

MODULE-5

Computer Numerical Control (CNC), Automation, Additive manufacturing Applications of AI in Mechanical Engineering

COMPUTER NUMERICAL CONTROL (CNC)

Introduction

Definition: Computer Numerical Control or CNC is an advanced form of the NC system where the machine control unit is a dedicated microcomputer instead of a hard-wired controller, as in conventional NC.

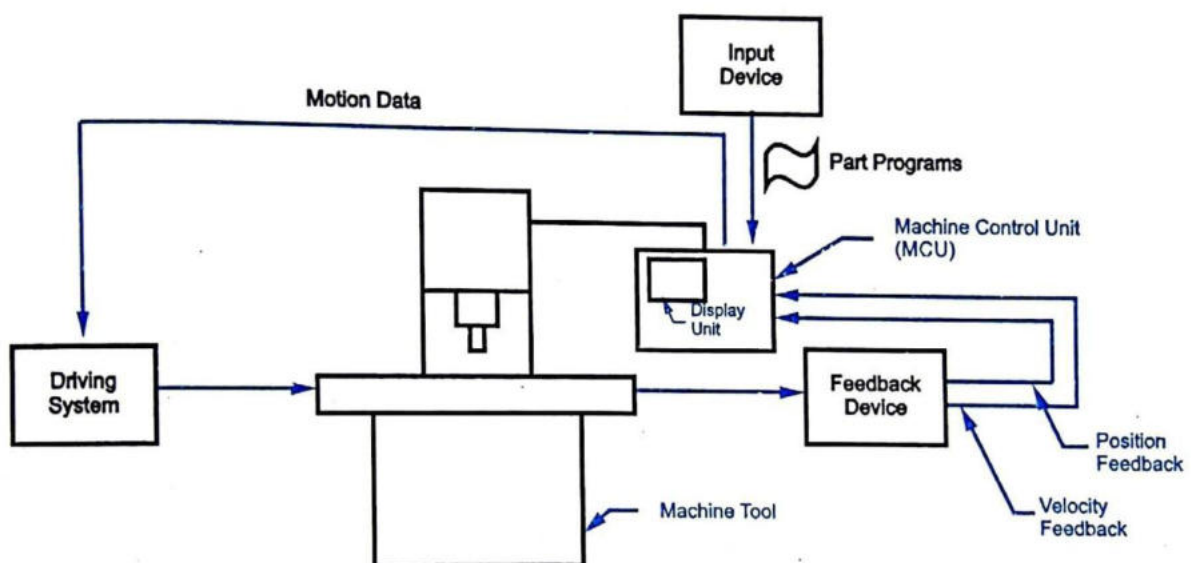
Computer Numerical Control has evolved during the rapid improvements of the computer technology. The advent of Microprocessors from the 1970s have helped in quick advancements in the Computer Technology and is in turn adapted in modern CNC Technology. Today's CNC Controller has latest features like high speeds of operation, large memories, bus architectures, improved servos, etc.

CNC Technology has powered the Machine Tool industry today. It is used in majority of machine tools like machining centers, turning centers, grinders, lathes, drilling machines, etc.

COMPONENT OF A CNC SYSTEM

A CNC System consists of the following elements:

1. Input Device
2. MCU or Machine Control Unit
3. Machine
4. Driving System
5. Feedback d
6. Display Unit



Elements of a CNC system

1. INPUT DEVICE: The part program is entered into the CNC Control or the MCU through the input device. There are various input devices used on a CNC Machine such as

a. USB (Universal Serial Bus) Flash drive: Here the USB flash drives transfer data to the control. USB is very common nowadays and its use is increased in modern computers.

b. Serial Communication: A serial communication port connects a computer system and a CNC Machine tool through an interface called RS-232. Most machines have RS-232 port and an RS-232 cable connects the computer and the CNC Machine to transfer data from the computer to the CNC Machine.

c. Ethernet Communication: The Ethernet communication is a more reliable and efficient means of transferring part programs from Computer to the CNC Control.

d. Conversational Programming: This is another way to input part programs to the controller through a keyboard. Built-in intelligent software inside the controller enables the operator to enter step by step data.

2. MCU OR MACHINE CONTROL UNIT: The Machine Control Unit or the MCU is the heart of the CNC System. It consists of the following components:

a. Central Processing Unit: The CPU is the brain of the MCU and it comprises of

- i. a control section that retrieves data from the memory and generates signals which in turn activates all MCU components.
- ii. An ALU (Arithmetic Logic Unit) that performs integer arithmetic operations like addition, subtraction, multiplication, counting, etc and logical operations
- iii. Immediate Access Store or Immediate Access Memory: This holds the data and programs temporarily that is required at that instant by the control section.

b. CNC Memory: The memory of the CNC is divided into i. Main Memory which consists of Read Only Memory (ROM) and Random Access Memory (RAM). The ROM stores the Operating System Software and machine interface programs. The RAM stores the Part programs. ii. Secondary Memory such as Hard disks which is used to store large programs and which can be used by the main memory when required.

c. Input/output Interface: The Input/output interface or the I/O interface establishes communication between the machine operator, the components of the CNC system and other connected computers. The Operator control panel is the interface through which the machine operator communicates with the CNC system. A keyboard and a display screen are also included in the panel.

d. Machine tool controls: A Machine Tool consists of various axes such as X, Y, Z, A, B, C and a spindle which rotates at the designed RPM. The position and velocity control of each of the axis and the rotational speed control are accomplished by certain hardware components in the MCU. The MCU generates control signals that are transformed into a form suitable for the specific position control systems that is required to drive the various axes of the machine.

e. Sequence controls for auxiliary functions: Apart from the general functions like spindle speed, feed rate, etc, certain auxiliary functions like cool emergency stop, tool changing function, etc are carried out under par control program controls.

3. MACHINE TOOL: This can be any type of machine tool such as a Machining center, a turning center, a lathe, milling machine, etc. The essential parts of the machine tool include the machine table, machine slide, the driving lead screw, ball screw, rigid and heavy machine Structure, and automatic tool changing system, spindle and spindle drive system, chip removal System etc. The machine table is controlled in the X and Y axes, while the spindle runs along the Z axis. In other machine tools, there are additional axes such as A, B or C that allows rotary motions around the X, Y and Z axes.

4 DRIVING SYSTEM: A drive system essentially is made up of amplifier circuits, drive motors, and ball lead-screws. The control signals (position and speed) of each axis are fed by the Machine Control Unit (MCU) to the amplifier circuits. Then, the control signals are augmented to actuate drive motors which in turn rotate the ball lead-screws to position the machine table. The commonly used types of electrical motors include DC Servo Motor, AC Servo Motor, Stepping Motor and Linear Motor.

5. FEEDBACK DEVICES: For the accurate operation of a CNC Machine, the positional values and speed of the axes needs to be continuously updated. This is done by the feedback devices.

6. DISPLAY UNIT: The display unit is the device that ensures interaction between the machine operator and the machine. Display unit displays the current status of operation such as the spindle RPM, the running part program, the feed rate, position of the machine slide, etc.

CNC Machining Centers and Turning Centers

Several of our application examples of single station manufacturing cells consisted of CNC machining centers. The machining center, developed in the late 1950s before the advent of CNC, is a machine tool capable of performing multiple machining operations on a work part in one setup under NC program control. Today's machining centers are CNC. Typical cutting operations performed on a machining center use a rotating cutting tool, such as milling, drilling, reaming, and tapping.

Machining centers are classified as vertical, horizontal, or universal. The designation refers to the orientation of the machine spindle. A vertical machining center has its spindle on a vertical axis relative to the worktable, and a horizontal machining center has its spindle on a horizontal axis.

Numerical control machining centers are usually designed with features to reduce nonproductive time. These features include the following:

- **Automatic tool-changer.** A variety of machining operations means that a variety of cutting tools is required. The tools are contained in a tool storage unit that is integrated with the machine tool. When a cutter needs to be changed, the tool drum rotates to the proper position, and an automatic tool changer (ATC), operating under part program control, exchanges the tool in the spindle for the tool in the tool storage unit. Capacities of the tool storage unit commonly range from 16 to 80 cutting tools.

- **Automatic work part positioned.** Many horizontal and universal machining centers have the capability to orient the work part relative to the spindle. This is accomplished by means of a rotary table on which the work part is fixture. The table can be oriented at any angle about a vertical axis to permit the cutting tool to access almost the entire surface of the part in a single setup.

- **Automatic pallet changer.** Machining centers are often equipped with two or more separate pallets that can be presented to the cutting tool using an automatic pallet changer while machining is being performed with one pallet in position at the machine; the other pallet is in a safe location away from the spindle. In this safe location, the operator can unload the finished part from the prior cycle and then fixture the raw work part for the next cycle.

A modern NC turning center is capable of performing various turning and related operations, contour turning, and automatic tool indexing, all under computer control. In addition, the most sophisticated turning centers can accomplish

- (1) Work part gaging (checking key dimensions after machining),
- (2) Tool monitoring (sensing when the tools are worn),
- (3) Automatic tool changing when tools become worn, and
- (4) Automatic work part changing at the completion of the work cycle.

Another development in NC machine tool technology is the mill-turn center, which has the general configuration of a turning center, but also the capability to position a cylindrical work part at a specified angle so that a rotating cutter can machine features into the outside surface of the part.

Advantages of CNC machines

1. The accuracy and repeatability obtained is high.
2. Complex shaped contours can be machined.
3. Can be easily programmed to handle variety of product styles.
4. High volume of production compared to conventional machines
5. Even lesser skilled or trained people can operate CNC Machines unlike the Conventional ones where highly skilled people are required.
6. CNC Machines can be used uninterruptedly without turning them off provided regular maintenance is done.
7. Prototypes can be produced faster and thus results in reduced lead times.
8. Avoids errors that were otherwise committed by humans operating conventional machines.
9. Since CNC machines can be programmed, one person may well take care of a number of CNC Machines. This reduces the employees and hence costs are reduced.
10. Using CNC Machines results in a safer work environment since the operator is not exposed to the machine area during machining.
11. CNC Machines can be upgraded to newer technologies by replacing the existing CNC Control with an advanced one.
12. Many CNC Machines can be linked together to a main 'computer. Programs from the main computer can be downloaded to any connected CNC Machine. This leads us to another type of NC concept called as the Direct Numerical Control (DNC).

Disadvantages of CNC machines

1. A thorough programming knowledge is required by the operators or programmers. This again requires skilled programmer and hence the cost of labour can be high.
2. Cost of a CNC Machine is high compared to the Conventional Machine Tools.
3. The spares of CNC Machines are relatively costlier than Conventional Machines.
4. CNC Machines require air conditioned environment and/or a chiller unit. Thus extra costs are involved.

CAD definition and concept

Definition: Computer Aided Design(CAD) is the technology concerned with the use of computer systems to assist in the **creation, modification, analysis, and optimization** of a design. [Groover and Zimmers, 1984]

Concept: In a design process, **Computer Aided Design** is considered as the basis of the generative design with many expectations for hands-off performance along with the knowledge based engineering which would result in a limited human involvement in the design process.

advantages of CAD systems

There are many of benefits of CAD software. Studies have proven that integrated CAD usage allows product developers meet their goals more efficiently, reduction in product development time, increased product quality and productivity, resulting in reduced manufacturing and product costs.

Some of the benefits of CAD are as follows:

1. Increase in the **productivity** of the designer.
2. Improve the **quality** of the design.
3. Better communications/ Integration/ collaboration among design engineers and other personnel.
4. Creating **documentation** of the designing.
5. Creating the **database** for manufacturing.
6. **Saving** of design data and drawings.
7. High **precision** and low **error**
8. **Automating** the design process.
9. **Saving** time/shorter lead time.
10. Simulation.
11. Re-use and share.
12. Easy to make **changes/modifications**.
13. Ease of design **standardization**.
14. Ease of **cost estimation**.
15. Ease of **Mass Properties** calculations.
16. Data supports in **optimization** of material and design.
17. Assists in Computer Aided **Inspection** CAI of complex part.

Disadvantages of CAD systems

Apart from advantages, adapting CAD systems may consists of few disadvantages as follows:

1. **Time** taking process and cost for **training** know how to operate or run the software.
2. High production or purchasing **cost** for new CAD systems.
3. Need for regular **updation** of software or operating systems.
4. Needs **less employment** because of CAD/CAM systems.

Scopes/applications of CAD in various fields

CAD systems can be utilized in various industrial applications. Some of the scopes and applications are listed as follows:

1. Mechanical drafting and drawings.
2. Aeronautical and Naval engineering.
3. Tool and Die manufacturing industry.
4. Welding and cutting industry.
5. Printed circuit board (PCB).
6. Electrical design.
7. Plant layout and space planning.
8. Process planning and assembly design.
9. Heat exchanger and pressure vessel design.
10. 3D factory design.
11. Fluid mechanics.
12. Microprocessor design.
13. Structure design.

Computer-aided manufacturing (CAM) can be defined as the use of computer systems to plan, manage, and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources. As indicated by the definition, the applications of computer-aided manufacturing fall into two broad categories:

1. *Computer monitoring and control.* These are the direct applications in which the computer is connected directly to the manufacturing process for the purpose of monitoring or controlling the process.
2. *Manufacturing support applications.* These are the indirect applications in which the computer is used in support of the production operations in the plant, but there is no direct interface between the computer and the manufacturing process.

COMPUTER INTEGRATED MANUFACTURING (CIM)

“CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency.”

CIM Objectives

- Simplify production processes, product designs, and factory organization as a vital foundation to automation and integration
- Automate production processes and the business functions that support them with computers, machines, and robots
- Integrate all production and support processes using computer networks, cross-functional business software, and other information technologies

POTANTIAL BENEFITS OF CIM

- Improved customer service
- Improved quality
- Shorter time to market with new products
- Shorter flow time
- Shorter vendor lead time
- Reduced inventory levels
- Improved schedule performance
- Greater flexibility and responsiveness
- Improved competitiveness
- Lower total cost
- Shorter customer lead tim

Computer-Aided Engineering (CAE) is the application of computer software to simulate, validate, and optimize product designs and manufacturing processes. It serves as a "virtual playground" or "superhero sidekick" for engineers, allowing them to predict how a product will behave under real-world conditions (such as stress, heat, fluid flow, or vibration) without building expensive, time-consuming physical prototypes.

Key Components and Techniques

- **Preprocessing:** Modeling the geometry and defining physical properties, loads, and constraints.
- **Solving:** Using algorithms to solve complex physics equations (e.g., Finite Element Method).
- **Post-processing:** Visualizing and analyzing results.

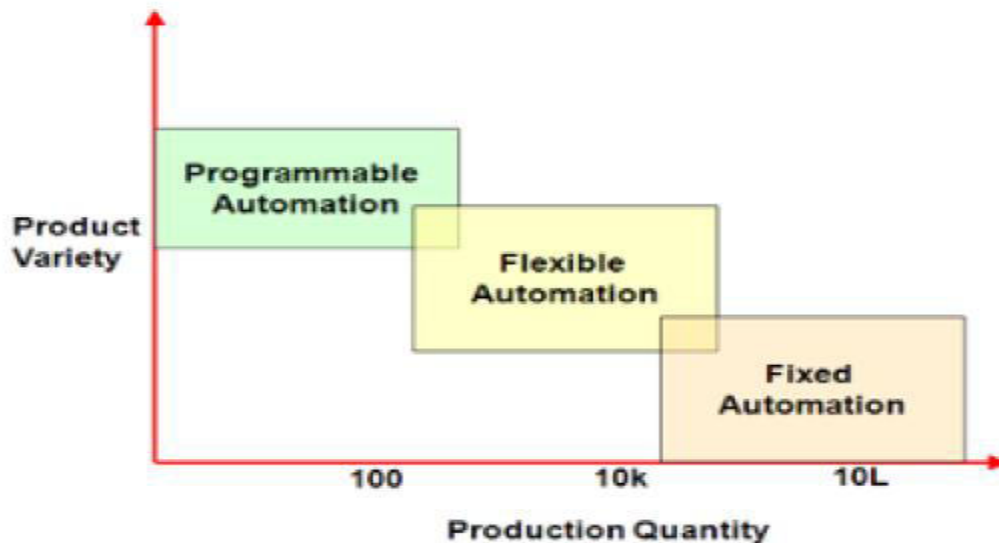
AUTOMATION

Definition: It is technology concerned with the application of Mechanical, electronic & computer-based systems to operate and control production in order to improve productions.

TYPE OF AUTOMATION

Automated production systems are classified into three basic types:

- 1) Fixed Automation
- 2) Programmable Automation
- 3) Flexible Automation



1) FIXED AUTOMATION

- Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration.
- The operations in the sequence are usually simple.
- It is the integration and coordination of many such operations into one piece of equipment that makes the system complex.

The typical features of fixed automation are:

- High initial investment for custom-engineered equipment
- High production rates
- Relatively inflexible in accommodating product changes

2) PROGRAMMABLE AUTOMATION

- In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations.
- The operation sequence is controlled by a program, which is a set of instructions coded so that the system can read and interpret them.
- New programs can be prepared and entered into the equipment to produce new products.

The typical features of programmable automation are:

- High investment in general-purpose equipment
- Low production rates relative to fixed automation
- Flexibility to deal with changes in product configuration
- Most suitable for batch production

3) FLEXIBLE AUTOMATION

- The concept of flexible automation has developed only over the last 15 to 20 years, and the principles are still evolving.
- A flexible automated system is one that is capable of producing a variety of products (or parts) with virtually no time lost for changeovers from one product to the next.
- There is no production time lost while reprogramming the system and altering the physical setup (tooling, fixtures and machine settings).
- Consequently, the system can produce various combinations and schedules of products, instead of requiring that they be made in separate batches.

The features of flexible automation can be summarized as follows:

- High investment for a custom-engineered system
- Continuous production of variable mixtures of products
- Medium production rates
- Flexibility to deal with product design variations

ADDITIVE MANUFACTURING

Introduction

Additive Manufacturing (AM) is a modern manufacturing process in which objects are created by adding material layer-by-layer from 3D model data. Unlike traditional manufacturing methods (such as machining or milling) that remove material, additive manufacturing builds parts from the bottom up.

This technology is commonly known as 3D printing and is widely used in industries like aerospace, automotive, healthcare, architecture, and consumer products.

Steps in Additive Manufacturing

The Eight Steps in Additive Manufacture

3D model creation:

STL file creation or Native CAD print:

STL file transfer or Native CAD transfer

Machine set up

Building

Part Removal

Post-processing

Application

- Step 1: 3D model creation: A 3D model of the desired specimen should be created using 3D CAD software or a 3D object scanner.
- Step 2: STL file creation or Native CAD print: CAD model is converted into a STL files which are the standard for 3D printers. But nowadays, more sophisticated 3D printers are where one can directly print from a native CAD file.
- Step 3: STL file transfer or Native CAD transfer: STL file has to transfer to the machine or printer. At this stage, the native file needs to be changed to the proper size, location, and orientation.
- Step 4: Machine set up: At this stage the machine has to be set up by loading the model material, and various process parameters should be taken care of.
- Step 5: Building: This is a mainly automated process where the printer builds the specimen by depositing or cutting the model material layer by layer. A minimum human contribution is required at this stage.
- Step 6: Part Removal: Once the building is completed, the desired specimen should be removed carefully from the building platform along with the support structure (if used).
- Step 7: Post-processing: Finally, the specimen is sent for post-processing operations like polishing, cleaning and painting if required.
- Step 8: Application: It is finally ready to use.

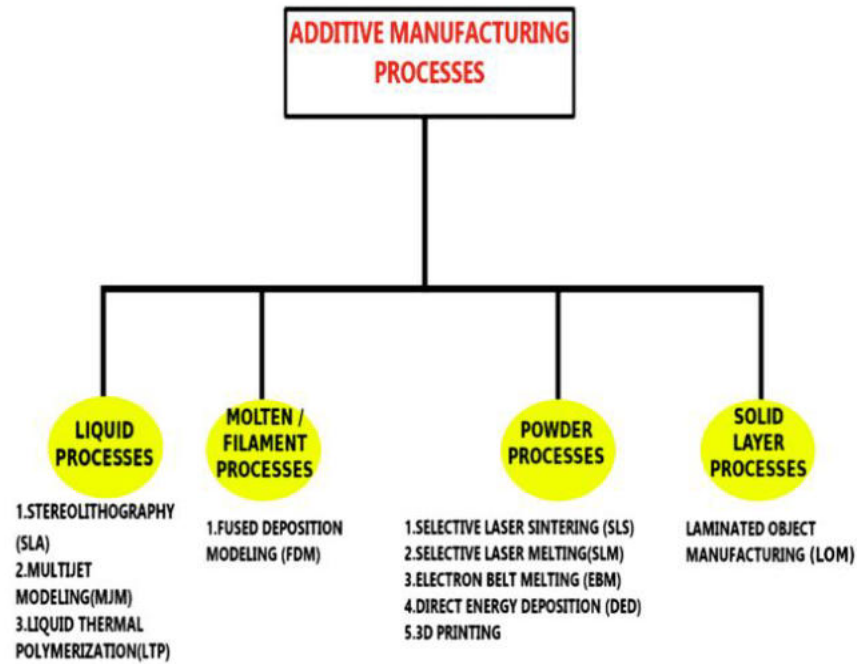


Fig. Classification of additive manufacturing (AM)

ADDITIVE MANUFACTURING PROCESSES:

1. Photopolymerization Technique
2. Material Extrusion Technique
3. Powder-Based Fusion Technique

1. PHOTOPOLYMERIZATION TECHNIQUE

Photopolymerization is an additive manufacturing process in which liquid photopolymer resin is cured (hardened) using ultraviolet (UV) light or a laser to form solid layers of a 3D object. It belongs to the vat polymerization family of 3D printing technologies.

Principle of Photopolymerization

The technique works on the principle that certain liquid polymers solidify when exposed to UV light.

Basic working steps:

1. A container (vat) is filled with liquid photopolymer resin.
2. A UV laser or digital light projector selectively exposes specific areas of the resin.
3. The exposed resin polymerizes and solidifies to form one layer of the object.
4. The build platform moves slightly to allow the next layer to be formed.
5. The process repeats until the entire 3D object is completed layer by layer.

Major Photopolymerization Technologies :

1. Stereolithography (SLA)

- Uses a UV laser beam to cure liquid resin.
- One of the earliest 3D printing techniques.
- Produces high precision and smooth surfaces.

2. Digital Light Processing (DLP)

- Uses a digital projector instead of a laser.
- Cures entire layers at once, making it faster than SLA.

3. Continuous Liquid Interface Production (CLIP)

- An advanced form of photopolymerization.
- Uses continuous curing instead of layer-by-layer exposure.
- Much faster than traditional SLA.

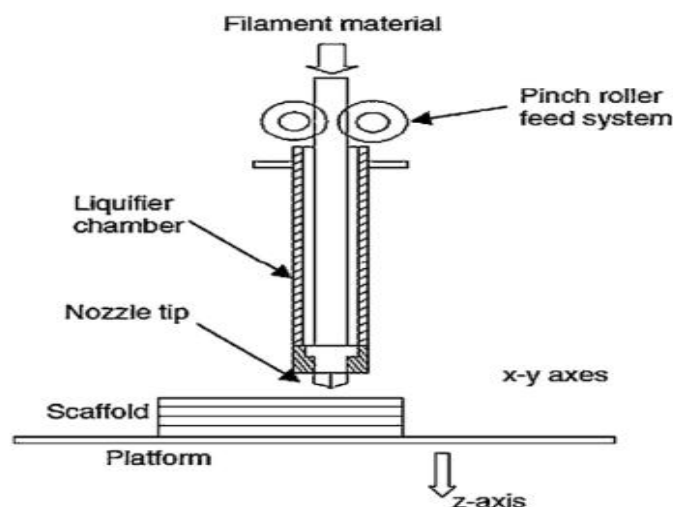
2. MATERIAL EXTRUSION TECHNIQUE

The Material Extrusion Technique is a 3D printing (additive manufacturing) process where material is pushed through a heated nozzle and deposited layer by layer to create a 3-dimensional object. It is one of the most widely used and affordable 3D printing methods.

What is Material Extrusion?

Material extrusion is an additive manufacturing process in which thermoplastic material is heated, extruded through a nozzle, and deposited in layers to build a part from a digital model.

Working Principle



Schematic of extrusion-based systems

The process follows these steps:

1. 3D Model Creation

- A model is designed using AutoCAD, SolidWorks, or similar CAD software.

2. Slicing

- The model is converted into thin layers using slicing software like Cura.

3. Material Heating

- Thermoplastic filament (e.g., PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene)) is fed into a heated nozzle.

4. Extrusion

- The molten material is extruded through the nozzle.

5. Layer-by-layer Deposition

- The printer moves in X, Y, and Z directions and deposits layers that fuse together to form the object.

3. POWDER-BASED FUSION TECHNIQUE

Powder-Based Fusion Technique is an additive manufacturing (3D printing) method where fine powder particles are fused (melted or sintered) layer-by-layer using heat energy to build a solid object. It is widely used in metal and polymer 3D printing industries.

How Powder-Based Fusion Works

1. Powder spreading – A thin layer of powder material is spread across a build platform.
2. Energy source – A laser or electron beam selectively heats specific areas of the powder.
3. Fusion – The powder particles melt or sinter together to form a solid layer.
4. Layer repetition – Another powder layer is spread and fused.
5. Final part – The process repeats until the full 3D object is completed.

This layer-by-layer process forms complex shapes with high precision.

Types of Powder-Based Fusion Techniques

1. Selective Laser Sintering (SLS)

- Uses a laser to sinter powdered plastic or metal.

2. Selective Laser Melting (SLM)

- Fully melts metal powder using a laser.

3. Electron Beam Melting (EBM)

- Uses an electron beam to melt metal powder in a vacuum.

4. Direct Metal Laser Sintering (DMLS)

- Similar to SLS but mainly used for metal parts.

Advantages and Disadvantages of Additive Manufacturing

Advantages

Free complexity: It requires less time and cost to build a complex job through additive manufacturing technology.

Variety-free: A computer-aided solid (CAD) model file makes replacement or modification of a part simple, and the new desired result may be printed straight away.

No assembly required: The product's moving parts, such as bicycle chains and hinges, may be printed in metal all at once, which might significantly reduce the product's component count.

No loss: There is no loss during production time when there is successive adding of materials. A minimal amount of material is sometimes built, called purged materials.

Low constraints: Almost anything that a human dream can easily be made using the additive manufacturing (AM) process.

Less manpower: Less but skilled manpower is required in this technique.

Disadvantages

Limited choice of materials, surfaces and colours.

Till now, this technique is for small production or batch production. Mass production cannot be done here.

A higher cost is required for a larger production.

Sometimes limited dimensions in production.

Any dangerous item should be checked carefully. Liability is an issue with the additive manufacturing technique.

Automotive Applications of Additive Manufacturing

1. Rapid Prototyping

Automotive companies use AM to quickly produce prototypes for design testing.

2. Lightweight Components

AM enables **topology optimization**, producing lightweight yet strong parts.

Applications:

- Engine brackets
- Structural supports
- Transmission housings

3. Tooling and Manufacturing Aids

3D printing is used to manufacture:

- Jigs
- Fixtures
- Assembly tools

4. Customization and Low-Volume Production

AM allows manufacturers to produce custom car parts or limited edition components.

Examples:

- Custom dashboards
- Personalized interior trims
- Motorsport components

5. Spare Parts Manufacturing

3D printing allows **on-demand production** of spare parts.

Aerospace Applications of Additive Manufacturing

1. Lightweight Aircraft Components

Examples of AM parts:

- Turbine components
- Fuel nozzles
- Aircraft brackets

2. Complex Geometry Components

AM allows production of parts that are impossible to make with conventional manufacturing.

Examples:

- Internal cooling channels
- Lattice structures
- Integrated assemblies

3. Satellite and Space Components

Additive manufacturing is used to build lightweight parts for satellites and spacecraft.

Applications:

- Antenna brackets
- Propulsion components
- Heat exchangers

4. Rapid Tooling and Repair

AM enables quick production of:

- Replacement aircraft parts
- Maintenance tools
- Repair components

5. Engine Components

Additive manufacturing is widely used in jet engines.

Examples:

- Combustion chambers
- Turbine blades

Applications of AI in Mechanical Engineering:

Artificial Intelligence (AI) is transforming Mechanical Engineering by improving efficiency, quality, safety, and automation. Below are the major applications of AI in three important areas: Automobile Industry, Manufacturing Industry, and Mechanical Design

1. AI in the Automobile Industry

AI helps automobile companies design safer, smarter, and more efficient vehicles.

1. Autonomous (Self-Driving) Vehicles

AI enables vehicles to drive without human intervention using sensors, cameras, and machine learning.

AI functions:

- Lane detection
- Traffic sign recognition
- Collision avoidance
- Route optimization

2. Predictive Maintenance

AI analyzes vehicle sensor data to predict component failures before they happen.

Example:

- Monitoring engine temperature, vibration, and oil condition.

3. Driver Assistance Systems

AI powers **Advanced Driver Assistance Systems (ADAS)**.

Features:

- Automatic emergency braking
- Adaptive cruise control
- Parking assistance
- Driver fatigue detection

4. Smart Traffic Management

AI analyzes traffic patterns to optimize traffic signals and reduce congestion.

Example:

- Smart city traffic control systems.

2. AI in the Manufacturing Industry

AI improves production efficiency, quality control, and automation.

1. Intelligent Robotics

AI-powered robots perform tasks like:

- Welding
- Assembly
- Material handling
- Packaging

2. Predictive Maintenance in Machines

AI monitors machine health using sensors.

3. Quality Inspection

AI uses **computer vision** to detect defects in manufactured products.

Applications:

- Surface defect detection
- Dimensional inspection
- Assembly verification

4. Production Planning and Scheduling

AI optimizes manufacturing processes by:

- Predicting demand
- Scheduling machines
- Managing supply chains

3. AI in Mechanical Design

AI helps engineers design better products faster.

1. Generative Design

AI automatically generates multiple design alternatives based on constraints like weight, strength, and materials.

2. Design Optimization

AI improves designs by analyzing large sets of parameters.

Applications:

- Aerodynamic optimization
- Structural optimization
- Heat transfer analysis

3. Simulation and Testing

AI speeds up engineering simulations.

Example:

- Predicting stress and deformation without extensive physical testing.

4. Intelligent CAD Systems

AI-integrated CAD tools assist engineers by:

- Suggesting design improvements
- Automating repetitive design tasks
- Detecting design errors