ULTRASONIC MACHINING

Introduction

Ultrasonic machining is a non-traditional machining process used to remove material from a workpiece through the use of high-frequency ultrasonic vibrations. It is a precise and versatile manufacturing technique that can be applied to a wide range of materials, including metals, ceramics, glass, and composites. It is particularly useful for materials that are hard, brittle, or difficult to machine using conventional methods.

Ultrasonic Machining is an advanced machining process that harnesses the power of high-frequency mechanical vibrations to remove through the application of ultrasonic vibrations, typically in the range of 20 kHz to 50 kHz. This unique technique employs abrasive slurry or particles that are introduced between the vibrating tool, known as the sonotrode and the workpiece, causing localised abrasion and material removal. USM is most commonly used to machining of glass, ceramics, zirconia, precious stones, and hardened steels.

History

The history of ultrasonic machining began with a paper by Wood and Loomi in 1927 in which the scope of using high frequency (about 70 kHz) sound waves were proposed. The first useful description of the technique of ultrasonic machining is contained in a British patent granted to Balamuth in 1945. This method of machining resorts to percussion or hammering of abrasives against the workpiece with the tool. So, we have a tool, it is not directly impacting the workpiece, but there are some abrasive particles.

Working Principle

The time spent on ultrasonic machine entirely depends on the frequency of the vibrating tool. It also depends on the size of grains of the abrasive slurry, the rigidity and the viscosity as well. The grains used in the abrasive fluid are usually boron carbide or silicon carbide as they are rigid than others. The used abrasive can be carried away easily if the viscosity of the slurry fluid is less.

Construction

Ultrasonic Machining consists of the following main parts:

- Ultrasonic Transducer
- Amplifier and Power Supply
- Horn or Sonotrode
- Tool Holder
- Worktable
- Abrasive Slurry System
- Control System
- Coolant and Filtration System
- Safety Features
- Monitoring and Feedback

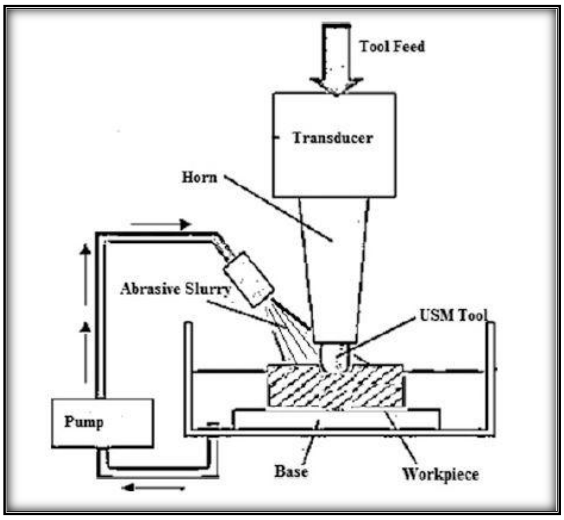


Figure: Construction of Ultrasonic Machining

- **Ultrasonic Transducer**: The heart of a USM system is the ultrasonic transducer. This component is responsible for converting electrical energy into high-frequency mechanical vibrations. Piezoelectric crystals or ceramics are commonly used in these transducers. When an alternating current (AC) is applied to the transducer, it generates ultrasonic vibrations.

- **Amplifier and Power Supply**: An amplifier is used to increase the amplitude of the electrical signal generated by the power supply. The power supply provides the necessary electrical energy to drive the transducer at the desired ultrasonic frequency.

- **Horn or Sonotrode**: A horn or sonotrode is attached to the ultrasonic transducer. This tool amplifies and transmits the high-frequency vibrations generated by the transducer to the workpiece. The shape and material of the horn are carefully designed to optimize the transmission of vibrations.

- **Tool Holder**: The horn is typically mounted on a tool holder, which allows for precise positioning and adjustment. The tool holder connects the horn to the machine's mechanical structure.

- **Worktable:** The workpiece is placed on a worktable or workpiece holder, which is part of the machine's structure. The worktable can be adjusted in multiple axes to control the position and orientation of the workpiece relative to the tool.

- **Abrasive Slurry System**: An abrasive slurry system is used to supply a mixture of abrasive particles and a liquid coolant to the machining zone. The slurry serves several purposes: it aids in material removal, cools the machining area, and flushes away debris.

- **Control System**: A control system, often integrated with computer numerical control (CNC) technology, is used to precisely control the movement of the worktable and the ultrasonic vibrations. Operators can program the desired machining parameters, including vibration frequency, amplitude, and feed rates, to achieve the desired results.

- **Coolant and Filtration System**: A coolant system is employed to maintain a stable and controlled temperature during the machining process. This prevents excessive heat build up in the workpiece and tool. A filtration system may also be used to remove debris and contaminants from the abrasive slurry.

- **Safety Features**: USM machines typically include safety features such as enclosures to protect operators from exposure to vibrations and abrasive materials. Emergency stop buttons and safety interlocks are also common.

- **Monitoring and Feedback**: Some USM systems incorporate monitoring and feedback mechanisms, including sensors and cameras, to assess the machining process in real-time. This allows for adjustments and quality control during the machining operation.

The construction of a USM system can vary depending on the specific application and requirements. Some systems may be relatively small and manually operated, while others can be large, automated, and integrated into advanced manufacturing processes. The key components mentioned above work together to create a controlled and precise environment for the ultrasonic machining process, enabling the efficient removal of material from the workpiece.

Ultrasonic Machining can be used machine brittle, non-conductive material, Hard and Fragile material. Heat is not generated in this Machining process so there is very little or negligible physical change in the workpiece. Non-metal that cannot be machined by EDM and ECM because of poor electrical conductivity, but can very well be machined by Ultrasonic Machining.

Working

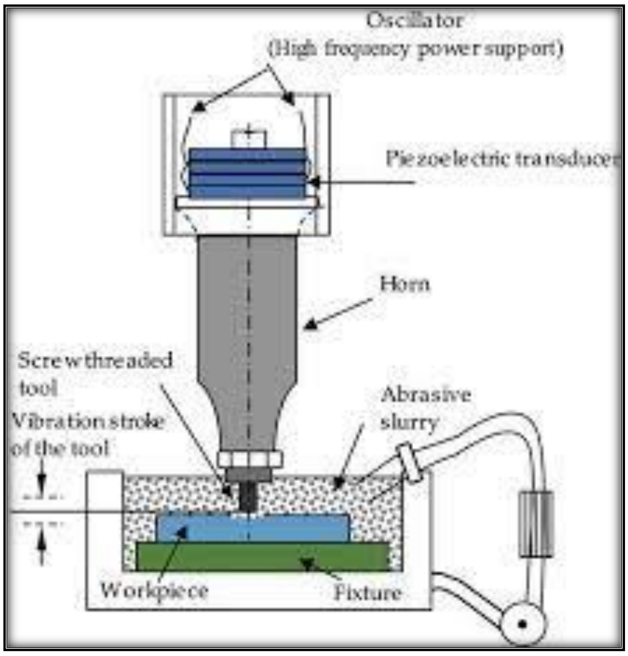


Figure: Working of Ultrasonic Machining

- Working of Ultrasonic Machining is: there is gap between tool and workpiece about 0.25 mm. The tool is made up of ductile material. Between tool and workpiece, there is a slurry of abrasive.
- Abrasive gets embedded into the tool and during the downward journey of the tool, abrasives hammer the workpiece, removing material.

- This material will be flushed away from the machining area by the flow of the slurry tool is made slightly tapered to produce straight holes.
- Upon increasing the viscosity of the carrier fluid material removal rate decreases due to difficulty in flushing. By increasing the frequency, MRR will increase because the number of impacts per unit time will increase.
- By increasing the amplitude, MRR will increase due to the increase in the momentum of abrasives.
- The amplitude of the vibration may vary from 5 to 75 µm and frequency may vary from 19 to 25 kHz.
- By increasing the concentration of abrasives, the impact will be there at more places which increases MRR (Material Removal Rate).
- But when the concentration increases beyond a certain value, due to Collision between the abrasives momentum is lost, decreasing the MRR.
- By increasing the size of the abrasive, an impact will appear in the larger area. But when the size increases beyond a certain value, the momentum of abrasives will decrease.

Process Parameter

The process parameters of USM play a crucial role in determining the efficiency and effectiveness of material removal. Here are some key process parameters in ultrasonic machining:

- **Frequency (kHz):** The frequency of the ultrasonic vibrations is one of the most critical parameters. Typically, ultrasonic frequencies range from 20 kHz to 40 kHz. Higher frequencies result in smaller abrasion particles and finer surface finishes.

- **Amplitude (Micrometres):** Amplitude refers to the maximum displacement of the tool during vibration. It affects the material removal rate and surface finish. A higher amplitude generally leads to a higher material removal rate.

- **Tool Material:** The choice of tool material can significantly impact the machining process. Typically, tools are made from materials like tungsten carbide or diamond. The tool's hardness and wear resistance are important considerations.

- **Tool Shape:** The shape of the tool tip can vary depending on the specific application. Common tool shapes include flat, conical, and cylindrical. The choice of tool shape affects the geometry of the machined features.

- **Abrasive Slurry:** USM often uses abrasive slurry to aid in material removal. The type and concentration of abrasive particles in the slurry influence the material removal rate and surface finish.

- **Feed Rate:** The feed rate, which is the rate at which the tool moves relative to the workpiece, determines the depth and rate of material removal. It needs to be optimized for efficient machining.

- **Workpiece Material:** The material being machined is a critical parameter. Different materials have varying hardness, ductility, and other properties that affect the machining process.

- **Gap Distance:** The gap distance between the tool and workpiece is essential. It affects the intensity of the ultrasonic vibrations and, consequently, material removal. The gap is typically filled with abrasive slurry.

- **Machining Time:** The duration of the ultrasonic machining process can be adjusted to achieve the desired material removal depth and surface finish.

- **Power Input:** The power input to the ultrasonic machining system determines the intensity of the vibrations and, consequently, the material removal rate. It should be controlled to avoid tool wear and excessive heating.

- **Clamping and Fixturing:** Proper clamping and fixturing of the workpiece are essential to ensure stability during machining and accurate results.

- **Tool Pressure:** The pressure applied by the tool to the workpiece can be adjusted. It affects the material removal rate and surface finish. However, excessive pressure can lead to tool wear and reduced tool life.

- **Cooling System:** Cooling is necessary to dissipate heat generated during the machining process. Cooling methods can include air or liquid cooling, depending on the application.

Optimizing these process parameters is crucial to achieving the desired material removal rates, surface finishes, and dimensional accuracy in ultrasonic machining. The specific values of these parameters will vary depending on the material being machined, the desired results, and the capabilities of the USM equipment being used.

ELECTROCHEMICAL MACHINING

Introduction

Electrochemical Machining is a non-traditional, precision machining process that uses the principles of electro chemistry to remove material from a workpiece. It is known for its ability to machine complex shapes and produce high-quality surface finishes on a variety of electrically conductive materials. Electrochemical machining is a method of removing metal by an electrochemical process. It is normally used for mass production and for working extremely hard materials.

Electrochemical Machining is the generic term for a variety of electro-chemical processes. It is used to machine workpieces through the anodic dissolution of metal. The process is used in aerospace engineering and the automotive, construction, medical equipment, microsystem and power supply industries.

History

Electrochemical machining is a type of non-traditional manufacturing processing. It was proposed by Gusseff in 1929, being applied to the industry from 1950 to 1960 and widely used in the aerospace industry. ECM is a method that finishes the workpiece surfaces by means of anodic metal dissolution. The machining tool is the cathode (-) that acts under DC current and in the presence of an electrolyte fluid to create the anodic reaction that removes workpiece (+) surface material in a precise. Electrochemical machining is a process of removing metal with the help of the electrolysis process. The electrochemical process is also known as the reverse of the electroplating process.

Working Principle

Electrochemical Machining is a non-traditional, precision machining process that uses the principles of electrochemistry to remove material from a workpiece. Electrochemical Machining is based upon Faraday's law of electrolysis. Faraday's law states that the mass of a metal altered by the electrode is proportional to the quantity of electrical charges transferred to that electrode. ECM is known for its ability to machine complex shapes and produce high-quality surface finishes on a variety of electrically conductive materials.

Construction

Electrochemical Machining consists of the following main parts:

- Work Piece and Tool Holder
- Electrolyte Supply System
- Electrical System
- Coolant System
- Clamping and Positioning Systems

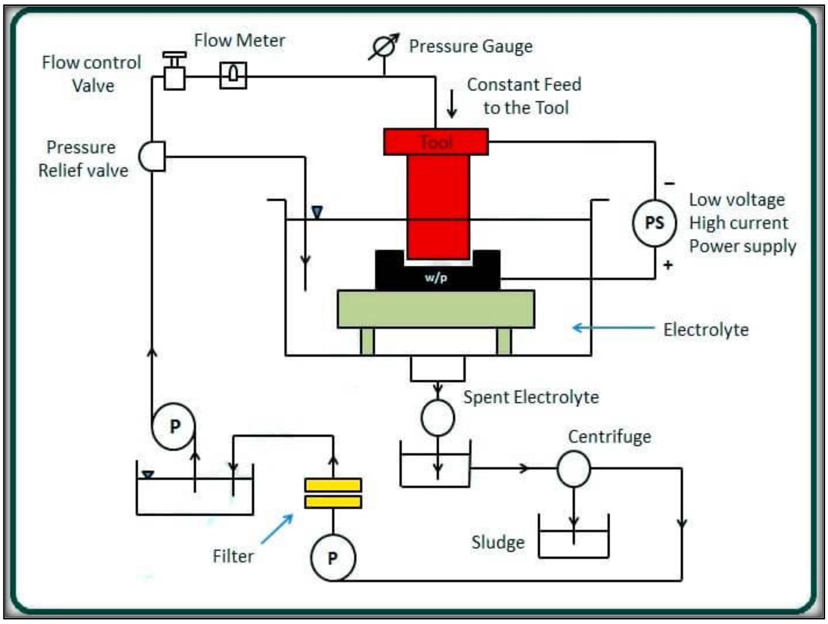


Figure: Construction of Electrochemical Machining

1. **Work Piece and Tool Holder**

- **Workpiece (Anode)**: The workpiece to be machined is mounted on a fixture or worktable. The workpiece must be made of an electrically conductive material.
- **Tool (Cathode)**: The tool, often made of materials like copper or brass, is positioned close to the workpiece but does not make physical contact. The tool is mounted on a toolholder.

2. **Electrolyte Supply System**

   - **Electrolyte Tank**: An electrolyte solution, usually a conductive salt-based solution, is stored in a tank.
   - **Pump**: A pump is used to circulate the electrolyte from the tank to the machining zone.
   - **Nozzles**: Nozzles or jets direct the flow of the electrolyte toward the machining area, ensuring efficient electrolyte transport and removal of reaction products.

3. **Electrical System**

   - **DC Power Supply**: A DC power supply is used to apply an electric potential (voltage) between the workpiece (anode) and the tool (cathode). This voltage drives the electrochemical reactions that result in material removal.
   - **Control Unit**: A control unit is responsible for setting and adjusting the machining parameters, such as voltage, current, and electrolyte flow rate, to achieve the desired machining results.

4. **Coolant System**

   - **Coolant Tank**: To manage the heat generated during ECM, a coolant tank is often used to maintain a stable and controlled temperature.
   - **Coolant Pump**: A pump circulates the coolant through the system, helping to dissipate_heat and maintain stable machining conditions.

5. **Clamping and Positioning Systems**

   - **Workpiece Fixture**: The workpiece is securely clamped or fixed onto a fixture or worktable to ensure precise positioning and stability during machining.
   - **Toolholder Assembly**: The toolholder, which holds the tool, is accurately positioned to maintain the desired gap between the tool and the workpiece.

The construction of an ECM machine can vary in complexity and size depending on the specific application and the level of automation required. ECM systems are highly specialized and carefully designed to provide precise control over the electrochemical machining process, allowing for the production of complex and high-precision components.

The part of the work piece metal where material is to be removed is brought into contact with a strong corrosive chemical called etchant. The etchant react with the workpiece in the material to be cut and causes the solid material to be removed. The electrolyte solution transfers charge in the gap between the cathode and workpiece, which causes electron transfer from the workpiece to remove surface material. The separation distance between the cathode and the workpiece is key to regulating the material removal process.

Working

ECM is known for its ability to machine complex shapes and produce high-quality surface finishes on a variety of electrically conductive materials. electrochemical machining process, the reactions take place at the electrodes i.e. at the anode (workpiece) and cathode (tool) and within the electrolyte.

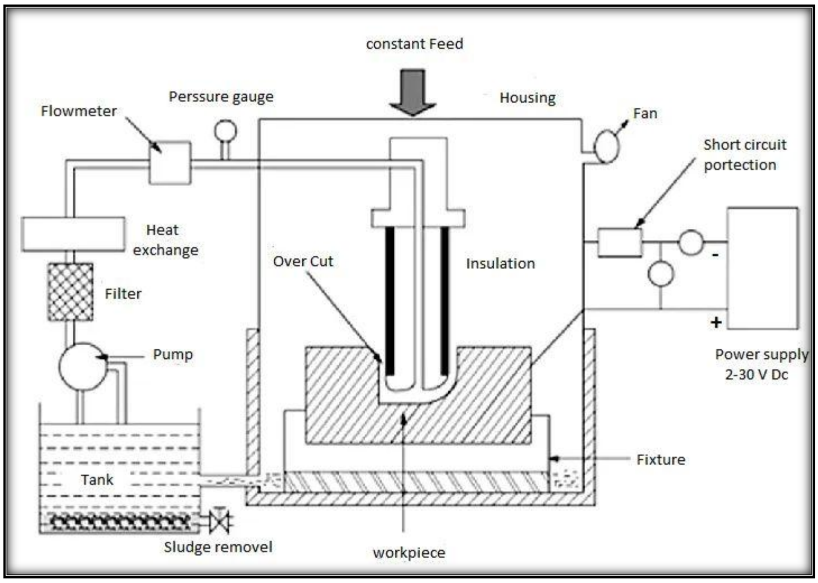


Figure: Working of Electrochemical Machining

- Electrochemical machining works based on Faraday’s laws of electrolysis.
- The amount of metal removed by machining or deposited is calculated from faraday’s laws of electrolysis, Which states.
- The amount of mass removed by machining, m, is directly proportional to the amount of electricity. The amount of different substances dissolved, m, by the same quantity of electricity is proportional to the substance’s chemical equivalent weight.

- The electrolyte removes the dissolution products, such as metal hydroxide, heat, and gas bubbles, generated in the interelectrode gap.
- The example of the dissolution reaction of iron in sodium chloride (NaCl) water solution as an electrolyte.
- The result of electrolyte dissolution and Nacl dissolution.
- At the cathode, the reaction involves the generation of hydrogen gas and hydroxyl ions.

Process Parameter

Electrochemical Machining is a complex process that relies on several key process parameters to achieve accurate and controlled material removal. Adjusting these parameters is crucial to achieving the desired machining results. Here are the primary process parameters in ECM:

- **Voltage**: Voltage is one of the most critical parameters in ECM. It determines the rate of the electrochemical reaction and, therefore, the material removal rate. Higher voltages typically result in faster material removal, but they can also lead to increased tool wear and a rougher surface finish.
- **Current**: The electric current passing through the electrolyte solution and workpiece affects the rate of material removal. Current density (current per unit area) is an important factor, as it determines the amount of material dissolved from the workpiece. Controlling the current is essential for precision machining.
- **Electrolyte Type and Concentration**: The choice of electrolyte solution and its concentration can significantly impact ECM. Different electrolytes are used for different materials.
- **Tool Material and Shape**: The tool in ECM is typically made of a conductive material such as brass, copper, or stainless steel. The tool shape and its gap distance from the workpiece surface determine the shape and dimensions of the machined features.
- **Feed Rate**: The feed rate is the rate at which the tool moves relative to the workpiece. It affects material removal and the final surface finish. Adjusting the feed rate allows for control over machining accuracy and productivity.

- **Gap Distance**: The gap distance between the tool and the workpiece is crucial. It determines the distribution of the electric field and affects material removal. Typically, a smaller gap results in finer control and higher precision.

- **Temperature Control**: ECM generates heat due to the electrochemical reaction. Controlling and monitoring the temperature of the electrolyte is important to avoid overheating, which can lead to poor machining results.

- **Pulse Duration and Frequency (for Pulse ECM)**: In Pulse ECM (PECM), the on-off time cycle and frequency of the voltage pulses are controlled parameters. PECM is used for precise and controlled material removal in certain applications.

- **Tool Wear Monitoring**: Monitoring the condition of the tool is important to ensure consistent machining results. Detecting tool wear allows for timely tool replacement or maintenance.

- **Process Control Systems**: Advanced ECM systems often incorporate computer-based control systems to precisely regulate voltage, current, and other parameters in real-time. These systems enhance machining precision and repeatability.

- **Electrode Shape and Size**: In some ECM applications, custom-designed electrodes are used to achieve specific machining requirements.

- **Workpiece Material**: The type of material being machined plays a significant role in determining the appropriate ECM parameters. Different materials require adjustments in voltage, current, and electrolyte composition.

- **Workpiece Fixturing**: Proper fixturing and clamping of the workpiece are essential to maintain stability during machining and ensure dimensional accuracy.

Optimizing these process parameters is essential for achieving the desired machining results in ECM. The specific values of these parameters will depend on the material, geometry, and quality requirements of the workpiece being machined. Additionally, ECM operators often rely on experience and experimentation to fine-tune the process for specific applications.

CHEMICAL MACHINING

Introduction

Chemical machining is the material removal process for the production of desired shapes through selective or overall of material by controlled chemical attack with acids or alkalis. This is one of the oldest non-traditional machining processes and also has some drawbacks. Chemical Machining also known as chemical etching or chemical milling, is a subtractive manufacturing process used to selectively remove material from the surface of a workpiece using chemical reactions.

Chemical machining is particularly useful for producing complex shapes, intricate patterns, and fine details in various materials, including metals, plastics, and ceramics. Chemical Machining is the clean removal of metal from pre-described areas without altering the integrity or properties of the metal by means of a photochemical process. It is the process of removal of material from the workpiece using chemical reactions by immersing the workpiece.

History

In its earliest and most basic form, photo etching utilized organic lactic acid and citric acid to corrode lead to create the pigment ceruse, circa 400 BCE. More effective chemical etching methods were developed in the first century CE, when alkaline etchants were first used. Chemical machining method which is used to shape copper with citric acid in the Ancient Egypt in 2300 BC . Until the 19th century this process was widely used for decorative etching. The development of photography provided a new dimension to chemical machining. Chemical milling or industrial etching is the subtractive manufacturing process of using baths of temperature-regulated etching chemicals to remove material to create an object with the desired shape.

Working Principle

The working principle of chemical machining is based on chemical etching. the part of the work piece metal where material is to be removed is brought into contact with a strong corrosive chemical called etchant. The etchant reacts with the workpiece in the material to be cut and causes the solid material to be removed. Chemical Machining (CM), also known as chemical etching or chemical milling, is a subtractive manufacturing process.

Construction

Chemical Machining consists of the following main parts:

- Workpiece Holder
- Masking and Pattern Transfer
- Chemical Etching Tank
- Temperature Control
- Agitation System
- Mask Removal
- Finishing and Inspection

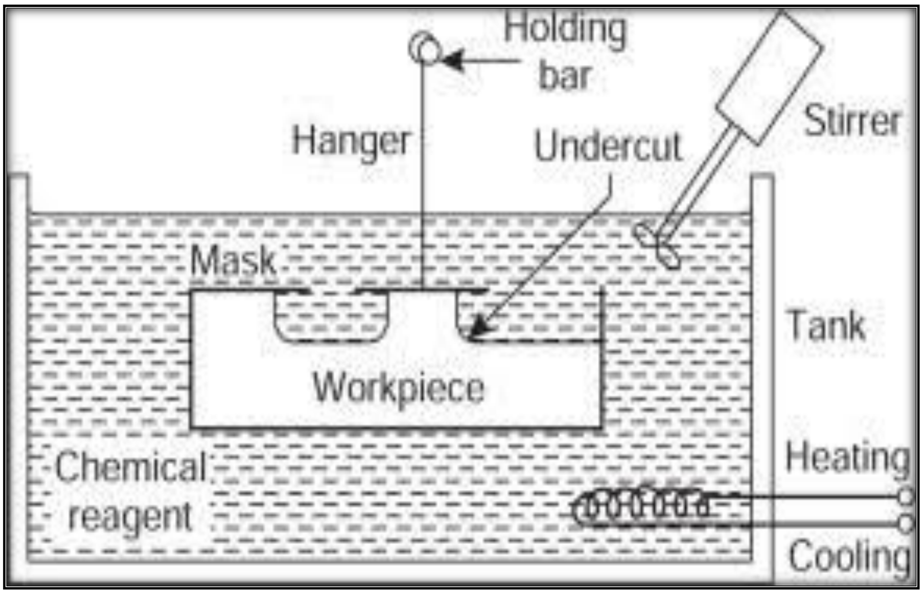


Figure: Construction of Chemical Machining

1. Workpiece Holder

- **Workpiece Fixture**: The workpiece to be machined is securely held in place on a worktable or fixture. The fixture ensures the workpiece remains stable and correctly positioned during the chemical machining process.

2. Masking and Pattern Transfer

- **Mask Application**: A mask, often made of photoresist, tape, or other protective materials, is applied to the surface of the workpiece. The mask is applied uniformly to the entire workpiece and will protect certain areas from the chemical etchant.
- **Pattern Transfer**: The desired pattern or design is transferred onto the mask. This can be done using methods such as photolithography, screen printing, or simply cutting the mask material into the desired pattern.

3. Chemical Etching Tank

- **Etchant Tank**: The workpiece, with the mask in place, is immersed in a chemical etchant solution contained in a tank or bath. The etchant is carefully chosen based on the material of the workpiece and the desired etching characteristics.

4. Temperature Control

- **Heating or Cooling System**: In some cases, a heating or cooling system may be used to control the temperature of the etchant solution. Temperature can influence the etching rate and uniformity.

5. Agitation System

- **Agitators or Stirrers**: An agitation system, which may include agitators or stirrers, is used to ensure uniform distribution of the etchant and to prevent the formation of localized concentration gradients.

6. Mask Removal

- **Mask Stripping Station**: A station or process is used to remove the protective mask from the workpiece once the chemical etching is complete. This step may involve chemical stripping, peeling, or other techniques depending on the mask material.

7. **Finishing and Inspection**

- **Deburring and Surface Treatment**: Depending on the application, the workpiece may undergo additional processes, such as deburring or surface treatments, to achieve the desired final surface quality.
- **Inspection**: The machined components are inspected to ensure that they meet the specified dimensional and surface quality requirements.

The construction of a CM machine can vary in complexity and size depending on the specific application and the level of automation required. CM systems are carefully designed to provide precise control over the chemical machining process, allowing for the production of complex and high-precision components. chemical machining is based on chemical etchant. An etchant is a mixture of strong chemical acids which are reactive to metal. When the workpiece is dipped in the etchant, the etchant reacts with the workpiece causing a uniform rate of dissolution of metal from the workpiece.

In the cleaning the work-piece is cleaned using solvent to removes the dust, oil contaminants from the work-piece otherwise further process that is masking will not be done properly due to dust or oil contaminants. Masking is process of applying the maskant or cover on the cleaned work-piece surface which prevents the inside desired portion of work-piece surface from being dissolve. This maskant or cover is does not reacts with chemical or etchant.

Working

The chemical machining process is also knowns as the Etching process. This process sounds like magic due to its easy outputs. In this process, we are just dipping the workpiece into a tank of chemical solution and in just a few seconds, we will be obtaining the desired structure on the workpiece. This machining process is not magic, but scientifically practical.

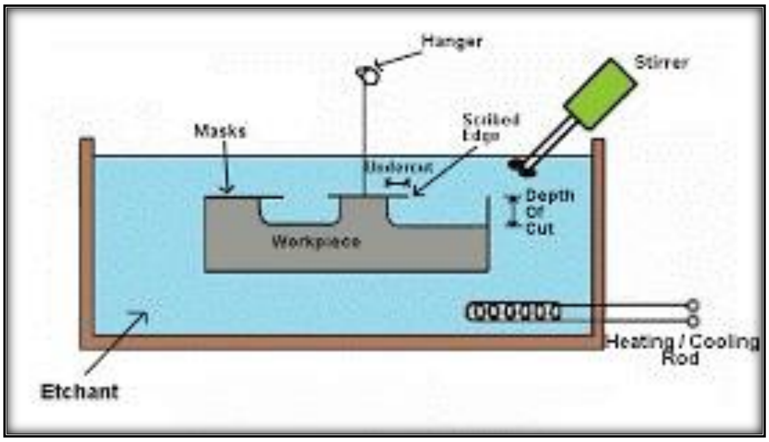


Figure : Working of Chemical Machining

- The working of chemical machining is based on chemical etchant.
- An etchant is a mixture of strong chemical acids which are reactive to metal. When the workpiece is dipped in the etchant, the etchant reacts with the workpiece causing a uniform rate of dissolution of metal from the workpiece.
- To obtain a desired shape or structure, an elemental coating that is non-reactive to a chemical reagent called 'Maskant' is applied on the workpiece before machining.
- Localized machining is achieved by applying a suitable mask on all the areas where we do not want the etchant to react. Thus, exposing the machining zone for the necessary removal of metal.
- The part of the workpiece whose material is to be removed is exposed to a chemical known as enchant. The enchantment removes the metal from the chemical attack**.** The method of contacting material by the enchant is masking.
- The parts are cleaned mechanically if the maskant is thicker and more durable and cleaned chemically if the maskant is thin or the parts to be cleaned are sophisticated.

Process Parameter

Chemical machining, also known as chemical milling or chem-milling, is a subtractive manufacturing process that selectively removes material from the surface of a workpiece through chemical reactions. Unlike many other machining processes, chemical machining does not rely on mechanical forces but instead uses chemical etchants to achieve material removal. The key process parameters in chemical machining include:

- **Etchant Solution**: The choice of etchant solution is critical. Different chemicals are used as etchants, such as acids (e.g., hydrochloric acid, sulfuric acid) or alkaline solutions (e.g., sodium hydroxide). The specific etchant depends on the material to be removed and the desired result.

- **Etchant Concentration**: The concentration of the etchant solution affects the rate of material removal. Higher concentrations typically result in faster etching but can also lead to less controlled and more aggressive material removal.

- **Temperature**: The temperature of the etchant solution influences the etching rate. Higher temperatures generally increase the rate of material removal. Maintaining a consistent temperature is crucial for achieving uniform results.

- **Immersion Time**: The duration for which the workpiece is immersed in the etchant solution determines the depth of material removal. Longer immersion times result in deeper etching. Precision control of immersion time is important for achieving the desired dimensions and surface finish.

- **Masking and Resist Materials**: Chemical machining often involves applying masking or resist materials (e.g., wax, photoresists) to protect specific areas of the workpiece from etching. The type and quality of masking materials are important for achieving accurate and well-defined patterns.

- **Masking Thickness**: The thickness of the masking material affects the depth of etching in unprotected areas. Precision control over masking thickness is necessary for achieving precise results.

- **Agitation**: Agitating the etchant solution helps ensure uniform material removal and prevents the buildup of reaction byproducts on the workpiece surface. Agitation methods can include mechanical stirring or ultrasonic agitation.

- **Rinse and Cleaning**: Proper rinsing and cleaning after etching are essential to remove residual etchant and prevent further chemical reactions. Rinse quality affects the final surface finish.

- **Quality Control and Inspection**: Inspection techniques, such as visual inspection, measurements, or non-destructive testing, are essential for quality control and ensuring that the workpiece meets specifications.

- **Safety Precautions**: Safety is a critical consideration in chemical machining due to the use of potentially hazardous chemicals. Proper safety measures, including personal protective equipment (PPE) and ventilation, are essential.

- **Environmental Considerations**: Proper disposal of waste chemicals and adherence to environmental regulations are essential for responsible chemical machining operations.

ELECTRICAL DISCHARGE MACHINING

Introduction

Electrical Discharge Machining is a non-traditional machining process used for shaping and machining electrically conductive materials. It is a machining method primarily used for hard metals or those that would be very difficult to machine with traditional techniques. Electrical discharge machining, also known as spark machining, spark eroding, die sinking, wire burning or wire erosion, is a metal fabrication process whereby a desired shape is obtained by using electrical discharges.

Electrical discharge machining, is a manufacturing process where material is removed from a workpiece using electric current discharges between electrodes submerged in a dielectric liquid. The process is used to manufacture parts that are impossible to machine. The workpiece electrode, anode, of an EDM machine is connected to the positive terminal of a DC power supply while the tool electrode, cathode, is connected to the negative terminal. The electrodes are submerged in the dielectric fluid and separated by the spark gap.

About

Electrical Discharge machining is a comparatively new machining method which has several decades of history since, it has been invented. At its beginning, it was developed as a precision machining method for hard materials. Electrical discharge machining is a powerful, nonconventional machining technique with the ability to machine any conductive material regardless of mechanical property. It is a process in which electrical energy is used to generate the Spark between the tool and workpiece submerged under the dielectric medium so that material removal takes place from the surface of the workpiece by local melting or Vaporization called as Electric Discharge Machining.

Working Principle

Electrical discharge machining is a process of removing material by exposing it to reoccurring controlled electric discharge. It works on the thermo-electrical phenomenon. As the electric discharge takes place between an electrode/wire and workpiece, the thermal energy is generated on a workpiece. It is a non-traditional machining process. In this, the tool electrode is connected to the -ve terminal of the DC power supply and workpiece is connected to the +ve terminal of the DC power supply. So, tool acts as a cathode and workpiece acts as an anode.

Construction

It consists of following parts:

- DC Pulse Generator
- Electrode Tool
- Servo Motor Mechanism
- Spark generator
- Di-electric fluid
- Workpiece

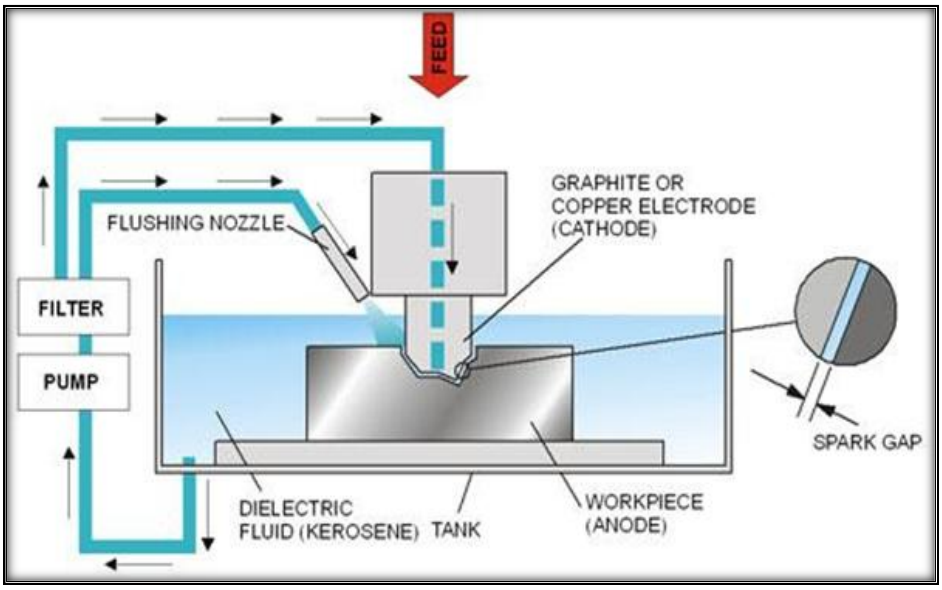


Figure: Construction of Electrical Discharge Machining

- **DC Pulse Generator**

This component converts the AC power supply to a pulsating DC supply high enough to generate a spark between the eroding tool and the work part.

- **Electrode Tool**

This part of the system is connected to the cathode of the power supply while being mounted on a tool post. The profile of your tool will be the exact same profile left on your work part. During the process, a very tiny gap called the arc gap (identified by manufacturing engineers) is maintained between the electrode tool and the work part. The most common materials used for electrodes are Copper, Tungsten alloy, graphite, steel, and cast iron.

- **Servo Motor Mechanism**

This mechanism controls the feed and movement of the tool in the EDM machine. The arc gap, previously mentioned above, is critically controlled by a programmed servo motor mechanism.

- **Spark generator**

This component supplies the right amount of voltage needed for spark generation and discharge maintenance. The generation of one hundred thousand sparks per second makes it possible to create a significant subtraction of material from the work part.

- **Di-electric fluid**

Both the electrode tool and the work part are submerged in a dielectric fluid while having the fluid supplied at the gap between the tool and the work part. Moreover, the dielectric fluid should be set to circulate at a constant pressure to flash away metal parts that have eroded from the work part.

- **Workpiece**

This completes the EDM machine ecosystem because the work part is connected to the anode. To make the process possible, the work part should be a good electric conductor.

Working

Electrical discharge machining is a non-traditional machining process based on removing material from a part by means of a series of repeated electrical discharges between tools, called electrodes, and the part being machined in the presence of a dielectric fluid. The electrical discharge machining working process is based on the generation of sparks and metal removal through spark erosion. The EDM electrode and the workpiece are mounted. A small gap of a calculated distance is kept between the electrode tip and workpiece. This is done using the servo mechanism. The supply of dielectric is turned on to immerse the workpiece in deionized water.

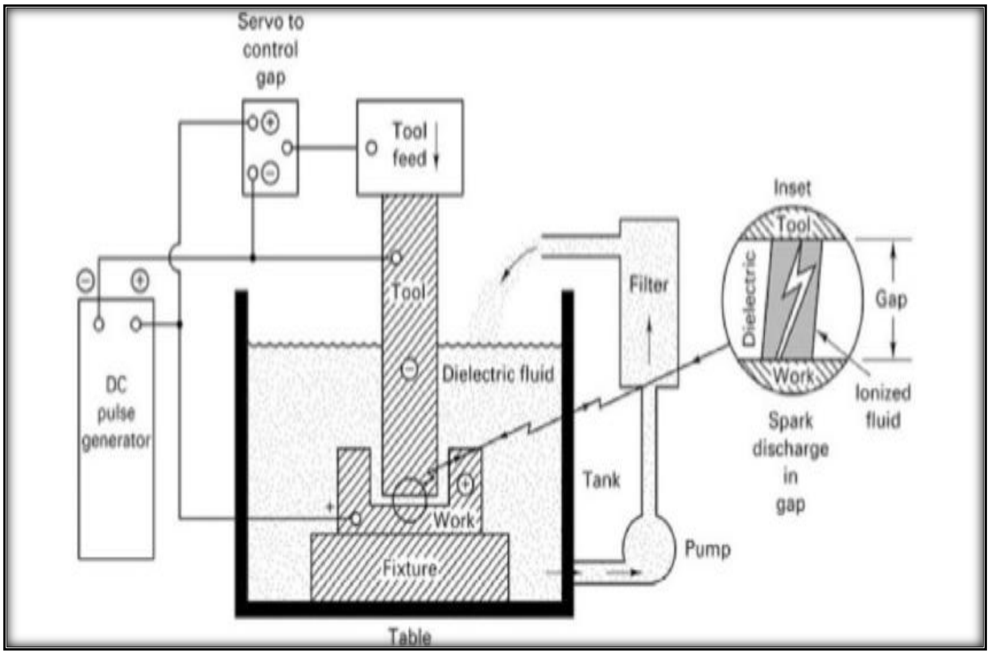


Figure : Working of Electrical Discharge Machining

- The workpiece is fixed in the dielectric container using a fixture.
- The tool is fed up by the Servo Feed Unit which can move downward in a vertical direction.
- The power supply is given to the electrical discharge machining process i.e. Positive terminal is given to the workpiece and a Negative terminal is given to the tool.
- The tool and workpiece are separated using dielectric fluid and an optimum gap is maintained between them.
- As stated above, that at normal conditions, the dielectric fluid acts as an insulator. In this sense, no electrical conductivity is taking place.
- The positive ions are attracted to negative ions and negative ions are attracted to positive ions and thereby the heat is generated.
- When positive and negative ions collide with each other then the spark is generated between the tool and workpiece which can remove the material from the surface of the workpiece.

- When there is no spark in the container, then the dielectric fluid again turns as an insulator.

- In EDM an electric spark is used as the cutting tool to cut (erode) the workpiece and produce the finished part to the required shape.

- EDM is a thermoelectric process used to remove metal via a series of discrete sparks between the metal and workpiece.

- The same procedure is repeated to remove the material from the surface of the workpiece.

Benefits

Electrical Discharge Machining offers several benefits, making it a valuable machining technique in various industries. The parameters considered are pulse current, gap voltage and pulse-on-time, whereas the responses are electrode wear rate and material removal rate. They used Taguchi method to determine the optimal setting of the EDM parameters. Here are some of the key advantages of EDM:

- **Machining of Hard Materials:** EDM can effectively machine extremely hard materials, including tool steel, carbide, and hardened metals. It does not rely on cutting forces, making it suitable for materials that are too tough for conventional machining methods.

- **High Precision:** EDM is known for its exceptional precision and the ability to achieve tight tolerances. It can create intricate and complex shapes with micron-level accuracy.

- **No Contact Machining:** Unlike traditional machining methods that involve cutting, grinding, or milling, EDM is a non-contact machining process. This means there is no physical contact between the tool and the workpiece, reducing the risk of tool wear and distortion of the workpiece.

- **Surface Finish:** EDM can produce fine surface finishes, often eliminating the need for secondary finishing processes like polishing or grinding.

- **No Cutting Forces:** Since there are no cutting forces involved in EDM, there is minimal mechanical stress applied to the workpiece. This is particularly advantageous for delicate or thin-walled parts.

- **Low Tool Wear:** In most EDM applications, the tool wear rate is relatively low compared to traditional cutting tools. This results in longer tool life and reduced tool maintenance.

- **Ability to Cut Small Features:** EDM can cut extremely small features, including micro-holes and narrow slots, with high accuracy.

ELECTRON BEAM MACHINING

Introduction

Electron Beam Machining is a non-contact machining process that uses a high-velocity beam of electrons to cut and shape materials precisely. EBM uses electron beam as energy source for powder melting along with powder bed maintained at high temperatures in vacuum atmosphere, also it requires an extended cooling period to cool the job after fabrication. EBM is quite similar to SLM process in operation**.**

Electron Beam machining is a non-conventional machining process, Where the electrons are focused and concentrated on a small spot on the metal, the kinetic energy of the electrons is converted into heat energy which is sufficient to melt the workpiece, Known as Electron beam machining. It is just similar to laser beam machining and electron beam machining is most appropriate for machines with very hard and brittle materials that cannot be machined using a conventional process.

History

The history of electron beam technology began with the experiments by physicists Hittorf and Crookes, who first tried to generate cathode rays in gases (1869) and to melt metals (1879). These cathode rays were an interesting physical phenomenon and lead to the discovery of a particular type of ray by Röntgen (1895), Thompson (1897) and Millikan (1905), which were described as "fast moving electrons". The heat created by electrons colliding was considered rather to have a damaging effect at the time of those experiments and attempts were made to prevent this by means of cooling.

Working Principle

EBM machining process works on the principle of the high-velocity beam of the electron is focused on the workpiece, the electrons strike on the workpiece and their kinetic energy is converted into heat energy. Electron-beam machining is a process where high-velocity electrons concentrated into a narrow beam that are directed towards the work piece, creating heat and vaporizing the material.

Construction

Electron Beam Machining consists of the following main parts:

- Electron Gun
- Magnetic lens
- Electronic lens
- Magnetic deflection coil
- Optical viewing system
- Vacuum chamber
- Electronic system
- Movable table

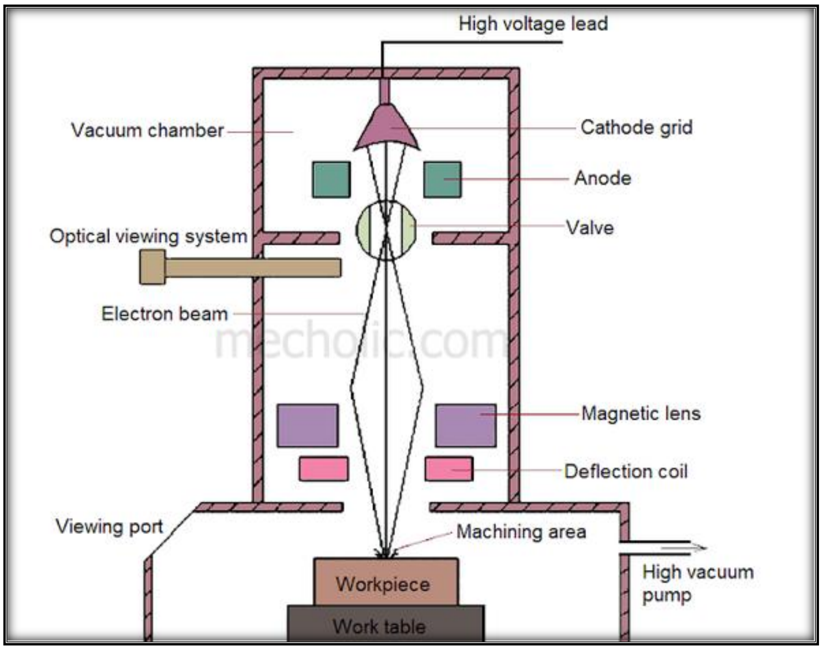


Figure: Construction of Electron Beam Machining

- **Electron Gun**

  An electron gun generates and directs a controlled beam of electrons of high energy density on the workpiece to change it chemically and physically.

- **Magnetic Lens**

  The magnetic lens is provided which shapes the beam and doesn't allow diverging electrons or reduce the divergence of the beam.

- **Electromagnetic lens**

An electronic lens is used to focus the electron beam at a spot.

- **Magnetic deflection coil**

  The Magnetic deflecting coil does not allow beam deflection and takes care of all the electron movements.

- **Optical viewing system-**

  It is a system to check whether the process is under control or not.

- **Vacuum chamber**

  EBM process is done in the vacuum chamber to avoid any air entering probability so Electron Beam Machining is required to be carried out in the vacuum. Because air can decrease the velocity of the electron beam, hence electron beam machining requires a vacuum during the entire operation.

- **Electronic system**

  An electronic system that controls the size and movement of the beam.

- **Movable table**

  The workpiece is mounted on the movable table fixture that is mostly operated with CNC. The table can be move in all three directions.

Working

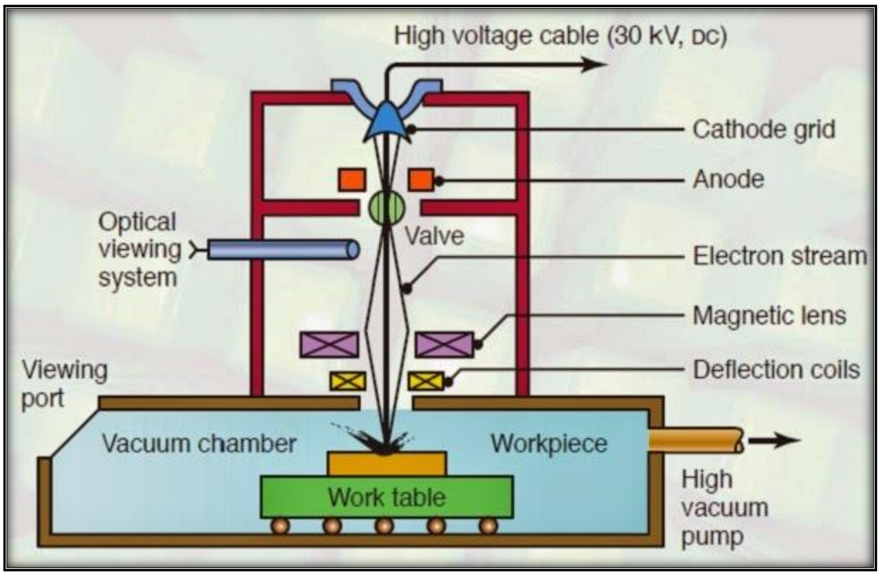


Figure: Working of Electron Beam Machining

The EBM works the same as laser beam machining. Here electron beam machining working can be summarized into the following points-

- When a very high voltage power supply is given to the electron gun, it is producing very high-velocity electrons in all the directions.
- By using a magnetic lens or the deflector, all these high-velocity electrons are collected and formed like a beam of electrons having the cross-section area less than 0.05-millimeter square.
- When this high-velocity electron beam is impinging onto the workpiece, the kinetic energy of electrons is converted into heat energy.
- An electron gun produces high-velocity electrons particles.
- Then, This high-velocity electrons particle moves towards the Anode.
- Here from the Anode, It gets concentrated and moves towards the magnetic lens.
- Here in the magnetic lens, the convergent electrons pass through it and all divergent and low energy electrons are absorbed by it, resulting in high-quality electron beam production.
- After passing through the magnetic lens, High-quality electrons move to the deflection coil which focuses the electron beam at the single spot point.
- Hence High-intensity electron beam is ready to bombard on the surface of the workpiece.
- Here kinetic energy of electrons converts into thermal energy.
- And due to the thermal energy, the material is removed from the contact surface by melting and vaporizing.

Process Parameter

Electron Beam Machining (EBM) is a non-traditional machining process that uses a high-velocity, focused beam of electrons to remove material from a workpiece. The process parameters in EBM play a crucial role in determining the efficiency, precision, and quality of the machining. Here are some key process parameters:

- **Beam Current (I)**

It is the measure of the quantity of electrons flowing in the beam per unit time. Affects the material removal rate and the depth of penetration. It is related to the emission of electrons by the cathode in the beam whose value is as low as 1µA.

- **Accelerating Voltage (V)**

Represents the kinetic energy of the electrons in the beam. (V_a) is 100 Kv. Higher accelerating voltage results in greater penetration and increased material removal rate.

- **Focus Current (IF)**

It controls the focus of the electron beam. Adjusting the focus current helps in achieving a sharp and precise beam.

- **Spot Size**

The diameter of the electron beam at the point of contact with the workpiece. A smaller spot size results in higher precision.

- **Beam Power (P)**

Calculated as the product of beam current and accelerating voltage. Affects the material removal rate and is crucial for controlling the depth of penetration.

- **Beam Deflection**

Controlled to move the beam across the workpiece surface. Enables the machining of complex shapes and patterns.

- **Beam Scanning Distance**

  The rate at which the electron beam is moved across the workpiece. Influences the material removal rate and surface finish.

- **Working Distance**

  The distance between the electron gun and the workpiece surface should be in the range of 0.05 to 0.5 mm. Affects the focus and intensity of the electron beam.

- **Gas Pressure in the Chamber**

  The machining is typically performed in a vacuum or low-pressure environment. Gas pressure affects the electron beam's ability to travel through the chamber.

It's important to note that optimizing these parameters requires a good understanding of the material being machined and the desired machining outcomes. Additionally, advancements in EBM technology continue to introduce new features and parameter controls for improved precision and efficiency.

BINDING MECHANISMS

Abstract

Layer Manufacturing (LM) technologies like Selective Laser Sintering (SLS) were developed in the late 80's as techniques for Rapid Prototyping (RP).

Today, SLS as well as its derived technology Selective Laser Melting (SLM) is used as well for prototyping, tooling and manufacturing purposes.

This widening of applications is caused mainly by the possibility to process a large variety of materials, resulting in a broad range of physical and mechanical properties.

The various binding mechanisms in SLS and SLM, which are responsible for the broad range of materials and applications.

Basic binding mechanisms <u>involve</u> solid state sintering, chemically induced binding, liquid phase sintering, partial melting and full melting Many subcategories can be distinguished based on the type of structural or binder powder composition: single component powder grains (single material or alloy), composite powder grains, mixtures of different powder grains, distinct binder material (sacrificial or permanent), etc.

Introduction

Selective Laser Sintering is a Layer Manufacturing process that allows generating complex 3D parts by consolidating successive layers of powder material on top of each other.

Consolidation is obtained by processing the selected areas using the thermal energy supplied by a focused laser beam.

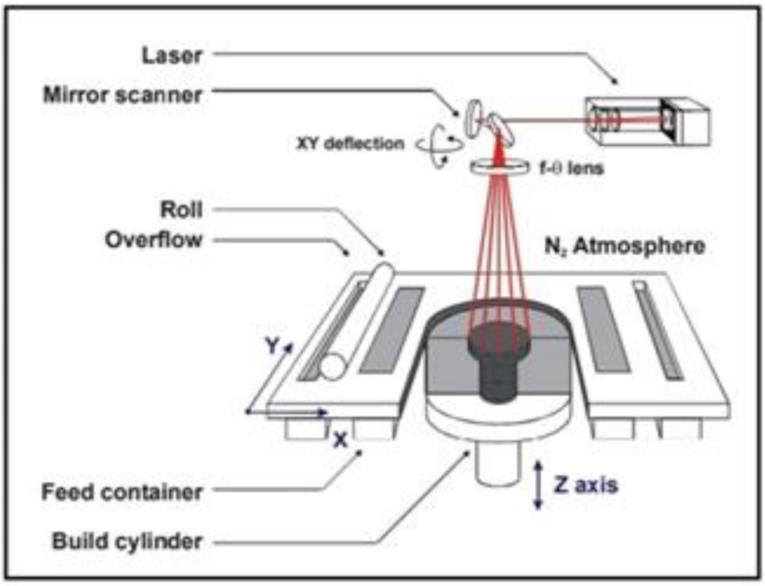
Using a beam deflection system (Galvano mirrors), each layer is scanned according to its corresponding cross section as calculated from the CAD model.

The deposition of successive powder layers with a typical thickness of 20 till 150 µm is realized using a powder deposition system.

Definitions and classification

Unlike Rapid Prototyping, Rapid Manufacturing and Rapid Tooling pursue the production of objects for long-term use.

Rapid Manufacturing concerns the production of long-term consistent components (e.g., a dental implant) while Rapid Tooling concerns the production of long-term consistent tools (e.g., a plastic injection mould insert).



RM and RT technologies can be classified in a number of ways.

Traditionally the technologies are being classified according to the materials they process (plastics, metals, ceramics or composites).

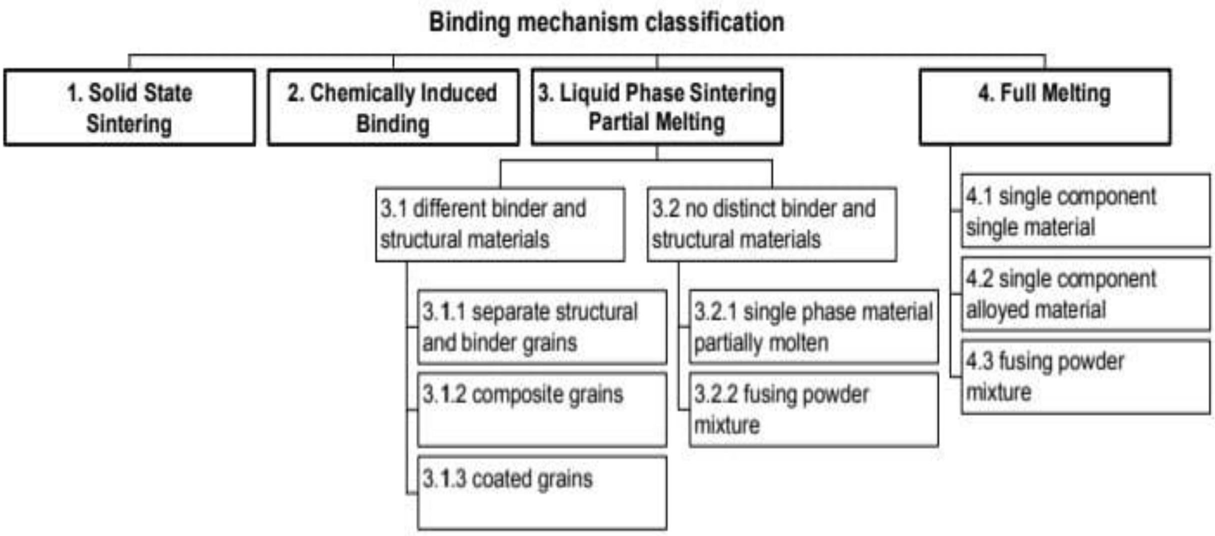
In this, a classification according to the SLS binding mechanism is used

Different Binding Mechanisms

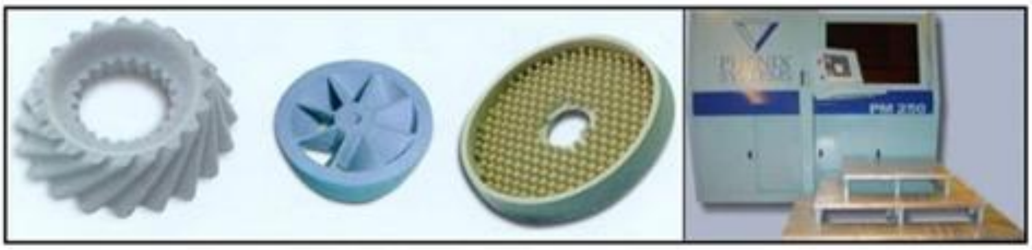
This explanation describes the state of the art in SLS and SLS-derived technologies.

According to the binding mechanism, SLS technologies (and derived technologies like SLM and DMLS) can be classified in four categories.

However, it has to be noticed that this classification is not absolute and the borders are not always very clear.



1. Solid State Sintering (SSS)



Solid State Sintering is a thermal process that occurs at temperatures between $\mathbf{T_{Melt}/2}$ and $\mathbf{T_{Melt}}$.

where T_{Melt} is the melting temperature of the material.

Various physical and chemical reactions occur, the most important being diffusion.

It involves neck formation between adjacent powder particles.

The main driving force for sintering is the lowering of the free energy when particles grow together.

A gradient in vacancy concentration between the highly curved neck (high vacancy concentration) and the flat surfaces (low vacancy concentration) causes a flux of vacancies from the neck and a flux of atoms towards the neck thus increasing the neck size.

2. Chemically Induced Binding

SLS-produced investment casting shell for impeller wheel (source: Fraunhofer Institute IPT)

No binder elements were used and the laser-material interaction times were very short, thus excluding the diffusion processes occurring in Solid State Sintering.

When heating the SiC particles to a very high temperature, partial disintegration of the SiC into Si and C occurs.

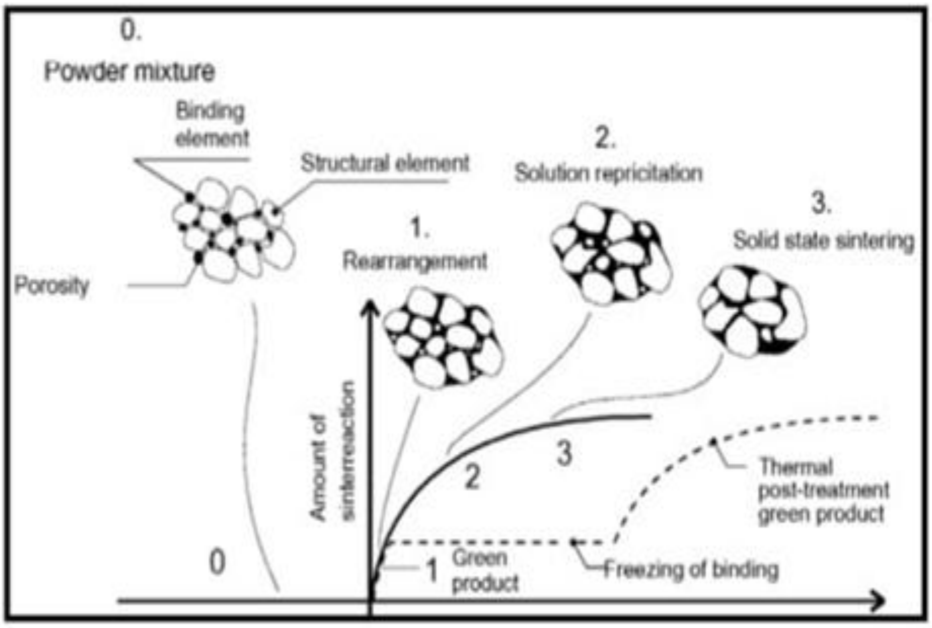
The free Si forms SiO2, which acts as a binder between the SiC particles. The parts are thus composed of a mixture of SiC and SiO, afterwards an infiltration step using Si yields full dense parts.

<u>3. Liquid Phase Sintering (LPS) - Partial Melting.</u>

The many different kinds of technologies, Most of these technologies combine a structural material remaining solid throughout the process and a binder material being liquefied.

In some cases, however, the solid and the liquid phases result from the same material.

A first group of technologies is characterized by a clear distinction between the binder and structural materials.



LPS mechanism is shown schematically. The solid line represents a conventional furnace sintering process.

The LPS mechanism, as it occurs in SLS, is represented by the first part of the dashed line, since only the rearrangement phase takes place.

The process is frozen at this stage resulting in a porous green product. A thermal post-treatment in a furnace may be used to complete the cycle.

4. Full Melting.

The mechanical properties comparable to those of bulk materials and by the desire to avoid lengthy post processing cycles, Selective Laser Melting has been developed.

Polymers as well as metals can be completely molten by a laser beam.

However, the appellation Selective Laser Melting (SLM) is reserved for metallic materials.

For each new material, a process-window needs to be determined experimentally, in order to ovoid scan track instabilities (spheroidization of the liquid melt pool, also known as "balling') and part porosity.

POLYMERIZATION

Polymerization is the process to create polymers. These polymers are then processed to make various kinds of plastic products.

During polymerization, smaller molecules, called monomers or building blocks, are chemically combined to create larger molecules or a macromolecule. Hundreds of such macromolecules collectively form a polymer.

Different polymerization techniques are applied to obtain polymers with unique properties suitable for various applications. For example, hundreds of ethylene monomers are polymerized to form polyethylene polymer used for making carry bags, milk jugs, storage containers, trash barrels, garbage liner, food packets, corrugated conduits, and several other applications that require unique properties.

Polymerization process is also referred to as polymer synthesis and the smaller molecules that are chemically bonded to form a polymer are called repeating units. In the example of polyethylene, the repeating units are ethylene monomers.

The repeating units creating the polymer could be all alike or could be representative of different constituents providing unique characteristics to the plastic products.

There are different mechanisms that govern the bonding of a repeating unit with adjacent molecules.

Polymerization can be classified depending on phase behavior:

a. Bulk polymerization
b. Solution polymerization
c. Suspension polymerization
d. Emulsion polymerization

GENERIC AM PROCESS

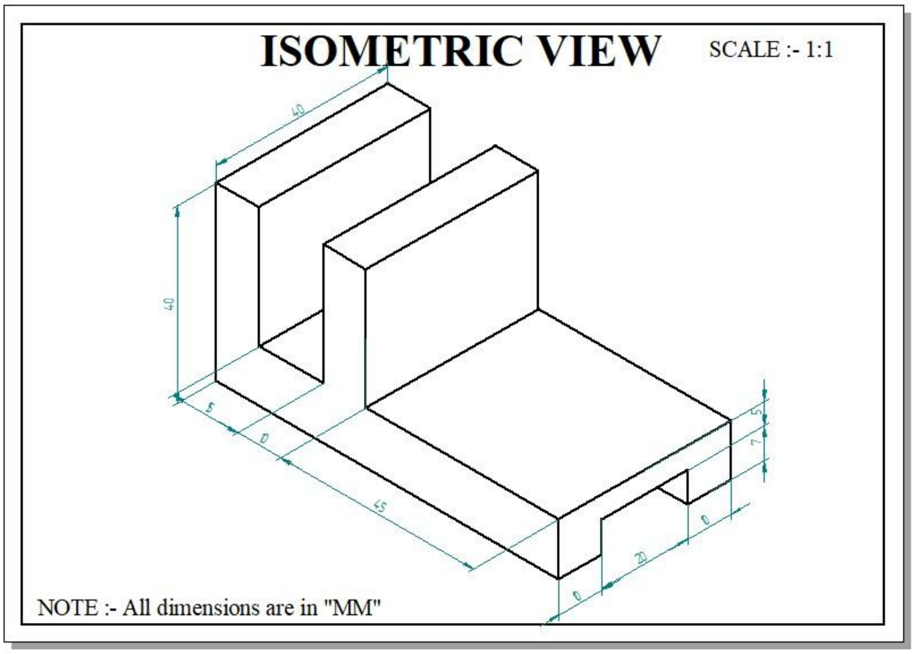


Figure: Isometric View of 3D Print Model

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 ways and to different degrees. Small, relatively simple products may only make use of AM for visualization models, while larger, more complex products with greater engineering content may involve AM during numerous stages and iterations throughout the development process. Furthermore, early stages of the product development process may only require rough parts, with AM being used because of the speed at which they can be fabricated. At later stages of the process, parts may require careful cleaning and post-processing (including sanding, surface preparation, and painting) before they are used, with AM being useful here because of the complexity of form that can be created without having to consider tooling. Later on, we will investigate thoroughly the different stages of the AM process, but to summarize, most AM processes involve, to some degree at least, the following eight steps.

<u>Step 1: CAD</u>

All AM parts must start from a software model that fully describes the external geometry. This can involve the use of almost any professional CAD solid modelling software, but the output must be a 3D solid or surface representation. Reverse engineering equipment (e.g., laser and optical scanning) can also be used to create this representation.

Step 2: Conversion to STL

Nearly every AM machine accepts the STL file format, which has become a de facto standard, and nowadays nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

Step 3: Transfer to AM Machine and STL File Manipulation

The STL file describing the part must be transferred to the AM machine. Here, there may be some general manipulation of the file so that it is the correct size, position, and orientation for building

Step 4: Machine Setup

The AM machine must be properly set up prior to the build process. Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc.

Step 5: Build

Building the part is mainly an automated process and the machine can largely carry on without supervision. Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place like running out of material, power or software glitches, etc.

Step 6: Removal

Once the AM machine has completed the build, the parts must be removed. This may require interaction with the machine, which may have safety interlocks to ensure for example that the operating temperatures are sufficiently low or that there are no actively moving parts.

Step 7: Post-processing

Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed. This therefore often requires time and careful, experienced manual manipulation.

Step 8: Application

Parts may now be ready to be used. However, they may also require additional treatment before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish. Treatments may be laborious and lengthy if the finishing requirements are very demanding. They may also be required to be assembled together with other mechanical or electronic components to form a final model or product. While the numerous stages in the AM process have now been discussed, it is important to realize that many AM machines require careful maintenance.

INSPECTION AND QUALITY CONTROL

Non-Destructive Inspection

Non-destructive inspection involves methods that assess the properties, quality, and performance of a material or component without causing permanent changes or damage. This type of inspection is particularly valuable when items must remain functional and intact after the assessment.

The importance of non-destructive testing in ensuring that assets are properly maintained cannot be overstated. NDT is an important quality control and quality assurance management tool in industries it may assist in preventing failures that could hurt safety, reliability, and the environment. It is a critical procedure that supports all of their operations. Every equipment piece, product, and material has defined design criteria and expected life. However, because of its faults that may go unnoticed throughout production, fabrication, or service delivery, they may need to undergo substantial repair or be replaced; otherwise, unsafe circumstances or catastrophic failures may result from ignoring their unfit conditions for service,

The important non-destructive tests for casting include
1) Visual inspection
2) Sound test
3) Pressure test
4) Radiographic inspection
5) Magnetic particle inspection
6) Electrical conductivity test
7) Florescent dye penetrant inspection
8) Ultrasonic test

Advantages of Non-Destructive Inspection:

- Does not cause damage to the inspected item, allowing it to be used or sold afterward.
- Enables frequent and routine inspections without disrupting operations.
- Offers a variety of methods for assessing different types of defects or properties.

Disadvantages of Non-Destructive Inspection:

- May have limitations in detecting certain types of defects or flaws.
- Requires specialized equipment and trained personnel for accurate results.
- Results may sometimes be less precise than those obtained through destructive testing.

Both destructive and non-destructive inspection methods have their place in various industries, and the choice between them depends on factors such as the purpose of inspection, the material being tested, safety considerations, and the need for subsequent use of the item. Non-destructive inspection is particularly crucial in industries where safety, performance, and the preservation of assets are paramount, such as aerospace, automotive, oil and gas, and infrastructure.

Need for NON destructive test

Non-Destructive Testing Needed Because- Before non-destructive testing was conceived, destructive testing was used to ensure batches of components were manufactured to safety standards) The logic was that destructive tests should provide an indication about whether a sample of parts was fit to endure the stresses placed on it during operation. However, despite destructive testing taking place, several incidents occurred where components were destroyed during operation and led to loss of property and human life. As a consequence, non-destructive testing methods were developed to eliminate such failures without damaging the product in use.

Inspection methods

Inspection methods are essential for quality control and ensuring that products meet the required specifications and standards. There are various inspection methods available, each suited to different types of materials, components, and products. Here are some common inspection methods:

1.Visual Inspection:
Involves visually examining the product or component for defects, surface imperfections, and deviations from specifications.

2. Dimensional Inspection:
Using calibrated measuring instruments like callipers, micrometres, and gauges to check dimensions and tolerances of components.

3. Coordinate Measuring Machine (CMM):
A machine that uses a probing system to measure the coordinates of points on a workpiece and create a detailed 3D model for dimensional analysis.

4 Ultrasonic Testing (UT):
Utilizes high-frequency sound waves to detect flaws, measure wall thickness, and assess the quality of materials, particularly in metals and composites.

5. Radiographic Testing (RT):
Involves passing X-rays or gamma rays through a material to create a radiographic image, revealing internal defects or inconsistencies.

6.Magnetic Particle Testing (MT):
Detects surface and near-surface defects in ferromagnetic materials by applying a magnetic field and observing particle accumulation at defect sites.

7. Liquid Penetrant Testing (PT):
Involves applying a liquid dye to the surface of a component, which penetrates defects, and is later removed to reveal defects through visual inspection

8. Dye Penetrant Testing (DPT):
Similar to liquid penetrant testing, but uses a coloured dye that is easier to observe.

9. Eddy Current Testing (ECT):
Uses electromagnetic induction to identify surface defects, measure thickness, and sort materials based on electrical conductivity.

10. Visual Testing (VT):
An in-depth visual examination of the product or component under proper lighting conditions, often aided by magnification tools.

11. Infrared Thermography:
Measures temperature variations on the surface of a material to detect defects, leaks, or other anomalies.

12. Hardness Testing:
Determines the material's hardness using methods like Rockwell, Brinell, Vickers, and micro hardness testing.

13. Leak Testing:
Checks for leaks or defects in sealed components or systems, often using methods like pressure decay, helium leak detection, or bubble testing.

14. Acoustic Emission Testing (AE):
Monitors and analyses acoustic signals emitted during material deformation or structural changes to detect defects or anomalies.

15. Optical Inspection:
Utilizes microscopy, endoscopy, and other optical tools to examine intricate details, surfaces, and internal structures. These inspection methods offer various levels of sensitivity and suitability for different types of materials, components, and industries. The choice of method depends on factors like the type of defect being sought, the material being inspected, and the desired level of precision.

Visual Inspection

Visual inspection is carried out to detect defects on the surfaces. This may be carried out with naked eye or using magnifying glasses Defects which are easily located by visual inspection are surface cracks, tears, blowholes, swells, surface roughness. shrinkage etc. visual inspection is the simplest, fastest and most commonly employed, but it needs greater skills on the part of the inspector to locate and identify different casting defects. Only visual inspection may be sufficient for many castings such as manhole covers, drains, counterbalance weighs, etc.

Sound Test or Percussion Test or Stethoscope Test

This is also one of the oldest non-destructive tests. A sound and homogeneous part is tapped with a hammer which is suspended by a chain or other equipment, which produces a certain characteristic tone, whereas a defective part gives a dull sound.

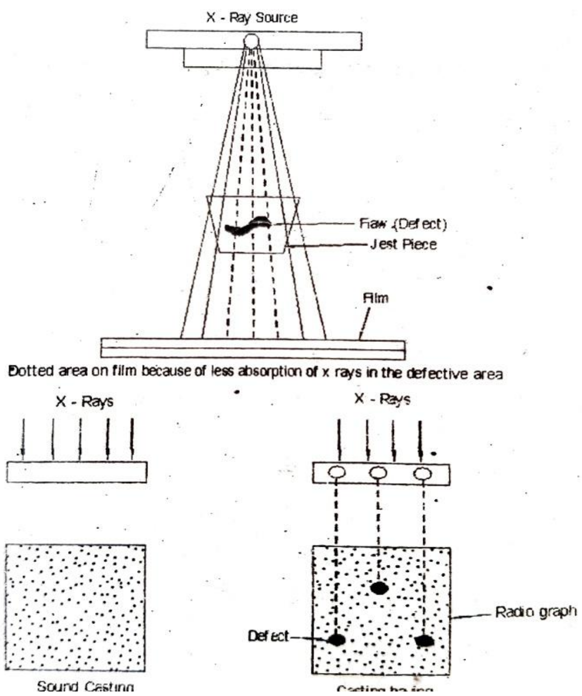
This method is suitable for simple materials such as simple shapes and uniform cross sections. Because complicated shapes modify the sounds and tend to confuse the inspector. The drawback of this is that it is difficult to judge the extent of the defect and locate the fault.

Pressure Test or Leak Test

Parts such as valves, pipes, fittings which carry liquid or gases are tested for leak. In this test, air, water or stream with double the working pressure is used to detect the leakage if any by immersing the parts. Air bubbles coming from the castings when they are immersed in water indicates leakage. Testing of leakage with the help of steam is more positive than water test because steam heat enlarges the cracks. For conducting a pressure test, all openings in a casting are sealed and water, steam or air is introduced in to the casting at a pressure which is more than one, casting is going to experience during service. Water pressure is applied with the help of hand pump. The surface of the casting is inspected carefully to detect the place where leakage is occurring. For testing leakage with air, the casting is submerged completely under water and air is pumped in to the casting under pressure. Air bubbles coming up from the casting through water indicates leakages and the place of leakage can be marked easily.

Radiographic Test (x- Ray Test)

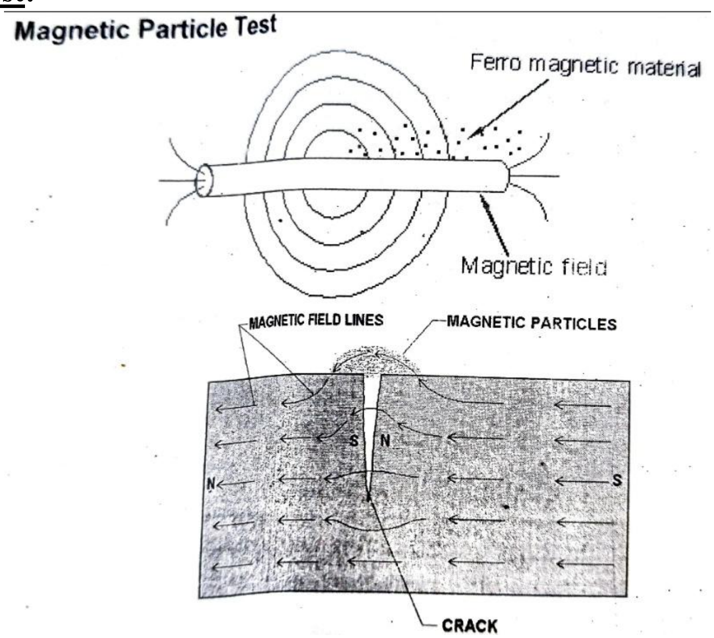
Radiographic examination is a non-destructive test used for detecting internal defects in parts by shortest wavelength radiations like X-rays and Gamma rays Use of gamma rays is somewhat risky, hence generally X-rays are used (The test can be applied to all grades of iron and steel castings and it is an expensive method of inspection. These X-rays can however be detected by a sensitive photographic film To test a component, it is placed in front of the X-rays source with a photographic film When X-rays pass through the sound material, material absorbs higher degree of waves while unsound material i.e. any defect like crack, blowholes, porosity etc., aborts little and allows x-rays to pass through. If there is a cavity or a hole in the casting under inspection and when such a casting is kept against the X-rays the rays finding less obstruction penetrate more freely than at the place where the metal is more dense and solid. The rays that penetrate and emerge from the casting are observed by a photographic plate. Thus the part of the plate opposite the defect will receive more rays than the rest of the plate. This will produce contracting image on the negative. Fig shows a simple block diagram of radiographic inspection.



Since most defects (such as blow holes, porosity, cracks, etc. possess lesser density than the sound metal of the casting, they transmit X-rays better than the sound metal does; therefore the film appears to the more dark where defects are in line of the X ray beam.

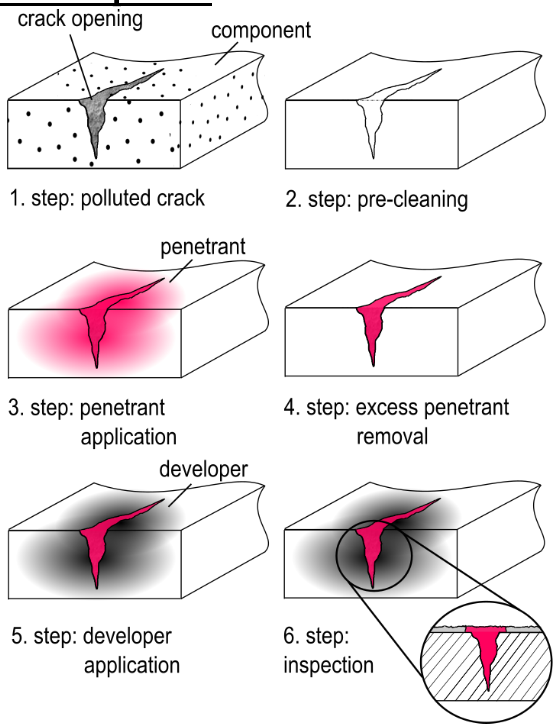
The exposed and developed X-ray film showing light and dark areas is termed as RADIOGRAPH (or precisely known as an EXOGRAPH). Fig shows the radiographs of sound casting and castings containing blow holes and porosity respectively.

Magnetic Particle Test:



This method is used for iron and steel and their alloys which show magnetic properties. This method of inspection is used on ferrous material for detecting invisible surface or slightly sub-surface defects In this method, the casting surface or area to be inspected is magnetized and then Ferro-magnetic particles are sprinkled all over the path of magnetic field at there is any defect, the Ferro-magnetic particles get concentrated around the defect. The reason is that is discontinuity in the casting causes the lines of force to bypass the discontinuity and to concentrate around the defect. By studying the concentration of the particles, the depth at which the defect occurs can be judged. However considerable experience is necessary for an accurate estimation of the defect.

Fluorescent dye penetrant inspection



Like magnetic particle inspection, fluorescent penetrant inspection is also carried out to detect small surface cracks, but it has the advantage that it can be used for testing both ferrous and non-ferrous castings. Penetrant testing helps to defect small surface cracks in castings, which cannot be observed with naked eye. The procedure of conducting this test is as follows:

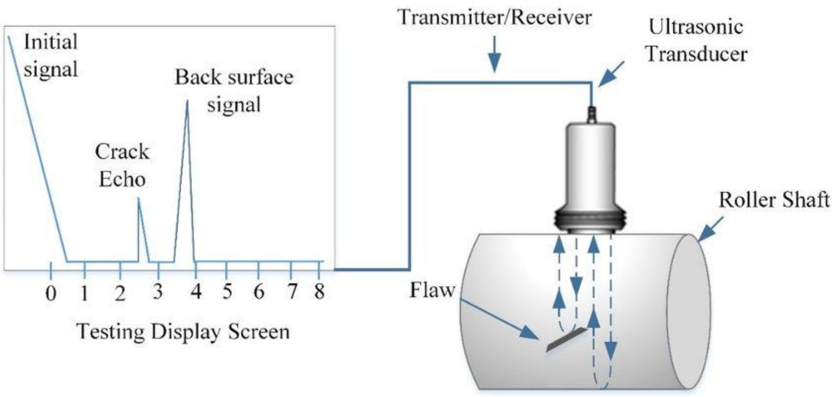
The method is very simple and can be applied to all cast metals. In this method thin penetrating oil is applied to the surface of the casting and allowing it to stand for some time so that the oil passes into the cracks by means of capillary action. The oil is wiped and cleaned from the surface. If the casting under inspection has any surface cracks, the oil will remain in these cracks and will tend to seep out. To detect defects the casting is painted with white wash or powdered with talk and then viewed- under ultraviolet light. The oil which is fluorescent can be easily detected under this light, and thus the defects are clearly revealed.

Advantages and disadvantages

The main advantages of DPI are the speed of the test and the low cost. The main disadvantages are that it only detects surface flaws and it does not work on very rough surfaces. Also, on certain surfaces a great enough colour contrast cannot be achieved or the dye will stain the workpiece.

Limited training is required for the operator - although experience is quite valuable. Proper cleaning is necessary to assure that surface contaminants have been removed and any defects present are clean and dry. Some cleaning methods have been shown to be detrimental to test sensitivity, so acid etching to remove metal smearing and re-open the defect may be necessary.

Ultrasonic inspection.



In ultrasonic testing (UT), very short ultrasonic pulse-waves with centre frequencies ranging from 0.1-15 MHz and occasionally up to 50 MHz are launched into materials to detect internal flaws or to characterize materials. This method is suitable to detect any sub-surface defect in a metal using supersonic wave. Supersonic and ultrasonic waves are similar to sound waves but are of high frequency above 16 Khz that are inaudible to human ear The principle of ultrasonic test involves the measurement of time required for the supersonic vibrations to penetrate the material and deflect back from the opposite side or from any internal defect, If there is any obstacle in the wave path like crack, blowhole, defect inclusions etc., the wave will not cross the obstacle but moves back. For detecting the length of the time, a of the Jimis, a CRO is used.

In ultrasonic testing, an ultrasound transducer connected to a diagnostic machine is passed over the object being inspected. There are two methods of receiving the ultrasound waveform, reflection and attenuation. In reflection (or pulse-echo) mode, the transducer performs both the sending and the receiving of the pulsed waves as the "sound" is reflected back to the device. Reflected ultrasound comes from an interface, such as the back wall of the object or from an imperfection within the object. The present are clean and dry. Some cleaning methods have been shown to be detrimental to test sensitivity, so acid etching to remove metal smearing and re-open the defect may be necessary diagnostic machine displays these results in the form of a signal with amplitude representing the intensity of the reflection and the distance, foresenting the arrival time of the reflection. In attenuation (or through-transmission) mode, a fransmitter sends ultrasound through one surface, and a separate receiver detects the amount that has reached it on another surface after traveling through the medium. Imperfections or other conditions in the space between the transmitter and receiver reduce the amount of sound transmitted, thus revealing their presence. Using the couplant increases the efficiency of the process by reducing the losses in the ultrasonic wave energy due to separation between the surfaces.

Advantages

1) High penetrating power, which allows the detection of flaws deep in the part.
2) High sensitivity, permitting the detection of extremely small flaws.
3) Only one surface need be accessible.
4) Greater accuracy than other nondestructive methods in determining the depth of internal flaws and the thickness of parts with parallel surfaces.
5) Some capability of estimating the size, orientation, shape and nature of defects.
6) Nonhazardous to operations or to nearby personnel and has no effect on equipment and materials in the vicinity.
7) Capable of portable or highly automated operation.

Disadvantages

1) Manual operation requires careful attention by experienced technicians
2) Extensive technical knowledge is required for the development of inspection procedure
3) Parts that is rough, irregular in shape, very small or thin, or not homogeneous are difficult to inspect.
4)-Surface must be prepared by cleaning and removing loose scale, paint, etc., although paint that is properly bonded to a surface need not be removed.

5) Couplants are needed to provide effective transfer of ultrasonic wave energy between transducers and parts being inspected unless a non-contact technique is used. Non-contact techniques include Laser and Electro Magnetic Acoustic Transducers.
6) Inspected items must be water resistant, when using water based couplants that do not contain rust inhibitors.

Applications of Ultrasonic Testing:

1) Flaw Detection: UT is used to identify defects such as cracks, voids, inclusions, and delamination in various materials and components. It is crucial in ensuring the structural integrity of critical components like welds, castings, and forgings.

2) Thickness Measurement: UT can measure the thickness of materials, making it

3) valuable for assessing wall thickness in pipes, vessels, and structural components. It is often used to monitor corrosion and erosion in industrial equipment.

4) Weld Inspection: UT is widely employed to inspect welds for defects such as lack of fusion, incomplete penetration, and cracks. It ensures the quality and safety of welded joints.

5) Bonding Quality: UT is used to assess the integrity of adhesive bonds in applications like aircraft structures, composite materials, and automotive components.

6) Material Characterization: UT can determine the material properties such as density, elastic constants, and sound velocity, aiding in material identification and quality control.

7) Piping Inspection: UT is used to inspect piping systems for internal and external corrosion, erosion, and wall thinning.

8) Aerospace and Automotive Industries: UT is crucial for inspecting aircraft components, engine parts, and critical automotive parts to ensure they meet safety standards.

9) Nuclear Industry: UT is used for inspecting reactor components, steam generators, and other critical equipment in nuclear power plants.

10) Rail and Transportation: UT is employed to inspect train wheels, rails, and other components for cracks and defects.

Recent development in inspection and testing of castings

Radiography

NDT trends indicate no major breakthroughs for radiographic nondestructive testing. Emphasis has been on equipment refinements and innovative application of robotics,computers, and microprocessor-based electronic controls to provide operator- free testing.

The limitations of conventional radiography have been overcome by the development of X-ray tubes with improved essential characteristics. They allow thick-walled castings to be examined with very high resolution and high-grade contrast.

Dynamic direct enlargemerit, up to 200X, within seconds, without loss of definition, is claimed. Micro-pores with a diameter of only 3 micrometer in soldered joints, for instance, have been identified "with absolute certainty. Rod anodes, to allow panoramic radiographs of complex components, are very small and facilitate inspection.

Portable and mobile X-ray systems are available commercially for practically every application likely to be encountered in industry ("soft" radiation for light alloys, and 300 kV units that produce high penetration power for heavy-walled cast steel components).

Ultrasonic

Among current techniques (visual examination liquid penetrant, magnetic particle, radio-graphic, and eddy current testing) only the ultrasonic technique is capable of providing a basis to characterize parameters such as density, porosity, elastic and mechanical properties, and other process and applications-related variables. Ultrasound is propagated through a material by physically coupling an excited piezo-electric transducer with material surface.

Since the recent development of dry coupling, the use of liquid couplants is no longer mandatory except for very rough metallic surfaces. The optimum ultrasonic frequency is the highest acceptable, for a given material, that still results in minimal attenuation.

However, the most important parameter in ultrasonic NDT is not transducer frequency but pulse width, because it establishes optimum resolution and accuracy of a given measurement.

Originally, ultrasound was used only to detect overt flaws in metals, but today's innovative ultrasonic scanning can also generate nondestructive microscopic images corresponding to the test material's surface and internal features. "Because the intrinsic nature of as material composition, atomic structure, and texture is sensitive to the frequency characteristics of input ultrasound, ultrasonic spectroscopy can yield extremely important information about the test material- this includes grain size,anisotropy, fracture strength, and grain growth. Moreover, processes such as polymerization and crystallization can be investigated with ultrasound."

Experience has shown that when problems such as loss of ultrasound penetration decrease in resolution and detectability, and appearance of "ghost signals" are encountered, modifications in transducer characteristics usually will solve the problem. The key to the success of any ultrasonic NDT application is the selection of a suitable transducer one with optimum frequency response, pulse width and shape, and the dimensions of the active transducer that most closely satisfy the objectives of the application.

PROFILE PROJECTOR

Introduction

A profile projector, also referred to as an optical comparator or shadowgraph, is a sophisticated optical instrument designed for the precise measurement and inspection of the dimensions and contours of objects. This tool plays a crucial role in quality control and manufacturing processes, allowing for accurate evaluation of the conformity of machined or manufactured parts to specified dimensions and tolerances.

A Profile projector are particularly useful for measuring 2D features of parts, and they are commonly employed in industries like manufacturing, where precision and accuracy in dimensional measurements are crucial. They are suitable for assessing the conformity of manufactured parts to engineering specifications and drawings. However, it's important to note that profile projectors have limitations and may not be suitable for measuring three-dimensional features or extremely tight tolerances. In such cases, more advanced metrology tools like coordinate measuring machines may be used.

History

1922 – 1930 –The first Profile Projector used as optical Shadowgraph Projector: Invented by James Hartness President of J & L Machine Company in 1922 to standardized the screw thread sizes by measuring the complex curves of screws. The first Profile Projector projected the shadow of the object on a screen which was few meters away and then the measurement of the shadow image of the screw was done against the drawings that is why the term was coined Shadowgraph Projector. A very strong boost to the sales of optical comparators was provided in world war II as Profile Projectors were used for manufacturing of every part used in World War II as a standard for US Artillery.

Working Principle

The working principle of a profile projector involves optical magnification and projection to enable accurate measurement and inspection of the dimensions and features of an object. The target is placed on the stage, and a light is shined on the target from underneath. This causes the target's profile, or shadow, to be projected on the screen. A telecentric optical system is used to enable accurate measurements. Profile projectors were originally developed to inspect the outlines of targets. Models equipped with measurement functions appeared later.

Construction

Profile Projector Includes Following Element

- Light Source
- Object Stage
- Optical System
- Projection Screen
- Magnification Control
- Focal Adjustment
- Angular Measuring Device (Optional)
- Digital Readouts and Displays (Optional)
- Base and Frame
- Electronics and Controls
- Calibration Standards

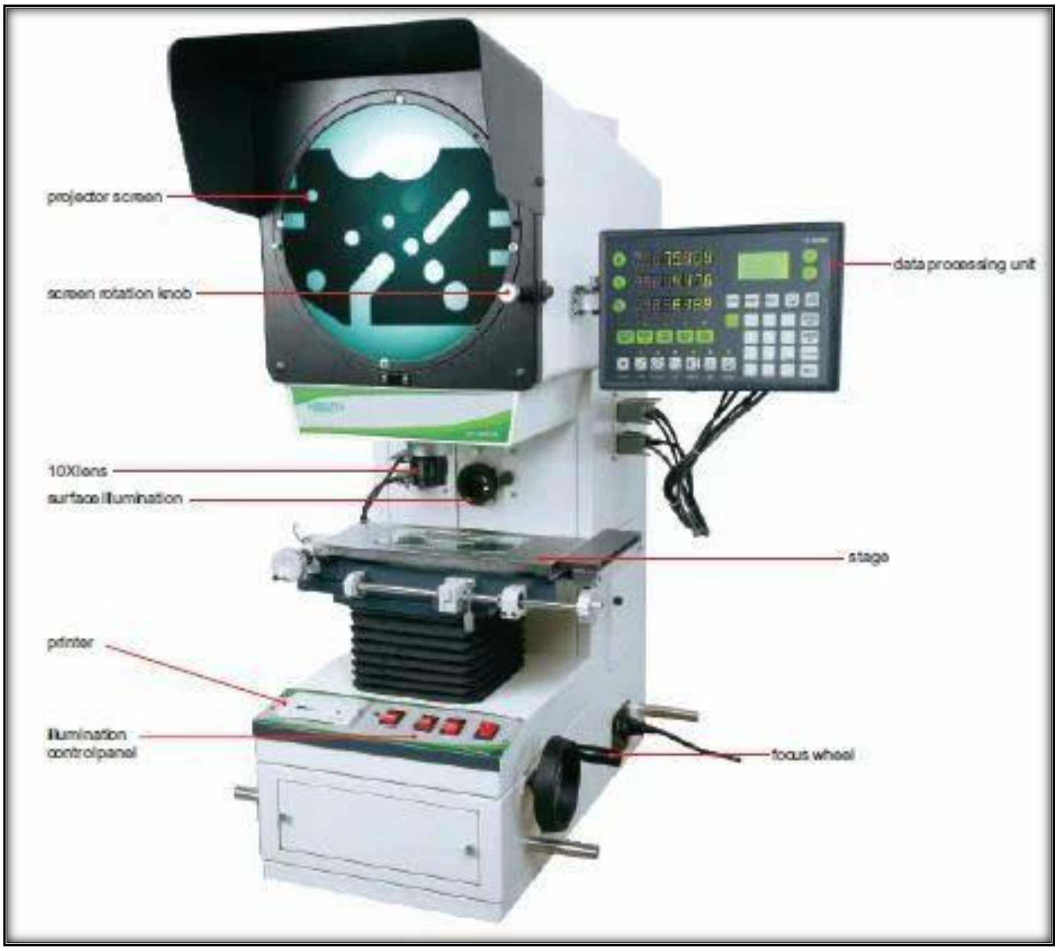


Figure: Construction of Profile Projector

- **Light Source:** A profile projector begins with a light source, often an adjustable lamp or halogen light. This light source provides illumination for the object under inspection.

- **Object Stage:** The object being measured is placed on a stage, which may have adjustable fixtures or clamps to secure the object in place. The stage allows for precise positioning and orientation of the object.

- **Optical System:** The optical system consists of lenses and mirrors arranged to project an image of the object onto a viewing screen. The quality of the optical components is critical for achieving accurate and clear magnified images.

- **Projection Screen:** The projected image of the object is displayed on a glass screen or a screen with a fine grid pattern. This screen often includes a crosshair or reticule for reference during measurements.

- **Magnification Control:** Profile projectors typically have multiple magnification settings. These can be adjusted to zoom in or out, allowing operators to inspect the object at different levels of detail.

- **Focus Adjustment:** A focus adjustment mechanism is included to ensure that the projected image is sharp and clear. This is important for accurate measurements.

- **Angular Measuring Device (Optional):** Some profile projectors may include a protractor or other angular measuring devices for assessing angles and rotations of features.

- **Digital Readouts and Displays (Optional):** In modern profile projectors, digital readouts and displays may be integrated to provide numerical measurements and facilitate data logging. Digital versions may also include image capture and analysis capabilities.

- **Base and Frame:** The entire assembly is supported by a stable base and frame. The construction of this base is crucial for maintaining the stability and accuracy of measurements.

- **Calibration Standards:** Calibration standards or reference artefacts are used to calibrate the profile projector, ensuring that measurements are accurate and traceable.

It's important to note that the design and construction of profile projectors may vary, and some models may include additional features or technologies such as computerized data processing, automated measurement capabilities, and connectivity with metrology software. The evolution of technology continues to influence the construction and capabilities of profile projectors in the modern era.

Working

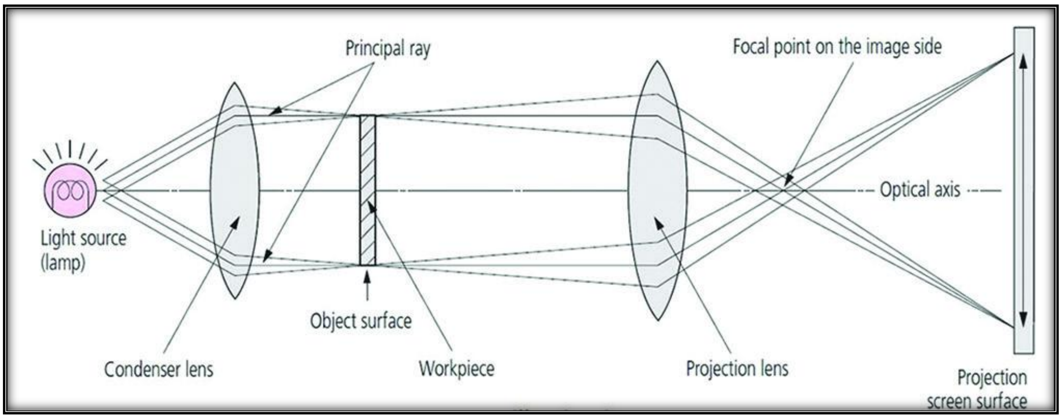


Figure: Working of Profile Projector

- **Preparation:**
  - The object to be measured is securely placed on the stage of the profile projector. Fixturing devices may be used to ensure stability during measurement.
- **Illumination:**
  - The profile projector incorporates a light source, usually located beneath the stage. This light source is directed towards the object, illuminating its features.
- **Magnification Adjustment:**
  - The profile projector allows for the adjustment of magnification levels. This feature enables operators to zoom in or out, providing different levels of detail for inspection.
- **Measurement Process:**
  - Operators visually inspect the projected image on the screen and make measurements using the reference markings, grid, or reticle. Dimensions such as lengths, angles, and other geometric features can be assessed.

- **Digital Readouts and Displays (Optional):**
  - In modern profile projectors, digital readouts and displays may provide numerical measurements. These displays can enhance accuracy and efficiency, especially when performing repetitive measurements.
- **Data Recording (Optional):**
  - Some profile projectors may have the capability to record measurement data digitally. This is useful for documentation and quality control purposes.

- **Calibration:**
    - Before measurements are taken, the profile projector needs to be calibrated using reference standards. Calibration ensures that the measurements are accurate and traceable.

It's worth noting that advancements in technology have led to the development of digital profile projectors, where images can be captured and analyzed using computerized systems. Digital versions may offer additional features such as automated measurement, image processing, and integration with metrology software.

Benefits

- The profile projector gives a much-enlarged image of the products which makes it very easy for the user to work on it.
- When the user is taking the measurements of an object, then he just has to place the scale on the image.
- When the user is checking the shape of the projector, it takes a reference chart with the screen and makes the comparison of the shape.
- The profile projector is best for the users who have to wear glasses as it becomes very easy for them to view the enlarged image of the object on the screen. Another advantage of using a profile projector is that the same image can be viewed by several people at the same time.
- Profile projectors provide manufacturers with the ability to accurately measure and inspect various dimensions, features, and surface details of manufactured components. This ensures adherence to quality standards and minimizes errors.

ROBOTS IN MANUFACTURING PROCESS

Introduction

The discussion and focus of the field of robotics have often been closely tied to its manufacturing application origins. However, over the past decade, robotics has exploded to include devices that augment surgery, assist with elderly care, lead search and rescue missions and monitor waterways.

The importance of robotics is not lost on the engineering community robotics-related content is continually the most read on the Wevolver platform. With that focus in mind, this report's purpose is to enable you to be up to date and understand the complexity and depth of robotics, and to help you gain specific insights into the current status of robotics manufacturing. Jersey plant that same year. In 1969, Victor Scheinman invented the Stanford arm at Stanford University. This was an all-electric 6-axis articulated robot.

History

The development of Numerically Controlled machines, and the rising popularity of the computer both helped bring out about the first industrial robots. The earliest known industrial robot that fits into the ISO definition of the term was created by Griffith "Bill" P. Taylor in 1937 and appeared in Meccano Magazine. It was a crane-like design that used Meccano parts and was powered by a single electric motor. It had five axes of movement, including a grab and grab rotation. The robot was automated through the use of paper tape with punches in it to energize solenoids. This would create movement in the control levers This first robot could stack wooden blocks in patterns programmed by the paper tape. George Devol placed the first industrial robot patent in 1954. His robot was able to transfer objects from one point to another within a distance of 12 feet or less. He founded a company called Unimation in 1956 to build the robot.

Types

- Articulated Robots
- SCARA Robots
- Delta Robots
- Cartesian Robots
- Polar Robots

- Collaborative Robots
- Mobile Robots

Articulated robots are among the most versatile and widely used types of industrial robots in manufacturing. These robots feature multiple joints, or axes of rotation, which allow them to move in a highly flexible manner. The most common configuration of articulated robots is the 6-axis robot, which provides six degrees of freedom. This allows the robot to move in any direction and reach any point within its workspace, making it suitable for a wide range of tasks.

- **Articulated Robots**

Figure: Articulated Robots

An articulated robot is a robot with rotary joints (e.g. a legged robot or an industrial robot). Articulated robots can range from simple two-jointed structures to systems with 10 or more interacting joints and materials. They are powered by a variety of means, including electric motors. These robots have joints 6 axis.

- **SCARA Robots**

Figure: SCARA Robots

SCARA, an acronym for Selective Compliance Assembly Robot Arm, is a type of robot specifically designed for high-speed assembly and material handling applications.

- **Delta Robots**

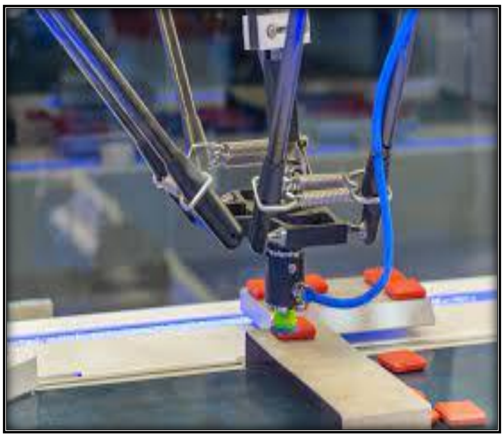


Figure: Delta Robots

Delta robots are a type of parallel robot known for their speed, precision, and lightweight design. They are particularly suited for high-speed pick-and-place applications, where rapid movement and accurate positioning are critical. Industries that commonly use delta robots include food and beverage, pharmaceutical, and electronics manufacturing.

- **Cartesian Robots**

Figure: Cartesian Robots

Cartesian robots, also known as gantry or linear robots, are a type of robot that operates within a three-dimensional Cartesian coordinate system. This design provides a straightforward and easily understood framework for robot movement, making cartesian robots ideal for a wide range of manufacturing applications, including assembly, material handling, and machining.

- **Polar Robots**

Figure: Cartesian Robots

Polar robots, also known as spherical or radial robots, are a type of industrial robot that operates within a spherical coordinate system. With a unique design consisting of a rotating base and an extendable arm, polar robots offer a wide range of motion and versatility, making them suitable for various manufacturing applications such as welding, painting, and material handling.

- **Collaborative Robots**

Figure: Collaborative Robots

Collaborative robots, commonly known as cobots, are a type of industrial robot designed to work safely alongside humans in various manufacturing and assembly environments. Cobots are equipped with advanced safety features, user-friendly interfaces, and highly adaptable configurations, making them a valuable asset for companies looking to enhance their production capabilities.

- **Mobile Robots**

Figure: Mobile Robots

Mobile robots are a class of autonomous robots designed to move and navigate through various environments, providing a flexible solution for a range of manufacturing tasks. These robots are equipped with advanced navigation and localization systems, enabling them to adapt to changing environments and dynamically adjust their paths.

Features

- The current focus of the industry tends to be on giving robots vision. Specifically, the rise of machine vision technology. This, combined with the advancement of the Internet of Things (IoT), gives machines the ability to process images and understand what they are "seeing."
- As this technology continues to proliferate, the next step is giving robots the ability to apply these things to learn on their own. For example, a robot can currently be programmed to pick up and place items, but in the future, it will combine machine vision with machine learning to figure out its own programming through trial and error.
- Another major trend that will continue into the future, are collaborative robots. This reflects the focus of the industry towards creating robots that are simpler, easier to program, and able to integrate into current processes.

Working

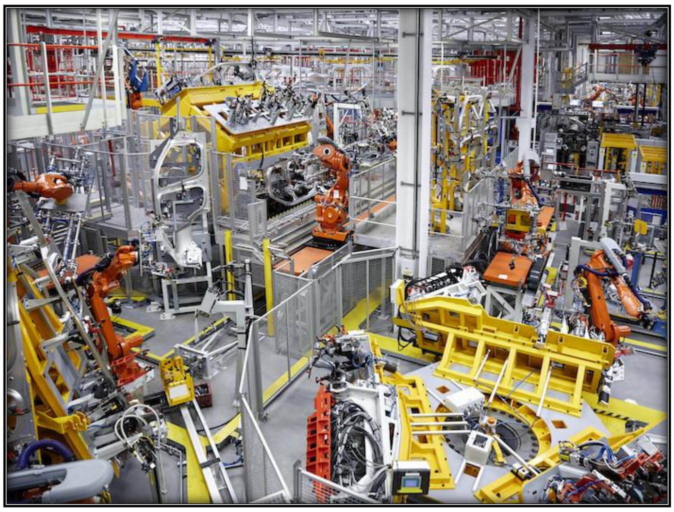


Fig: working of robotics in manufacturing

- Human-robot collaboration is one of the most exciting innovations to come out of robotics yet. Robots and humans coexisting creates a whole new robotics sector: lightweight, speed-controlled robots designed to work alongside people.
- There's the example of the Tokyo hotel staffed entirely by robots, but did you know that it actually created more work for humans because of constant malfunctions and complaints? But with a rapidly aging population and not enough caregivers to go around, Japan isn't the only country experimenting with robot bartenders and restaurant waitstaff and it might be the pointy end of the spear to usher cobots into industrial manufacturing.

Applications

- **Automotive Manufacturing**

  The automotive industry has been at the forefront of adopting robotics technology in its manufacturing processes. From welding and painting to assembly and inspection, robots play a crucial role in producing vehicles with precision, accuracy, and speed.

- **Electronics Manufacturing**

  Electronics manufacturing is another industry where robotics plays a significant role in enhancing productivity, quality, and efficiency. With the increasing demand for electronic devices, manufacturers have turned to robotics for various tasks, such as component placement, soldering, and assembly.

- **Aerospace Manufacturing**

  Aerospace manufacturing involves the production of aircraft, spacecraft, and related components. The industry's stringent quality and safety requirements have led to the adoption of robotics.

- **Metal and Plastic Manufacturing**

  In metal manufacturing, robotics are widely used for welding applications. High-quality welds are critical for the structural integrity of various components, particularly in industries with strict safety requirements, such as automotive and aerospace.

Advantages

- **Increased Efficiency**

Robots work tirelessly without breaks, leading to continuous production. They can perform tasks at a consistent pace, often faster than humans, which boosts overall efficiency.

- **Improved Accuracy and Precision**

Robots execute tasks with high precision, reducing errors and ensuring consistent quality. This is particularly important in tasks like welding, painting, or assembly.

- **Cost Savings**

While initial setup costs can be significant, in the long run, robotics can reduce manufacturing costs. They lower labor expenses, decrease waste, and often lead to energy savings.

- **Enhanced Safety:**

Robots handle dangerous and strenuous tasks, improving workplace safety by reducing the risk of injuries to human workers. Additionally, advancements in collaborative robots allow them to work alongside humans, further enhancing safety measures.

- **Increased Production Capacity**

With robots working around the clock, manufacturing facilities can operate for longer hours, leading to increased output and meeting higher production demands.

- **Flexibility and Adaptability**

Modern robots are designed to be more flexible, allowing for quick reprogramming and adaptation to new tasks. This agility enables quicker shifts in production lines and rapid adjustments to varying product demands.

- **Quality Control**

Robots are precise in executing tasks, leading to consistent quality in manufacturing. Additionally, they can integrate sensors and quality control measures to detect defects, ensuring better product quality.

- **Data Collection and Analysis**

Robotics systems often come equipped with sensors that collect data during production. This data can be analyzed to optimize processes, predict maintenance needs, and improve overall efficiency.

- **Customization and Innovation**

Robotics facilitates the production of customized or complex products that might be challenging for manual labor. It encourages innovation by enabling the creation of intricate designs and tailored products.

Disadvantages

- **Robots are Expensive**

Robots replace humans. Fast, errorless, accurate, and continuous working is possible if robots do the job. Businessman looks forward to maximizing profit in every possible way. Like for doing repetitive jobs, he prefers robots to men. But it is not feasible to have robots all the time because the upfront cost is very high.

- **Maintenance and Security**

The upfront cost is not the only aspect of making the robots expensive. The maintenance is also costly. You need an expert or engineer to fix the machine, which can be expensive.

- **Human capabilities and Emotionlessness**

It is a challenge to human capabilities if robots take over the world. The internet has connected us worldwide and disconnected us from real life. The crowd staring at the screen can be seen everywhere. What if robots take over our daily routine or tasks. Many more problems will add to depression, loneliness, and isolation. Robots have no emotions, therefore they can run only in the way they are calibrated for.

- **Power and Programming**

Robots are power-driven so, they need lots of electricity. Hence, they are not eco-friendly. On the other hand, they add to global warming issues and greenhouse gases. To meet the growing demand for robots, we directly or indirectly harm the environment, which is not good for global health.

INDUSTRY 4.0

Introduction

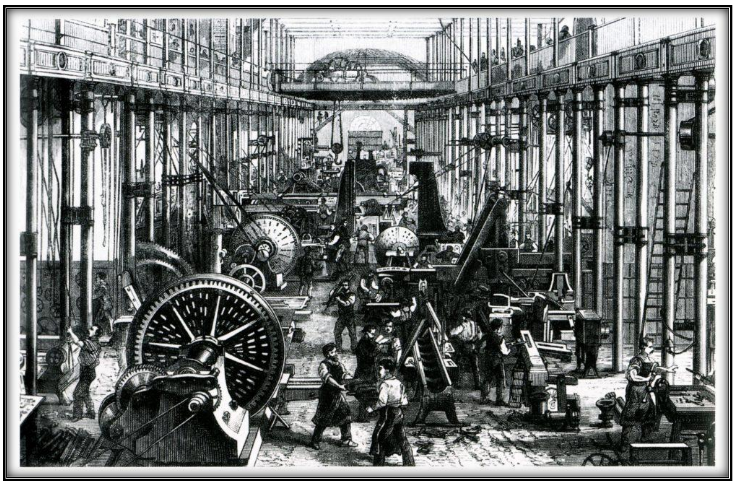


Figure 12.1: Introduction of Industrial Revolution

The Industrial Revolution, also known as the First Industrial Revolution, was a period of global transition of human economy towards more efficient and stable manufacturing processes that succeeded the Agricultural Revolution, starting from Great Britain, continental Europe, and the United States, that occurred during the period from around 1760 to about 1820–1840. This transition included going from hand production methods to machines; new chemical manufacturing and iron production processes; the increasing use of water power and steam power; the development of machine tools; and the rise of the mechanized factory system.

The textile industry was the first to use modern production methods, and textiles became the dominant industry in terms of employment, value of output, and capital invested. The Industrial Revolution was a period of major mechanization and innovation that began in Great Britain during the mid-18th century and early 19th century and later spread throughout much of the world.

History

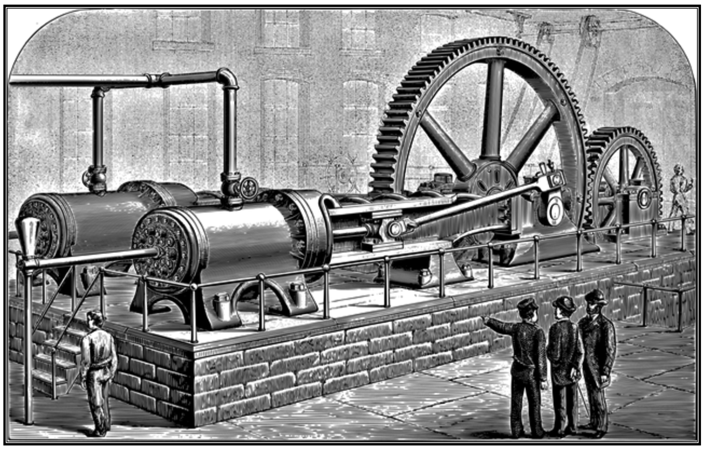


Figure 12.2: History of Industrial Revolution

The Industrial Revolution began in Great Britain, and many of the technological and architectural innovations were of British origin. By the mid-18th century, Britain was the world's leading commercial nation, controlling a global trading empire with colonies in North America and the Caribbean. Britain had major military and political hegemony on the Indian subcontinent; particularly with the proto-industrialised Mughal Bengal, through the activities of the East India Company. The development of trade and the rise of business were among the major causes of the Industrial Revolution.

The Industrial Revolution marked a major turning point in history. Comparable only to humanity's adoption of agriculture with respect to material advancement, the Industrial Revolution influenced in some way almost every aspect of daily life. In particular, average income and population began to exhibit unprecedented sustained growth. Some economists have said the most important effect of the Industrial Revolution was that the standard of living for the general population in the Western world began to increase consistently for the first time in history, although others have said that it did not begin to improve meaningfully until the late 19th and 20th centuries. GDP per capita was broadly stable before the Industrial Revolution and the emergence of the modern capitalist economy.

Stages of the Industrial Revolution 1.0 to 4.0

The transitions of the industrial revolution were mainly evident in three different regions: The United States, Great Britain and continental Europe. However, by the 20th century, the revolution had already spread to almost every other part of the world, bringing about a new era of modern industry. We have gone through three industrial revolutions: Industry 1.0, industry 2.0 and Industry 3.0. And now, we are in the midst of the fourth industrial revolution (industry 4.0). In this article, we look into all the four stages of the industrial revolution, what each involved and the kind of technologies that characterize each era of revolution. Now, let's learn more about Industry 1.0 to 4.0!

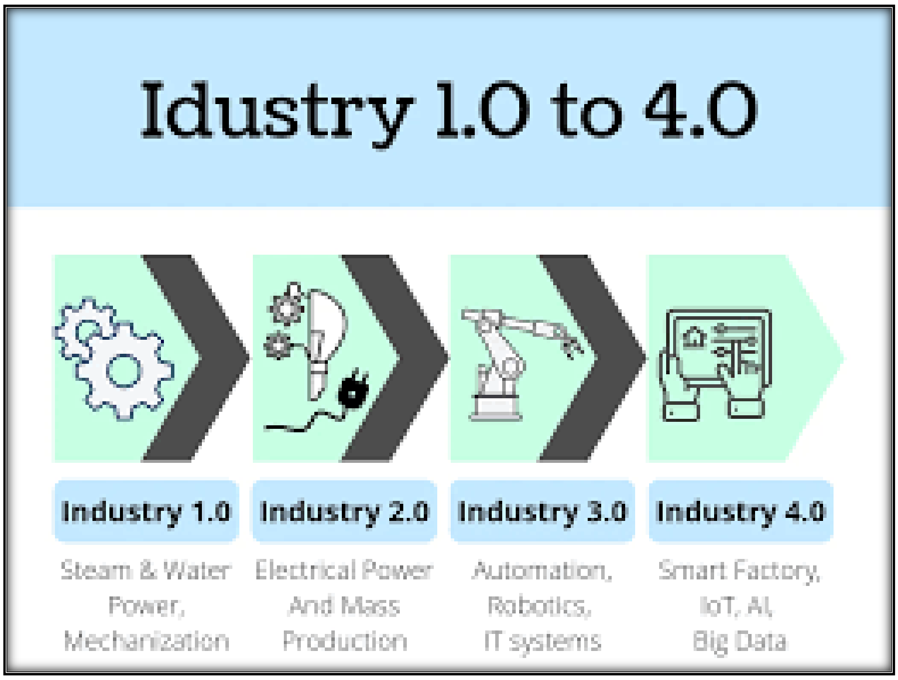


Figure 12.3: Different Stages of Industrial Revolution

Different Stages of Industrial Revolution

- IR 1.0 or Industry 1.0 meaning: The First Industrial Revolution
- IR 2.0 or Industry 2.0 meaning: The Second Industrial Revolution
- IR 3.0 or Industry 3.0 meaning: The Third Industrial Revolution
- IR 4.0 or Industry 4.0 meaning: The Fourth Industrial Revolution

Industry 1.0

Figure 12.4: Industry 1.0 Highlights

Industry 1.0 is the first industrial revolution. It began in England, in the 18th century; it covered the period from around 1760 to 1840. By the latter period of the 18th century, the industrial revolution had already spread to the United States. Industry 1.0 is related to the mechanization of production and vast usage of steam power. It also marked the first major transition from a handicraft economy to one involving the use of machines in the manufacturing processes. The industries that were impacted by industry 1.0 included the glass, mining, agriculture and textile industries. For example, before the revolution, threads and textiles were manufactured at home using simple spinning wheels.

The basic tools, materials and equipment used to make the textiles were usually provided by merchants. Using these tools made it difficult to manage production, and also to produce large quantities of items. However, with the uprising of industry 1.0, mechanization was introduced in the production process, leading to faster processes and relatively large-scale production. In fact, the mechanized version led to a thread production that was eight times more in volume than the former production process.

➢ Industry 1.0 Technologies

Figure : Industry 1.0 Technologies

The landmark technologies that characterized industry 1.0 were the machines powered by water and steam. A good example of such machines is the weaving loom which was first developed in 1784. Other machines that were invented during this period include the water wheel, more complex spinning wheels and the steam engine. These newly invented machines allowed workers to produce goods in large quantities. As a result, most small businesses grew and developed to become large organizations that served a larger number of people. The advancing of technologies especially brought significant benefits to the textile and transportation industries. These benefits became even more evident when coal began to be used as an additional source of fuel for different manufacturing processes.

One major downside of the first industrial revolution was that there was greater demand for production machines than the supply. After all, these machines had just been invented, which meant that there were relatively fewer machines and technologies to meet all of the customers' demands. This led to more pressure, especially on workers who were considered as the lower class.

These workers are forced to work for long hours, and under unhealthy working conditions. However, in 1833, the Factory Act was put in place in the UK to ensure that high standards were followed in all workplaces, guaranteeing the safety and protection of all employees.

➢ Impact of Industry 1.0

The impact of Industry 1.0, which corresponds to the first Industrial Revolution, was profound and far-reaching, transforming societies, economies, and daily life in several significant ways.

Here are some key impacts of Industry 1.0:

❖ **Mechanization of Production:**

- **Shift from Handicrafts to Machinery:** Industry 1.0 marked the transition from manual labour and traditional handicrafts to the use of machinery in manufacturing processes.
- **Increased Efficiency:** Mechanization led to increased production efficiency, allowing for the mass production of goods.

❖ **Introduction of Steam Power:**

- **Revolution in Power Sources:** The widespread adoption of steam engines powered by coal or water drastically changed the sources of energy used for production.
- **Expansion of Industries:** Steam power enabled the establishment of large-scale factories, particularly in textile and iron production, leading to the growth of industrial centres.

❖ **Impact on Employment and Labour:**

- **Shift in Employment Patterns:** The demand for labour shifted from agrarian and craft-based work to industrial jobs in factories.

❖ **Economic Transformation:**

- **Creation of Wealth:** The Industrial Revolution contributed to significant economic growth, creating wealth for industrialists and entrepreneurs.
- **Formation of Capitalism:** The emergence of industrial capitalism replaced feudal and agrarian economic systems.

❖ **Technological Innovation:**

- **Invention of New Technologies:** Innovations such as the spinning jenny, power loom, and mechanized weaving processes revolutionized the textile industry.

- **Catalyst for Further Innovation:** The first Industrial Revolution set the stage for subsequent technological advancements in later industrial phases.

❖ **Social and Cultural Changes:**

- **Emergence of New Social Classes:** The industrial era witnessed the emergence of distinct social classes, including industrial capitalists, the working class, and the middle class.
- **Changes in Lifestyle:** The shift from agrarian to industrial societies brought about changes in living conditions, family structures, and social norms.

❖ **Global Impact:**

- **Expansion of Trade:** The Industrial Revolution had a global impact, leading to increased international trade as industrialized nations sought raw materials and new markets.
- **Colonialism:** Industrialized nations engaged in colonial expansion to secure resources and markets for their growing industries.

While Industry 1.0 laid the foundation for modern industrial societies, it also brought about significant challenges, including social inequality, labour exploitation, and environmental impacts. Subsequent industrial revolutions aimed to address some of these challenges.

Industry 2.0

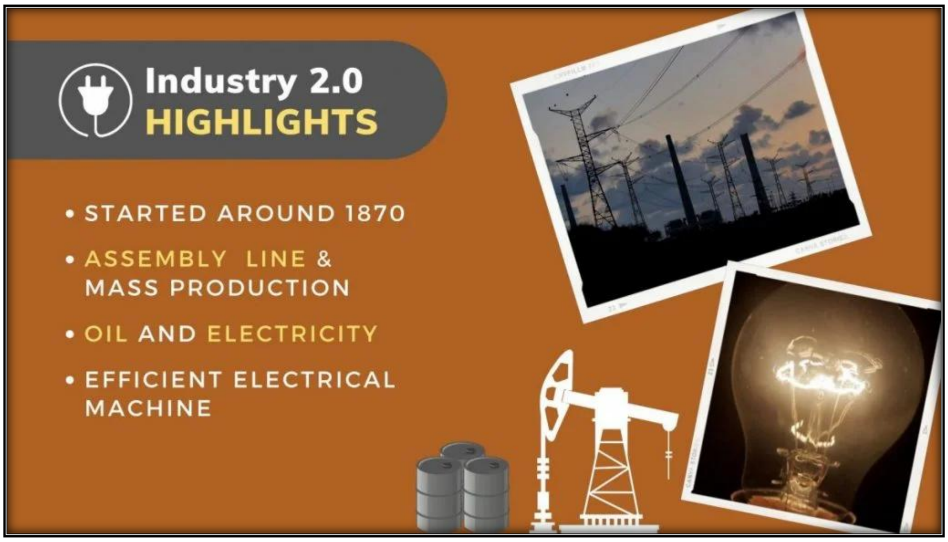


Figure: Industry 2.0 Highlights

The second industrial revolution (Industry 2.0) began in the 19th century, around the 1870s. It mainly occurred in Germany, America and Britain. Some historians also refer to this period as the

“Technological Revolution” era. It mainly involved industrial processes that used machines powered by electrical energy. Industries were already using electricity as one of the driving forces. However, it was not until the second industrial revolution that electrical machines were invented. Compared with the water and steam-based machines, electrical machines were much more efficient, easier to operate and maintain.

Industry 2.0 also featured a more streamlined mass production process. This was happened after creating the first assembly line, which made it easier to produce items in larger volumes and better quality. In fact, mass production of items was considered a standard practice during this period. During industry 2.0, more techniques and programs were put in place to improve the quality of output and ensure better management of production. These techniques involved lean manufacturing principles.

➢ Industry 2.0 Technologies

Figure : Industry 2.0 Technologies

There are many technological systems that were developed during the second industrial revolution. The major aspect of this era was the use of electrical energy and steel in production industries. The use of electricity made it possible for many industries to incorporate modern production lines and carry out mass production of goods. Also, industry 2.0 was characterized by extensive telegraph and railroad networks. These networks facilitated a faster transportation system. More so, it allowed for faster communication and transfer of information. In 1901, Ransom E. Olds established the very first assembly line. As the producer of Oldsmobile cars, Ransom started a system that produced at least 20 units each day. And in just one year, the company increased its production, registering an output that was 500% more than their former output. Thanks to the creation of more vehicles by Oldsmobile, this period saw a major decrease in the overall pricing of automobiles.

Henry Ford was the first person to bring about the idea of mass production. He cultivated a keen interest in how the pigs at a Chicago slaughterhouse would be hung on conveyor belts. There were different butchers, and each would perform just part of the work of butchering the pigs. Henry then applied these principles into the production of automobiles, changing how the process used to be carried out. For instance, before his invention, only one station would assemble the whole automobile. However, by applying the principles that he learnt from the conveyor belts and distribution of labour, Henry Ford is also credited as the father of automotive mass manufacturing.

➢ Impact of Industry 2.0

The impact of Industry 2.0, or the second industrial revolution, was profound and transformative, shaping the course of history in various domains.

Here are some key impacts of Industry 2.0:

❖ **Economic Transformation:**

- **Mass Production:** Industry 2.0 saw the rise of mass production through the use of assembly lines and standardized manufacturing processes. This significantly increased the efficiency of production, lowered costs, and made goods more affordable for a broader population.

❖ **Technological Advancements:**

- **Electrification:** The widespread adoption of electricity revolutionized industries, leading to increased efficiency in manufacturing processes. It enabled the use of more versatile and powerful machinery, contributing to overall economic growth.
- **Mechanization:** Industries such as textiles, mining, and agriculture experienced a shift towards mechanization. This reduced the reliance on manual labour and increased output.

- **Urbanization and Social Changes:**
  - **Urban Migration:** The growth of industries led to the migration of people from rural areas to urban centres in search of employment. This resulted in the rapid expansion of cities and the emergence of an urban working class.

- **Labour and Workforce:**
  - **Factory Labour:** The demand for labour in factories led to the establishment of the factory system, where workers were employed in large-scale production Facilities. This marked a shift from traditional craftsmanship to industrial employment.
  - **Labour Unions:** The challenges and hardships faced by industrial workers led to the formation of labour unions, advocating for workers' rights, better working conditions, and fair wages.

- **Globalization:**
  - **Expansion of Markets:** Industry 2.0 facilitated the expansion of markets beyond local and national boundaries. Improved transportation and communication networks allowed for increased international trade and economic globalization.

- **Infrastructure Development**:
  - **Transportation Networks:** The development of railroads and steamships during this period played a crucial role in the transportation of raw materials and finished goods. This, in turn, facilitated economic growth and expanded markets.
  - **Urban Infrastructure:** The growth of cities required significant investments in infrastructure, including roads, bridges, and utilities, leading to the modernization of urban areas.

- **Impact on Agriculture:**
  - **Agricultural Changes:** The industrial revolution had repercussions for agriculture as well. Mechanization and technological advancements in farming practices led to increased productivity and a shift in the rural labour force.

Understanding the impact of Industry 2.0 is essential for grasping the roots of modern industrial and technological trends.

- **Differences Between Industry 1.0 And 2.0**

FEATURES	INDUSTRY 1.0	INDUSTRY 2.0
Source of power	Water and steam were the main power sources for machines and industrial processes.	Electricity and oil were the main source of power for most machines and industrial processes.
Labour	More labour force and human resources were required for most industrial processes – This is because there was more demand than supply, which meant more people being employed and working for lengthy hours.	Less labour force was required, and more people lost their jobs – This is because machines replaced workers, carrying out most of the activities that these would undertake.

Industry 3.0

Figure: Industry 3.0 Highlights

The third industrial revolution is also commonly referred to as the 'Digital Revolution' or the 'First computer era.' It began in the 20th century, around the 70s. During this period, simple, yet relatively large computers were developed. These computers had quite a good computing power, and they laid a strong foundation for the development of modern-day machines. The industrial revolution 3.0 began through partial automation; a technological process that was achieved using simple computers and Programmable Logic Controllers (or memory-programmable controls). Before the revolution, some simple automated systems had been developed. However, these still relied heavily on human intervention and input.

Information technology (IT) and electronics were introduced in many production processes, furthering automation in the manufacturing processes. Furthermore, the automation processes advanced even further following the use of renewable energy in the production industries, as well as the development of connectivity and internet access. It is crucial to note that Industry 3.0 (the third Industrial revolution) is still present even today. In fact, most modern-day factories and production industries are currently at this evolution level.

➢ Industry 3.0 Technologies

Figure: Industry 3.0 Technologies

During the latter period of the 20th century, great advancements were made in the electronics industry. For example, different varieties of electronic devices were invented, such as integrated circuits and transistors. These electronic devices brought about a partial automation of the machines which were used in the production processes. In turn, this led to greater accuracy in production, increased speeds, better competency, and even replacement of human labour in some manufacturing processes. In the 1960s, the Programmable Logic Controller (PLC) was invented; one of the landmark inventions that triggered automated processes using electronics. Also, the incorporation of electronic machines in the production processes led to a demand for software systems to control this electronic hardware. Consequently, this fuelled the software development market of the time.

In addition to enabling electronic devices, the software systems also made it possible to carry out different management processes. For example, activities such as inventory management, tracking of products, enterprise resource planning, scheduling of product flows and shipping logistics were enabled by the software systems. And from that period, the systems are constantly being developed and automated using information technology and electronics. Other electronic machines that were invented during the third industrial revolution include integrated circuit chips, digital logic systems, MOS transistors, as well as their respective derived technologies

➢ Impact of Industry 3.0

Industry 3.0, often referred to as the third industrial revolution, represents the integration of digital technologies and automation into manufacturing processes. This era, which began in the late 20th century, brought about significant changes in industrial production.

Here are some key impacts of Industry 3.0:

❖ **Automation and Robotics:**

- **Increased Efficiency:** Automation and the use of robotics in manufacturing processes led to increased efficiency and precision. Tasks that were previously manual and time-consuming could now be performed by machines, reducing production times.
- **Consistency and Quality:** Automation improved product consistency and quality by minimizing human error in repetitive tasks. This had a direct impact on the reliability and uniformity of manufactured goods.

❖ **Computerization and Control Systems:**

- **Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM):** The adoption of CAD and CAM systems allowed for more sophisticated and precise product design and manufacturing. This integration of computer technology enhanced the overall production process.
- **Process Control Systems:** Advanced control systems enabled real-time monitoring and control of manufacturing processes, optimizing production and resource utilization.

❖ **Integration of Information Technology:**

- **Enterprise Resource Planning (ERP):** The implementation of ERP systems streamlined business processes by integrating various aspects of operations, such as supply chain management, finance, and human resources. This integration improved overall organizational efficiency.
- **Communication Networks:** The development of communication networks facilitated faster and more efficient information exchange between different parts of a manufacturing organization. This connectivity contributed to better decision-making.
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- **Globalization and Supply Chain Management:**
  - **Global Production Networks:** Industry 3.0 saw an increase in global production networks, with companies sourcing components and resources from various parts of the world. This globalization was facilitated by improved communication and transportation networks.
  - **Supply Chain Optimization:** Digital technologies allowed for better supply chain management, reducing lead times, minimizing inventory costs, and improving overall logistics.

- **Customization and Flexibility:**
  - **Flexible Manufacturing Systems:** The adoption of flexible manufacturing systems allowed for quicker shifts between different product lines and customization of products. This flexibility was a response to changing consumer demands and market dynamics.

- **Environmental Considerations:**
  - **Efficiency Improvements:** The adoption of Industry 3.0 technologies contributed to more efficient resource utilization, reducing waste and energy consumption in manufacturing processes.
- **Innovation and Product Development:**
  - **Rapid Prototyping:** Advanced technologies enabled rapid prototyping and iterative product development processes, reducing time-to-market for new products.

Industry 3.0 laid the groundwork for the ongoing Industry 4.0, characterized by the further integration of digital technologies, the Internet of Things (IoT), artificial intelligence, and data analytics into industrial processes.

- **Differences Between Industry 2.0 And 3.0**

FEATURES	INDUSTRY 2.0	INDUSTRY 3.0
Production systems	Mechanical machines and aides were mainly used in large-scale production.	Automated systems are used in mass production; these systems have the ability to carry out complicated human tasks.
Major invention	The use of electricity in production processes was a major invention during this era.	The introduction of computers and automation were the landmarks of Industry 3.0.

Industry 4.0

Figure: Industry 4.0 Highlights

Industry 4.0 is the industrial revolution being currently implemented in our modern world. As a development of the Third Industrial Revolution, this era is characterized by the use of communication and smart information technologies in various industries. Also, network connections are used to expand production systems that already incorporate automation and computer technologies. Therefore, the fourth industrial revolution has led to efficient networking (or interconnectivity) of systems, also known as the “cyber-physical production systems.” In turn, this invention has led to the development of smart manufacturing and factories, where all production is almost completely automated production systems, people and components communicate thanks to a unique network.

Also, this current revolution era has dramatically changed how people work. It allows a more efficient way of working by pulling individuals into smarter networks. The manufacturing industry is almost entirely digitalized, making it easier to pass information to the right people at the right time. The industrial revolution 4.0 is considered the era of production facilities, storage systems and smart machines that can trigger actions, control other devices and exchange information autonomously without any human intervention.

➢ Industry 4.0 Technologies

Figure: Industry 4.0 Technologies

The initial developments of Industry 4.0 began in the 1990s, following the advancements in the telecommunication and internet industry. However, the major changes in this era were noticeable from 2011. During this year, a project was conducted in Germany, promoting computerization in manufacturing. In fact, it was during the Hannover Fair (held in the same year) that the term “Industry 4.0” was launched publicly. Among the major technologies invented during the fourth industrial revolution Are Cyber-Physical Systems (CPS).

These systems are used in various industrial processes to analyse, guide and share intelligent actions, making the devices smarter. Also, there are smart machines that can monitor and detect failures in manufacturing processes. Such machines allow industries to be prepared well for any drastic changes that could result in high downtimes and losses. Cyber-Physical Systems have also made it possible for industries to be virtually visualized; hence, they can be easily monitored and regulated even from remote locations. More so, the systems, infrastructure and different manufacturing processes can be monitored in one single place and data can be analysed both in the cloud or locally, thanks to edge computing. This makes the management of industries easier and highly efficient.

➢ Impact of Industry 4.0

Industry 4.0, often referred to as the fourth industrial revolution, represents a new phase in the evolution of industrial systems characterized by the integration of digital technologies, the Internet of Things (IoT), artificial intelligence (AI), and data analytics. The impact of Industry 4.0 is wide-ranging and transformative, affecting various aspects of industrial processes and business operations.

Here are some key impacts of Industry 4.0:

❖ **Smart Manufacturing:**

- **Interconnected Systems:** Industry 4.0 involves the extensive use of IoT to connect machines, devices, and systems in a manufacturing environment. This interconnectedness allows for real-time data exchange and communication between different components of the production process.
- **Digital Twins:** Digital twins, virtual replicas of physical objects or systems, are used for simulation and analysis. This technology enables manufacturers to optimize processes, predict maintenance needs, and enhance overall efficiency.

❖ **Data-Driven Decision-Making:**

- **Big Data Analytics:** The vast amount of data generated by interconnected systems is analysed using advanced analytics tools. This data-driven approach enables better decision-making, process optimization, and the identification of trends and patterns.
- **Predictive Maintenance:** Industry 4.0 allows for predictive maintenance based on real-time monitoring and analysis of equipment performance. This reduces downtime, extends the lifespan of machinery, and lowers maintenance costs.

❖ **Advanced Robotics and Automation:**

- **Collaborative Robots (Cabot's):** Industry 4.0 sees the integration of collaborative robots that can work alongside human workers. These robots enhance productivity, precision, and flexibility in manufacturing processes.
- **Autonomous Systems:** The use of autonomous systems in manufacturing, such as autonomous vehicles and drones, contributes to improved logistics and material handling.

- **Cyber-Physical Systems:**
  - **Integration of Physical and Digital Systems:** Cyber-physical systems combine physical processes with digital technologies, allowing for seamless integration and communication between the two realms. This integration enhances overall system efficiency and responsiveness.
  - **Real-Time Monitoring:** The ability to monitor physical processes in real-time using digital systems enables better control, optimization, and responsiveness to changes in the production environment.

- **Supply Chain Optimization:**
  - **End-to-End Visibility:** Industry 4.0 provides end-to-end visibility into the supply chain, from raw material sourcing to product delivery. This transparency allows for better inventory management, demand forecasting, and coordination with suppliers.
  - **Blockchain Technology:** The use of blockchain in supply chain management ensures data integrity, security, and traceability throughout the supply chain.

- **Customization and Flexible Production:**
  - **Batch Size of One:** Industry 4.0 enables the cost-effective production of small batches and even individualized products. This supports the trend toward mass customization to meet diverse consumer demands.
  - **Agile Manufacturing:** The flexibility provided by Industry 4.0 technologies allows manufacturers to quickly adapt to changes in market demands and customize products in response to customer preferences.

- **Workforce Transformation:**
  - **Skill Requirements:** Industry 4.0 has led to changes in the skill sets required for the workforce. There is a growing demand for employees with expertise in data analytics, cybersecurity, AI, and digital technologies.
  - **Human-Machine Collaboration:** The integration of AI and automation does not replace human workers but emphasizes collaboration. Employees work alongside intelligent

machines, focusing on tasks that require creativity, problem-solving, and complex decision-making.

- **Environmental Sustainability:**
  - **Energy Efficiency:** Industry 4.0 technologies contribute to energy efficiency by optimizing processes and reducing waste. Smart energy management systems help minimize environmental impact.
  - **Circular Economy Practices:** Digital technologies support circular economy practices by enabling better recycling, reuse, and sustainable resource management.

- **Innovation and New Business Models:**
  - **Rapid Innovation Cycles:** Industry 4.0 fosters a culture of rapid innovation with shorter product development cycles. Companies are better positioned to adapt to changing market conditions and introduce new products more quickly.
  - **Servitization:** The shift from selling products to offering services, known as servitization, is facilitated by Industry 4.0. Companies can provide value-added services such as maintenance, upgrades, and performance monitoring.

- **Cybersecurity Challenges:**
  - **Security Concerns:** The increased connectivity in Industry 4.0 raises cybersecurity challenges. Protecting digital systems and sensitive data becomes a critical aspect of industrial operations.
  - **Data Privacy:** As more data is collected and analysed, ensuring the privacy and security of this data becomes paramount. Compliance with data protection regulations becomes a key consideration.

The impact of Industry 4.0 is multifaceted, revolutionizing the way products are manufactured, businesses are operated, and value is delivered to customers. It represents a paradigm shift in industrial processes, emphasizing connectivity, intelligence, and adaptability.

- **Differences Between Industry 3.0 And 4.0**

FEATURES	INDUSTRY 3.0	INDUSTRY 4.0
Human intervention	Most production processes are automated using information technology and logic processors. However, they rely on some human intervention.	Most production processes use huge quantities of data and smart & interconnected machines that do not rely on any human intervention.
Manufacturing process plan	It is having lean manufacturing and it decides by experience it saves money in manufacturing process.	It is having smart manufacturing and it decides by information it creates new revenue streams.

Advantages

Industry 4.0 offers many advantages compared to the previous industrial revolutions:

- **Competitive Advantages:** Industry 4.0 smart solutions and services offer a wide range of competitive advantages for organizations that are able to successfully launch these new strategies and technologies.

- **Increase in Operational Efficiency:** The hope for Industry 4.0 is that the next generation of industrial revolution will drive even greater profitability for organizations, as they are able to squeeze greater output from the same resource input.

- **Better Products and Services:** Whether it be product quality, safety, or customer experiences, Industry 4.0 will drive greater visibility and throughput for operations, allowing them to continue driving value for customers to retain business.

- **Growth of Markets and New Markets:** With any technological revolution, new services, products, and software will be needed to support the transformation of organizations. This will create entirely new product categories, new jobs, and more.

- **Improving Lives Overall:** With new technologies, higher profitability, and growth in economies, peoples' lives as a whole generally get better, with income rising, better health solutions, and overall a higher quality of life.

Disadvantages

The implementation of Industry 4.0 has not been an entirely smooth journey. Despite the many business opportunities and advantages that the industrial revolution has brought about, these also have challenges and obstacles:

- **High Costs:** Not only is technology a major cost to consider, but the expertise in enabling the technology to be implemented. Having the know-how in newer fields like IoT, Augmented Reality, and AI can lead to major budget constraints, not to mention a lack of understanding among all parties involved.

- **High Rate of Failure:** The difficulty in launching Industry 4.0 initiatives is that there is often a lack of direction when it comes to establishing objectives. They are often cross-functional projects with many stakeholders, which can mean projects can become mired in conflicting goals, and may simply sputter out.

- **Cybersecurity:** People, products, and equipment is, and will increasingly be, connected to the internet. Although this gives us greater access to data via the cloud, it opens up opportunities for hackers to access networks.

- **Need for Highly Skilled Labour:** Manufacturing, and industry as a whole, continues to rely on humans to enable production. However, with the move to digitally connected systems, there is a greater need for highly skilled labour, which may unintentionally reduce the need for low-skill labour.

- **Industry and Market Disruption:** With new technologies available, existing solutions will eventually be phased out. Similar to the Blockbusters of the world, certain industries will be unable to survive what Industry 4.0 brings to market.