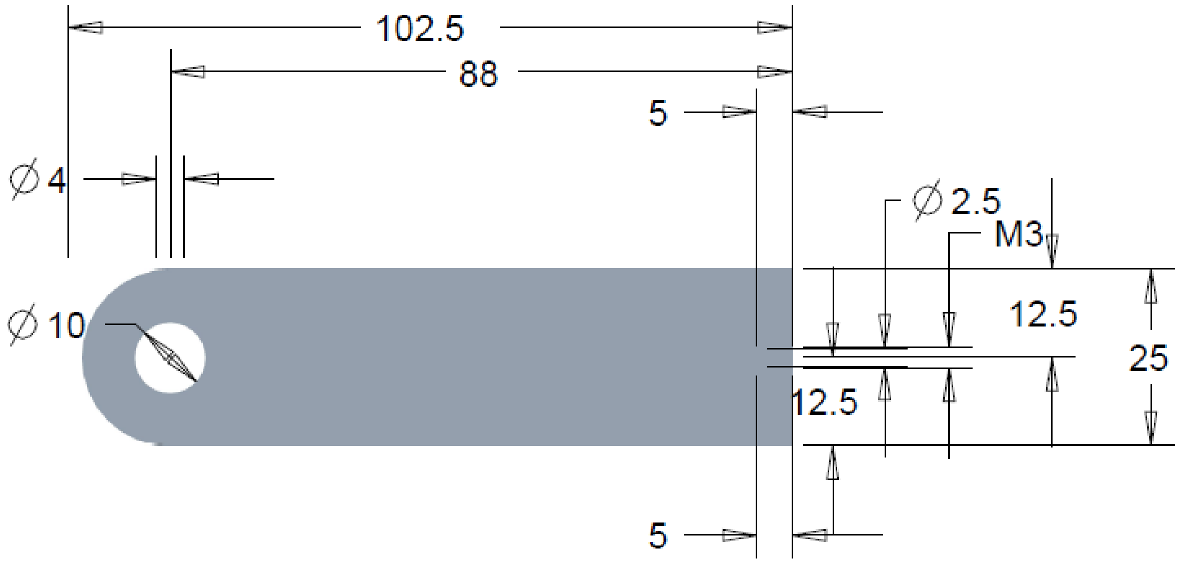

Figure 12: Arm CAD Model Top View (mm)

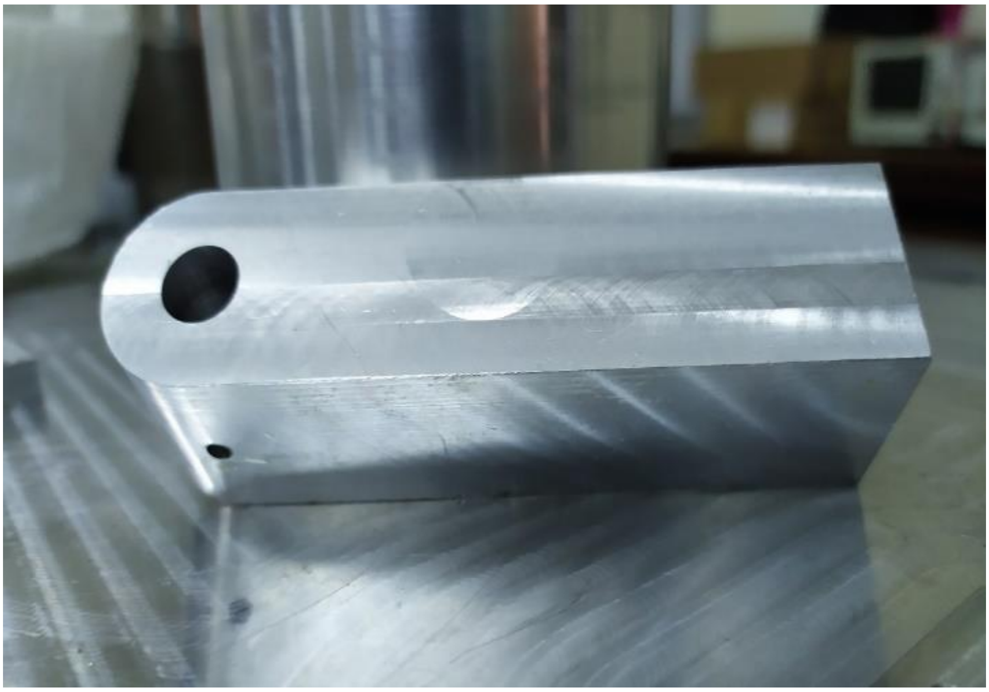

Figure 13: Fabricated Arm

3.6 Shaft

Shaft is responsible for the transfer of motion from stepper motor to the hopper. Shaft is made of Mild Steel and the 25 mm and 10 mm steps shown in the Figure 14 are for arm and the bearing respectively. Shaft is fixed in bearing and shaft movement is controlled by the stepper motor attached to its bottom through coupler.

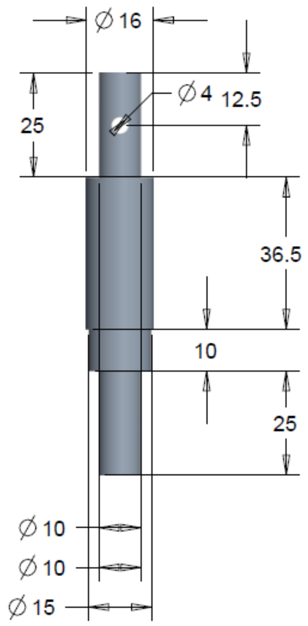

Figure 14: Shaft CAD Model (mm)

3.7 Z Axis Mechanism

Z axis mechanism is responsible for the layer height and the movement of piston in cylinder in the vertical direction. This is specially designed to deposit the powder layer of about 10 microns. It contains the Cylinder in which will move the piston. Piston's top surface will be the area at which Part will be made.

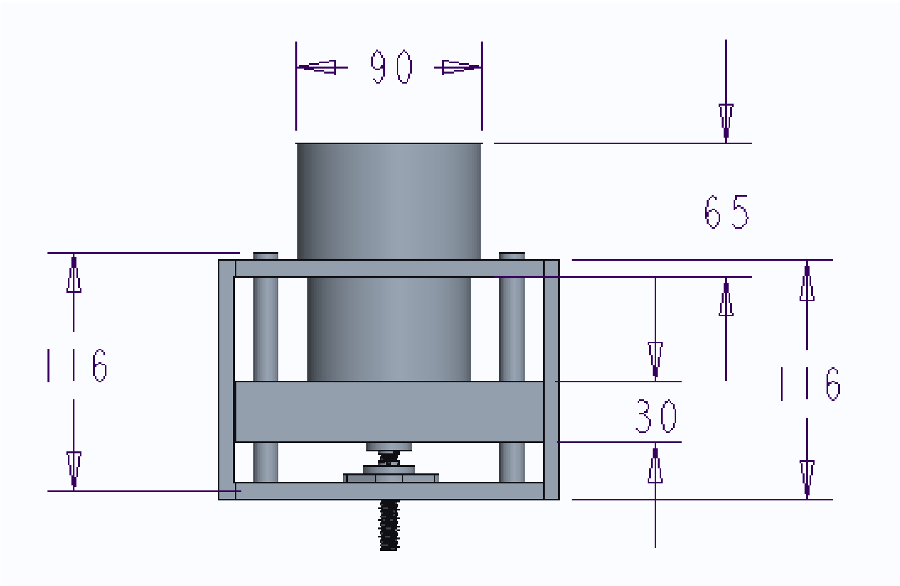

Figure 15: Z Axis Mechanism CAD Model Front View (mm)

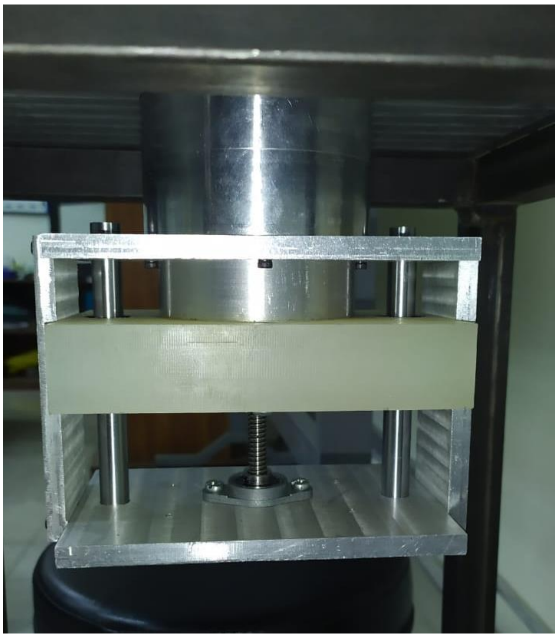

Figure 16: Fabricated z-axis mechanism

3.8 Z-Axis Mechanism Components

3.8.1 Cylinder

Cylinder is made of Aluminium and is fixed on the bottom side of the main chamber box through set screws. From the lower side it is fixed on the upper plate of the Z Axis Mechanism. The piston will move inside the cylinder hence guiding the vertical motion of the piston.

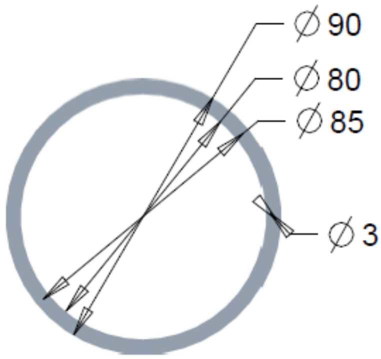

Figure 17: Cylinder Top View CAD Model(mm)

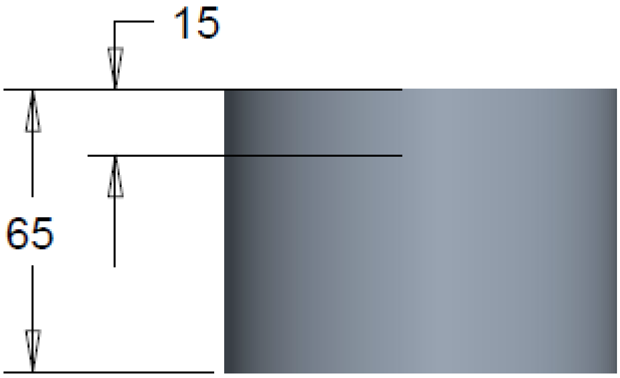

Figure 18: Cylinder Front View CAD Model(mm)

Figure 19: Fabricated Cylinder

3.8.2 Piston

Piston is made up of solid aluminium and holes are drilled inside for the movement of screw and the screws which will hold it in its position on the moving plate. Surface of the piston will be used as the powder bed surface. And its motion is controlled by the stepper motor attached to the lead screw which is fixed on the moving plate through brass nut.

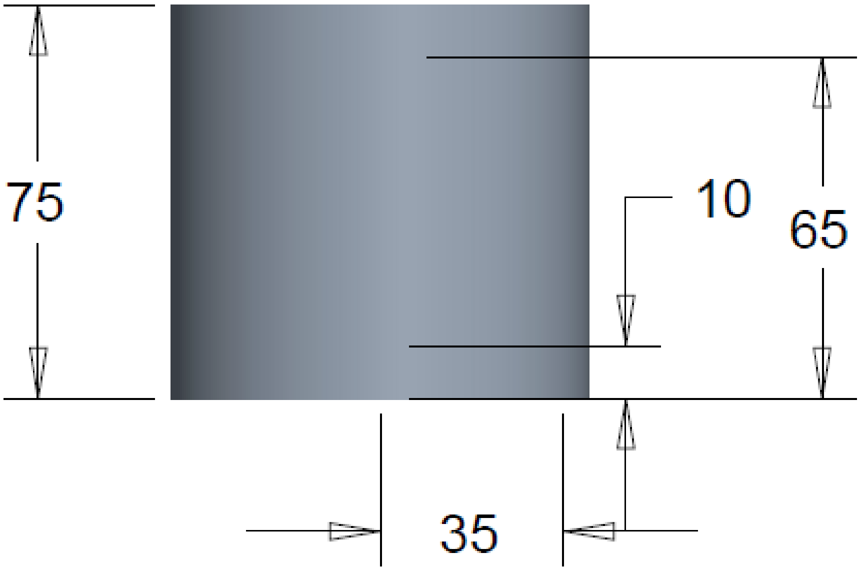

Figure 20: Piston Front View CAD Model(mm)

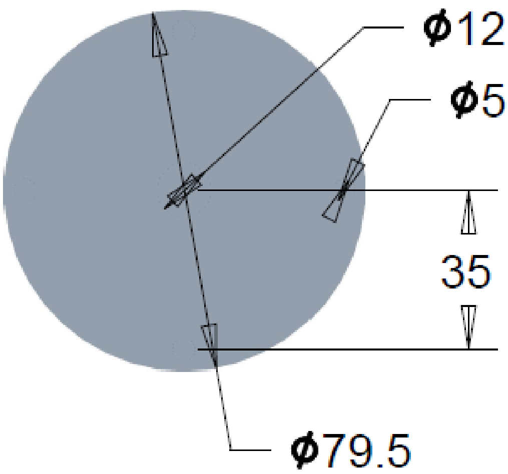

Figure 21: Piston Bottom View CAD Model(mm)

3.8.3 Lead Screw

Lead Screw is one of the most important components in z-axis mechanism and is responsible for the conversion of rotational motion to the vertical motion. It is connected to the stepper motor at one end and the other end is fixed in brass nut which is assembled to moving plate. The pitch of the lead screw is 2mm and is being for the motion of powder bed.

Figure 22: Lead Screw

3.8.4 Brass Nut

Brass Nut is fixed below the moving plate. The lead screw moves through this brass nut and rotation of the lead screw through brass nut moves the moving plate up or down according to the direction of rotation of stepper motor. This brass nut holds the weight of the moving plate and the piston across its threads.

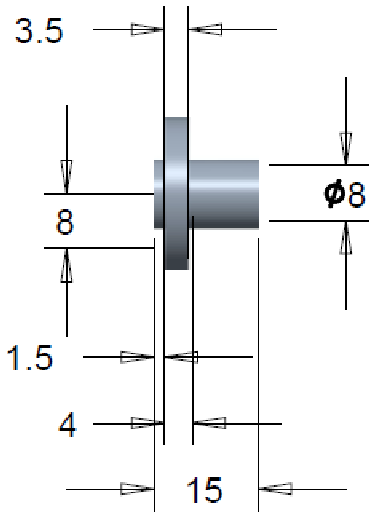

Figure 23: Brass Nut Side View CAD Model(mm)

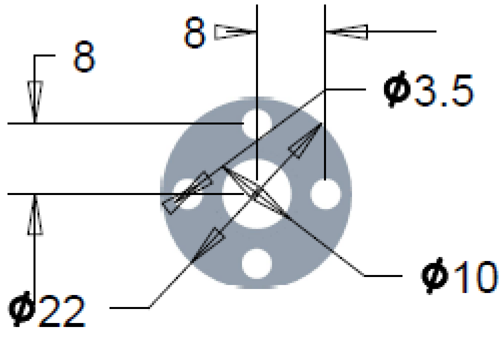

Figure 24: Brass Nut top view CAD Model(mm)

3.8.5 Guide Rods

Guide rods are made up of Mild Steel and are fixed between the upper and lower plate of the Z axis mechanism. Guide rods are placed so that the vertical motion of the piston is not affected by the motors’ frequent commands .

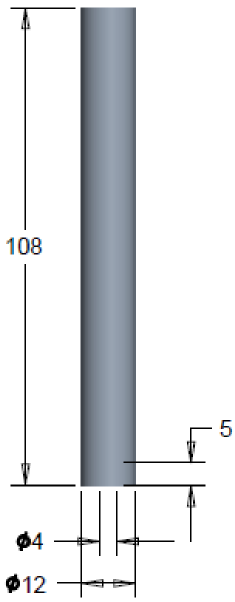

Figure 25: Guide Rod CAD Model(mm)

Figure 26: Fabricated Guide Rods

3.8.6 Moving Plate

Moving plate is the one on which piston is fixed and is responsible for the motion of powder bed. The plate is vertically fixed through the guide rods which slide across the linear bearings fixed on the moving plate. It is made up of Acrylic and is very light weight. Acrylic plate was fabricated with the purpose of lessening the load on the z-axis stepper motor.

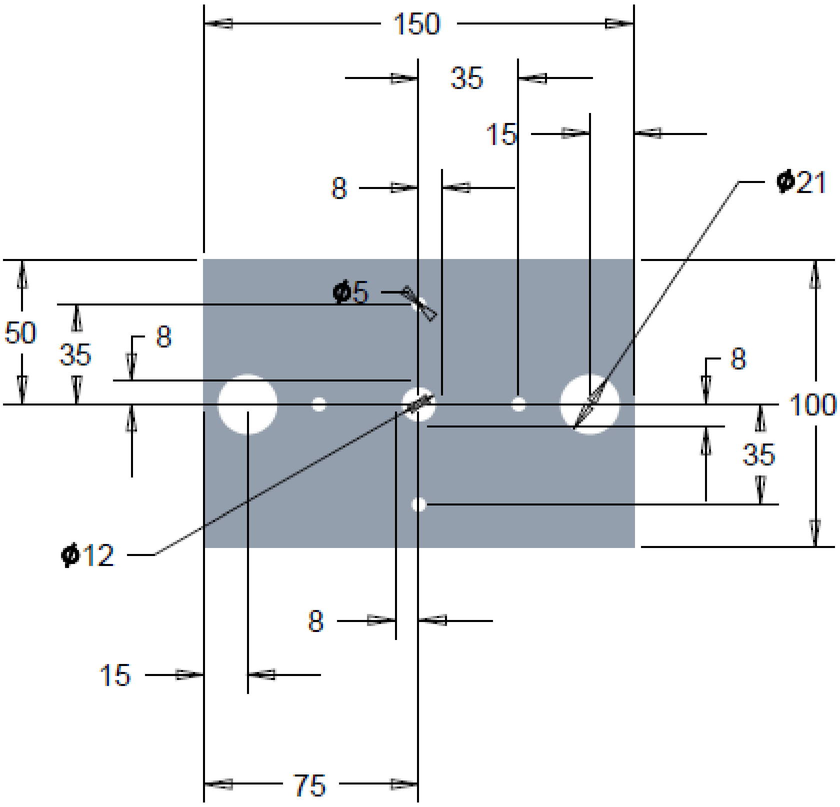

Figure 27: Moving Plate CAD Model(mm)

3.8.7 Top Plate

Top plate of the z-axis mechanism is made up of Aluminium and holds the cylinder as well as guide rods in place.

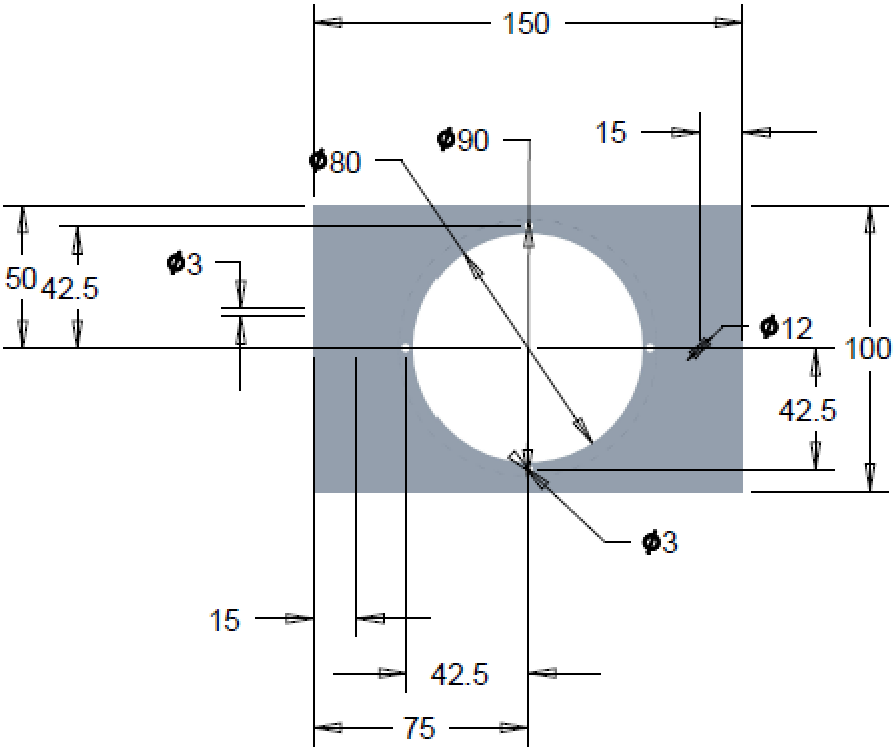

Figure 28: Z-axis mechanism top plate CAD Model (mm)

3.8.8 Base Plate

Base Plate of Z-axis is made up of Aluminium and holds the bearing of the lead screw and the guide rods. The side plates are assembled to the top and base plate to hold the assembly in its place. Lead screw goes through the base plate and is connected to the stepper motor through coupler.

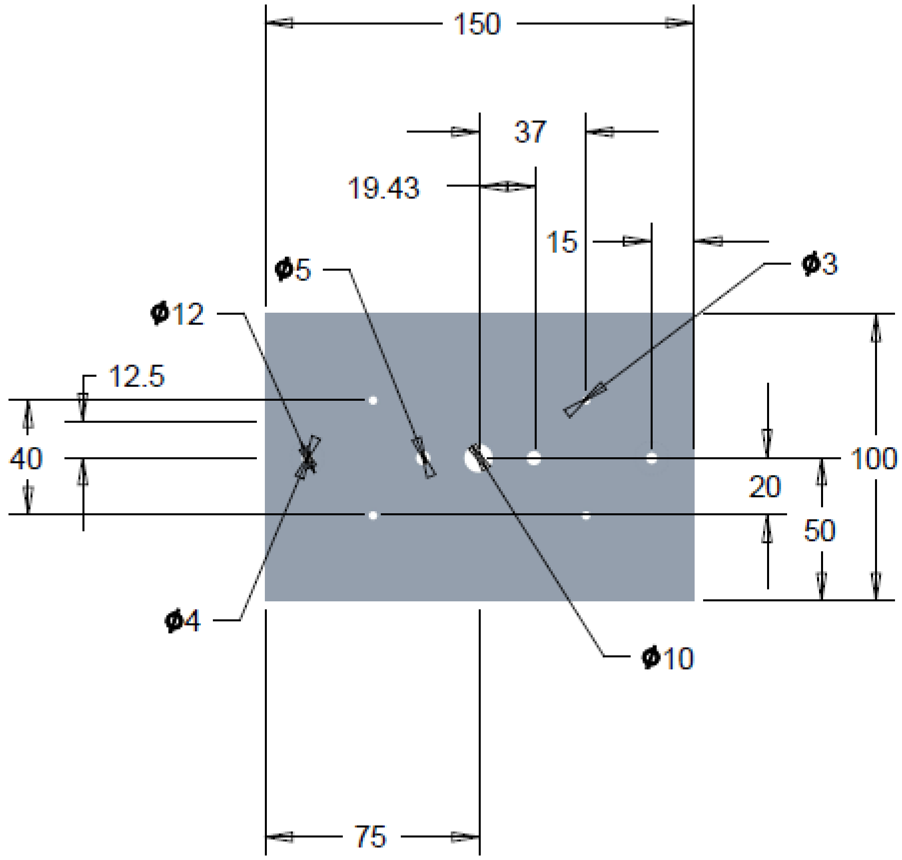

Figure 29: Z-axis mechanism Base Plate CAD Model(mm)

3.8.9 Side Plate

Side plates are used to keep the mechanism fixed vertically. 2 side plates are fabricated and assembled on both sides of the z-axis mechanism. These plates are assembled through M3 x 15 mm Allen bolts.

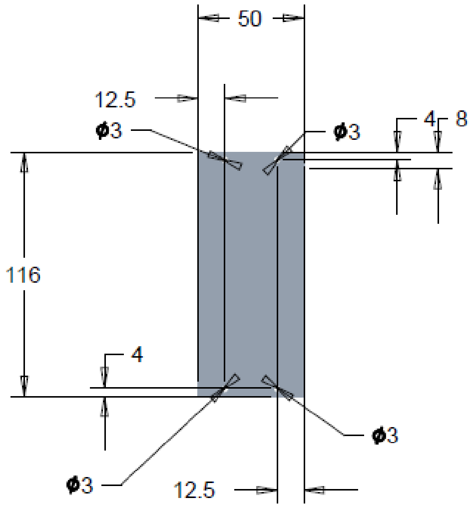

Figure 30: Side Plate CAD Model(mm)

Chapter 4: Conclusion and Future Work Recommendations

4.1 Conclusion

The objective was to design and develop a mechanism for layer deposition in the selective laser melting process. The design of deposition mechanism consisted of two main components which were the hopper and the z axis. Hopper assembly is responsible for the powder deposition and the smoothing of layer whereas z axis assembly is responsible for the layer thickness which is intended to make as thin as 10 microns. The mechanisms were complete and both the mechanisms were checked after attaching stepper motors to each assembly. The layer thickness was achieved through micro stepping. The build platform size has diameter of 79 mm and height of 40 mm.

4.2 Recommendations for the Future Work

Further recommended design modifications include the addition of following items;

- Oxygen Sensor
- Inert Gas
- Camera
- Light
- Feedback Mechanism for the powder layer
- Proper sealing

➢ Oxygen Sensor can be used to monitor the oxygen level within the chamber so that positive pressure of inert gas does not breaks.

➢ Camera can be installed so that the process can be observed easily from the screen and the powder layer deposition as well as the laser melting process can be observed. Proper light should be installed inside so that the camera catches the motion easily and each item is visible.

➢ Box should be properly sealed so that no gas can leak from the box

➢ One of the very important modifications that can be done is to introduce feedback mechanism so that when a powder layer is deposited it can be confirmed that the layer height is same as that given in the command.

References

1. Gibson, I., Rosen, D., & Stucker, B. (2014). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing (2nd ed. 2015 ed.). Springer.
2. Renk, K. F. (2017). Basics of Laser Physics: For Students of Science and Engineering (Graduate Texts in Physics) (2nd ed. 2017 ed.). Springer.
3. Meschede, D. (2017). Optics, Light and Lasers: The Practical Approach to Modern Aspects of Photonics and Laser Physics (3rd ed.). Wiley-VCH.
4. Hecht, J. (2018). *Understanding Lasers: An Entry-Level Guide* (4th ed.). Wiley-IEEE Press.
5. Wei, C., Li, L., Zhang, X., & Chueh, Y. H. (2018). 3D printing of multiple metallic materials via modified selective laser melting. *CIRP Annals*, *67*(1), 245–248. https://doi.org/10.1016/j.cirp.2018.04.096
6. Chen, H., Wei, Q., Wen, S., Li, Z., & Shi, Y. (2017). Flow behavior of powder particles in layering process of selective laser melting: Numerical modeling and experimental verification based on discrete element method. *International Journal of Machine Tools and Manufacture*, *123*, 146–159. https://doi.org/10.1016/j.ijmachtools.2017.08.004
7. Nazarov, A., Skornyakov, I., & Shishkovsky, I. (2018). The Setup Design for Selective Laser Sintering of High-Temperature Polymer Materials with the Alignment Control System of Layer Deposition. *Machines*, *6*(1), 11. https://doi.org/10.3390/machines6010011
8. Gokuldoss, P. K., Kolla, S., & Eckert, J. (2017). Additive Manufacturing Processes: Selective Laser Melting, Electron Beam Melting and Binder Jetting—Selection Guidelines. *Materials*, *10*(6), 672. https://doi.org/10.3390/ma10060672
9. Li, J., Hu, J., Cao, L., Wang, S., Liu, H., & Zhou, Q. (2021a). Multi-objective process parameters optimization of SLM using the ensemble of metamodels. *Journal of Manufacturing Processes*, *68*, 198–209. https://doi.org/10.1016/j.jmapro.2021.05.038
10. Zhang, J., Wang, M., Niu, L., Liu, J., Wang, J., Liu, Y., & Shi, Z. (2021). Effect of process parameters and heat treatment on the properties of stainless steel CX fabricated by selective laser melting. *Journal of Alloys and Compounds*, *877*, 160062. https://doi.org/10.1016/j.jallcom.2021.160062
11. Soltani-Tehrani, A., Shrestha, R., Phan, N., Seifi, M., & Shamsaei, N. (2021). Establishing specimen property to part performance relationships for laser beam

powder bed fusion additive manufacturing. *International Journal of Fatigue*, *151*, 106384. https://doi.org/10.1016/j.ijfatigue.2021.106384

12. Oliveira, J., LaLonde, A., & Ma, J. (2020). Processing parameters in laser powder bed fusion metal additive manufacturing. *Materials & Design*, *193,* 108762. https://doi.org/10.1016/j.matdes.2020.108762
13. King, W. E., Barth, H. D., Castillo, V. M., Gallegos, G. F., Gibbs, J. W., Hahn, D. E., Kamath, C., & Rubenchik, A. M. (2014). Observation of keyhole-mode laser melting in laser powder-bed fusion additive manufacturing. *Journal of Materials Processing Technology*, *214*(12), 2915–2925. https://doi.org/10.1016/j.jmatprotec.2014.06.005
14. Herzog, D., Seyda, V., Wycisk, E., & Emmelmann, C. (2016). Additive manufacturing of metals. *Acta Materialia*, *117,* 371–392. https://doi.org/10.1016/j.actamat.2016.07.019
15. Khan, M., & Dickens, P. (2010). Selective Laser Melting (SLM) of pure gold. *Gold Bulletin*, *43*(2), 114–121. https://doi.org/10.1007/bf03214976
16. Steen, W. M., Mazumder, J., & Watkins, K. G. (2010). *Laser Material Processing* (4th ed. 2010 ed.). Springer.