A Project Report on Prosthetic arms via Additive Manufacturing

Design Process Planning and Management
J Component - Project Report

MEE 3502

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Submitted to

School of Mechanical Engineering

VIT University, Vellore – 632 014

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1.Abstract

This report presents the making of Prosthetics arms using additive manufacturing. Bionic prosthetic arms are rapidly evolving. An in-depth knowledge of this field of medicine is currently only required by a small number of individuals working in highly specialist units. However, with improving technology it is likely that the demand for and application of bionic hands will continue to increase and a wider understanding will be necessary. We review the literature and summarize the important advances in medicine, computing and engineering that have led to the development of currently available bionic arms prostheses. The bionic arms of today have progressed greatly since the hook prostheses that were introduced centuries ago. We discuss the ways that major functions of the human hand are being replicated artificially in modern bionic arms. Despite the impressive advances bionic prostheses remain an inferior replacement to their biological counter-parts. Finally, we discuss some of the key areas of research that could lead to vast improvements in bionic arms functionality that may one day be able to fully replicate the biological hand or perhaps even surpass its innate capabilities.

2. Aim, objectives and scope: -

Aim: To develop Prosthetics for the differently abled people at affordable costs.

Objectives: To use SolidWorks to develop a prototype and use 3D printing to manufacture them at an affordable cost, having reduced the material cost via Topology Optimization.

Scope:

- Development of A hand prosthetic which substitutes a full arm.
- Rapid manufacturing of prosthetics that have a common design which make production cheaper and less time consuming.
- Materials Planned to be Used: Plastic, Titanium, Silicone, Aluminum

2.1 Tools and method of approach: -

Tools: SolidWorks, Cura

Method of approach: Develop the general prosthetic design on SolidWorks and tweak lengths or requirements as per the customer and send themfor 3D Printing.

- Requirement Gathering via surveys with patients at select hospitals/Clinics and general public.
- Feasibility and Cost benefit Analysis
- Designing prototypes and produce the prototype and test the prototype.
- Improve Design based on feedback and test results.
- Start Supplying custom prosthetics to customers as per their requirements.

2.2 Benefits:

- No skin problems
- Stable and safer standing and sitting
- A sense of the artificial limb belonging to the body
- Easy and quick attachment and removal
- Improved quality of life

3 . Literature Review: -

Realistic Electric Prosthetic Hand Created with a 3D Printer

Most of the forearm amputees use cosmetic prosthetic hands that provide a realistic appearance like hands. Their light weight is less burden on users. However, since they have no function to grasp objects, the users are likely to feel inconvenient in their daily living. Myoelectric prosthetic hands provide an appearance with five fingers and a grasping function to forearm amputees. However, they have problems in weight, appearance, and cost. This paper reports on the Rehand, a realistic electric prosthetic hand created with a 3D printer. It provides a realistic appearance that is same as the cosmetic prosthetic hand and a grasping function. A simple link mechanism with one linear actuator for grasping and 3D printed parts achieve low cost, light weight, and ease of maintenance. A simple link mechanism with one linear actuator for grasping and 3D printed parts achieve low cost, light weight, and ease of maintenance. An evaluation using the SHAP test demonstrated that an amputee was able to operate various abstract objects and do everyday activities with it.

Expected outcome: Expected outcome of our project will is a useable drawing and simulation of a prosthetic arm which will be different from products available in market.

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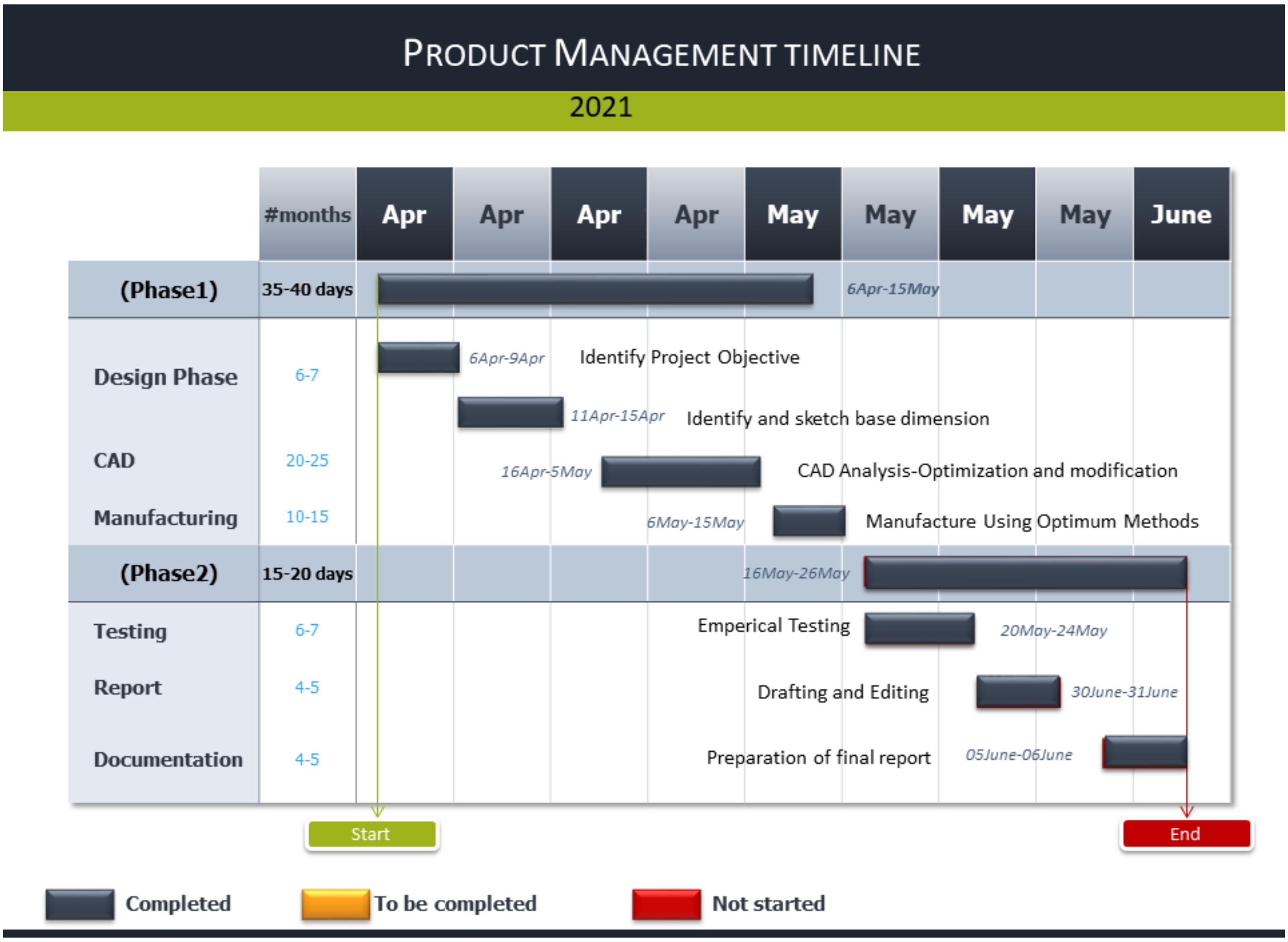
3.1 Surveys conducted: -

- A google form was created to understand the demand for Prosthetics and the overall exposure to this field for the common public as well as awareness about this field. One of the problems has always been affordability just because of how untapped this field is.
- the prosthetics market has a chance to grow and the younger/older generation is ready to welcome it with more or less open arms. Things will definitely improve with proper attention given to this field and not written off just because it looks odd.
- With any new field, it's always met with opposition. Even when theories were created, they always met opposition. This opposition is what helped the theories to improve and become legacies on which most of the world's devices run on. Implantable Technology is also a new field. The more opposition it faces, the better it's chances of becoming a revolution in medical science.
- People in general are willing to spend Rs15000 to 45000 and wish for lightweight and durable prosthetics that don't stand out and do not require too much of maintenance.

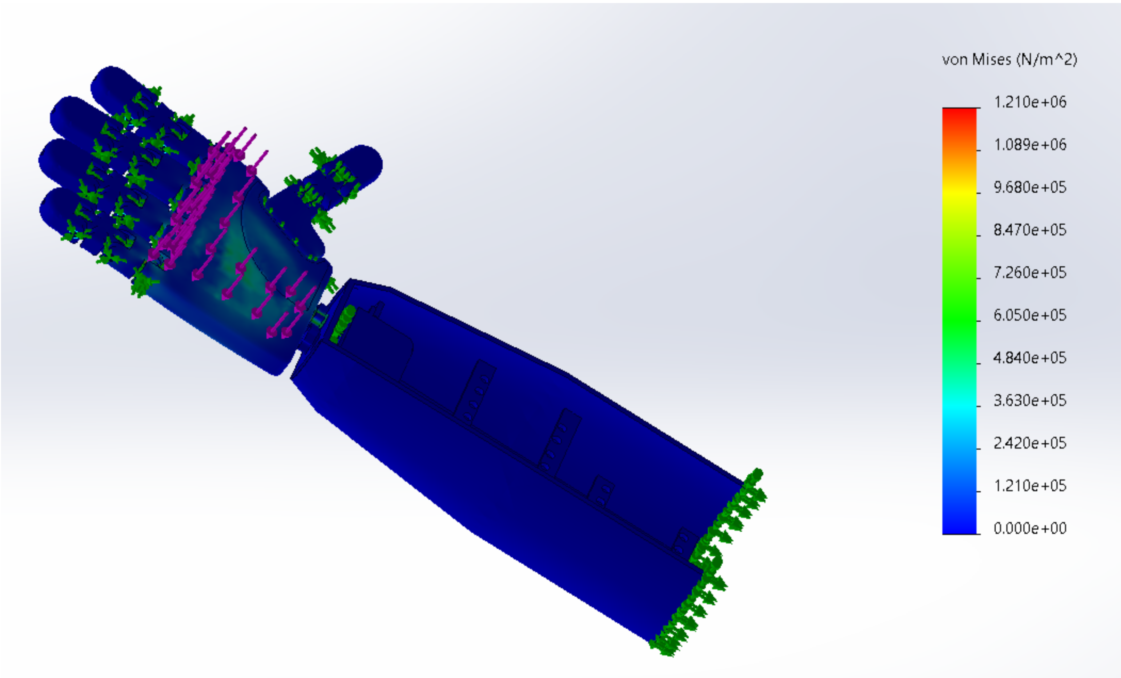
3.2 Gantt Chart: -

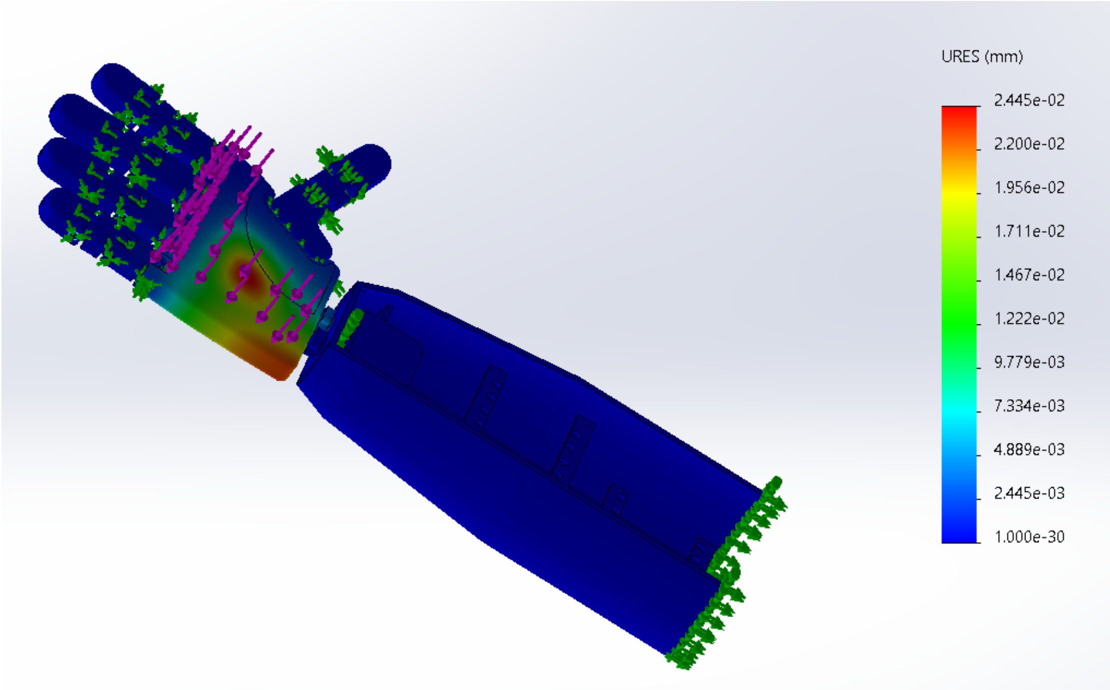


4. Model Overview

Prosthetic Arm CAD on SolidWorks: -

4.1 Stress Analysis




URES (mm)
2.445e-02
2.200e-02
1.956e-02
1.711e-02
1.467e-02
1.222e-02
9.779e-03
7.334e-03
4.889e-03
2.445e-03
1.000e-30

5. Industry Experts Consulted: -

➢ **Vendor 1: -**

- We have tried contacting this Mumbai based 3D Vendor Services **"NAAKASHI 3D Print".** We have sent him the **.stl** file and told him about the material we want to use and we asked him to forward the price quotation for the same. We got the price quotation from him with the approximate price estimate with the delivery date.
- **Parameters Considered while dealing with Vendor 1:**
  - 3D Printing parameters: Layer Height- 250 microns, 30% Infill
  - 3D Printing Material and Technology: FDM /PLA
- 3D Printing Charges: INR 4,500/- + 18% GST
- Total Amount: 5,310/-
- **Technology Used -FDM:**

  One of the most widely and easily used technologies under Additive Manufacturing is Fused Deposition Modelling. FDM technology works with production grade thermoplastics to build strong, durable and dimensionally stable outputs. This technology is simple to use and user friendly.

NAKKASHI 3D PRINT

NAKKASHI 3D PRINT
Shop No.D/43, Shree Sharman, Kanakia,
Laxmi Park, Mira Road,Mumbai- 401107
nakkashi3dprint@gmail.com
GSTIN:27BLGPV6186G1ZH

Quotation

Invoice : NAK_013
Date : 19/05/2021

Place Of Supply : Delhi

Bill To
VIT UNIVERSITY
Contact person :Akash

Ship To

Sr. No	Item & Description	HSN /SAC	Qty	Rate	CGST %	CGST Amt	SGST %	SGST Amt	Amount
1	**Prosthetic arm** 3d Printing (FDM)	998920	1	4,500.00	9%	405.00	9%	405.00	4,500.00

Total In Words
Rupees Five Thousand Three Hundred Ten Only

Sub Total	4,500.00
CGST (9%)	405.00
SGST (9%)	405.00
Total	5,310.00

Looking forward for your business.

Payment Detail
Name: Nakkashi 3d print
Ac.No: 920020054268480
IFSC : UTIB0003392
Branch: Kandivali
Pincode : 400101

For Nakkashi 3D Print

Authorized Signatory

Terms
1.Payment to be received 50% in advance and Balance 50% before Delivery.
2.This is just as estimated price quote and may vary at a margin between 10-15% as per the design.
3.Quotations are valid for 15 days from the date of the quotation and needs to be confirmed via E-mail.

- **<u>Vendor 2: -</u>**
  - We have tried contacting this Delhi based 3D Vendor Services **"3D Paradise".** We have sent him the **.stl** file and told him about the material we want to use and we asked him to forward the price quotation for the same. We got the price quotation from him with the approximate price estimate with the delivery date.
  - **<u>Parameters Considered while dealing with Vendor 1:</u>**
    - 3D Printing parameters: Layer Height- 250 microns, 30% Infill
    - 3D Printing Material and Technology: FDM /PLA
  - 3D Printing Charges: INR 1,533/- + 18% GST
  - Total Amount: 1,808.94/-
  - **<u>Technology Used -FDM:</u>**

    One of the most widely and easily used technologies under Additive Manufacturing is Fused Deposition Modelling. FDM technology works with production grade thermoplastics to build strong, durable and dimensionally stable outputs. This technology is simple to use and user friendly.

3D PARADISE

3D Paradise
07AABFZ9058J1ZL
www.paradise-3d.com
hello@paradise-3d.com
8861925181

H-43, Second Floor,
Lajpat Nagar 1
New Delhi, Delhi 110024
India

QUOTE

Quote Number	1079	**Kumar Aakash**
Quote Date	19-May-2021	kumaraakashvit2000@gmail.com
Valid Until	26-May-2021	
Total	1,808.94 INR	

Item	Description	HSN/ SAC:	Unit Cost	Quantity	Line Total
chothipipe	PLA	39269099	10.00 INR	1	10.00 INR
front index 1	PLA	39269099	55.00 INR	4	220.00 INR
front second index 2	PLA	39269099	42.00 INR	4	168.00 INR
front Third index 3	PLA	39269099	60.00 INR	4	240.00 INR
palm	PLA	39269099	680.00 INR	1	680.00 INR
parallel pin hardened_iso_ ISO 8734 - 3 x 18	PLA	39269099	10.00 INR	8	80.00 INR
pin main	PLA	39269099	45.00 INR	1	45.00 INR
thumb	PLA	39269099	70.00 INR	1	70.00 INR
thumbpin	PLA	39269099	10.00 INR	1	10.00 INR
Thumbplate	PLA	39269099	10.00 INR	1	10.00 INR

Terms

Subtotal 1,533.00 INR

6. Manufacturing Process: -

- **<u>Methodology for System Development: -</u>**

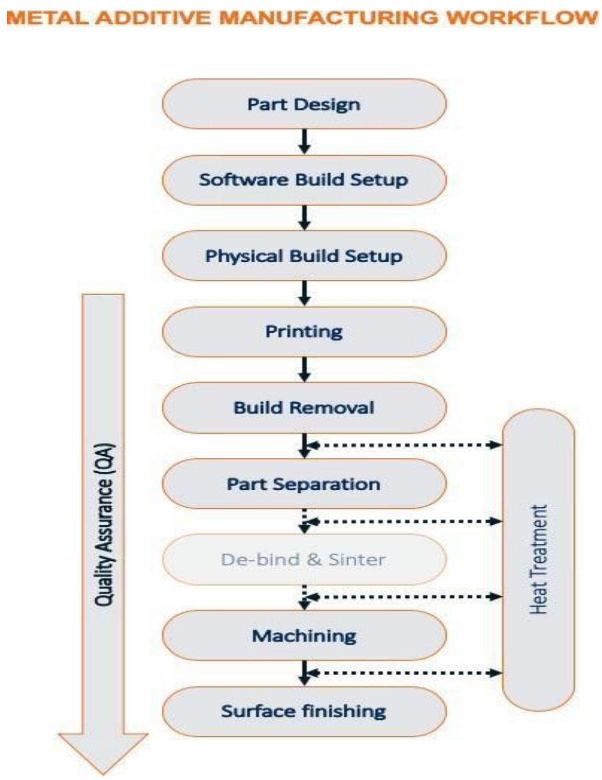
  The additive manufacturing process: Additive manufacturing is a method of manufacture where layers of a material are built up to create a solid object. While there are many different 3D printing technologies this article will focus on the general process from design to the final part. Whether the final part is a quick prototype or a final functional part, the general process does not change.

  It Includes 4 stages:

  - Creating the 3D Model
  - Slicing the 3D Model
  - Print part layer by layer Fused Deposition Method
  - Generating Final Part

- **<u>Process Steps in the Additive Manufacturing Workflow: -</u>**

  AM process steps depend on many factors including the technology, equipment, industry, and application. This post describes a general workflow which applies in most cases. We have structured this post by five key sections: Design, Pre-processing, Printing, Post-processing and Quality Assurance.



- **<u>Detail Process Occurrence: -</u>**

1) Design:

- The objective is usually to select a production process that requires few modifications to the part.
- This reduces the costs of redesign and requalification.
- The time-to-value for AM is generally shorter if an existing part design is selected.

2) Pre-Processing:

- The first pre-processing step is to convert a 3D CAD file into instructions the printer uses to build each layer of the part.
- These instructions are created by a “slicer”, which slices the design file into layers of “voxels” (3D pixels) and generates a tool path for the printing process.
- The tool path incorporates both position information and print-process parameters (for example, power used to melt metal) for each voxel.

Once the software pre-processing and parameter development are complete, there is the physical setup of the machine. Physical setup includes:

- Loading and aligning the build plate or substrate.
- Preparing the printing chamber atmosphere.
- Preparing and loading the feedstock for the printer.

3) Printing:

- 3D printers heat the build plate or whole build envelope before printing. This can add considerable time which must be factored into cycle time calculations.
- Some processes require heat treatments for stress relief during the printing process which also adds time and cost to the printing step.
- Once a printing process is predictable enough that it doesn't need monitoring, the operator can spend print time on other tasks, improving overall productivity.

4) Post Processing: Post-processing involved in the AM processes, equipment, applications etc. And the steps are designed carefully to meet all the part requirements. Most of the key steps are outlined below.

- **Build Removal** :Removing excess material from the build inside the printer.
- **Part Separation** :Removing parts from the build plate, using EDM, band saw or machining
- **Machining** : Machining to remove remaining supports, smooth surfaces, add critical features, and hit critical tolerances.
- **Surface Finishing :**Tumbling or Shot peening to smooth and/or work harden surfaces, or mitigate issues with loose powder on unfinished surfaces.

5) Quality Assurance: Unlike most conventional manufacturing processes, the repeatability of most metal AM processes cannot be taken for granted. Certain processes are particularly sensitive to material input and process variables which are hard to control. This is what reinforces the need for a robust QA strategy that addresses software, hardware and materials. Processes which are able to directly measure and control the metal deposition (printing) process will have an advantage.

➢ **Selection Of Materials: -**

Criterion to be fulfilled: -

Since the human hand physiology is very complex as it involves a large number of joints and different possible motions resulting in multiple degrees of freedom for it. Keeping in view the complexity of human hand, one has to develop the artificial hand in such a way that it can be used worldwide by the possible user. A prosthetic hand must have the Following characteristics:

- **Lightweight:** the weight of the prosthetic hand as well as of its fitting arrangement is directly connected to the body of the operator. Blood flow can be obstructed in the skin and resulting symptoms can range from discomfort to skin breakdown.
- **Compact**: length of the residual limb of the users vary, so all its drives and power sources should retain in the device as small an possible, if possible within the hand profile.
- **Reversible**: It must ensure that the device can be used by a large number of people and due to simplicity of manufacturing it can be used for both left and right hands.
- **Noiseless**: The functioning of a prosthetic hand should be such that it must not attract the attention of the user unnecessarily.

- **Strength**: It should be able to withstand the load which the user may carry. It should not get deformed or distorted while carrying the small load within a predefined region. Hence the prosthetic hand should have high strength.

<u>Advantages of PLA Over Other Materials: -</u>

Production:

- PLA is made from renewable raw materials.
- It has a reduced carbon footprint compared to fossil-based plastics. two reasons:
- It takes less energy and this produces less greenhouse gas to produce PLA than fossil-based plastic

Material:

- PLA melts more easily because it has a lower melting point than many fossil-based plastics. It's easy to work with PLA and it requires less energy to transform.
- One of the two most used plastics in 3D printing (45% market share). It has a low melting point, inexpensive, easy-to print, no fumes. It's the best option in case of 3D printing.

End-of-life:

- PLA is compostable
- When PLA is Incinerated, it emits less toxic fumes than oil based plastics

Properties of PLA:

Property	Value
Chemical Formula	$(C_3H_4O_2)_n$
Melt Temperature	PLLA: 157 - 170 °C (315 - 338 °F)
Typical Injection Moulding Temperature	PLLA: 178 - 240 °C (353 - 464 °F)
Heat Deflection Temperature (HDT)	PLLA49 - 52 °C (121 - 126 °F) at 0.46 MPa (66 PSI)
Tensile Strength	PLLA: 61 - 66 MPa (8840 - 9500 PSI)
Flexural Strength	PLLA: 1.24
Specific Gravity	PLLA: 1.24
Shrink Rate	PLLA: 0.37 - 0.41% (0.0037 - 0.0041 in/in
Shear Modulus	2.4GPa
Flexural Modulus	345-450 MPa
Specific Heat	1800J/Kg K
Thermal Conductivity	0.13W/M K

7 . Break EVEN analysis: -

- **Volume of arm:**
    - For the volume of the arm, i.e., from the elbow to the wrist, a titanium sheet of
    - thickness 4mm is considered and modelled into the shape of a truncated hollow cone. The
    - dimensions of the truncated cone are considered as follows:
    - Outer Radius 1 (R) = 30mm
    - Outer Radius 2 (r) = 20mm
    - Inner Radius 1 (S) = 26mm
    - Inner Radius 2 (s) = 16mm
    - Height of the cone (H) = 250mm
    - Thickness = 4mm
    - Volume of a truncated cone is given by the formula:
    - $V= (1/3) * \pi * H * (r^2 + r * R + R^2-S^2-S*s-s^2)$
    - Therefore, substituting the given values, we get:
    - Volume = 173.415 cm3
    - The density of titanium is 4.5g/cm3. Mass of titanium is then calculated by using the
    - formula:
    - Mass=Density*Volume
    - Mass= 4.5*173.415 = 780.354g = 0.78Kg
- **Palm volume:**
    - We assume the palm of the hand to be in the shape of a tapered cuboid made of Polylactic acid (PLA). The volume the palm is calculated using the given dimensions:
    - Outer Width= 40 mm
    - Inner width = 36 mm
    - Length= 50 mm
    - Outer height = 20 mm
    - Inner height = 12 mm
    - Volume of the palm is calculated using the formula:

- $V=L*w1*h1 - L*w2*h2$
- Total Volume = 18400mm^3 = 18.4 cm^3

- **Volume of fingers:**
  - The fingers of the hand are considered to be a hollow cylinder made of Polylactic acid (PLA). The following dimensions are followed:
  - Average length of 5 fingers = (7+8+6+5+9)/5 = 7 cm
  - Outer radius= 7.5mm
  - Inner radius= 5mm
  - Thickness= 2.5mm
  - The volume of a hollow cylinder is calculated using the formula: V= $\pi*L*(R2 - r\ 2)$ = 6.872 cm^3
  - Total volume of fingers are: 6.872*5 = 34.36 cm^3
- **Final volume**
  - Total volume of titanium used: 173.414 cm^3
  - Mass of titanium used: 780.345g
  - Total volume of PLA used: 18.4+34.36= 52.76 cm^3
  - Mass of PLA used = 1.27*52.76 = 67.0052 g
- Materials used: titanium and Polylactic acid (PLA)
  - Total Fixed cost (includes interest, taxes, salaries, rent, depreciation costs, labour costs, energy costs etc) = 10,00,000 Rs
- **Final cost**
  - The cost of 3d printing 1000 g of titanium is 2000 Rs. So, for 780.345 g , the cost is 1560.69 Rs .
  - The cost of 3d printing 1000 g of PLA is 1100 Rs. So, for 67.0052 g, the cost is 68 Rs.
  - Therefore, the final cost would around 1628.89 Rs approximately.
  - Selling cost = 2000 Rs
  - Variable cost = 1628 Rs
  - Contribution per unit = selling cost – variable cost
  - **Break-even point** (in quantity) = fixed cost / contribution per unit

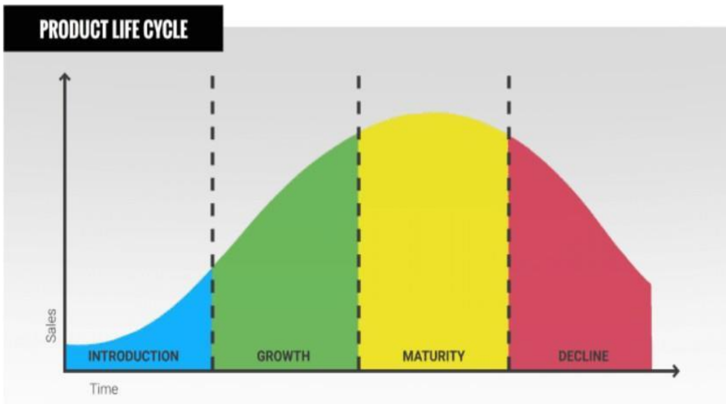
=10,00,000/ (2000-1629)
=2695.4

Therefore, break-even point can achieve by selling 2696 units.

8. Simulation links: -

- https://drive.google.com/file/d/1U9Ju_VDO_jLb0dJ7i9Q34K7xkuMcupo6/view?usp=sharing
- https://drive.google.com/file/d/1GLGdqpVIpYHuo4dUaBvhcZrCXvZ7wRva/view?usp=sharing
- https://drive.google.com/file/d/18oULGpPNHcWtN9oR-iR5uqrBl3a-sXjY/view?usp=sharing
- https://drive.google.com/file/d/1nCFGHdNxjAx_r5T75PaklZ4JastfJzjD/view?usp=sharing
- https://drive.google.com/file/d/1HuDBrPWG8KSs9m0eoxnr82t80P-JbwcY/view?usp=sharing

9. Product life cycle: -



<u>Introduction:</u>

- This the stage we introduce prosthetic arm
- As our product is new, we will have few customers and struggle financially
- Low sales and minimal competitors
- Need huge marketing to take our product to the people

<u>Growth</u>:

- At this stage, people start to notice our product
- We might get support from govt in terms of subsidiary because it can help disabled people
- Our sales start to increase and profit also increases
- We reach our break-even point in this phase, that is by selling 2700 units
- Competitors start to grow

Maturity:

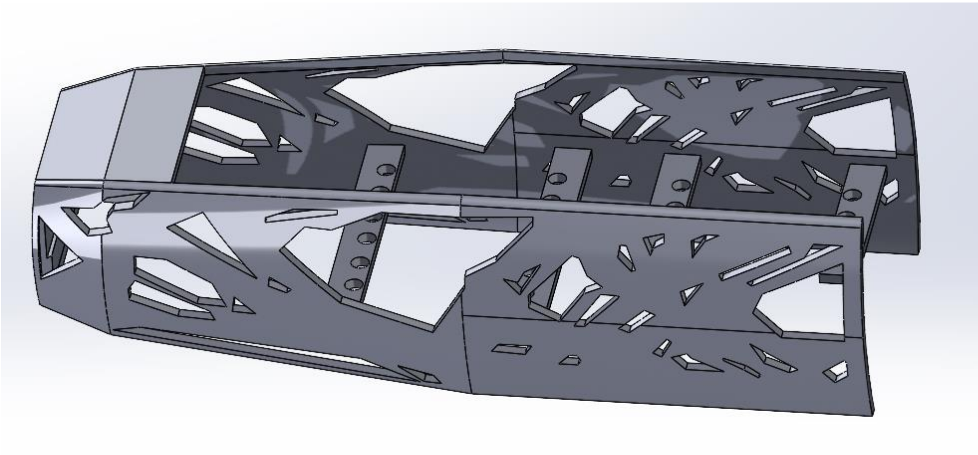
- Peak sales will be achieved
- As our product has materials which can recycled, the raw material cost can be cut down by recycling old or damaged products
- Profits are high and More discounts can be given
- Stable number of competitors
- Need to give some update to the product in order to stay in competition

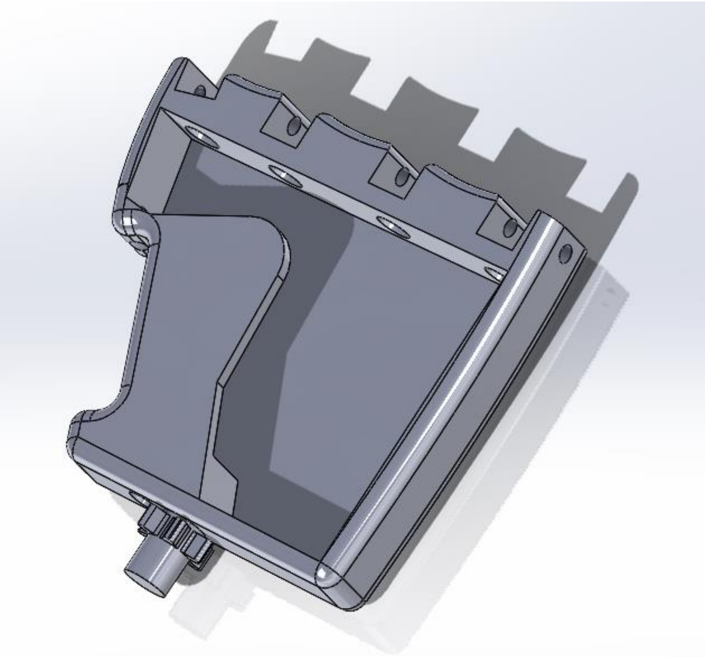
Decline:

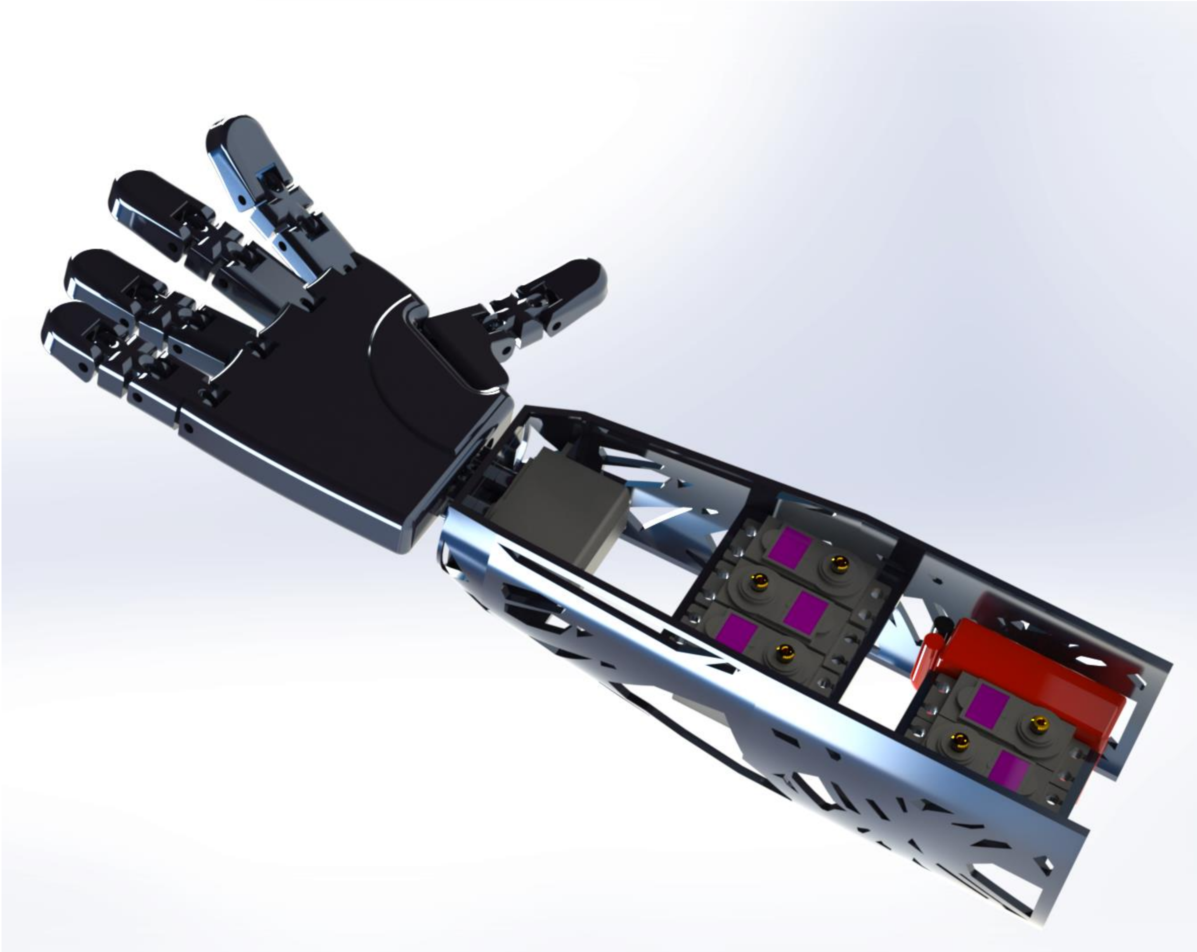
- Sales start to decrease, most of people in market will our product.
- Competition becomes too high
- Less production pf products
- We start to recycle old and damaged products even more, so that we no longer need to buy some raw materials and be environment conscious

9.1 Topology Optimization: -

Topology Optimization was done to reduce the material used. The criteria used were to minimise mass by 30%, and ensure that the displacement does not increase by more than 1.2 times. The forearm and the hand were optimized, as they were the largest and most promiment components of the arm, and were also the main load bearing parts of the arm. The total mass reduction was 17.35%.







10. Efforts for Improving Productivity: -

10.1 Modifications for fast additive Manufacturing:

- According to the law of conservation of mass, the extrusion rate of a FDM printer is mainly determined by the gear feeding speed. Efforts have been taken to increase the gear feeding speed, as shown in below ***figure (a)*** for the purpose of improving the extrusion rate and further increasing FDM printing rate.

Fig.(a) Drive gear having same diameter size as bearing roller

- For instance, a motor shaft pinches filament against a ball race (small circle), driving it down through the chamber and pushing it out through a nozzle, as shown in figure (b).

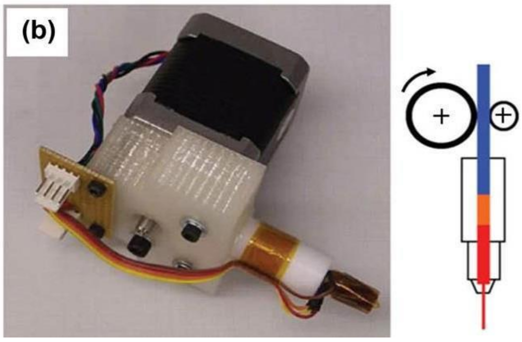


Fig.(b) Drive gear having larger diameter size than bearing roller

- Figure(c) shows another solution for increasing pinch force, thereby improving the filament feeding speed. Given the circumstances of intrinsic high resistance of thermal penetration of polymeric filament, however, higher filament feeding speed would result in a higher risk for extruder clicking, gears slipping, and nozzle clog.

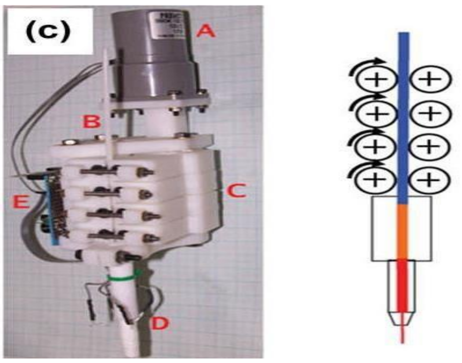


Fig.(c) Multiple drive gears and bearing rollers but drive gears having same diameter size as bearing rollers.

10.2 Modifications for large Extrusion Force and Rate:

- We know that an FDM printer can't print at a higher rate than the one dictated by its rate-limiting module; otherwise, failure of a single module would occur, resulting in failure of the process altogether. This is because, for a given extrusion rate, the extruder must feed the filament at a commanded velocity, while providing sufficient force to overcome the flow resistance in the chamber.
- The chamber, in turn, must be capable of heating the filament to the target temperature at a specified heating rate. The motion system must then move the printhead (the extruder and chamber) at a rate commensurate to the exit velocity of material from the nozzle. Thus, for fast printing, as shown in below **figure d**.
- In addition to a conventional heating block within the printhead, a laser heating element was mounted on purpose, which ensures the melting of polymeric filament prior to entering the chamber (conventional heater block). We also use threaded filament rather than using regular filament products to increase extrusion force.

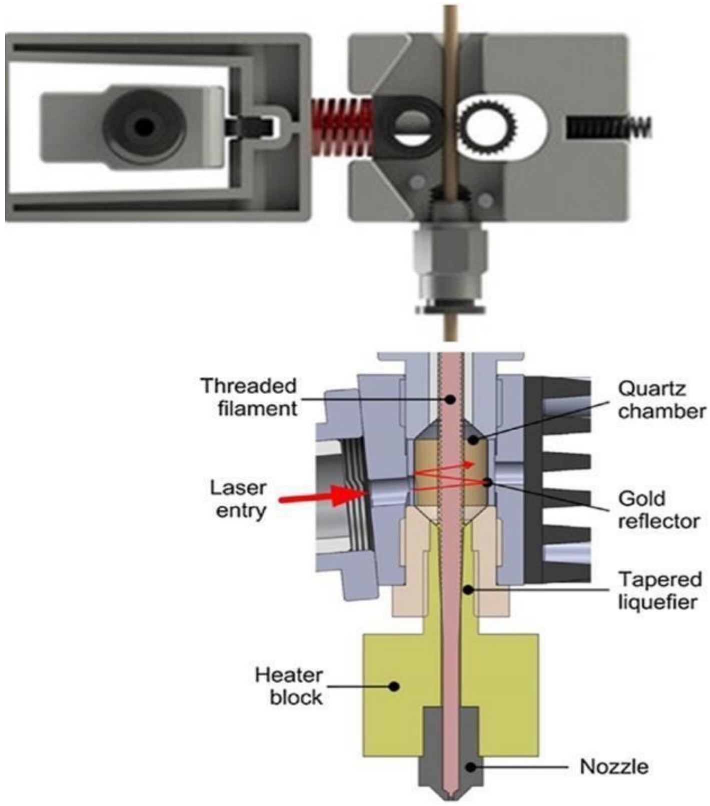


Fig. d

- **Comparison after improvements:**

	After Improvements	Before Improvements
Extrusion Rate(cm^3/hr)	141	21
Extrusion Force(N)	160	30
Nozzle size(mm)	0.05	0.05

Result:

The shear engagement area between filament and textured driving wheel has been remarkably increased. As a result, the designed printhead was able to extrude materials at a rate of 141 cm^3/h for a 0.5 mm nozzle. The extrusion force approached up to 160 N. As compared to previous print parameters a 3D structure at a volumetric infill rate of 21 cm^3/h for a 0.5 mm nozzle, corresponding to an estimated extrusion force of 30 N.

11. Tool Selection: -

- Effort for resolution improvement

  - In FDM, resolution is the quality, or level of details, at which the product is created. Higher resolution value means more printing details. In general, by using FDM, the movement of printhead on both *X*–*Y* and *Z* planes determines how fine the resolution would be.

  - At its most basic level, the *X*–*Y* resolution is controlled by the size of nozzle and the movement of printhead. But for *Z* resolution, heat is the dominant factor in determining the outcome. This is because, due to heat transfer, a small layer height will distort previous layers. In this we mainly focused on the efforts for *X*–*Y* resolution improvement

  - In **figure e** it shows typical FDM nozzles with different sizes as well as examples telling the resolution difference between 0.25 and 0.4 mm nozzles. Obviously, smaller nozzle gives higher printing resolution (i.e., more detailed prints). But, with a smaller nozzle size (0.2 mm diameter, for example), drawbacks of the printing process are blocking and buckling and even slippage of the wire on the pinch wheel. This is because the filament is extruded to a very tight diametric tolerance with a gear-driven-based nozzle. A variation in filament diameter may cause blocking and/or slippage of the wire on the pinch wheel.

Fig.(e) Typical commercial FDM nozzle with different sizes and printed texts with different nozzle sizes.

- **Effort for getting rid of excessive backpressure:**
  - One of the great issues resulting from small nozzles is the build-up of backpressure against the filament extruding. Regular solutions to this problem are either to print at a low speed or to avoid using small nozzles. At higher printing speed, the backpressure builds up by the geometry of nozzles.

- Thus, high speed printing is usually not suggested when using a nozzle with small size. Efforts have been made to overcome these challenges. An interchangeable nozzle based on mini screw extrusion for the sake of fast printing when using a 0.4 mm nozzle. The difference between a commercial FDM nozzle and screw-based nozzle is shown in **Figure (f).**
- In Figure f(1), the filament is driven by pin wheels and extruded through the nozzle at a relatively low speed, ensuring to be completely melted within the chamber.

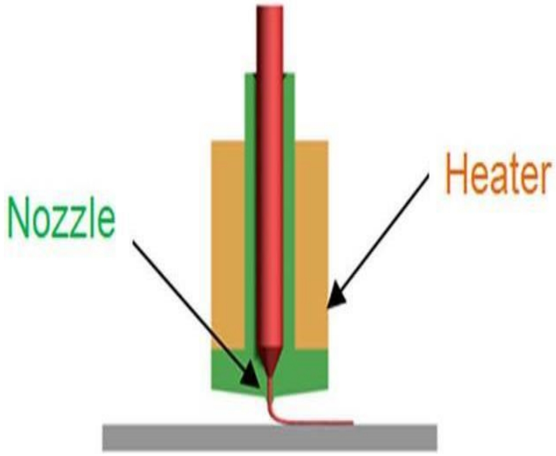


Fig. f(1)

- As shown in Figure f(2), a mini screw extrusion-based FDM nozzle unit consists of a nozzle, screw, and barrel as well as peripherals. The printing material is driven forward by a mini screw, but extruded through the nozzle at a relatively high speed. By extruding PCL, the extruding rate has been improved to 65 cm^3/h.

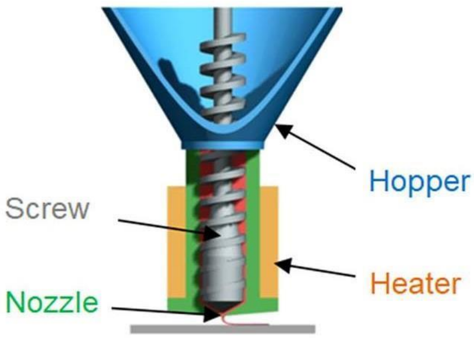


Fig. f(2)

- After an optimization on configuration of screw section and screw geometry, the extruding rate has been greatly improved to 167 cm^3/h. The configuration and geometry of screw-based FDM nozzle unit are shown in

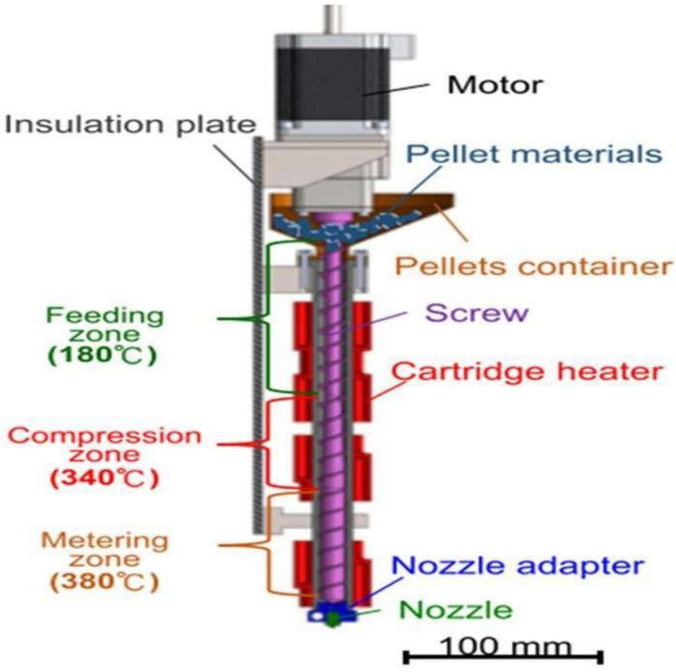


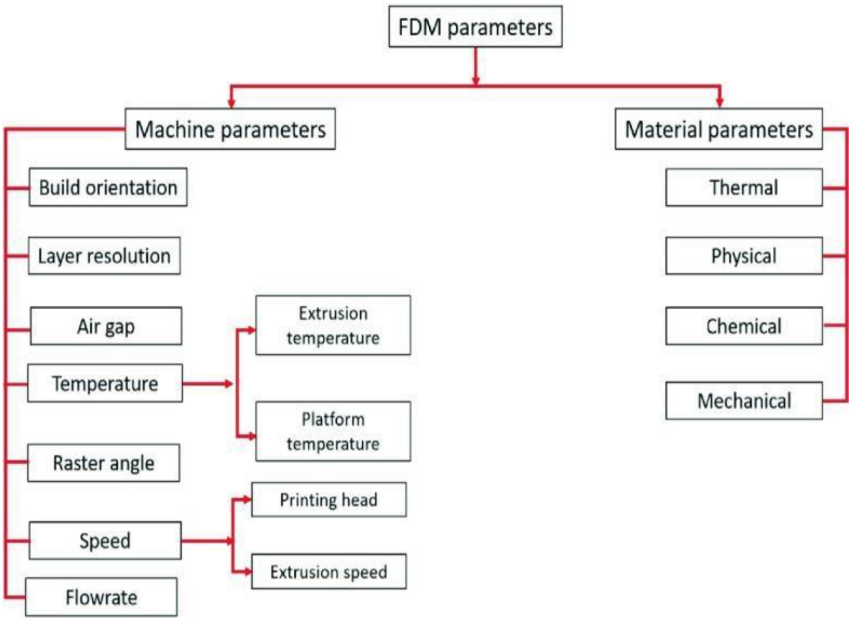
Fig. f(3)

- **Comparison:**

	After Improvements	Before Improvements
Extrusion Rate(cm^3/hr)	167	65

12. Manufacturing Control: -

- **Process Parameters in FDM**
  - The **machine parameters** will be used by the 3D printer user will specify on the slicing software during the generation of the G-code files whereas the material parameters are the properties of the filament material or materials being extruded through the nozzle.
  - The **quality and performance** of the printed parts depend on the choice of these parameters and there are various efforts in the literature on evaluating the effects of various parameters on the process and quality of the prints.
  - **Layer resolution** indicates the minimum thickness of every layer in one run of the print head and it may vary from a few micrometres to millimetres depending on the accuracy and application of the 3D printer.
  - The **build orientation** basically indicates the angle at which the longest length is inclined to the base of the build plate. The printed components may be inclined at 0°, 45°, 90°, etc. depending on the choice of the user.



- **Technical Specifications:**

Standard lead time	**Minimum of 4 working days (or 48 hours**
Standard accuracy	±0.15% (with a lower limit on ± 0.2 mm)
Layer thickness	0.18 – 0.33 mm
Minimum wall thickness	1 mm
Surface structure	FDM parts can be smoothed, painted and coated

13. Strategies for Improving Quality: -

- **Surface Finish:**
  - Since FDM systems are based on a layer-by-layer additive process, the staircase effect is present and affects the part surface finish. The staircase effect depends on the surface inclination and the layer thickness. The average surface roughness (*Ra*) can be estimated by the following equation: where *L* is the layer thickness, θ is the surface angle, and φ is the profile surface angle, as shown in Figure h . The surface finish in FDM depends not only on the part orientation, layer thickness, layer orientation, and surface angle, but also on the material, intricate features, distortion, shrinkage, and warping.
  - Distortion, shrinkage and warping are present in FDM parts. If these defects are not considered at the design and manufacturing stages, the accuracy and quality of the part could be reduced since the small features, surface finish, dimensional tolerances and shape tolerances may be affected.

$$Ra = \frac{L}{2}\left|\frac{\cos(\theta - \phi)}{\cos\phi}\right|,$$

Surface Roughness (Ra)

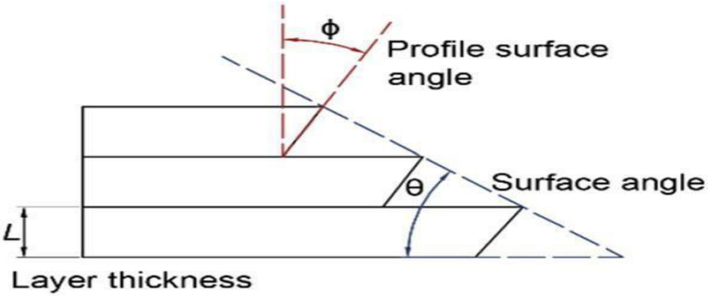


Fig. h

- **Distortion, Shrinkage & Warping*:***
  - The quality and dimensional accuracy of FDM parts are affected by distortion, shrinkage, and warping, which are known to be caused by the internal stresses generated during fabrication.
  - The internal stresses depend on the volume shrinkage during the cooling period from the glass transition temperature to the building room temperature.
  - According to, the largest warping deformation (d) of FDM parts depends on the number of layers (*n*), the section length of the part (*L*), the material shrinking coefficient (α), the thickness of layer (Δs) the build room temperature (*Te*), and the glass transition temperature (*Tg*), as follows:

$$\delta = \frac{n^3 \Delta s}{6\alpha (T_g - T_e)(n-1)}\left\{1 - \cos\left[\frac{3\alpha L}{n\Delta s}(T_g - T_e)\frac{n-1}{n^2}\right]\right\}.$$

13.1 Strategies for Improving Sustainability: -

Design for sustainability consider the creation of products that maximize their economic and social impact and minimize harmful environment effects. Thus, the AM strategies for sustainability must consider the design of durable parts, the use of recycled materials, the use of high-efficiency manufacturing processes, the reduction of toxic materials, and a deep link between the product and the user. Products that meet these criteria usually have longer life and reduced negative impact on the environment

- **Part Cost:**
  - The cost of a part fabricated in FDM depends on the material consumption, material cost, build time, energy use, system's cost, and post-processing work.
  - The material consumption and cost depend on the part volume and the material unit cost
  - Build time also affects the part cost because it increases the energy consumption and the use of the system.

  - The following mathematical model to estimate the Feedstock Material Consumption (*FMC*) in FDM

$$\begin{aligned} \text{FMC (cm}^3) = {} & 0.972 - 0.545A - 2.423B + 6.301 \times 10^{-4}D \\ & + 3.866E + 0.025F + 0.332AB - 1.439AE \\ & + 1.185BE + 0.113BF - 0.049EF + 1.888A2 \\ & + 1.088B^2 - 7.410 \times 10^{-6}D2 - 3.248E^2 \end{aligned}$$

where *A*, *B*, *C*, *D*, *E* and *F*, are the layer thickness, air gap, raster angle, part road width, build orientation and number of contours process parameters, respectively.

- **Energy Consumption:**

Energy consumption in AM systems depends on the percentage of utilizing the machine (build time), the material consumption and the part orientation. The FDM process has the lowest ecological impact per part over the CNC and polyjet processes.

  - To minimize the energy environmental impact, it is essential to reduce the non-productive time of the extrusion system and reduce the amount of productions to dilute the pre-heating between productions.

  - Since the build orientation and material consumption affect the build time, the energy consumption and environmental impact depend directly on the build time; the larger the build time, the greater the energy consumption.

- The following mathematical model to estimate the Build Time (*BT*) in FDM

$$
\begin{aligned}
\text{BT (min)} = {} & 21.616 - 129.180A - 3.732B + 0.022C \\
& + 0.056D + 4.395E + 0.777F + 11.039AB \\
& - 1.26AF - 0.073DE - 0.627EF + 224.347A2 \\
& - 2.307 \times 10{-}4C2 - 1.721 \times 10{-}4D2,
\end{aligned}
$$

where *A*, *B*, *C*, *D*, *E* and *F*, are the layer thickness, air gap, raster angle, part road width, build orientation and number of contours process parameters, respectively.

14. Market analysis and favorability towards prosthetics in general: -

- First research was done on the topic to see exactly what is wrong with the current topic at hand. Various science journals elaborating on the technology were referred to and were studied to understand the basic constitution of these Implantable Technologies. Then we saw articles regarding the advent of such technology and how it has been a game changer for many amputees ranging from small kids to fully grown adults. There was absolutely no doubt that this field is for the betterment of mankind but we were also aware that the general consensus towards such technology was not very positive. We read about the reasons behind society’s non acceptance to such technology and were introduced to a variety of factors.

Target market:

- With surveys done to understand the general consensus towards Prosthetics and trying to gauge the market presence in India we arrived at the following conclusion
- Based on the above data we can conclude that people are:
    1. Open to the technology
    2. Hopeful all disabled can purchase prosthetics
    3. Believe that people can live in peace with enhanced and non-enhanced
- Our final conclusion is that in India, the prosthetics market has a chance to grow and the younger/older generation is ready to welcome it with more or less open arms. Things will definitely improve with proper attention given to this field and not written off just because it looks odd.
- Hence our target market is all age groups who have any sort of limb problems or amputees.

15. Policies: -

- Ensure workplace cleanliness.
- Follow 5S.
- Ensure compliance with customer order.
- Ensure zero defects.
- Test properly before shipping to customers.
- Run required simulations on the CAD model before manufacturing the actual arm.
- Ensure comfort for the customers. Maximum comfort is a priority.
- Ensure that the arm is usable on a daily basis.
- Ensure that the designs do not stand out in public and people feel comfortable wearing them at all times.

16. Design of Experiments (DOE): -

- There are 5 steps to Design of Experiments

  1) Define research question
  2) Define variables
  3) Arrange conditions
  4) Decide blocks and trials
  5) Set instruction and procedure

- **Define research Question and variables:**

  - The question at hand was to understand reception towards prosthetics especially Prosthetic arms and try to find out the optimal design for production via additive manufacturing to make it as cheap as possible while ensuring it is durable.
  - The Variables in place were overall cost, arm length range, fingers, Body weight comparisons, materials to be used, production process, location. Strength vs Weight, Attachment

- **Arranging condition and deciding blocks and trials:**
  - We needed to test our arm via a topology simulation conducted in SolidWorks. Stress was applied in different regions of the arm to arrive at out final prosthetic shape thatwas well optimized to minimize material use while ensuring durability.

- **Setting Instructions and Trials:**
  - A Policy document was created to set instructions for manufacturing as given in previous slides
    - Ensure workplace cleanliness.
    - Follow 5S.
    - Ensure compliance with customer order.
    - Ensure zero defects.
    - Test properly before shipping to customers.
    - Run required simulations on the CAD model before manufacturing the actual arm.
    - Ensure comfort for the customers. Maximum comfort is a priority.
    - Ensure that the arm is usable on a daily basis.
    - Ensure that the designs do not stand out in public and people feel comfortable wearing them at all times.

Tests were conducted like a stress analysis to ensure our arm is ready for production and to go for public use.

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