CBCS SCHEME

USN

Model Question Paper

Seventh Semester Degree Examination

Additive Manufacturing (BME714A)

Time: 3 hrs. **Max. Marks: 100**

Note: Answer any FIVE full questions, choosing ONE full question from each module.

			M	L	C
		Module-1			
Q1	a	Differentiate between CNC & Additive Manufacturing.	10	L2	CO1
	b	Explain additive manufacturing process chain.	10	L2	CO1
		OR			
Q2	a	What is Additive Manufacturing? What are the benefits of AM?	10	L2	CO1
	b	With a block diagram, explain general integration of AM machine.	10	L2	CO1
		Module-2			
Q3	a	With a neat sketch, explain photopolymerisation process.	10	L2	CO2
	b	What are benefits and drawbacks of use of photopolymerisation technology?	10	L2	CO2
		OR			
Q4	a	With a neat sketch, explain Selective Laser Sintering (SLS) process.	10	L2	CO2
	b	What is extrusion based system? With a neat sketch, Fused Deposition Modelling (FDM).	10	L2	CO2
		Module-3			
Q5	a	With a neat sketch, explain the working of Laminated Object Manufacturing (LOM).	10	L2	CO3
	b	Write a note on research achievements in printing deposition process.	10	L2	CO3
		OR			
Q6	a	Explain with a neat sketch, Beam Deposition Process. List advantages and limitations of the process.	10	L2	CO3
	b	What is direct write technology? Explain Ink based direct write technology	10	L2	CO3
		Module-4			
Q7	a	Write a note on selection method for a part.	10	L2	CO4
	b	Explain the following post processing operations: i) Support material removal ii) Surface texture improvements	10	L2	CO4
		OR			
Q8	a	Explain different types of problems that occur in STL file.	10	L2	CO4
	b	Explain the following post processing operations. i) Accuracy improvements ii) Preparation for use as pattern	10	L2	CO4
		Module-5			
Q9	a	Write a note on AM applications in the field of	10	L2	CO5

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		i) Medical ii)Automobile			
	b	Write a note on i) Align technology ii) Siemens and Phonak	10	L2	CO5
		OR			
Q10	a	Write a note on AM applications in the field of Aerospace ii) Industrial design	10	L2	CO5
	b	i) Life cycle costing ii) Future of direct digital manufacturing	10	L2	CO5

* * * * *

Q1.a. Distinction b/w AM & CNC machining:

CNC is primarily a subtractive rather than additive process, requiring a bigger material.

1) Material:

AM technology: polymeric materials, waxes, paper laminates

next - composites, metals & ceramics.

CNC machining: initially: metals & alloys.

next: soft materials, MDF, machineable foam.

2) Speed: CNC can remove materials @ faster rate at which AM can add material, but AM can be used to produce a part in single stage.

3) Complexity: AM has got advantage of greater geometric complexity over CNC. Since AM process is not constrained, undercuts & internal features can be easily built without specific process planning.

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4) Accuracy: Accuracy of CNC is higher compared to AM (with the present technology).

Resolution of AM: few tens of microns.

" " CNC: few microns.

5) Geometry: AM m/c generally breaks up a complex 3D problem into a series of simple 2D cross sections with a normal thickness. While AM does complex geometries easily, it cannot be easily done on CNC, it requires multi axis machines (4-axis, 5axis etc) for complex geometries.

6) Programming: Determining the program sequence for a CNC m/c can be very involved, including tool selection, m/c speed settings, approach position, & angle etc. These choices are minimal in AM.

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Q2b. **Additive Manufacturing Process chain:**

AM involves a number of steps that move from the virtual CAD description to the physical resultant part. Different products will involve AM in different degrees. Most AM processes involve the following eight steps.

Step 1: CAD: All AM parts must start from a S/w model that describes the external geometry. Usage of CAD S/w for creating 3D model.

Step 2: Conversion to STL: 3D model created in any CAD S/w is converted into STL file which can be accepted by any AM machine

Step 3: Transfer to AM machine & STL file manipulation

After 3D modeling, before it is sent to m/c, it should be verified that part is correct or not. AM system s/w normally has a visualisation tool that allows the user to view & manipulate the part.

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Step 4: Machine Setup

AM m/c is properly set prior to build process to build parameters like material constraints, energy source, layer thickness, timings etc.

Step 5: Build: Actual part building process.

It is mainly an automated process & machines can carry on without supervision.

Step 6: Removal

Step 7: Post processing – Parts may require additional cleaning up before they are ready for use. Supporting features have to be removed.

Step 8: Application – Usage of component for required application. They may require additional treatment like priming & painting to give required surface texture & finish.

Q2a. Additive manufacturing is a manufacturing process, where in a component is manufactured by adding the material layer by layer. Here a model initially generated using 3-dim computer aided design (CAD) system can be fabricated directly without the need for process planning.

Benefits of AM:

1) AM can be used for prototyping (Product development) Rapid prototyping.

2). Cost reduction in new product development.

3) Usage of generic machines for product manufacturing.

4). Less supplier dependency.

5). No need of programming like :- CNC

6). Avoid of tooling & fixturing.

7) No. of processes & resources required can be significantly reduced.

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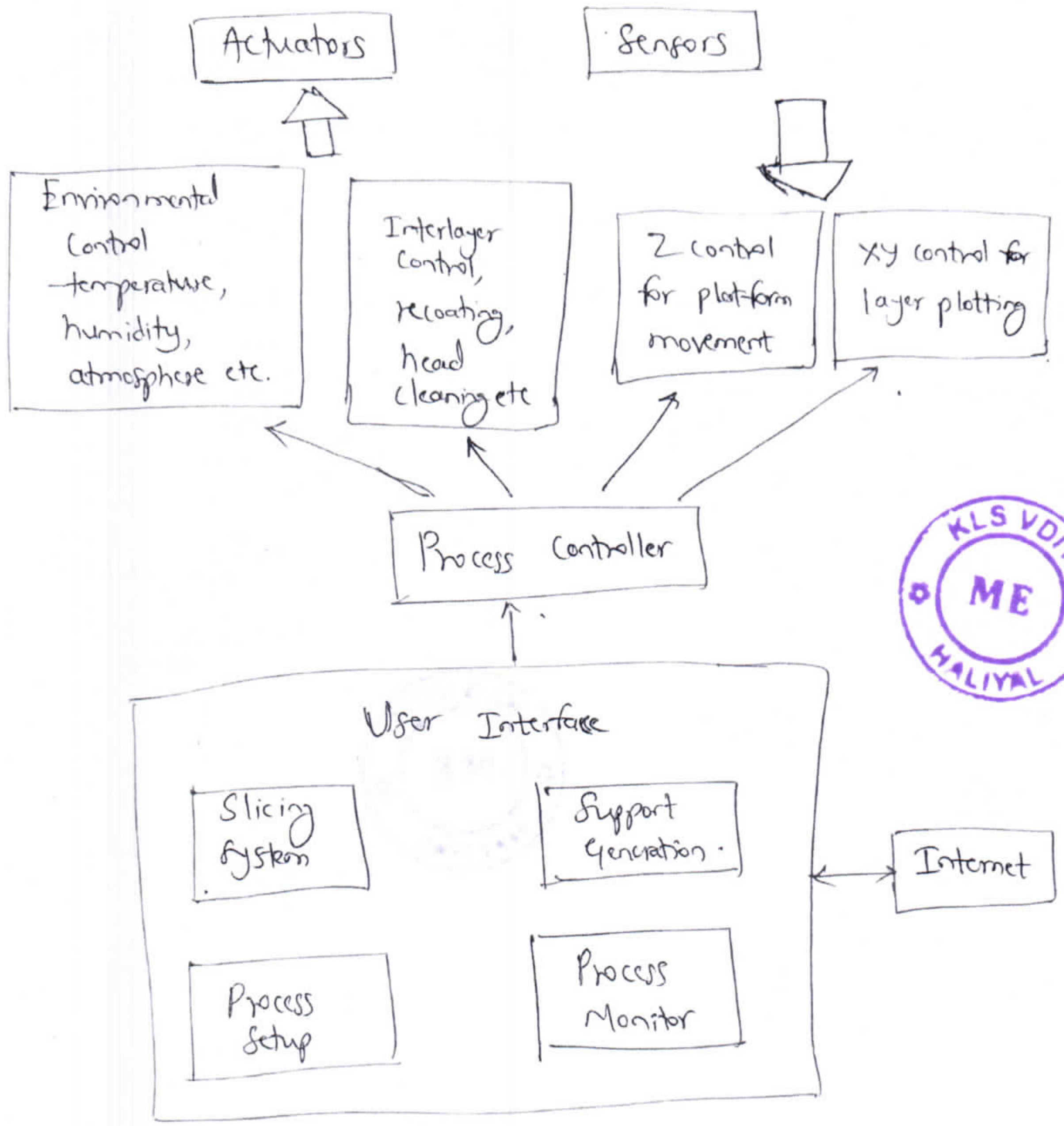
8) AM can be used to remove/simplify multistage processes.

9) Workshops/industries which adopt AM can be much cleaner, more streamlined & more versatile.

10) Easy prediction of mfg lead time.

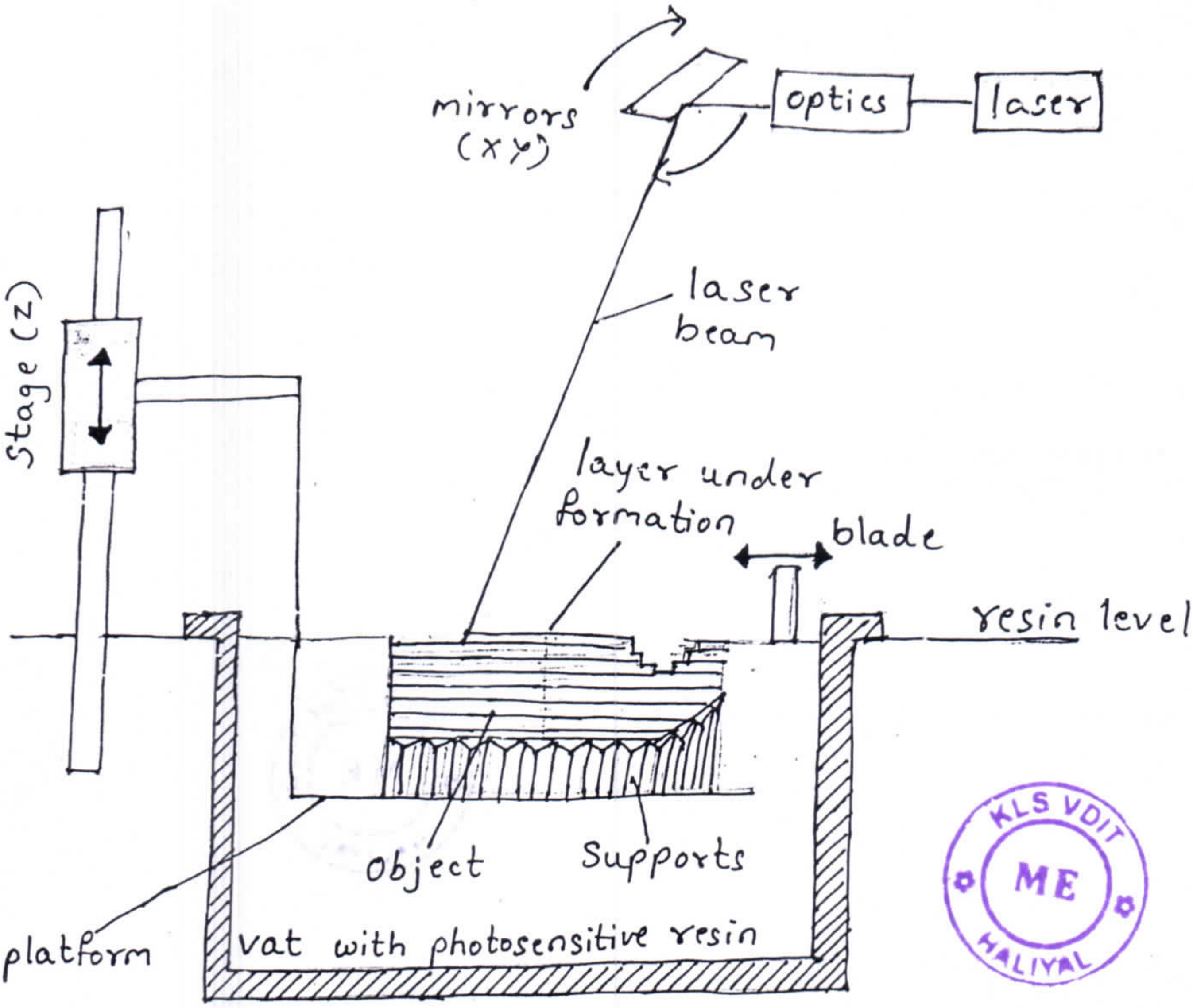
Q2b. General integration of AM machine.



Block diagram of Integration of AM m/c.

General integration of AM m/c is as shown in the block diagram. It consists of process setup, process monitor, slicing system, support generation, actuators & sensors. Process controller is used the m/c for control of parameters like temp, humidity, recoating, head cleaning etc. Position control in 3 axes X, Y, Z is accomplished by the controller. The integration of AM m/c should comply with working principle. (8 step generic process of additive manufacturing.

Q3a. Photopolymerisation process:



Stereolithography (3D printing) makes use of 2D process (lithography/printing) & extending them into 3rd dimension. It is a technique in which layer by layer structure fabrication takes place. A laser beam is focussed to a free surface of

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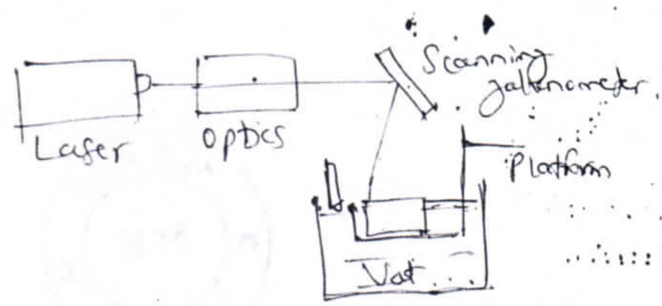
a photosensitive liquid to induced polymerisation of the liquid in that region and transform it to a polymerised solid. Gamma rays, X-rays, electron beams, UV radiation can also be used. The various configurations which are used are:

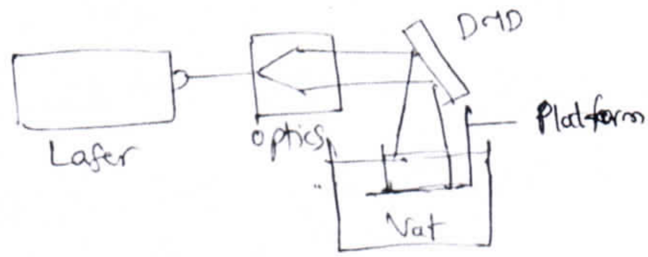
a)- Vector scan or point wise (typical commercial SL machines)

b) - mask projection or layerwise approaches, that irradiate entire layers at one time.

c)- Two- photon approaches (high resolution point by point approaches)

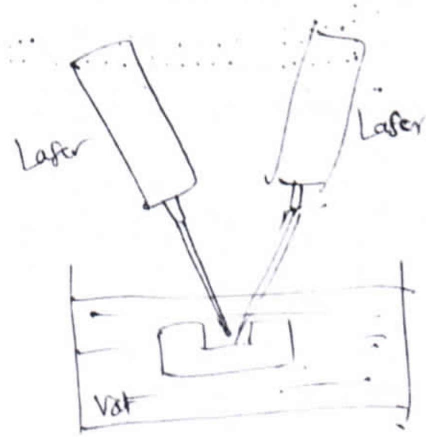


(a) Vector scan



b) Mask projection approach

DMD- Digital micromirror device



c) 2 - photon approach.
[recoating not required]

Q3 b. <u>Process benefits:</u>

1) This process has got the ability to produce parts with a wide range of mechanical & optical properties. This is decided by choice of monomers.

2) Engineers can create complex multifunctional materials & have control over applications.

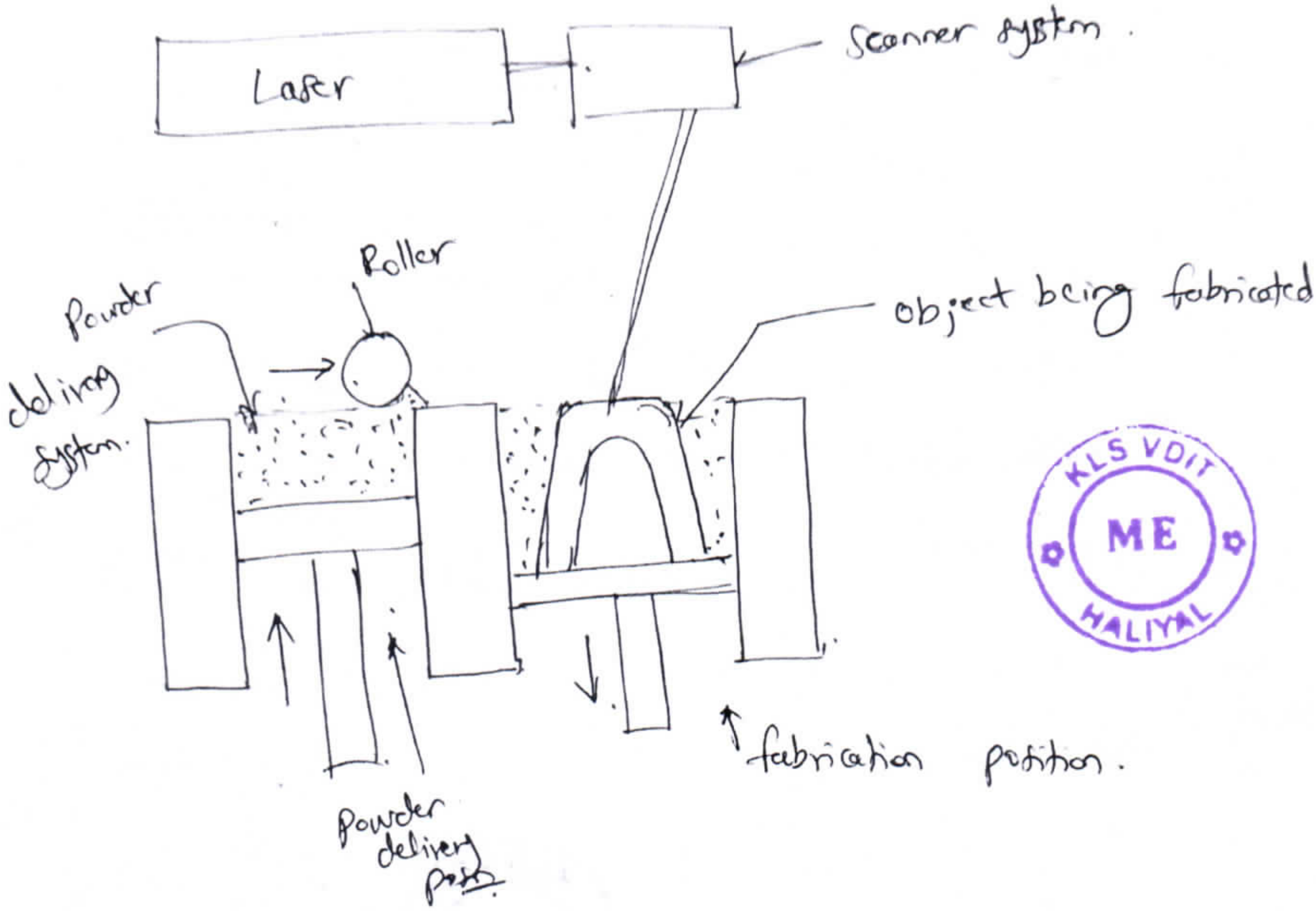
3) Parts with complex shapes can be created.

4) This process can build up layers of materials that can be subsequently sculpted into desired shape.

<u>Disadvantages:</u>

- costly in comparison.
- They must be post cured for an extended period to get significant strength from them
- Lack of photo-resin material choices
- Inadequate strength & durability

4a. Selective Laser Sintering (SLS)



- SLS is ~~the~~ most prominent of the powder bed fusion processes.
- In SLS a layer of powdered material is spread out and levelled over the top surface of the growing structure.

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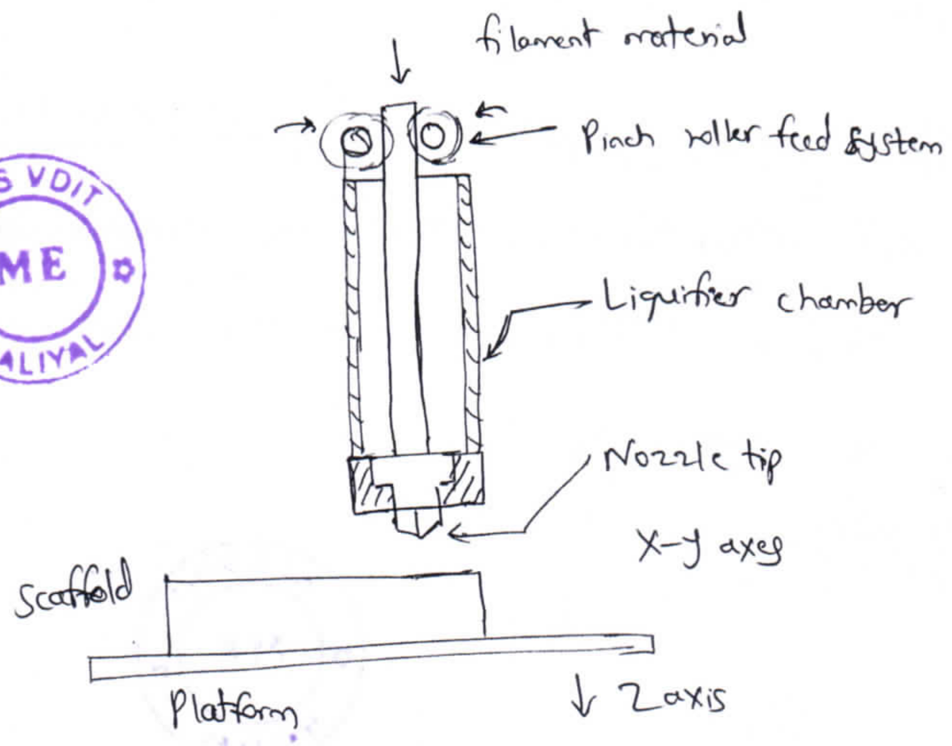
- A laser then selectively scans the layer to fuse those areas defined by the geometry of the cross section; the laser energy also fuses layers together.

- The unfused material remains in place as the support structure. After each layer is deposited an elevator platform lowers the part by the thickness of the layer & the next layer of powder is deposited.

Q4.b. In "Extrusion based systems" - material is extruded through a nozzle & then deposited layer by layer to produce a component. Fusion deposition modeling - principles.



- Fused deposition modeling (FDM) is a filament based technology where a temperature - controlled head extrudes a thermoplastic material layer by layer onto a build platform.
- A support structure is created where needed & built in water soluble material.
- Filament is made of thermoplastic material:

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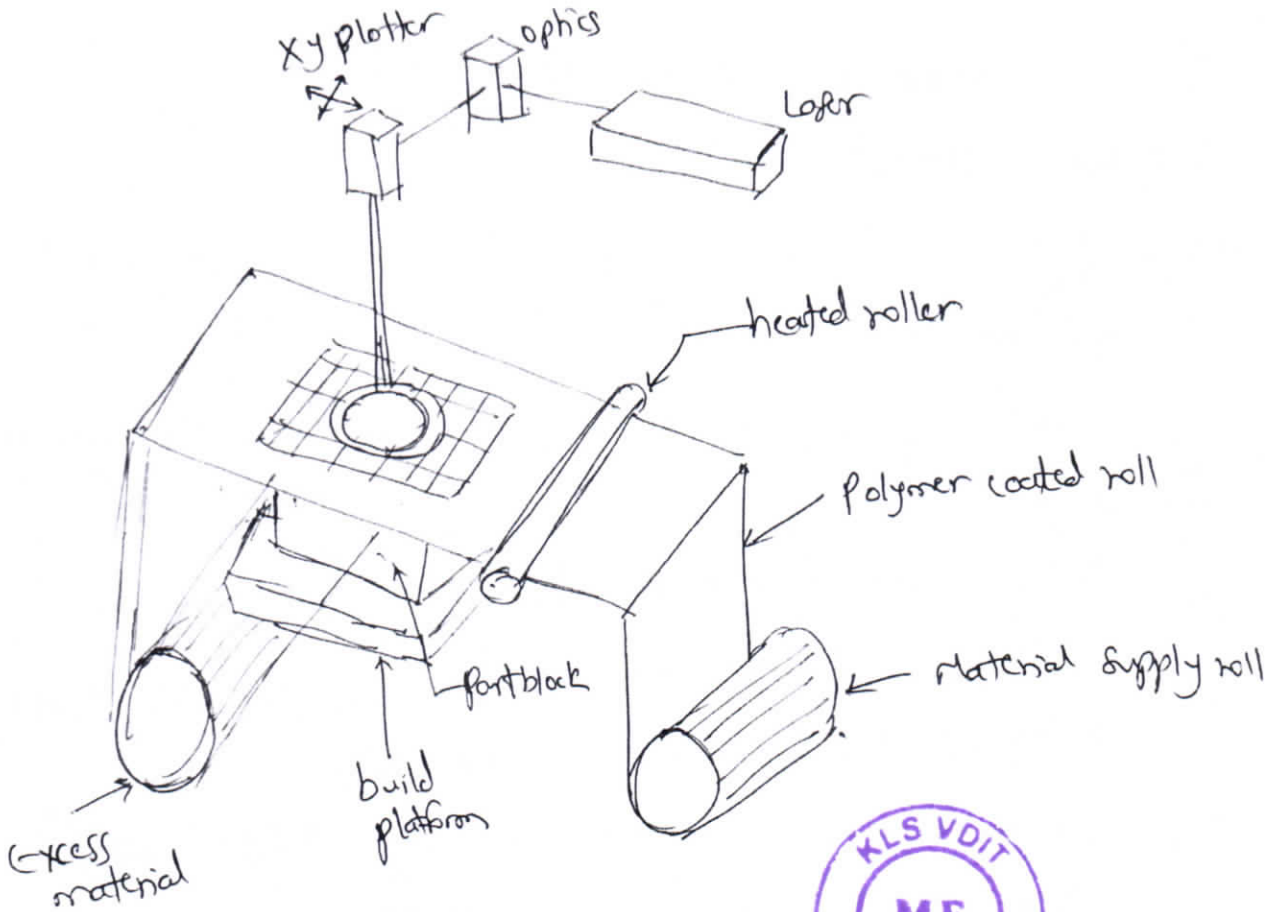
- ABS (Acrylonitrile butadiene styrene)
- PLA (Poly latic acid).

There a number of key features that are common to any extrusion based system:

- Loading of material
- Liquification of the material
- Application of pressure to move the material through nozzle]
- Extrusion
- Plotting according to predefined path
- Bonding of the material to itself or secondary build materials to form a coherent solid structure
- Inclusion of support structures to enable complex geometrical features.

15a. <u>Laminated object manufacturing</u>



4 processes:

1) gluing or adhesive bonding
2) thermal bonding processes
3) clamping
4) ultrasonic welding.

- Paper coated with thermoplastic material on one side
  Paper thickness = 0.07 to 0.2 mm.

- Paper is precisely cut using laser / mechanical cutter & then bonded with adhesive.

a) Bond then form process
   - Placing the laminate
   - bonding it to substrate
   - cutting it according to slice contour

b) Form then bond processes [metallic & ceramic parts]
   - Placing sheet material (laminate) thermally bonded
   - cutting to required shape
   - bonding to substrate.

Q5b.

Research achievements in printing deposition:

Process for bioprinting organs.

- creating a blueprint of an organ with its vascular architecture.
- Generating a bioprinting process plan
- isolate steam cells.
- differentiate the steam cells into organ specific cells.
- Prepare bioink reservoirs.
- place the bioprinted organ in a bioreactor prior to transplantation.

Medical applications:

- Tissue & organ fabrication
- creation of customised prosthetics.
- Implants & anatomical models.
- Pharmaceutical research — drug dosage forms, delivery & discovery.

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Research achievements in printing process deposition.

Several research works are carried out in the field of materials & process parameters. Few are listed below.

Polymers: Research work done by Gao & Sonin.

Work: Deposition & solidification of molten polymer microdr

3 modes of deposition: columnar, sweep (linear), repeated sweep (vertical wall).

Materials used: candelila wax, microcrystalline petroleum wax

Droplet size: 50 μm.

Variables which affect the quality: print head speed, droplet volume & size, droplet frequency etc.

Ceramics:

Work: Spreading of deposited material & formation of independent droplets.

material: zirconia powder + solvent + additives

Size of droplet: 62 μm.

Metals: Find application in electronic industry — formation of traces, connections & soldering

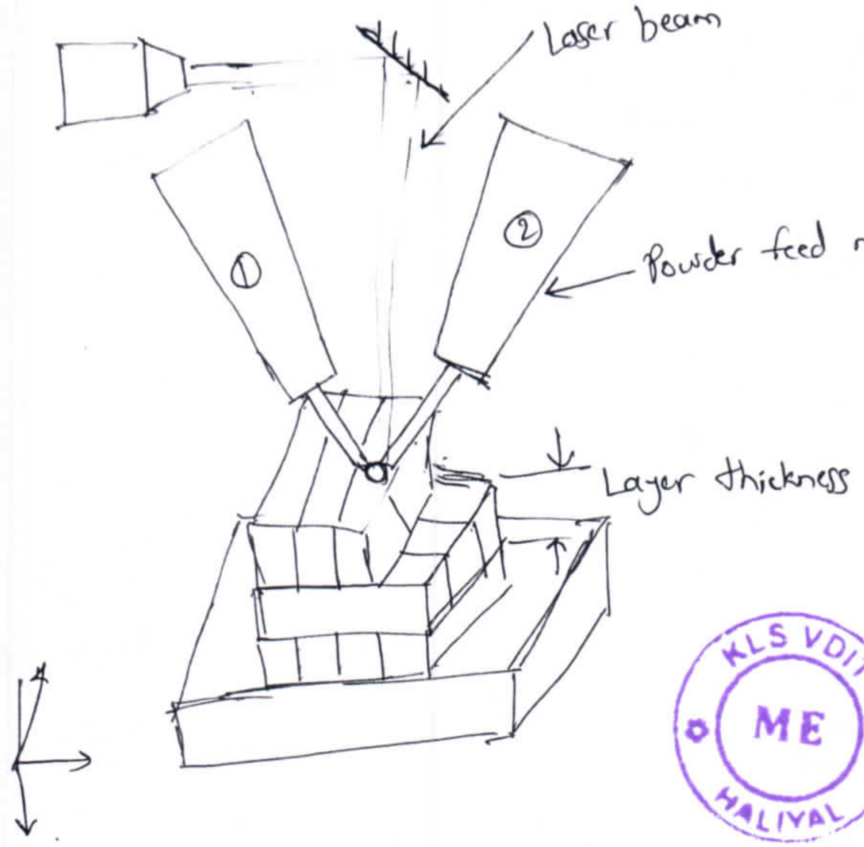
Work done by: Liu & Orme.

Work: Solder droplet deposition

material: alloy of bismuth, lead & tin

Parts with less porosity (less than 0.03%) & uniform microstructure are obtained.

Q6 a. Beam deposition process



Laser beam / electron beam / plasma arc

Beam deposition process enables the creation of parts by melting & deposition of material from powder or wire feedstock. Although this approach works for polymers, ceramics & MMC, predominantly it is used for metal powders.

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Different processes:

1) Laser engineered net Shaping (LENS)
2) Direct Light fabrication (DLF)
3) Direct Metal Deposition (DMD)
4) 3D Laser cladding
5) Laser Based Metal Deposition (LBMD)

Metal powders are fed through nozzles & then cured through laser beam. The layer thickness is controlled by rate of material powder deposition & Laser beam focus. There are different approaches [mentioned above (5)] used in beam deposition. Orientation of the material deposition can be changed from one layer to another which can result in better strength of the part.

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Q6b.

Direct write technologies: (DW) - Background & introduction

The term Direct write in its broadest sense means any technology which can create 2D or 3D functional structures directly onto flat or conformal surfaces in complex shapes without any tooling or masks.

Many processes fall under this category. But generally in additive manufacturing technology, DW refers to those technologies which are designed to build free form structures in dimensions of 5 mm or less, with feature resolution in one or more dimensions below 50 μm.

- "Small scale" interpretation.

- "DW" technologies are those processes which create meso, micro & nanoscale structures using a freedom deposition tool.

Ink based DW

The most varied, least expensive & most simple approaches to DW involve the use of liquid inks. These inks are deposited on a surface & contain the basic materials which become desired structure.

Different types:

- Colloidal inks
- Nanoparticles filled inks
- Fugitive organic inks
- Polyelectrolyte inks
- Sol-gel inks

After deposition, these inks solidify due to evaporation, gelation, solvent driven reactions, or thermal energy to leave a deposit of the desired properties. DW inks are

- extruded as continuous filament through nozzle
- deposited as droplets using printhead.

Q7.a. Selection methods for a part:

Decision theory: (Based on utility theory approach).

There are 3 elements of any decision.

1) Options – the items from which the decision maker is selecting
2) Expectations – of possible outcomes for each option
3) Preferences – how the decisionmaker values each outcome

Set of decisions options – $A = \{A_1, A_2, \ldots, A_n\}$

Outcome might consist of the time, cost, surface finish of the built part, accuracy etc.

Expectations of outcomes are modeled as functions of options, $X = g(A)$.

Preferences model the importance assigned to outcomes by the decision maker. For ex. a designer may prefer low cost & short turn around time for a concept model, with some compromise on surface finish.

In many ad hoc decision support methods, preferences are modeled as weights or importances, which are represented as scalars.

Decision support ~~techniques~~ ~~&~~ problem (DSP) technique is being developed which provides means for mathematically modeling design decisions involving multiple objectives, and supporting human judgement in design systems.

Few ex of decisions:

- selection
- compromise
- coupled & hierarchical.

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Q7. b.

i) Surface texture improvements:

- AM parts have common surface texture features that may need to be modified for aesthetic or performance reasons.

- Common surface textures are: stair steps, powder adhesion, fill patterns from extrusion, or beam based systems & witness marks from support material removal.

- Post process used depends upon required surface finish.

- For matte surface finish - bead blasting of the surface.
- " smooth/polished surface - wet/dry sanding & hand polishing.

- It is desirable to paint the surface prior to sanding or polishing.

- Painting the surface has dual benefit - sealing porosity & smoothing the stair-step effect.

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Q7b.

ii) <u>Support material removal:</u>

It is the process of removing the structural supports that encase parts after 3D printing. Traditional methods require technicians to manually spray off supports with high pressure hoses or chip away at the supports.

Support materials can be classified into 2 categories:

- Materials which surround the part as a naturally occurring by product of the build process.

- Rigid structures which are designed & built to support, restrain or attach the part being built to a build platform.

  - Natural support post processing
  - Synthetic support removal
  - Supports made from build materials
  - " " " secondary ".

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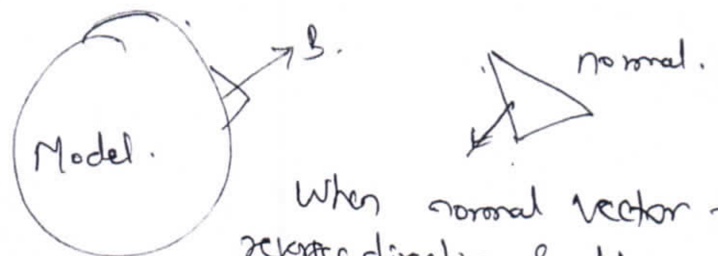
Q8. a.

STL file errors : Errors in STL files can lead to defect in parts manufactured & incomplete part building.

1) holes or gaps in a mesh : Missing Δle in mesh.

This occurs when adjacent Δles fail to share 2 common vertices.

2) Flipped normals :



When normal vector faces the reverse direction & this can lead to confusion during printing process.

3) Intersecting & overlapping Δles : This error occurs when 2 surfaces overlap or cross one another due to the complexity.

4) Bad edges

When edges of the Δles are not properly connected. Creating holes & bad contours.

5) Noise Shells. (outer layers of print)

When shell size is not small, it becomes redundant it is called noise shell. It can be dealt by flipping inverted Δles.

Q8.b.

i) <u>Accuracy improvements:</u>

- Accuracy improvement is possible by positioning accuracy improvement in 3 axes – x, y, z.
  (Accurate parts have to be used in AM m/c).
- Head of AM m/c / nozzle have to be made accurate & positioned accurately.
- There is wide range of accuracy capabilities in AM.
- Some processes are capable of submicron tolerances, where as others have accuracies around 1mm.
- Typically larger the build volume & faster the build speed the worse the accuracy for particular process.

ii) <u>Preparation for use as a pattern:</u>

- The parts made using AM are intended as patterns for investment casting, sandcasting, room temp vulcanisation (RVT) molding, spray metal

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deposition or other pattern replication processes.

- The accuracy & surface finish of an AM pattern will directly influence the final part accuracy & surface finish.

- As a result, special care must be taken to ensure the pattern has the accuracy & surface finish desired in the final part.

- In addition pattern must be scaled to compensate for any shrinkage that takes place in pattern replication steps.

Q 9 a.

i) Medical / Surgical models:

AM technologies are applied in the medical / surgical domain for building models that provide visual & tactile information.

1. Operation planning: Using real size AM models of patient's pathological areas, surgeons can more easily understand physical problems & gain a better insight into the operations to be performed.

2. Surgery rehearsal: AM models offer unique opportunities for surgeons & surgical teams to rehearse complex operations using the same techniques & tools as in actual surgery. [optimum method / changes can be made]

3. Training: AM models of specimens of unusual medical deformities can be built to facilitate the training of student surgeons & radiologists. These can be used for examinations also.

4. Prosthesis design: AM models can be used to fabricate master patterns which are then replicated using biocompatible plastic material. Implants are cost effective & accurate also.

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Q9a. ii) AM applications in automobiles

- In prototyping of automobile components.
- ~~Prom~~ Manufacturing of automobile interior parts like dashboard, plastic & composite parts.
- Different techniques used: Selective laser sintering, Stereolithography, binder jetting, fused filament fabrication, Selective laser melting.
- Seating parts, mirror cases, wiper links, containers/tanks are manufactured by AM process.

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Q9 b. i) <u>Align technology</u>:

Align technology is an organisation in Santa Clara, California. It is in the business of providing orthodontic treatment devices.

- Their invisalign treatments are essentially clear braces, called aligners that are worn on the teeth.
- Every 1-2 weeks, the orthodontic patient receives a new set of aligners that are intended to continue moving their teeth.
- The need for many different geometries in a short period of time requires a mass customisation approach to aligner production.
- Align's manufacturing process has been extensively engineered. first impression of patient's mouth is taken using dental clay & then it is scanned using laser digitizer. Then it's converted into tessellation.
- Required components are 3D printed using different appropriate technology.

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Q9b.

ii) Siemens & Phonak.

Siemens & Phonak are pioneers in the hearing aid business. In early 2000s they teamed up to investigate the feasibility of using SLS technology in production of shells for hearing aids.

In the product development process,

= an impression is taken from patient's ear & these are scanned by a laser scanner, rather than used directly as pattern.

- The point cloud is converted into a 3D CAD model which is manipulated to fine tune the shell design so that a good fit is achieved.
- This CAD model is then exported as an STL file for processing by SLS machine.
- Finally the part is 3D printed & inspected against scanned file.

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Q 10 a.

i) AM applications in aerospace:

- AM is being increasingly used for manufacture of complex shaped parts of aerospace.

- The techniques like SLA, SLS, BJ, FFF are used for fabrication of parts.

- Some of the ex are as below:

  - Borescope bosses — Turbofan TM engine.
    material — Ni alloy 718.
    method — Selective laser melting, laser beam melting

- Benefits of this process are:

  Lower development / production lead time, lower costs, suitable for materials which are difficult to machine, complex & intricate shapes etc.

- Support to satellite antenna.

  Material: $Ti6Al4V$.

  Method: Electron beam melting

  Benefits: weight reduction, complex & intricate shapes.

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ii) AM applications in industrial design

* Modeling / test units / prototyping.

AM is an ideal solution for creating quick concept models & prototypes & is widely used in industries to rapidly produce prototypes.

— Design concepts as well as validation testing can be done faster which reduces development time.

* Replacement parts, tooling & maintenance.

AM becomes a viable option, as it facilitates the cost effective & relatively quick production of parts & tools on demand.

Q10b. i) <u>Life cycle costing:</u>

- In addition to the part costs, it is important to consider the costs incurred over the life time of the part from both the customer's & supplier's perspectives.

The different splitups are:

- Equipment cost: cost of the m/c used for manufacturing.
- Material cost: Raw material cost
- Operation cost: actual manufacturing cost (power cost, labour cost, overhead cost).
- Tooling cost: Cost of fixture/ tools/ moulds/ nozzle.
- Service cost: repairing/ replacing part.
- Retirement cost: This is the cost associated with taking product out of service, dismantling it, & disposing it.

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ii) Future of direct digital manufacturing:

In future DDM is applicable in the shape complexity capabilities for economical low production volume manufacturing. Longer time-frames will see emergence of applications that take advantage of functional complexity capabilities (ex: mechanisms, embedded components & material complexities).

- An example of development is - 3D Systems Sinterstation Pro - all future models of machines will be designed with production manufacturing in mind. Many companies are focussing on Art material development with flame resistant nylon materials to enable parts manufacturing for commercial aircraft, as well as high temp & higher recyclability materials.

- Direct digital manufacturing is becoming more widely adopted because of its ability to produce manufactured parts more quickly and cost effectively compared to traditional manufacturing methods - in a world built on speed and rapid changes.

(Gurunath Hewundi)

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