A

Lab Report

On

“Synchronized Cam and Follower Mechanism”

Submitted by

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Master of Technology

(**Additive Manufacturing**)



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CERTIFICATE

This is to certify that Project Report entitled "***Synchronized Cam and Follower Mechanism"*** with Additive Manufacturing" which is submitted by Danish Anwer in partial fulfilment of Additive Manufacturing Laboratory in Department of Mechanical Engineering at NIT Warangal. He has undergone intensive hands on project. He has carried out the lab work under my supervision and guidance in academic year 2021- 2022.

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I am thankful to the **PhD Scholars and Seniors** for giving me guidance regarding SolidWorks, Cura, Magics & all those who have been instrumental directly or indirectly in the process of completion of this Lab work.

I am thankful to all my **Batch mates** for their help in the completion of this Lab work. I also wish to express my sincere thanks to all those who helped me directly or indirectly in completing my Lab work.

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ABSTRACT

Additive manufacturing technologies performs layer-wise fabrication of complex parts directly from CAD files without part-specific tooling. Additive manufacturing offers many strategic advantages, including increased design freedom for building complex internal and external part geometries that cannot be made in any other way, the ability to rapidly iterate through design permutations, the ability to build functional parts in small lot sizes for end-user customization or bridge manufacturing.

One of them is Extrusion AM process. Extrusion-based technology is currently the most popular on the market.

By far the most common extrusion-based AM technology is fused deposition modeling (FDM), produced and developed by Stratasys, USA. FDM uses a heating chamber to liquefy polymer that is fed into the system as a filament. The filament is pushed into the chamber by a tractor wheel arrangement and it is this pushing that generates the extrusion pressure.

This project report emphasis upon Synchronized cam and follower mechanism.

This mechanism can be used for transmission purpose in industries instead of belt and conveyor assembly. This will reduce manpower requirement and systemized transmission will be there.

It can be used as a prototype to convey its benefits over belt and conveyer assembly.

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1. ADDITIVE MANUFACTURING

Additive manufacturing (AM) is a transformative approach to industrial production that enables the creation of lighter, stronger parts and systems. It is a technological advancement made possible by the transition from analog to digital processes.

The term “additive manufacturing” references technologies that grow three-dimensional objects one superfine layer at a time. Each successive layer bonds to the preceding layer of melted or partially melted material. Objects are digitally defined by computer-aided-design (CAD) software that is used to create STL files that essentially "slice" the object into ultra- thin layers. This information guides the path of a nozzle or print head as it precisely deposits material upon the preceding layer. Or, a laser or electron beam selectively melts or partially melts in a bed of powdered material. As materials cool or are cured, they fuse together to form a three-dimensional object.

Additive manufacturing now enables both a design and industrial revolution, in various industrial sectors such as aerospace, energy, automotive, medical, tooling and consumer goods.

1.1 History

Additive manufacturing first emerged in 1987 with stereolithography (SL) from 3D Systems, a process that solidifies thin layers of ultraviolet (UV) light‐sensitive liquid polymer using a laser. The SLA‐1, the first commercially available AM system in the world, was the precursor of the once popular SLA 250 machine.

In 1991, three AM technologies were commercialized, including fused deposition modeling (FDM) from Stratasys, solid ground curing (SGC) from Cubital, and laminated object manufacturing (LOM) from Helisys.

Selective laser sintering (SLS) from DTM (now a part of 3D Systems) became available in 1992.

Binder jetting was developed by Ely Sachs and Mike Cima at the Massachusetts Institute of Technology in 1993 and Z Corporation obtained an exclusive license for the process in 1995.

In the 1990s, Powder-sintering methods emerged, and the first major creations fueled a growing interest in additive manufacturing. The first prosthesis was implanted into a human in 1999.

The 2000s are synonymous with expansion and strongly growing accessibility to individuals.

1.2 Applications and advantages of AM Processes

Field	Applications	Advantages
Aerospace and Defense	a) Functional prototypes b) Tooling c) Lightweight components	a) Light volume production b) Weight reduction c) Material efficiency d) Part consolidation e) Maintenance and repair
Automotive	a) 3D printed custom seats b) Prototypes c) Tooling d) Spare and replacement parts	i) Faster product development ii) Greater design flexibility iii) Customization iv) Creation of complex geometry
Medical and Dental	a) Digital dentistry b) 3D printed implants and prosthetics c) Bioprinting d) Surgical planning and testing	i) Enhanced medical devices ii) Personalized healthcare
Consumer Goods	a) Footwear b) Beauty and cosmetics c) Personal care products d) Jewelry e) Bikes	i) Enhanced product development ii) Faster time-to-market iii) Mass customization
Industrial Goods	a) End use parts b) Tooling c) Spare parts	i) Design complexity ii) Shorter lead times iii) On-demand production

Future of 3D printing

a. **Process Innovation**: refers to the greater flexibility and agility 3D printing brings to manufacturing and supply chains. It includes the digitization and decentralization of production, as well as the ability to create tools and spare parts on-demand.
b. **Product Innovation**: refers to the expanded design possibilities to create innovative new parts and products, including complex lattice structures and other geometries,

light weighting, customization, part count reduction and multi-material 3D printing.

Table 1.1 Applications and advantages of AM processes

1.3. Additive vs subtractive process

Additive Manufacturing processes build objects by adding material layer by layer, while subtractive manufacturing removes material to create parts. Though these approaches are fundamentally different, subtractive and additive manufacturing processes are often used side by side due to their overlapping range of applications.

Subtractive manufacturing is an umbrella term for various controlled machining and material removal processes that start with solid blocks, bars, rods of plastic, metal, or other materials that are shaped by removing material through cutting, boring, drilling, and grinding.

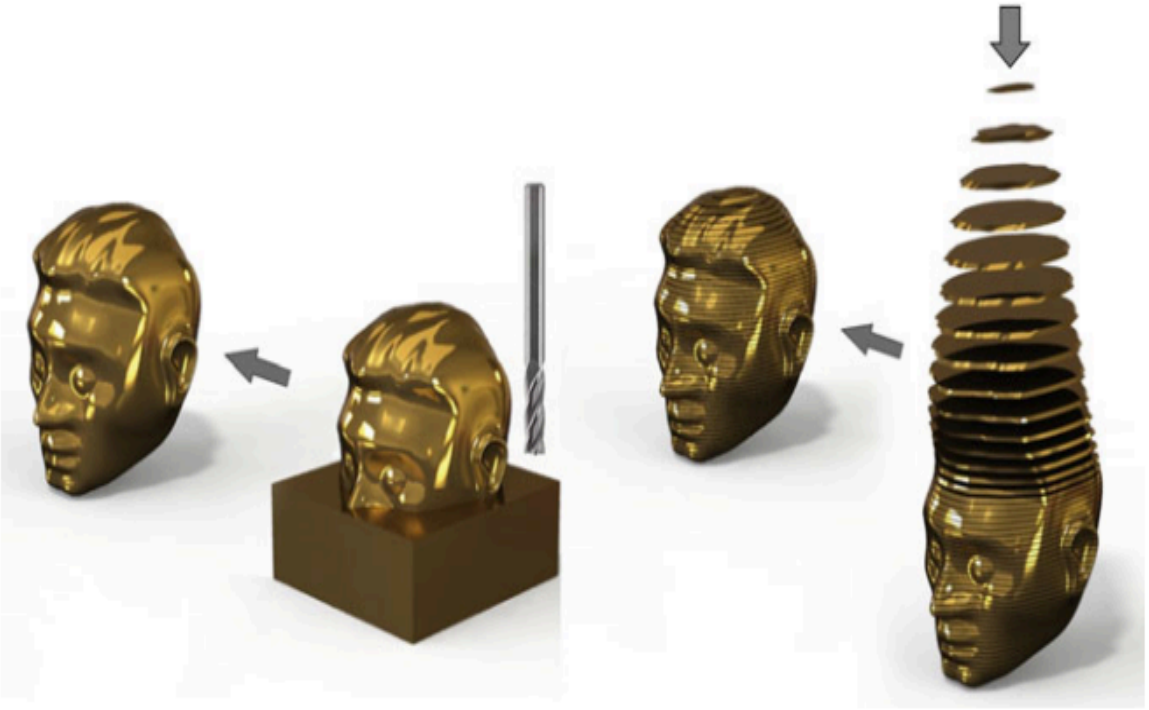


Fig 1.1 Illustration of Additive vs Subtractive Manufacturing Processes

Additive Manufacturing	Subtractive Manufacturing
Adds layers to create an object	Removes material from an object
3D printing, direct digital manufacturing, rapid prototyping, additive fabrication	Manual removal or CNC machining (computer numerical control)
Uses 3D printers to create prototypes and products	Uses computers to aid machine processes such as drilling or milling.
End result is a rough surface that needs to be finished by sanding or blowing.	End result can be machined - smooth, stepped etc.
Ideal for small parts (plastic)	Ideal for bigger parts (metal)
Slow process (depending on the job)	Relatively fast process
Parts that require a lot of detail can be built in layers.	Not ideal for parts that require certain intricacies and details.
The 3D printer can be linked directly to the software	A CNC programmer needs to set the machine. Code is no longer needed with new automated software.
Cheap process	More expensive process

Table 1.2 Additive Vs Subtractive Manufacturing Processes

2. DETAILS OF AM PROCESS USED IN THE PROJECT

2.1 Types of AM processes

In 2010, the **American Society for Testing and Materials** (ASTM) group "ASTM F42 – Additive Manufacturing", formulated a set of standards that classify the range of Additive Manufacturing processes into 7 categories (Standard Terminology for Additive Manufacturing Technologies, 2012).

1. Vat photopolymerization
2. Powder bed fusion
3. Material extrusion
4. Material jetting
5. Binder jetting
6. Sheet lamination
7. Directed energy deposition

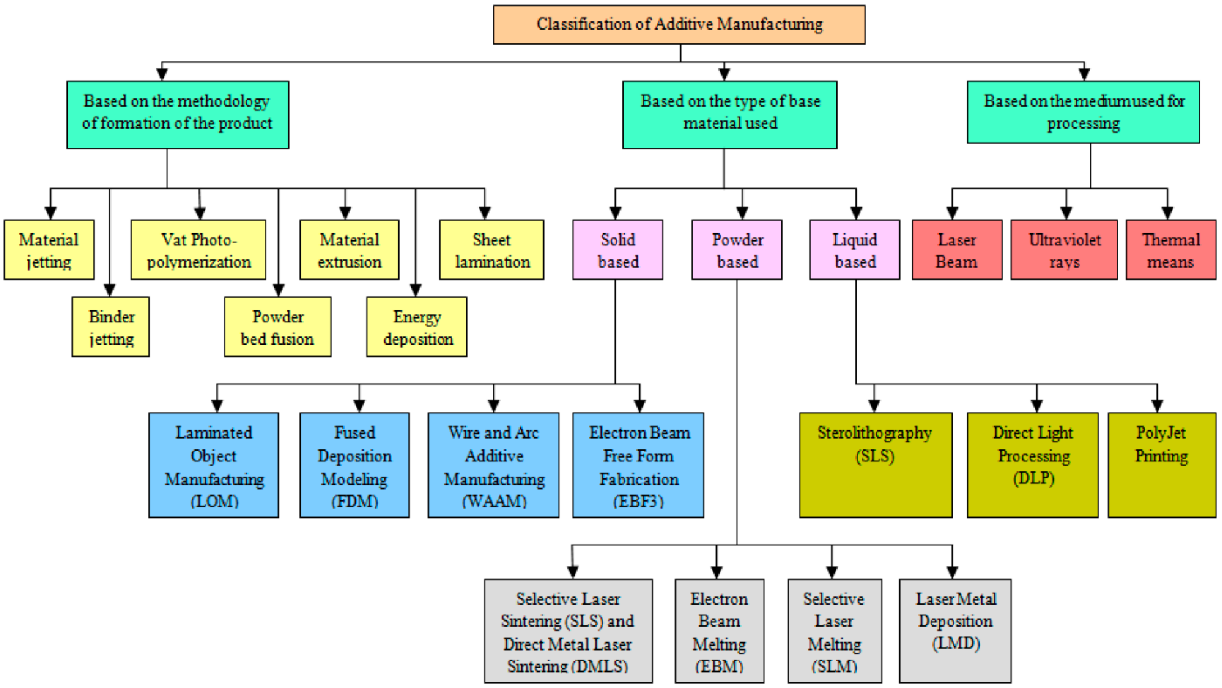


Fig 2.1 Types of AM technology

2.2. Fused Deposition Modelling

An FDM printer prints a 3-dimensional object by extruding a stream of heated or melted thermoplastic material, which is carefully positioned into layer upon layer, working from the bottom up.

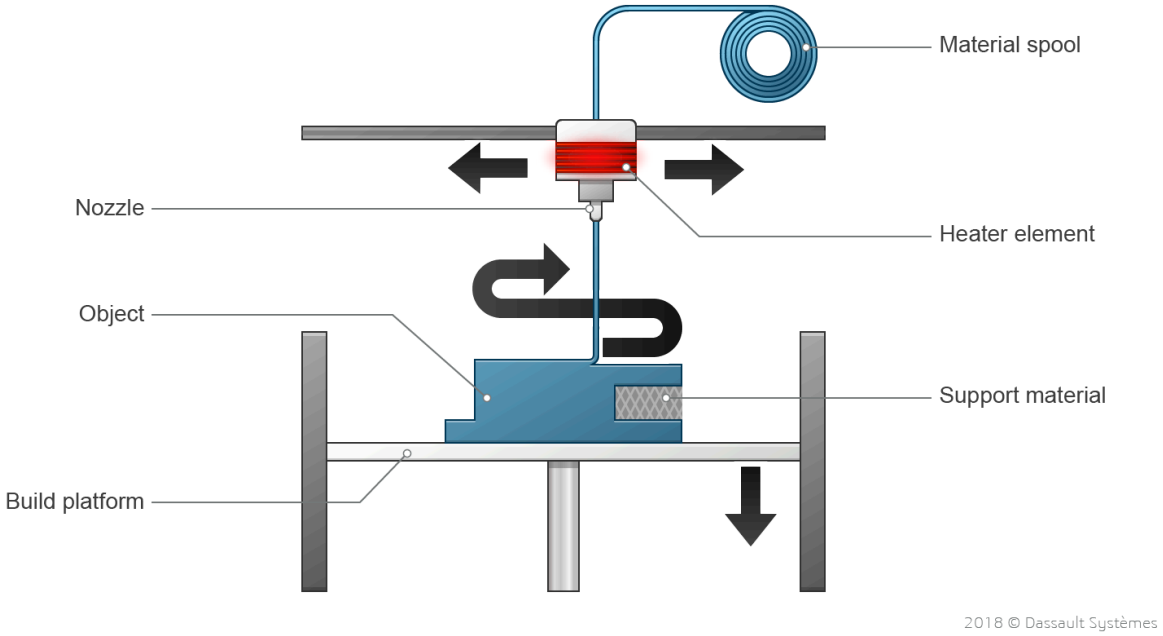


Fig 2.2 Schematic diagram of Fused Deposition Modelling Process

2.3. Working Principle

The principle of the FDM is based on surface chemistry, thermal energy and layer manufacturing technology.
The material in filament (spool) form is melted in a specially designed head, which extrudes on the model.
As it is extruded, it is cooled and thus solidifies to form the model. The model is built layer by layer, like the other RP systems.

Parameters which affect performance and functionalities of the system are:

1. Material column strength
2. Material flexural modulus
3. Material viscosity
4. Positioning accuracy
5. Road widths
6. Deposition speed
7. Volumetric flow rate
8. Tip diameter
9. Envelope temperature
10. Part geometry.

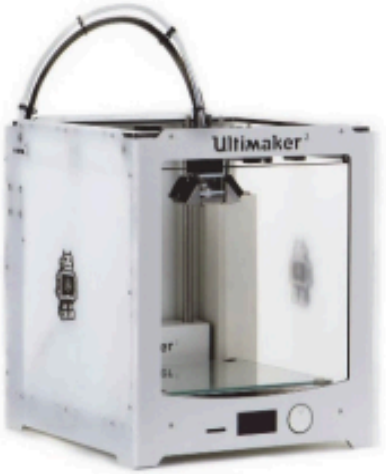
2.4 FDM Machine



Fig 2.3 FDM machines

In this project to manufacture parts of wall mounted adjustable mobile holder, ***UltiMaker 2+*** is used.

2.5 Specification of Ultimaker 2+



Ultimaker 2+ Quick Specs

Layer Resolution	Up to 20 micron (0.02mm)
Build Volume	230 x 225 x 205 mm
Speed	30 - 300 mm/sec
Print Surface	Heated bed, 20 - 100 C
Nozzle Temperature	180 - 260 C
Nozzle Diameter	0.25, 0.4, 0.6, 0.8mm
Filament Diameter	2.85mm
Supported Filaments	PLA, ABS, CPE
Printing Software	Cura (Download)
Overall Size	357 x 342 x 388 mm
File Transfer	Standard SD card
Print Technology	Fused Filament Fabrication (FFF)
What's Included	Ultimaker 2+ Printer
	Australian power cord
	Power supply
	USB cable (for firmware upgrades)
	0.75kg filament spool
	SD card
	Glass build plate
	Glue stick
	User manual
	Grease & Hex wrench
	Filament spool spigot & Filament guide post
Optional Accessories	Redstack Front Cover (for ABS printing)
	Redstack Ultimaker Advanced Stand

Fig 2.4 Specifications of Ultimaker2+

3. GENERIC AM PROCESS

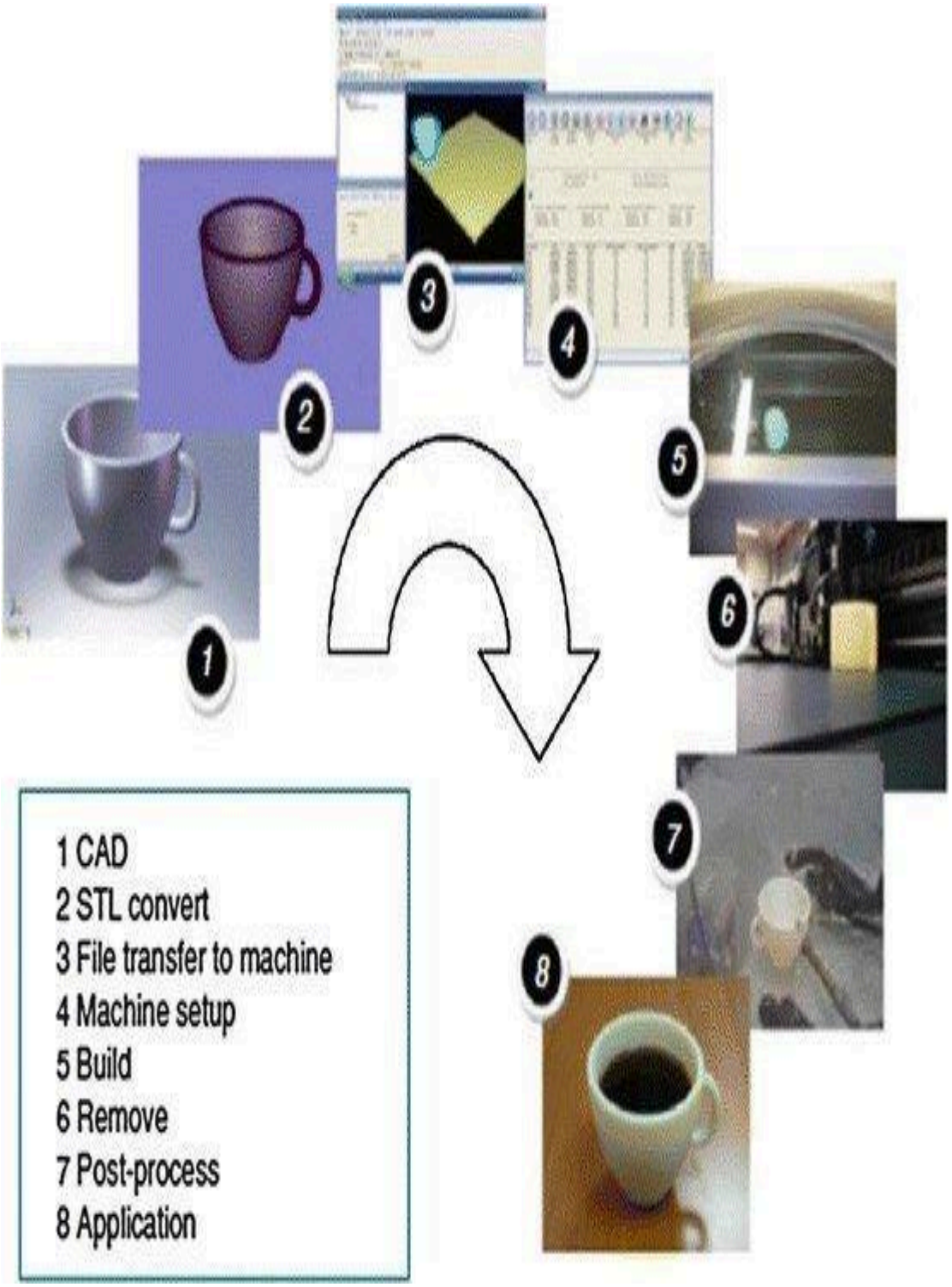


Fig 3.1 Generic AM process

4. MATERIAL USED

Material used for manufacturing parts is **PLA**. Its properties are as given below-

Characteristics	Unit	Amount
Physical:		
Mw	g/mol	66,000
Specific gravity	–	1.27
Solid density	g/cm^3	1.252
Melt density	g/cm^3	1.073
T_g	°C	55
T_m	°C	165
Specific heat (Cp)	J/kg °C	
190 °C		2060
100 °C		1955
55 °C		1590
Thermal conductivity	W/m °C	
190 °C		0.195
109 °C		0.197
48 °C		0.111
Optical:		
UV light transmission		
190 to 220 nm		<5%
225 to 250 nm		85%
>300 nm		95%
Visible light transmission		95%
Color		
L*		90.64 ± 0.21
a*		−0.99 ± 0.01
b*		−0.50 ± 0.04
Mechanical:		
Tensile strength	Mpa	59
Elongation at break	%	7
Elastic modulus	MPa	3500
Shear modulus	MPa	1287
Poisson's ratio	–	0.36
Yield strength	MPa	70
Flexural strength	MPa	106
Unnotched izod	J/m	195
Notch izod impact	J/m	26
Rockwell hardness	HR	88
Heat deflection temp	°C	55
Vicat penetration	°C	59
Ultimate tensile strength	MPa	73
Percent of elongation	%	11.3
Young's modulus	MPa	1280

Table 4.1 Properties of PLA

“Following sections explains each of these steps in detail used for manufacturing of *Synchronized Cam and Follower* by Fused Deposition Modelling (FDM)”.

5. CAMS

The basic idea of a cam is by rotating the cams, bars will have either translational or oscillatory motion.

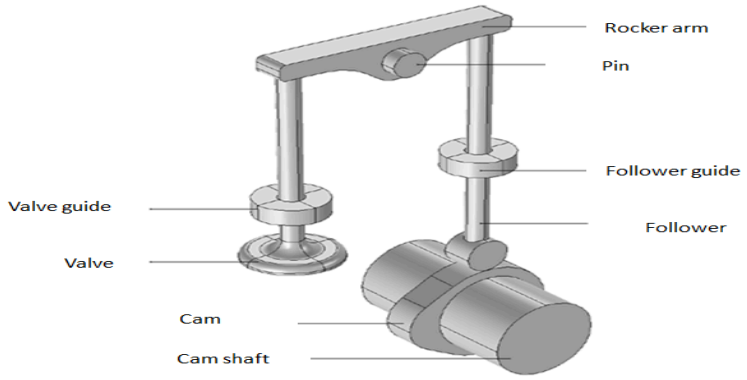


Fig 5.1 Schematic of cam

5.1 Types of Cams

a) Disk or plate cam

b) Cylinderical cam

c) Translating cam

a) Disk or plate cam: The disk (or plate) cam has an irregular contour to impart a specific motion to the follower. The follower moves in a plane perpendicular to the axis of rotation of the cam shaft and is held in contact with the cam by springs or gravity.

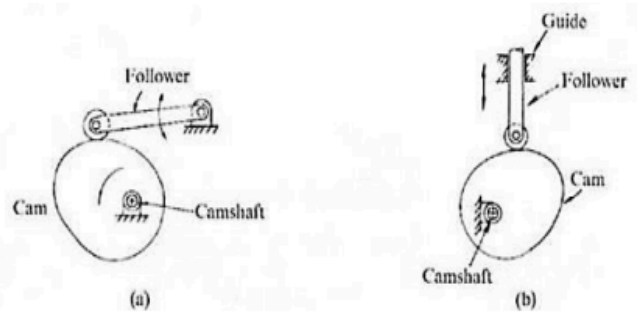


Fig 5.2 Plate or disk cam

5.2 Nomenclature of Cams

Cam Profile: The contour of the working surface of the cam.

Trace Point: The point at the knife edge of a follower, or the centre of a roller, or the centre of a spherical face.

Pitch Curve: The path of the trace point.

Base Circle: The smallest circle drawn, tangential to the cam profile, with its centre on the axis of the cam shaft. The size of the base circle determines the size of the cam.

Prime Circle: The smallest circle drawn, that can be drawn from the centre of the cam and tangent to the pitch curve.

Prime circle radius: Base circle radius for knife edge and flat faced follower.

Prime circle radius = Base circle radius + radius of roller for roller follower

Pressure Angle: The angle between the normal to the pitch curve and the direction of motion of the follower at the point of contact.

Lift of stroke: It is the maximum travel of the follower from its lowest position to the topmost position. The maximum rise is called lift.

Pitch Point: It is a point on the curve having maximum pressure angle.

Pitch Circle: It is the circle drawn from the centre of the cam through the pitch points.

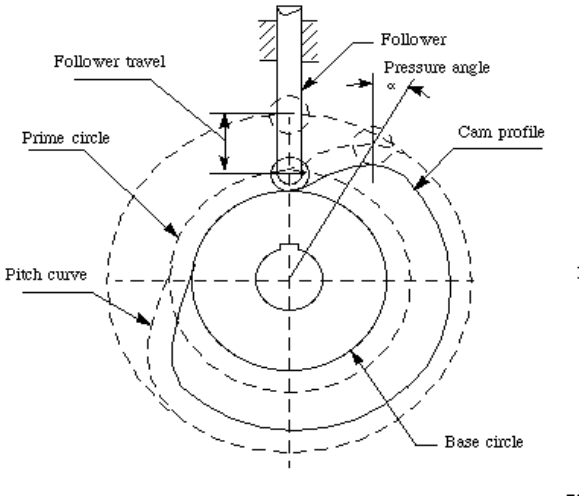


Fig 5.3 Schematic of cam nomenclature

6. FOLLOWER

A follower is a rotating or an oscillating element of a machine that follows the motion of cam by direct contact.

6.1. Types of followers

Based on surface in contact

(a) Knife edge follower

(b) Roller follower

(c) Flat faced follower

(d) Spherical follower

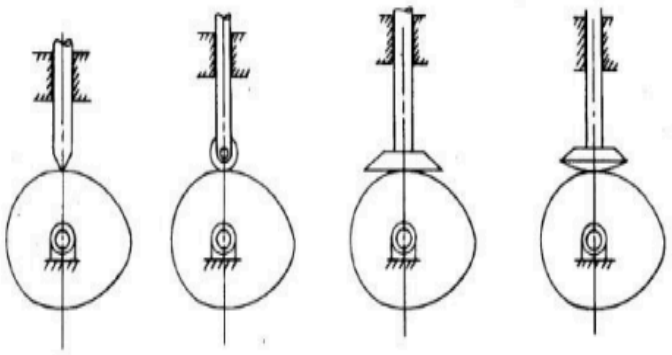


Fig 6.1 Different kind of followers

6.2 Types of follower motion

Cam follower systems are designed to achieve a desired oscillatory motion. Appropriate displacement patterns are to be selected for this purpose, before designing the cam surface. The cam is assumed to rotate at a constant speed and the follower raises, dwells, returns to its original position and dwells again through specified angles of rotation of the cam, during each revolution of the cam.

Some of the standard follower motions are as follows:

They are, follower motion with-

(a) Uniform velocity

(b) Modified uniform velocity

(c) Uniform acceleration and deceleration

(d) Simple harmonic motion

(e) Cycloidal motion

6.3 Displacement diagrams

In a cam follower system, the motion of the follower is very important. Its

displacement can be plotted against the angular displacement θ of the cam and it is called as the displacement diagram. The displacement of the follower is plotted along they-axis and angular displacement θ of the cam is plotted along x-axis. From the displacement diagram, velocity y and acceleration of the follower can also be plotted for different angular displacements θ of the cam. The displacement, velocity and acceleration diagrams are plotted for one cycle of operation i.e., one rotation of the cam. Displacement diagrams are basic requirements for the construction of cam profiles.

6.4 Follower motion with Uniform velocity

Fig.3.8 shows the displacement, velocity and acceleration patterns of a follower having uniform velocity type of motion. Since the follower moves with constant velocity, during rise and fall, the displacement varies linearly with θ. Also, since the velocity changes from zero to a finite value, with in no time, theoretically, the acceleration becomes in finite at the beginning and end of rise and fall.

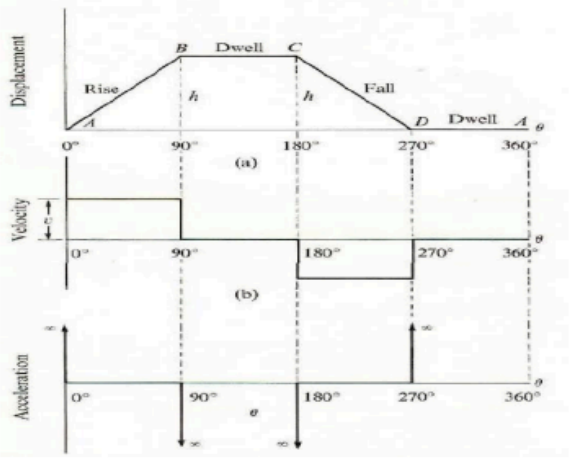


Fig 6.2 Follower motion (Uniform velocity)

<u>“We will go with Disc type Cam and Knife edge Follower working with Uniform velocity”.</u>

7. SKETCHING, MODELLING and PART FABRICATION

7.1 Free Hand Sketch

All dimensions are in cm

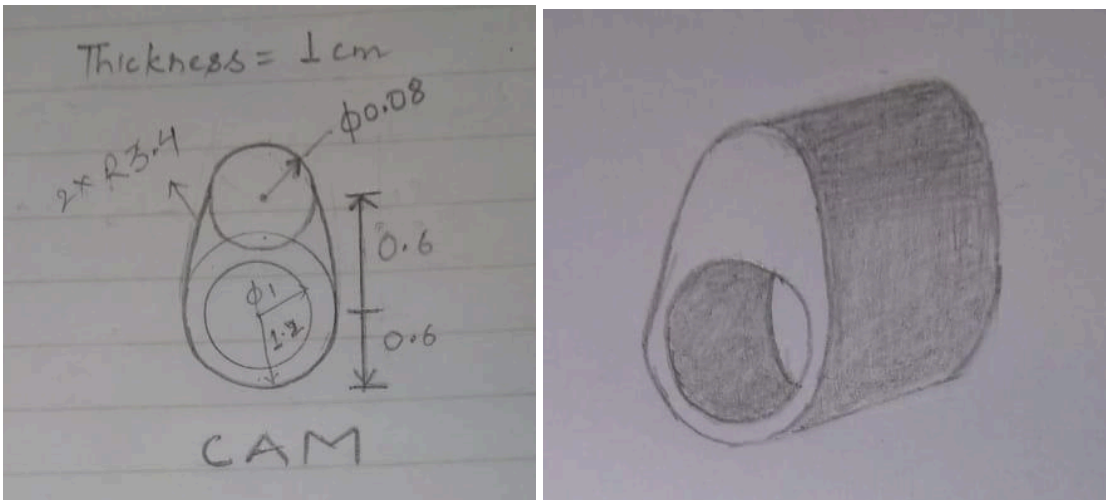


Fig 7.1

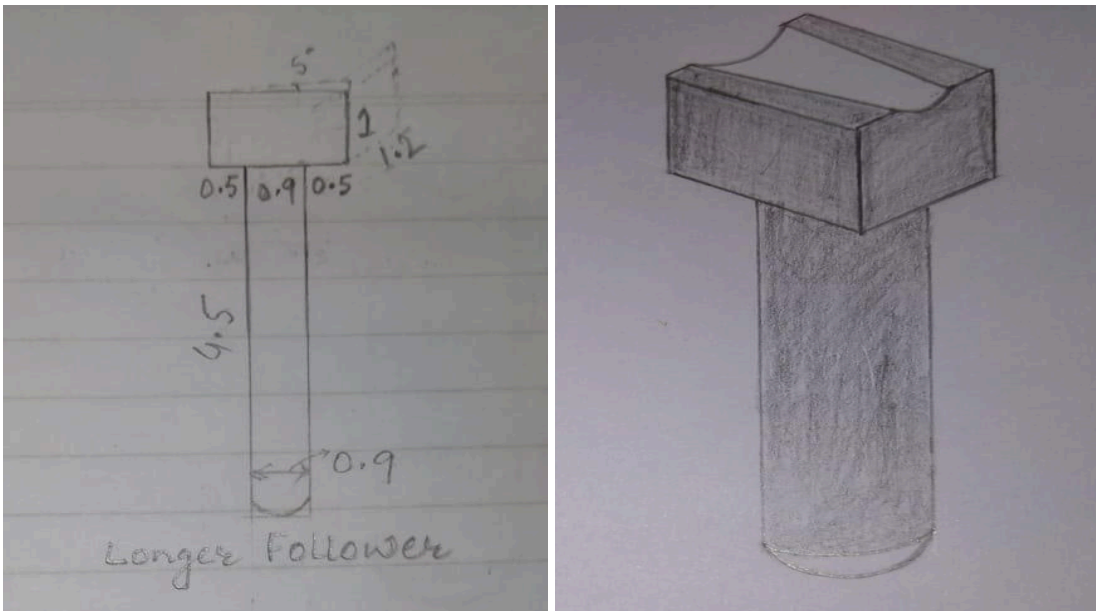
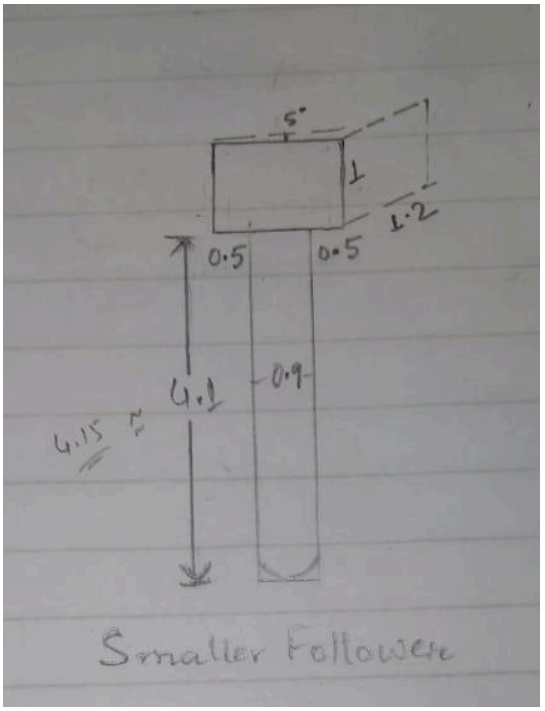


Fig 7.2



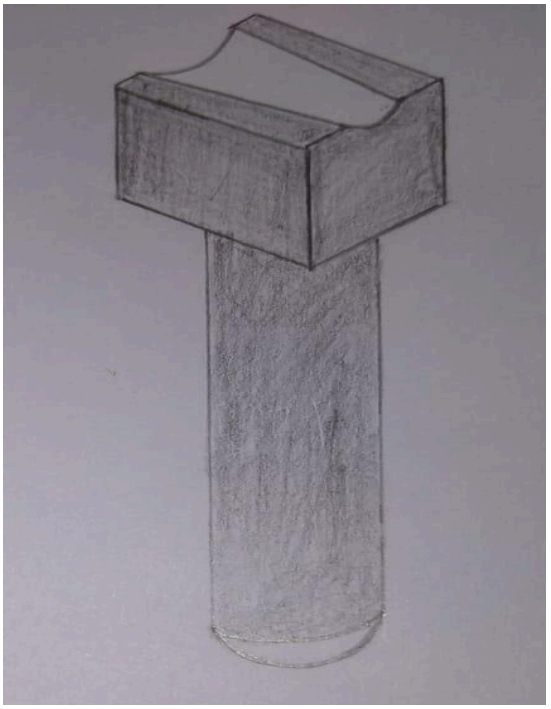
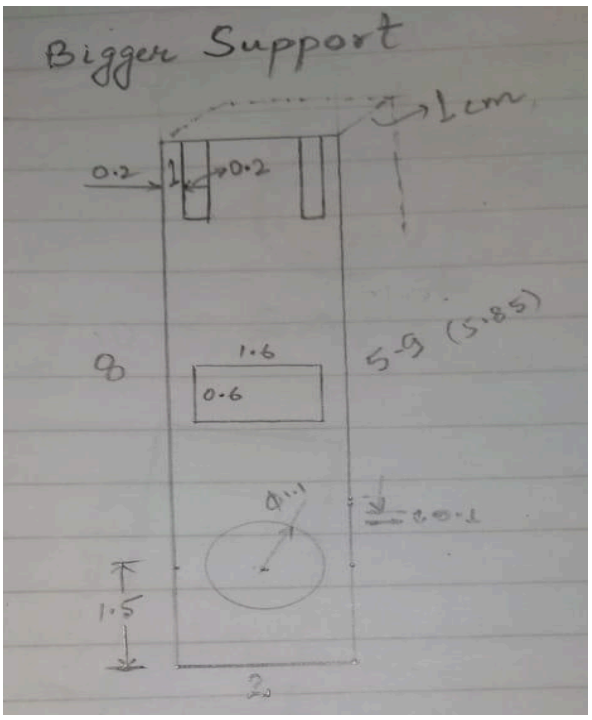


Fig 7.3



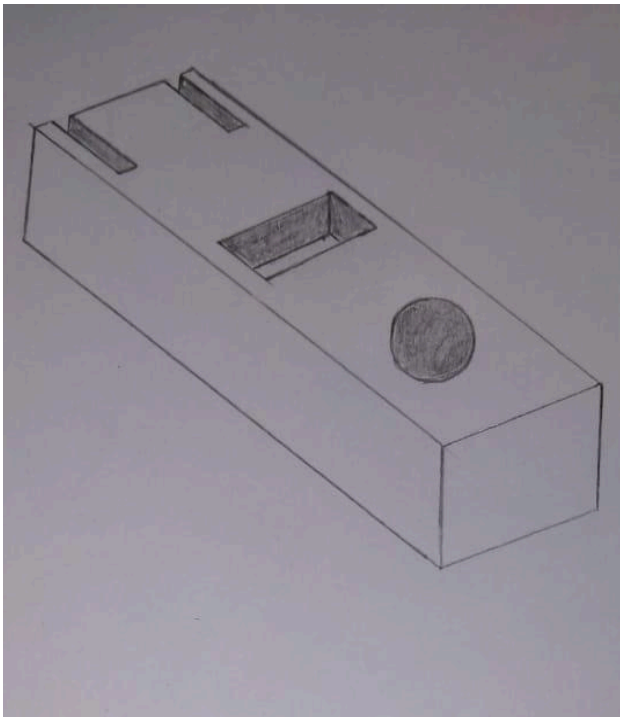


Fig 7.4

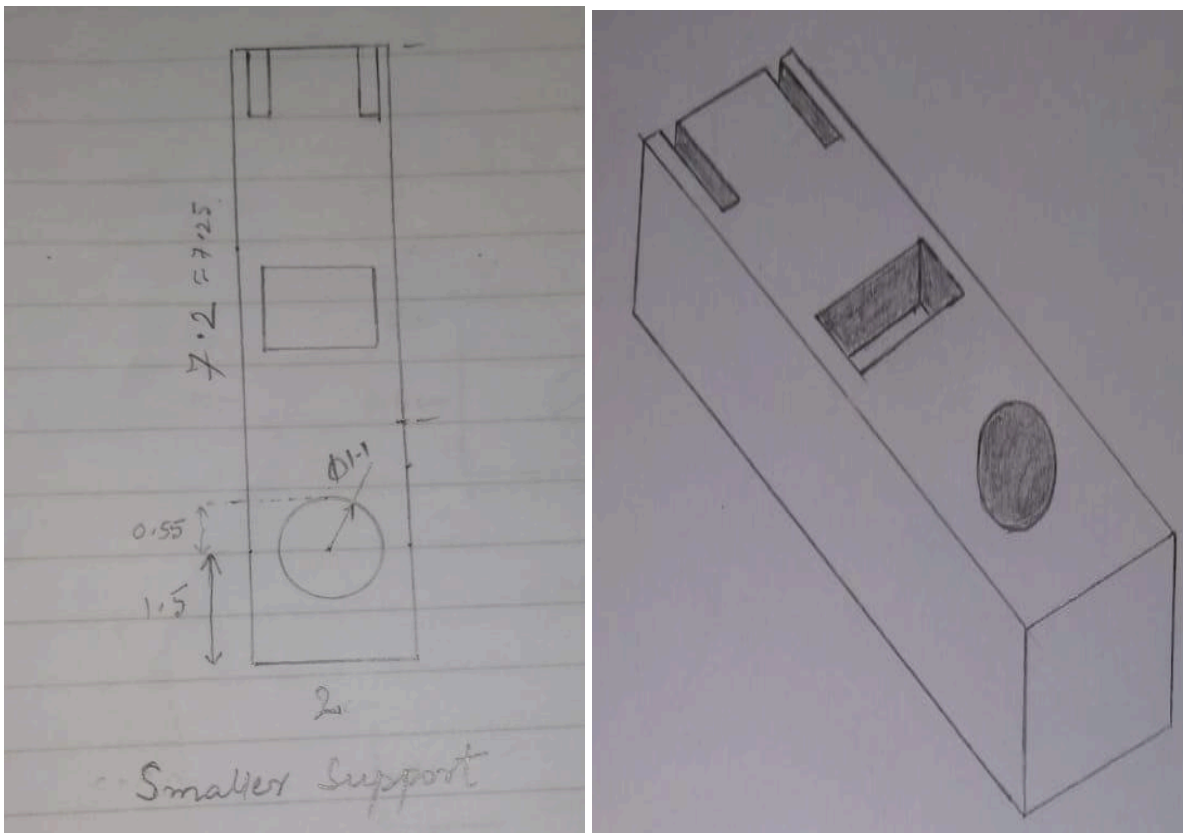

7.2 ≈ 7.25
Φ1.1
0.55
1.5
2
Smaller Support

Fig 7.5

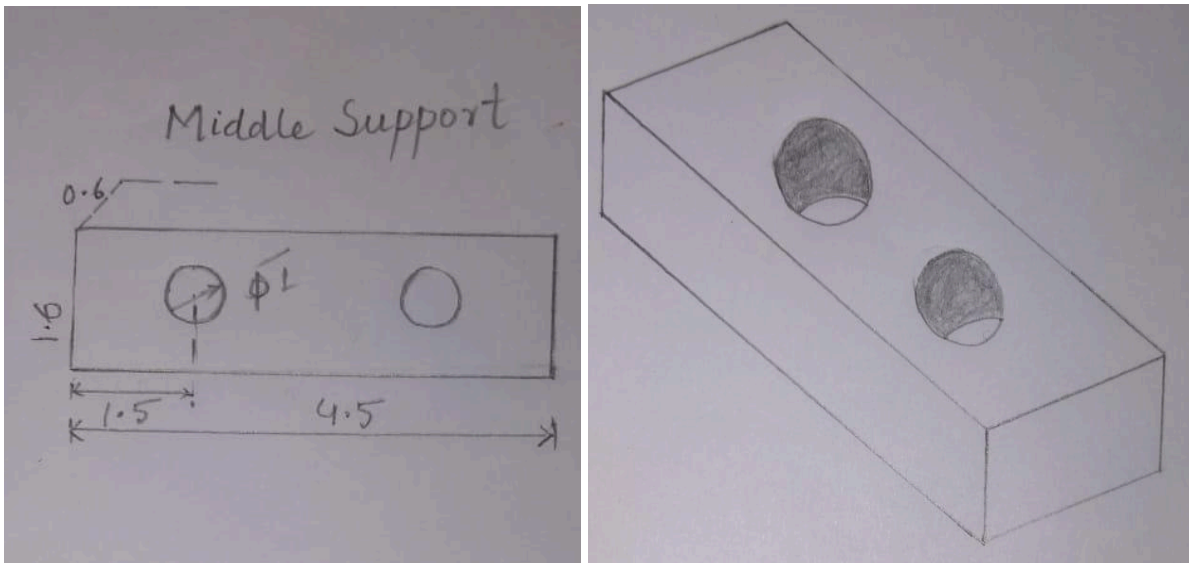
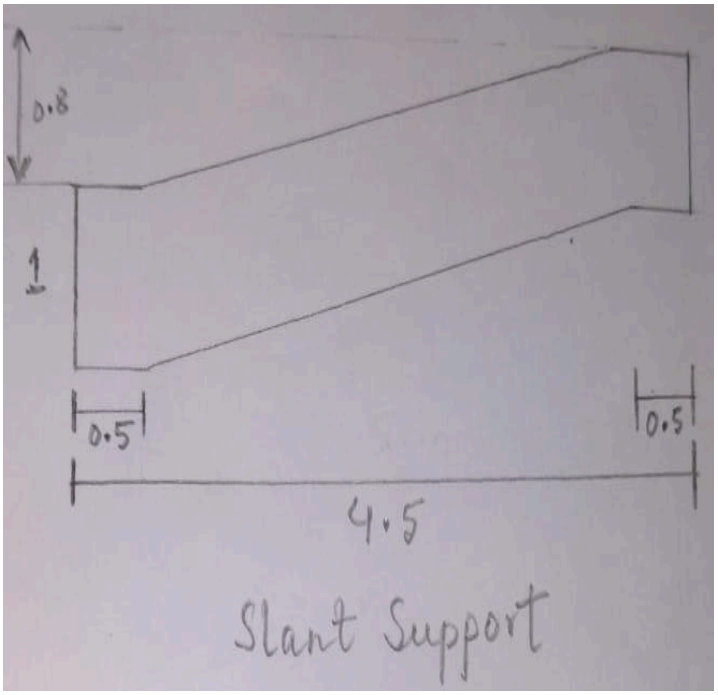

Middle Support
0.6
Φ1
1.6
1.5
4.5

Fig 7.6



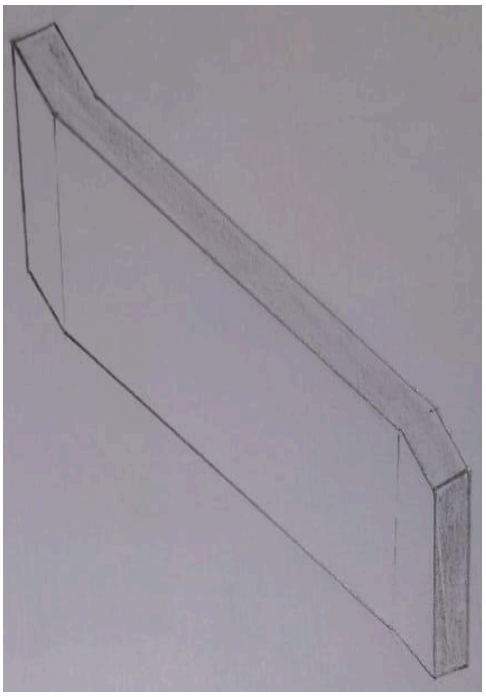


Fig 7.7

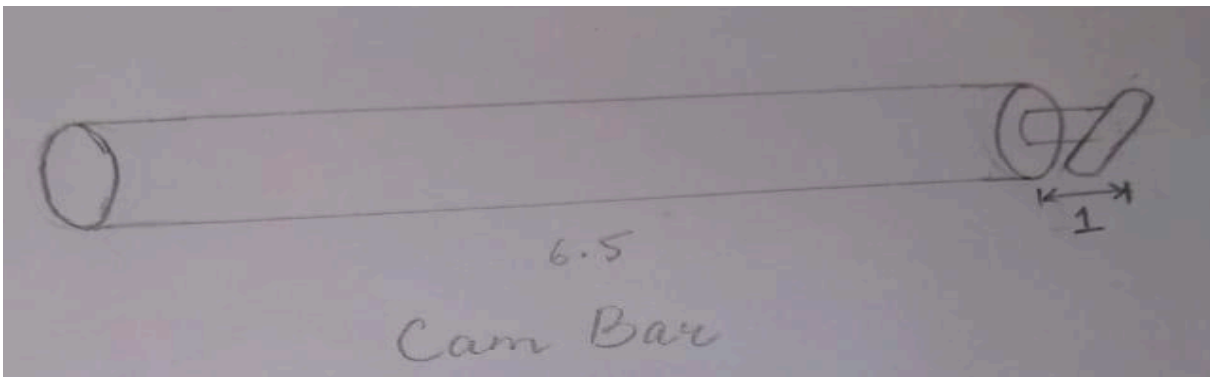


Fig 7.8

7.2 Modelling on SolidWorks

For modelling and assembling of all the components required for ***Synchronized cam and follower***; SolidWorks 2019 software is used.

A. Part Modelling

Step 1: Open SolidWorks 2019

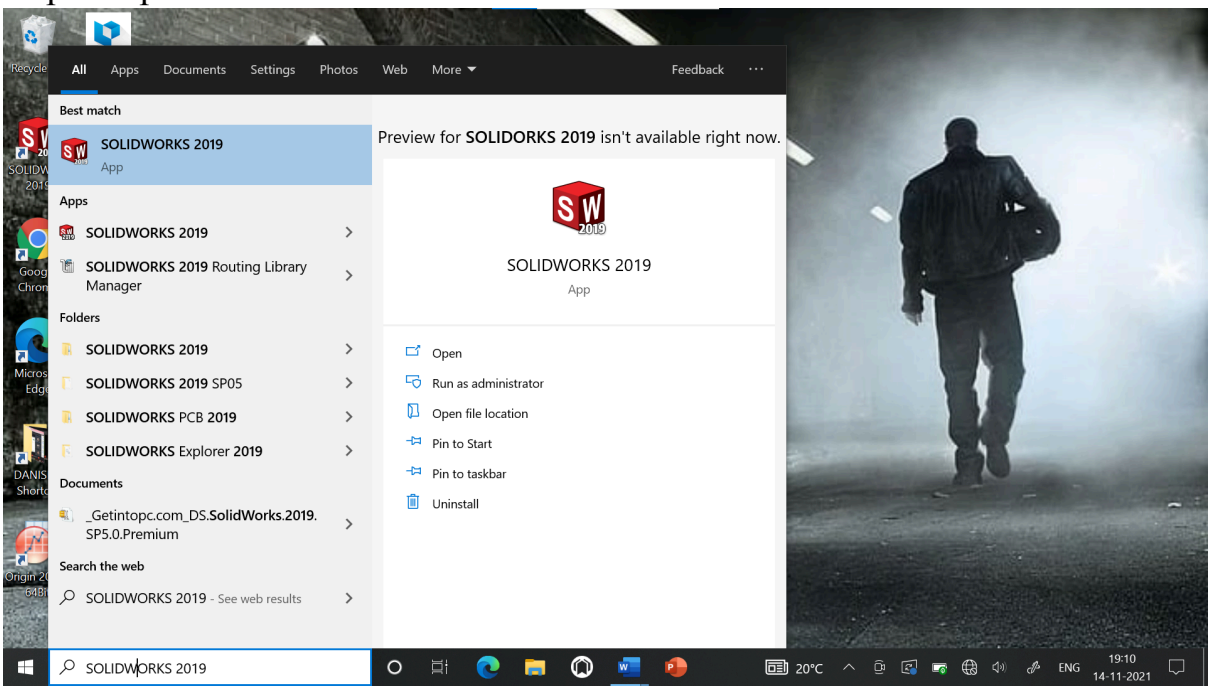


Fig 7.9

Step 2: Choose new part and press OK

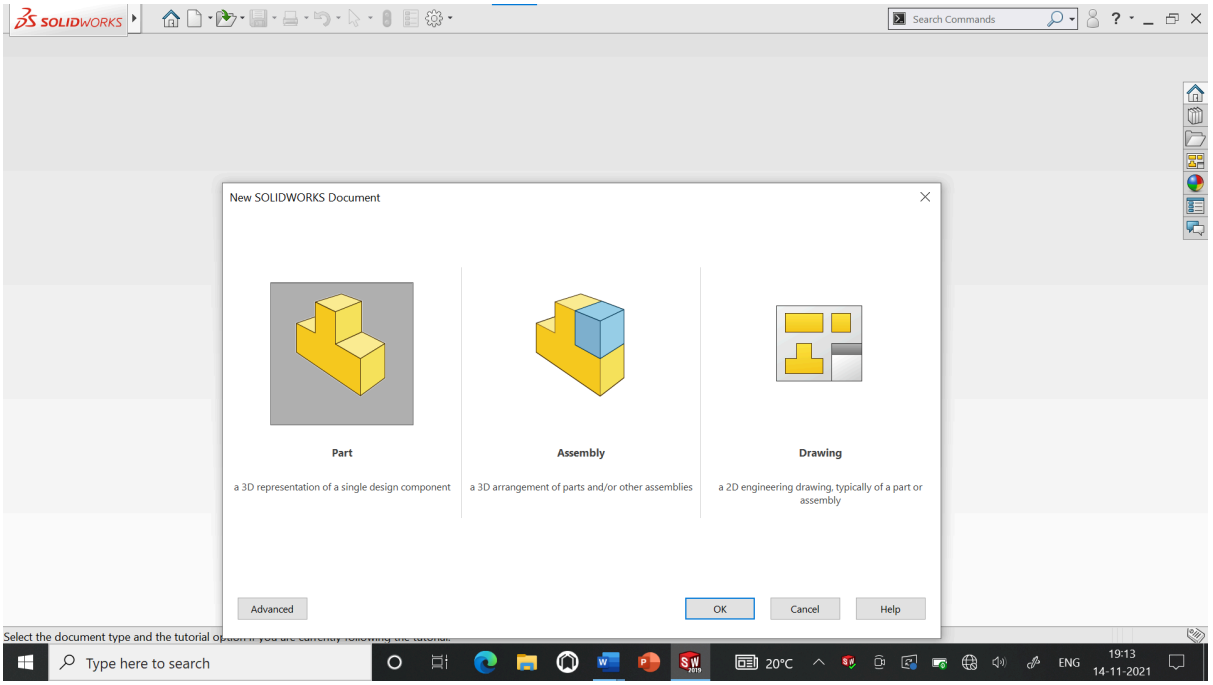


Fig 7.10

Step 3: Select right plane > Click on sketch > Draw sketch according to selected dimensions

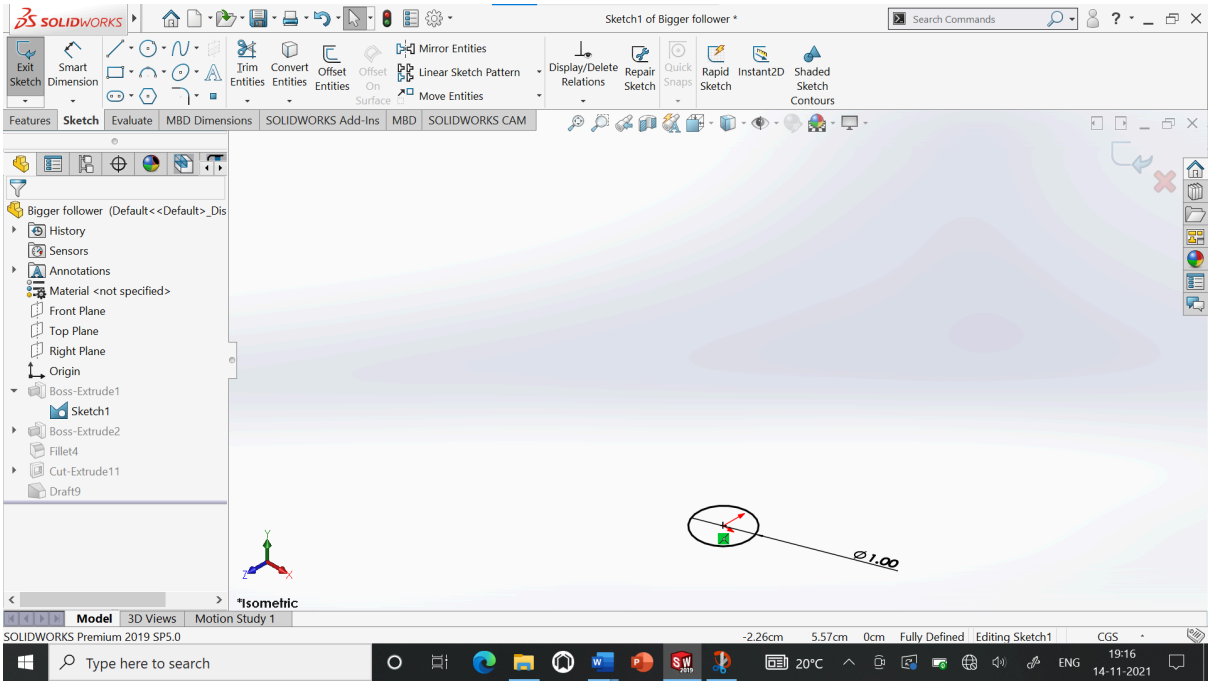


Fig 7.11

Step 4: Extrude the sketch by required dimensions

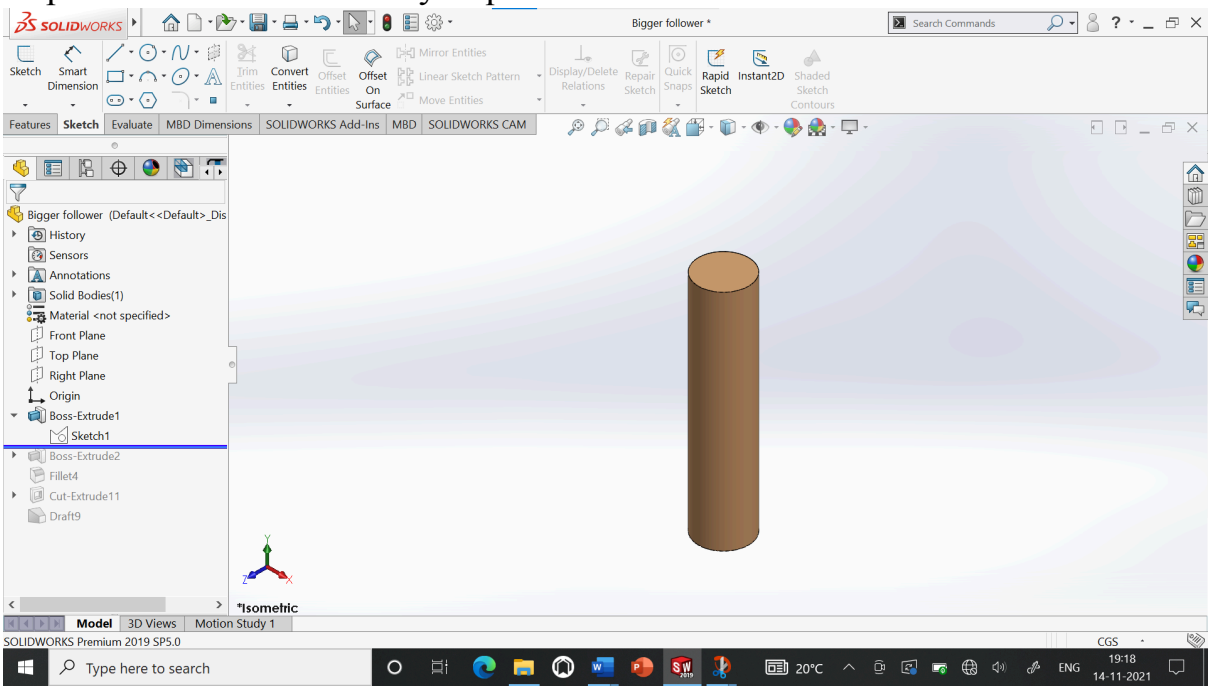


Fig 7.12

Step 5: Draw other features as defined and save file as ‘Bigger follower’

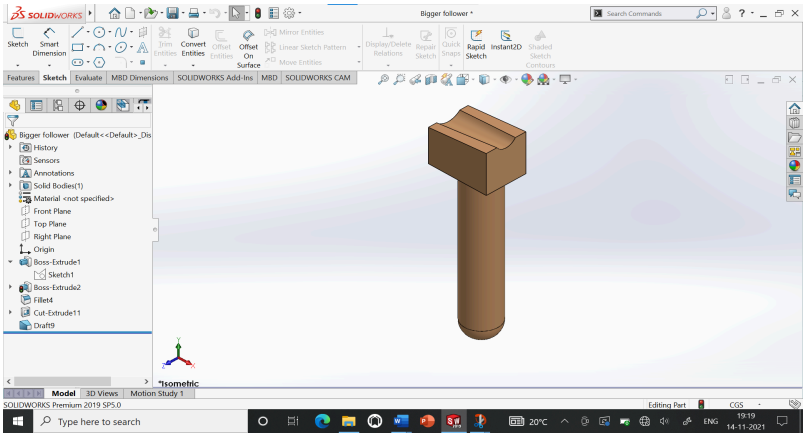


Fig 7.13

Bigger follower:

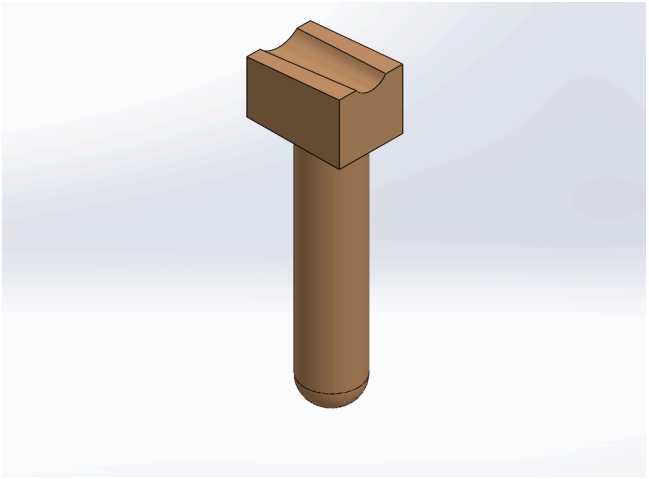


Fig 7.14

Smaller Follower:

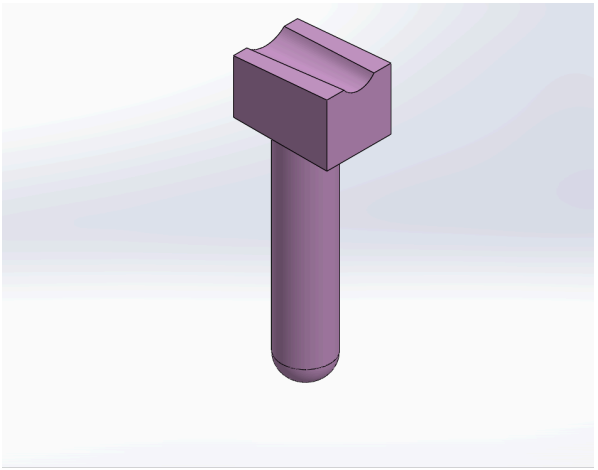


Fig 7.15

Bigger Side Support:

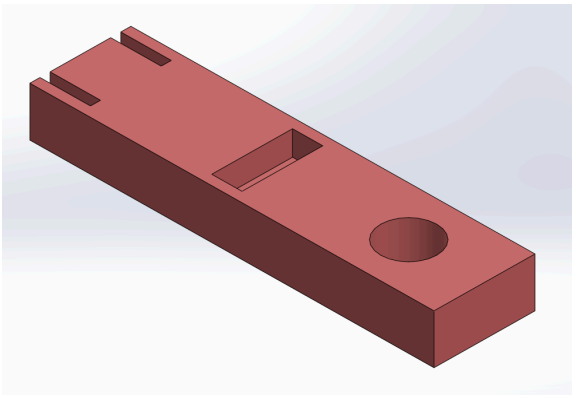


Fig 7.16

Smaller Side Support:

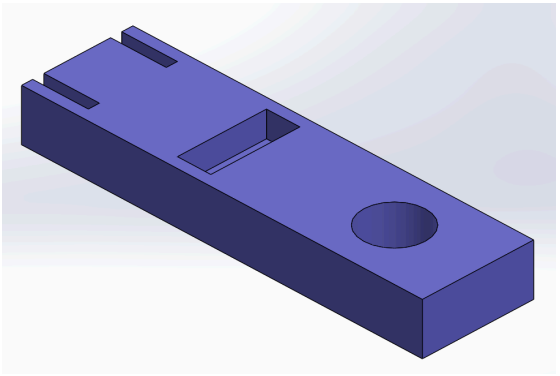


Fig 7.17

Middle Support:

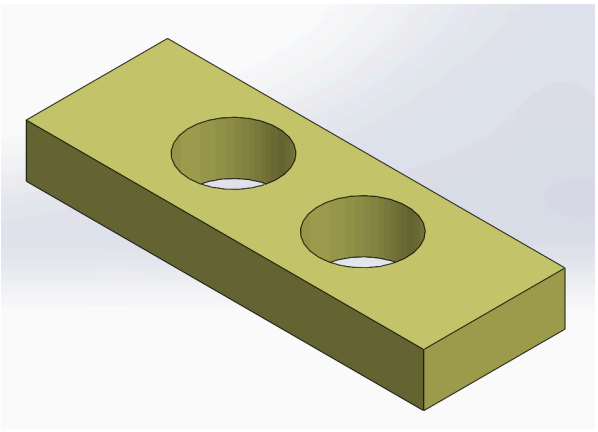


Fig 7.18

Slant Support:

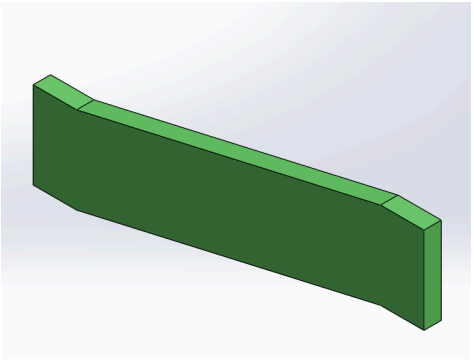


Fig 7.19

Cam Bar:

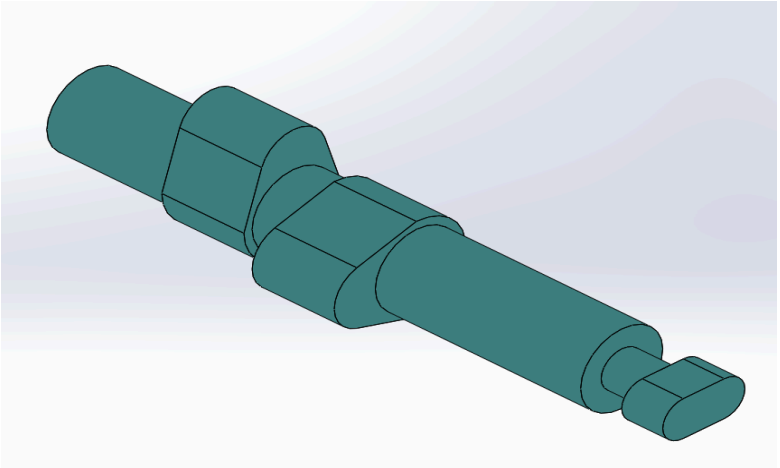


Fig 7.20

B. Assembly

Assembly is done in SolidWorks 2019. This step is not compulsory for AM process but very important in the view of design validation. By doing assembly we can check the final product for fits and interferences. This step helps in reducing errors which might occur due to wrong dimensions of components.

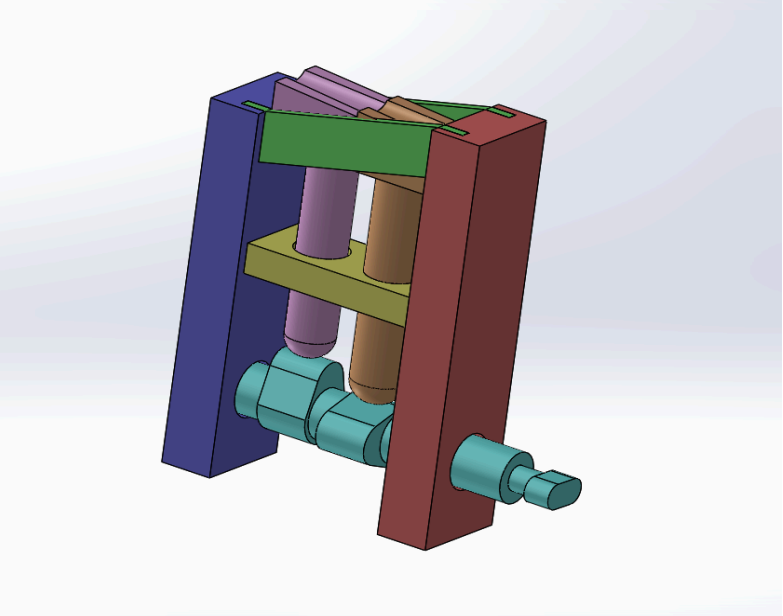


Fig 7.21

7.3 Conversion to STL File

The STL is the standard file format used worldwide for 3D Printing. STL stands form **'Standard Triangle Language' (OR) 'Standard Tessellation Language'**. STL files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. An STL file describes a raw, unstructured triangulated surface by the unit normal and vertices of the triangles using a three-dimensional Cartesian coordinate system.

STL file can be represented in both ASCII and Binary format but Binary is more common because they are more compact.

All modern CAD software have ability to convert their native file into STL format.

In SolidWorks 2019, for saving file in STL follow the following process File > Save As >STL

Options > Choose output format > Enter values of Deviation and Angle > OK

Selected values of tolerance are:

a. Deviation = 0.0045 mm
b. Angle = 5 deg

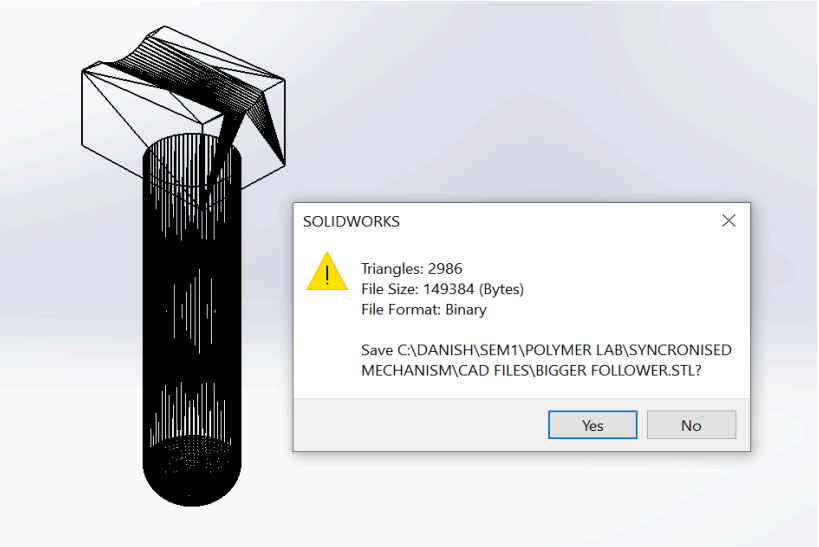


Fig 7.22

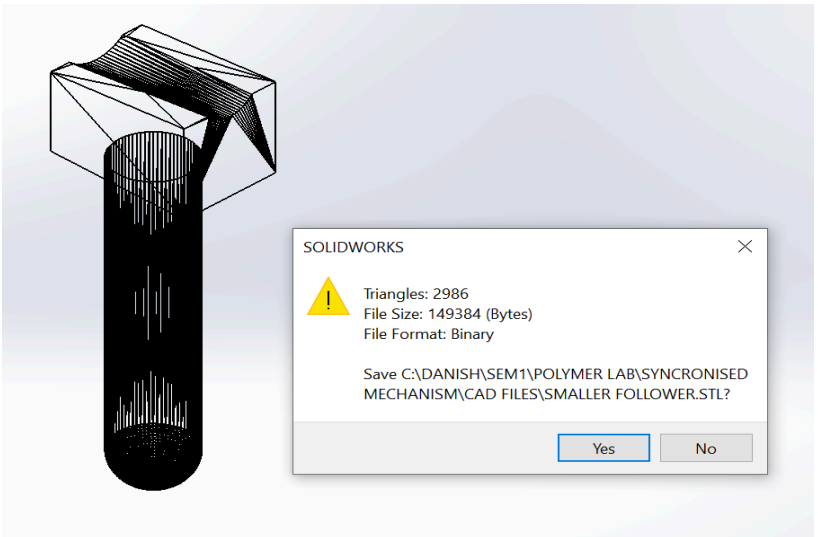


Fig 7.23

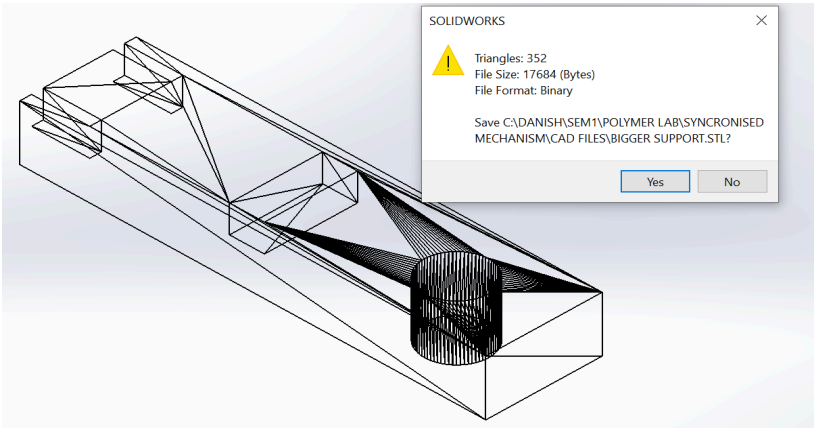


Fig 7.24

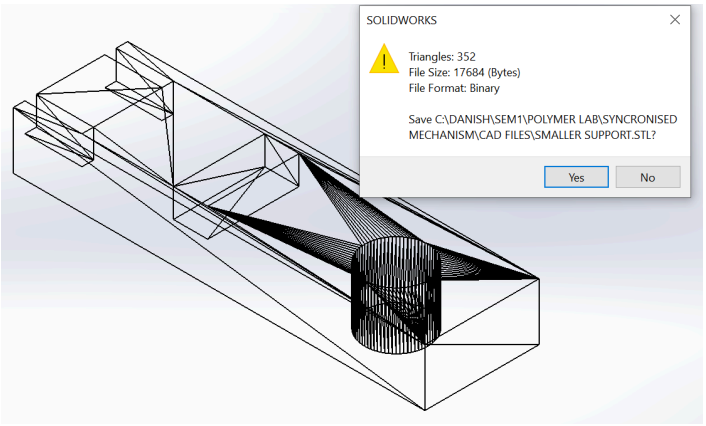


Fig 7.25

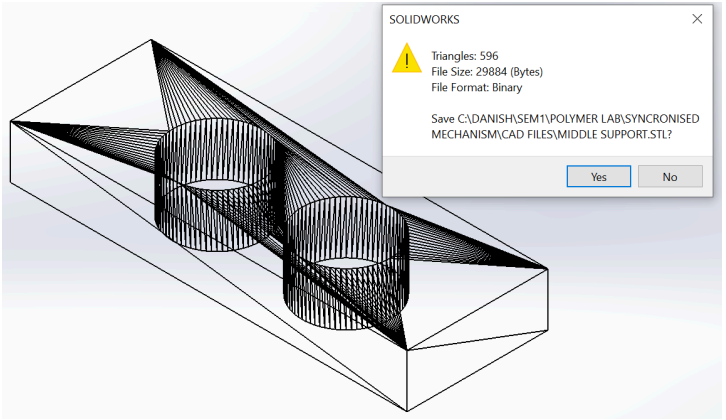


Fig 7.26

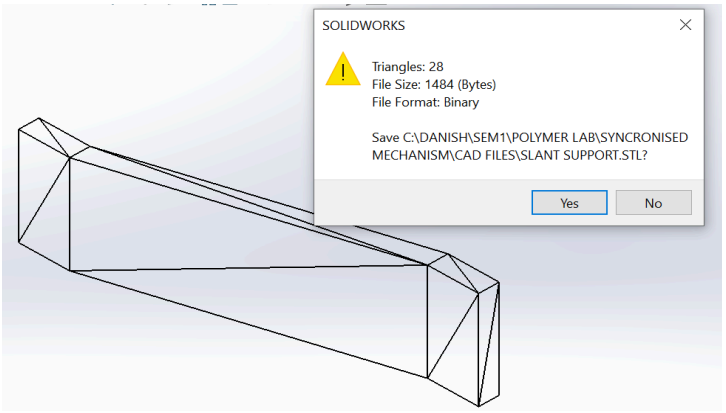


Fig 7.27

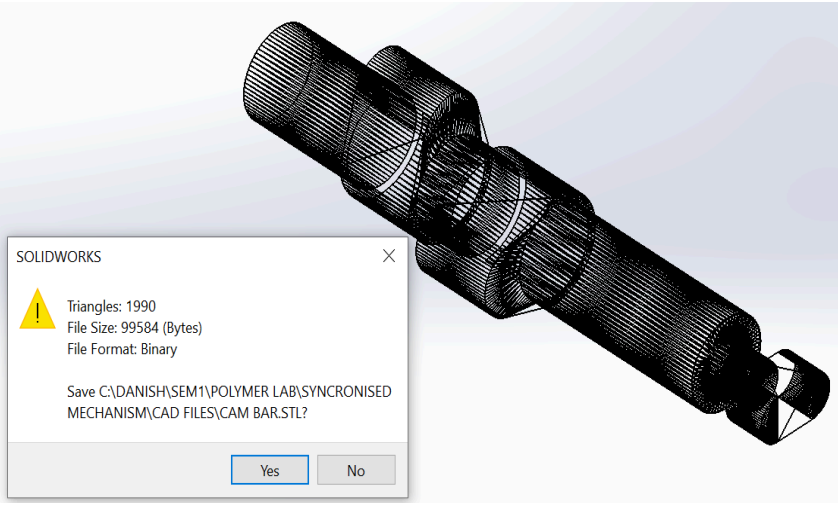


Fig 7.28

7.4 Correction of STL Files using Magics software

Magics software has been used for correction of stl files. Using this software we can automatically correct our stl files.

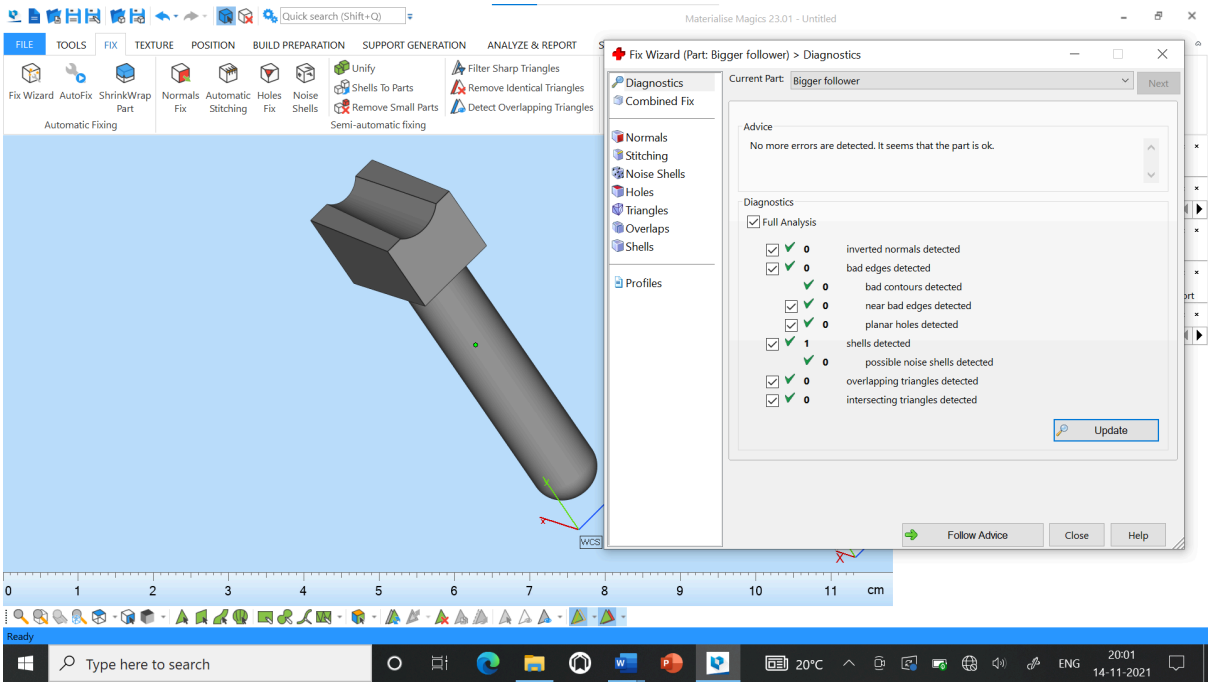


Fig 7.29

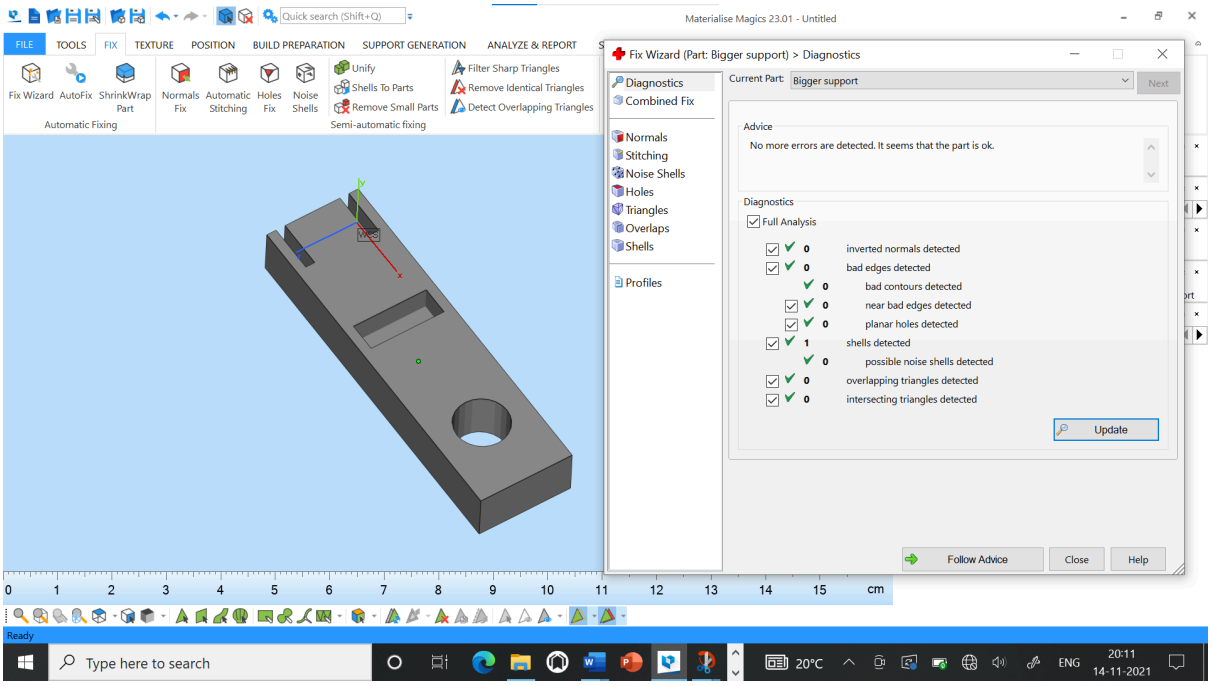


Fig 7.30

30

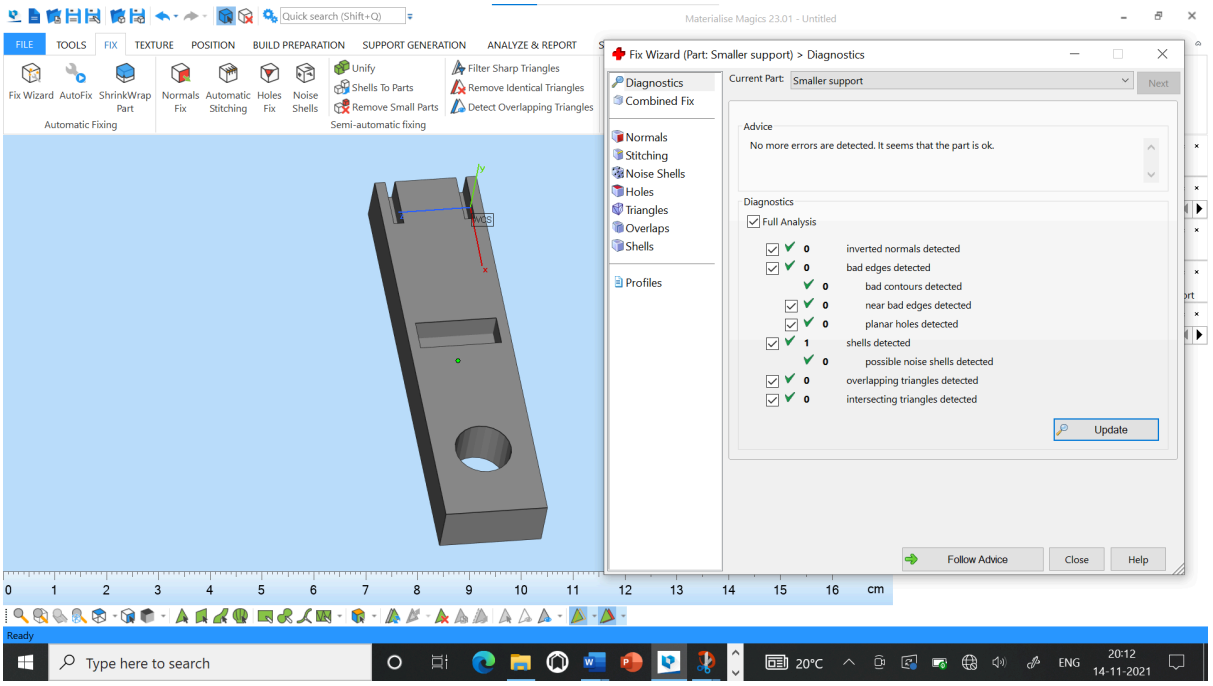


Fig 7.31

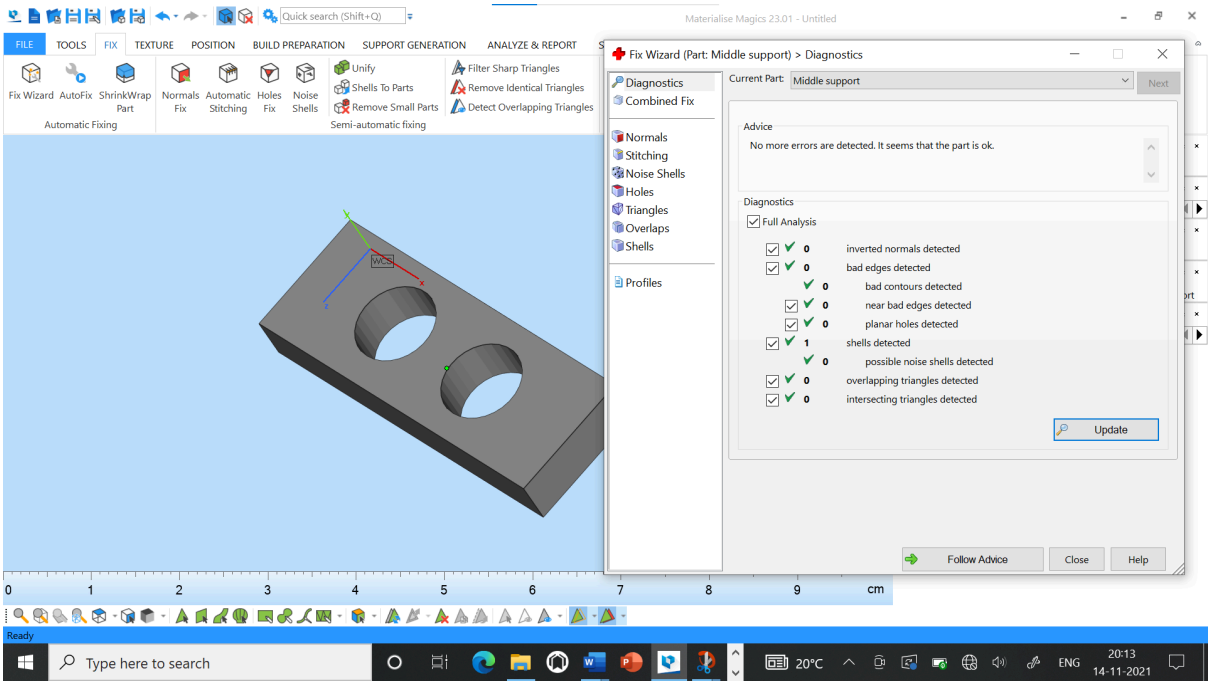


Fig 7.32

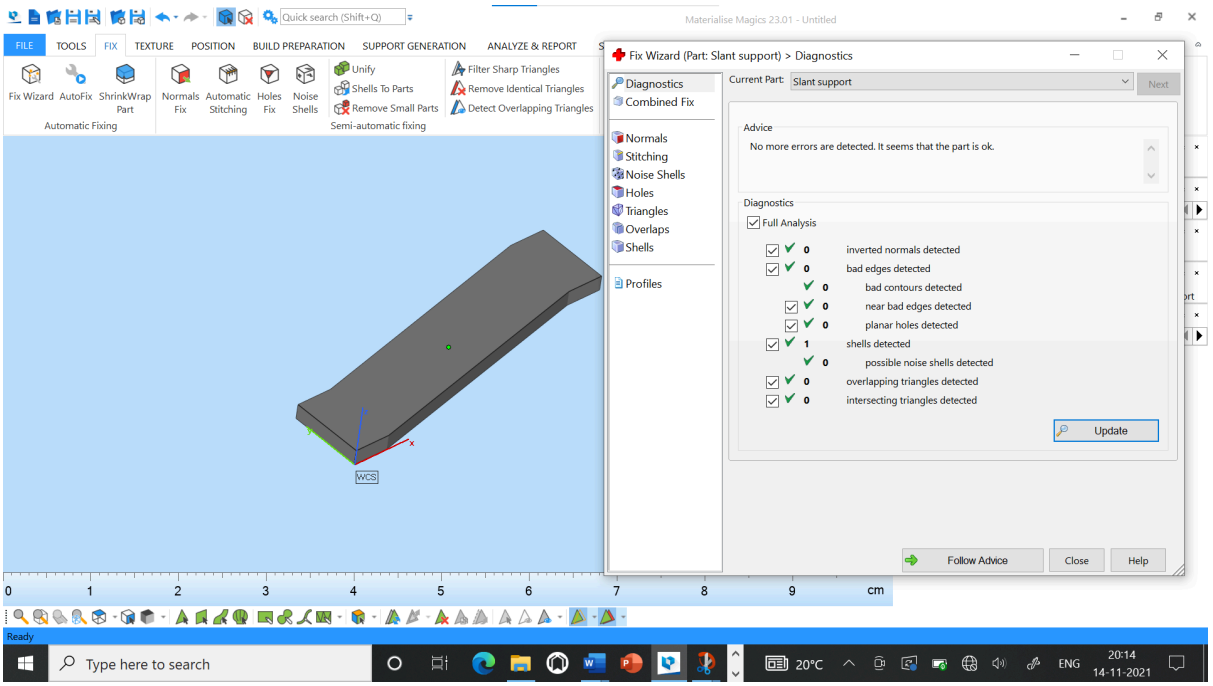


Fig 7.33

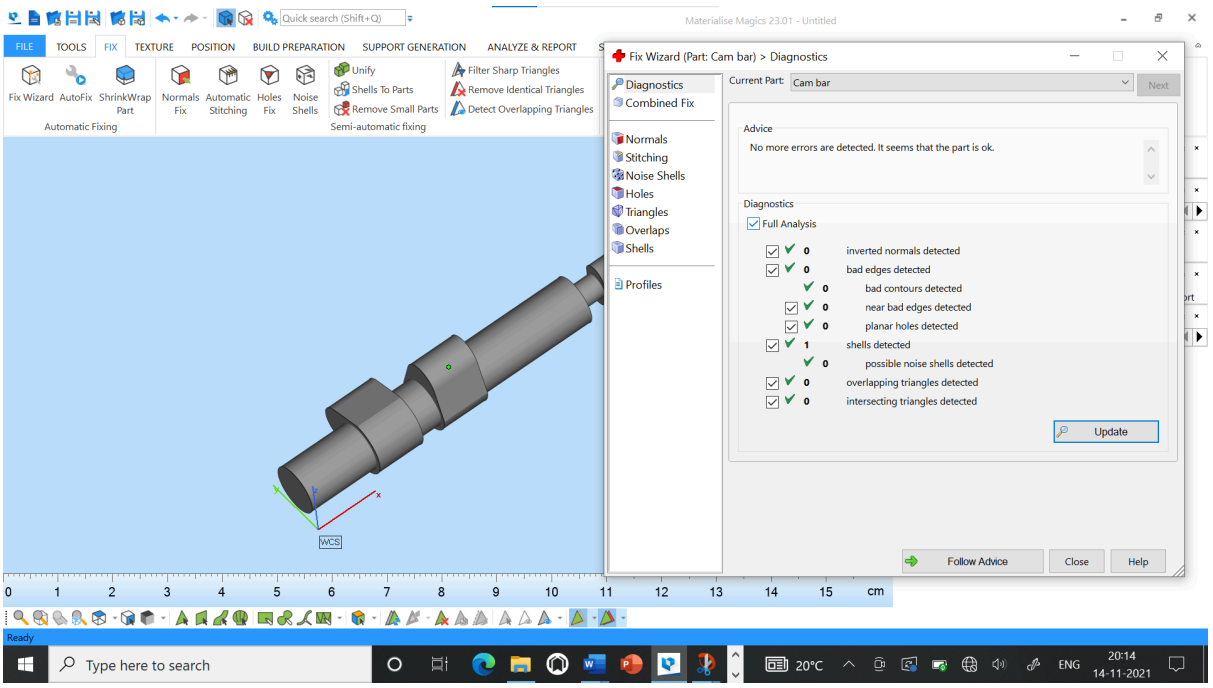


Fig 7.34

7.5 Slicing of STL file on CURA software

Slicing is the process in which 3D object model in converted to specific instructions for printer. Particularly object in STL format is converted to printer commands in G-Code format.

Slicing software divides object into number of flat layers followed by describing these flat layers in terms of movement of extruder in plane to trace and fill them.

Slicer program allows the calibration of printer settings using following inputs:

Layer Height

Infill Density

Fill Pattern

Print Speed

Travel Speed

Platform Temperature and many others.

In this project CURA software is used for slicing operation. Steps involved are as follow:

Step 1: Open CURA

Step 2: Load > Select STL file of component

Step 3: Process parameters > Input all the parameters

mentioned above as per requirement > OK

Parameters selected for this product are:

Layer thickness=0.1mm

Infill density=100%

Print speed=50mm/min

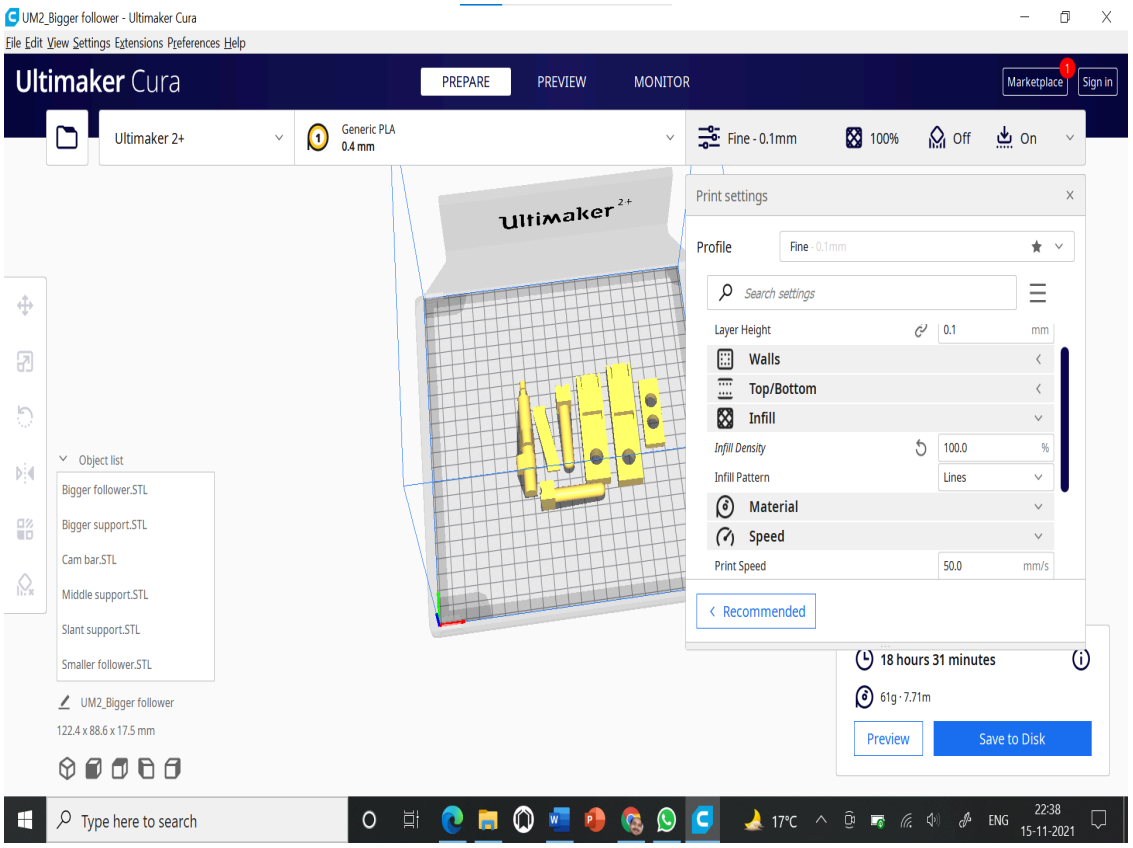


Fig 7.35

So, it will take 18 hrs 31 min to completion of one whole assembly print, and the mass required will be 61 gms.

Also in one build volume a total of whole **3** assembly parts can be printed.

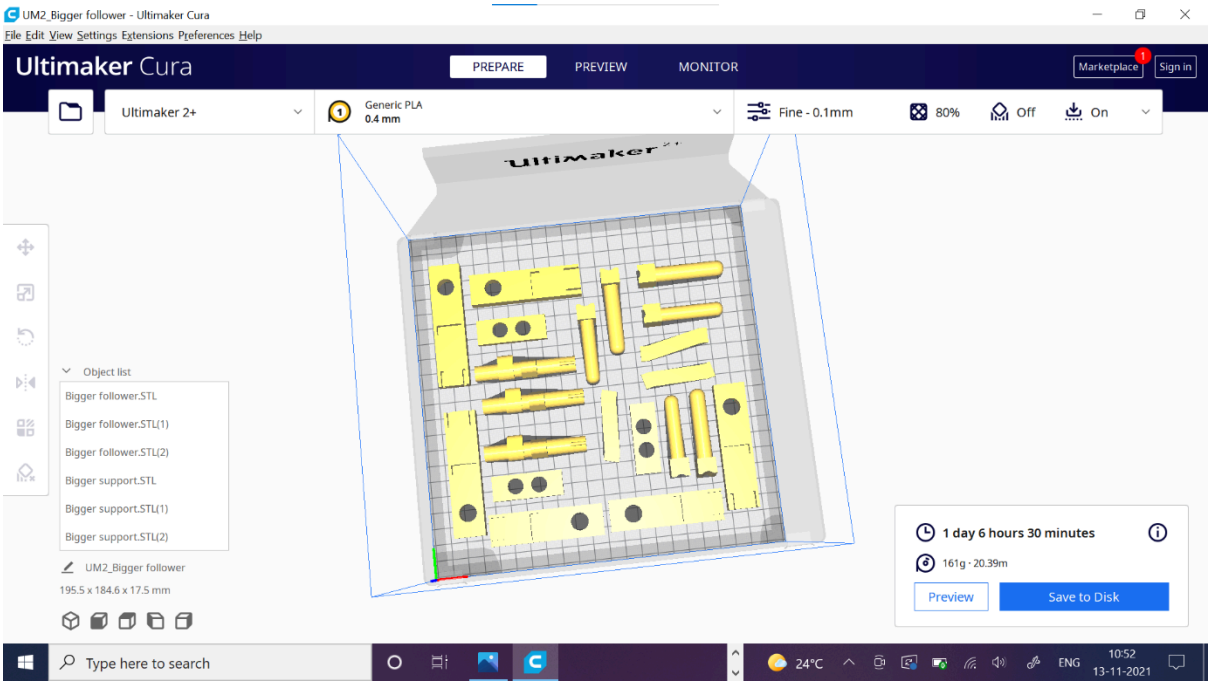

UM2_Bigger follower - Ultimaker Cura
File Edit View Settings Extensions Preferences Help
Ultimaker Cura
PREPARE
PREVIEW
MONITOR
Marketplace
Sign in
Ultimaker 2+
Generic PLA
0.4 mm
Fine - 0.1mm
80%
Off
On
Object list
Bigger follower.STL
Bigger follower.STL(1)
Bigger follower.STL(2)
Bigger support.STL
Bigger support.STL(1)
Bigger support.STL(2)
UM2_Bigger follower
195.5 x 184.6 x 17.5 mm
1 day 6 hours 30 minutes
161g · 20.39m
Preview
Save to Disk
Type here to search
24°C
ENG
10:52
13-11-2021

Fig 7.36

8. DISPLACEMENT DIAGRAM

A cam is to give following motion to a knife-edge follower:

a) Outstroke during 90^0 of cam rotation.

b) Return stroke during 90^0 of cam rotation.

c) Dwell for remaining 180^0 of cam rotation.

The stroke of follower is 4mm and minimum radius of cam is 12mm.

Follower moves with uniform velocity during both outstroke and return stroke.

So, using above data-

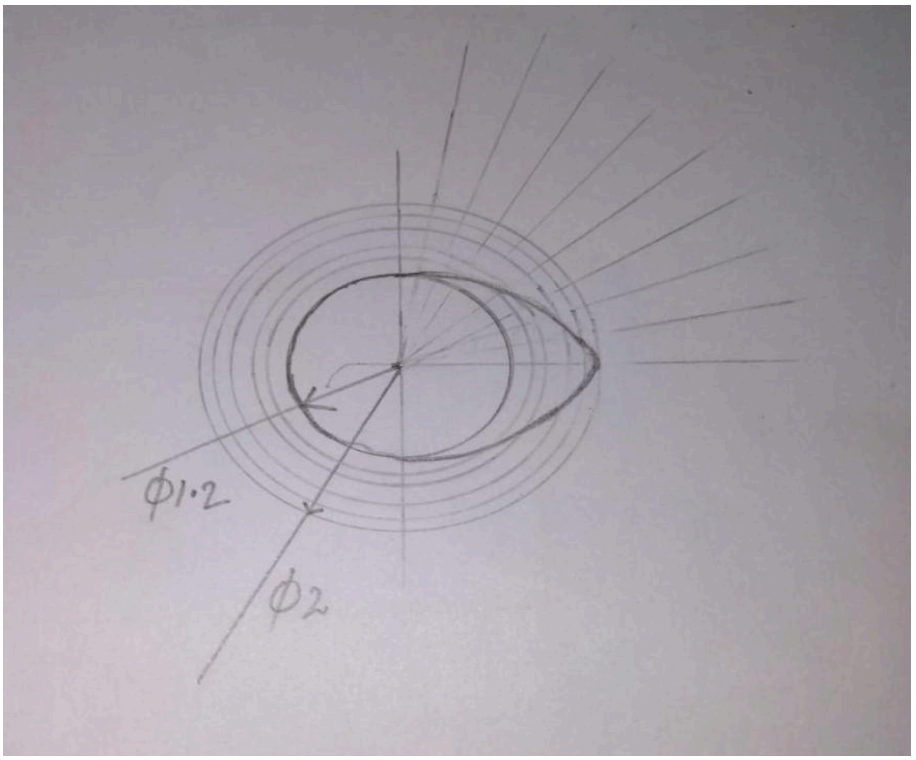


Fig 8.1 Design of cam

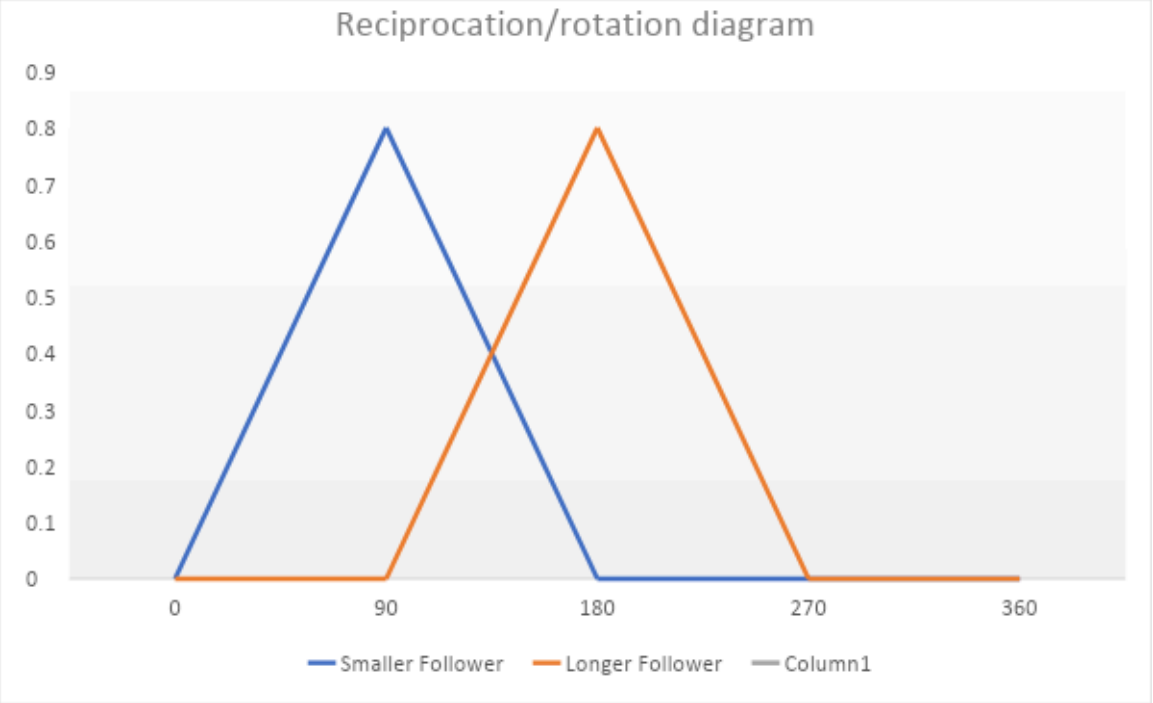


Fig 8.2 Displacement diagram

9. COST ANALYSIS OF SYNCHRONIZED CAM AND FOLLOWER

Total Cost = Fixed cost + Variable cost

$$C_{\text{total}} = C_{\text{machine}} + C_{\text{labour}} + C_{\text{material}} + C_{\text{electricity cost}}$$

$$C\,machine = \frac{\frac{E}{10}+M}{\frac{NH}{T}}$$

Where,

E = Machine Purchase Cost (≩ 2lacs)

M = Maintenance Cost Per Year (13% of E) (≩ 26000)

H = Machine Working Time In Hours Per Year (4800 hrs)

N = No Of Components In One Build (3)

T = Time For One Build In Hrs (1day 6hrs 30min = 30.5 hrs)

C machine = $\left(\frac{\frac{200000}{10}+26000}{\frac{3*4800}{30.5}}\right)$ = ≩ 97.43

$$Clabour = \frac{W*(S+P)}{N}$$

W = Minimum Wage Per Hour (≩ 30/hr, 8 hr work day)

S = Setup Time (Usually between 3-4 mins)

P = Post Processing Time (5-10 secs/part)

N = No of Components In One Build

C labour = $\frac{30\times(1/15)}{3}$ = ≩ 0.67 /part

$Cmaterial = (M\ model \times C\ model) + (M\ support \times C\ support)$

Where,

M = Mass of material used

C = Cost per kg of respective material

In our case both support material and model material are same cost will be same for both.

$$Cmaterial = (M\ model + M\ support) \times C\ model$$

C material = (0.161×1000) = ≙ 161

Material required for one part= ≙ 53.67

*C electricity = Power consumed * Charge per unit*

Total Power consumed = Power*Running Time [Power = Voltage X current = 220 X 16 (W)]

= 220 X 16 X 30.5 = 107.36 kWh

HT I(A): Industry General			
11 kV	kVA	390	6.65
33 kV	kVA	390	6.15
132 kV and above	kVA	390	5.65

Table 9.1 Electricity rates in Warangal

C electricity = 107.36 * 6.15 = ≙ 660.24

Electricity cost for one part= ≙ 220.08

Cost	Value
$C_{machine}$	97.43
C_{labour}	0.67
$C_{material}$	53.67
$C_{electricity}$	220.08
C_{total}	371.84

Table 9.2 Total assembly cost

10. BREAK EVEN ANALYSIS

Total cost function = Fixed cost + Variable cost

Fixed cost=Equipment cost (E)+Overhead cost (O)(13.5% of E)

Variable cost=Cost per part, CPP

$$TC = E\times\left(1 + \frac{O}{100}\right) + CPP$$

Where,

E = Machine Cost

O% = Overhead Cost (13.5% of Equipment cost)

CPP = U (no of units) X cost of each build (≧ 371.84)

$$TC = 200000\times\left(1 + \frac{13.5}{100}\right) + U\times 371.84$$

Total revenue function= U × Selling Price

$$Selling\ price = Cost\ of\ part(1 + \frac{P}{100})$$

$$TSR = U\times(1 + \frac{P}{100})$$

Fixing price of our product at 500 with approximately 135% profit margin(P)

Where,

P = profit percentage

U = no of units

TRF = U X 500

At breakeven point, TRF = TCF

So, from TCF and TRF, we get no of units (U) = 1771.22 ~ 1772 units

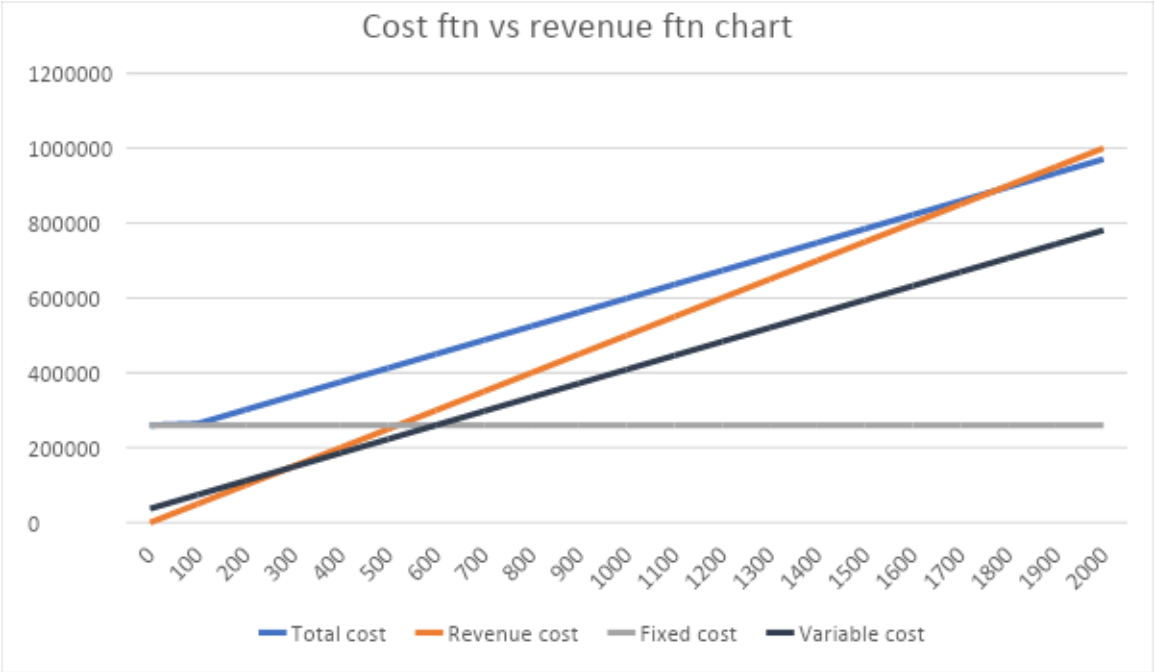


Table 10.1 Cost ft^{n} vs revenue ft^{n} chart

11. POST PROCESSING

- Parts require clean up before they are ready to use.
- Supporting features must be removed which may involve chemical or thermal treatment
- Use of infiltrations or surface coating can be done to improve strength of final part.
- This process might take some time depending upon condition of build part.

14. CONCLUSION

- We started with learning Different AM related software and parallelly done brainstorming for Lab related project.
- Synchronized Cam and follower is finalized as the project.
- It is easier to produce the assembled parts with FDM.
- It might be costlier than conventional manufacturing.
- Cost analysis and breakeven analysis is done, 1772 units for break even point.
- We can display it as a prototype for replacement of conveyor belt assembly for transportation lines in industry.
- It can be concluded that Polymer printing can be used for prototyes and low strength materials.

15. REFERENCES

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4. Physical and mechanical properties of PLA, and their functions in widespread applications, Shady Farah, Daniel G. Anderson, Robert Langer