1. Explain the neat diagram, construction and working principle of Plasma arc machining (PAM)

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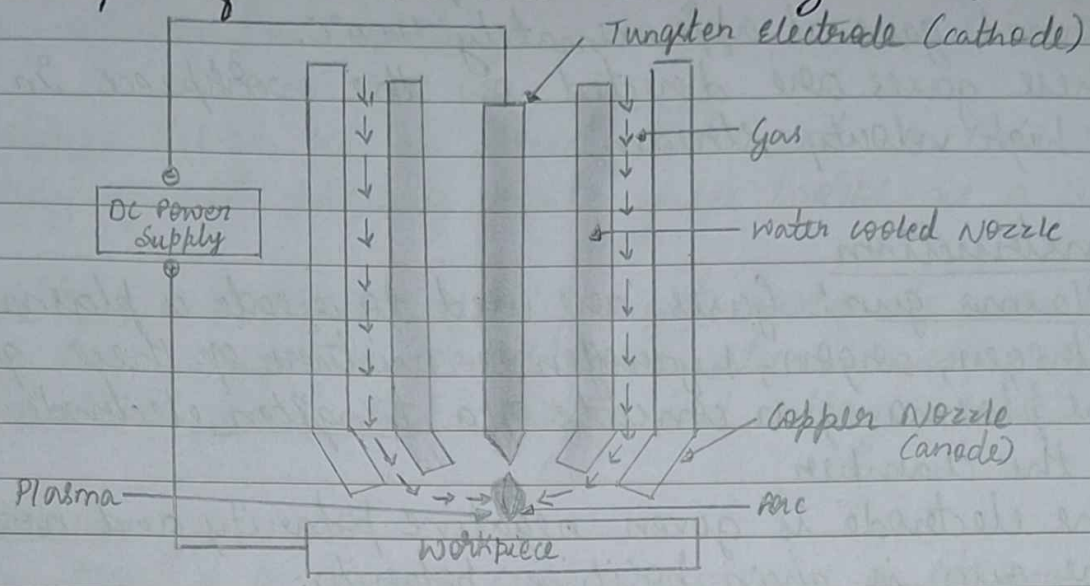

Plasma Arc Machining

Working Principle:

- When heated to elevated temperatures, gases turn into a distinctly different type of matter, which is plasma. When gases are heated by an applied electric field, an igniter supplies the initial electrons, which accelerated in the field before colliding and ionizing the atoms.
- The free electrons, in turn, get accelerated and cause further ionization and heating of the gases.
- The avalanche continues till a steady state is obtained in which the rate of production of the free charges is balanced by recombination and loss of the free charges to the walls with electrodes.
- The actual heating of the gas takes place due to the energy liberated when free ions and electrons recombine into atoms or when atoms recombine into molecules

- In PAM, gases are heated and changed to plasma state. Plasma state is superheated and electrically ionized gases at approximately 5000°C.
- These gases are directed on the workpiece in the form of high velocity stream.

Construction

* Plasma gun: Gases are used to create a plasma like, nitrogen, argon, hydrogen or mixture of these gases
- The plasma gun consists of a tungsten electrode fitted in the chamber.
- The electrode is given negative polarity and nozzle of the gun is given positive polarity.
- Supply of gases is maintained into the gun.
- A strong arc is established between the two terminals anode and cathode.
- There is a collision between molecules of gas and electrons of the arc. As a result of this collision gas molecules get ionized and heat is evolved.
- This hot and ionized gas called plasma is directed to the workpiece with high velocity.
- This established arc is controlled by the supply rate of gases

* Power supply and terminals: Power supply (DC) is used to develop two terminals in the plasma gun.
- A tungsten electrode is inserted to the gun and made cathode and nozzle of the gun is made anode.
- Heavy potential difference is applied ~~acro~~ across the electrodes to develop plasma state of gases

Cooling mechanism: The hot gases continuously come out

of nozzle so there are chances of its overheating. A water jacket is used to surround the nozzle to avoid its collision & overheating.

* Tooling: There is no direct visible tool used in PAM. Focused spray of hot, plasma state gases works as a cutting tool.

* Workpiece: workpiece of different materials can be processed by PAM. These materials are aluminium, magnesium, stainless steels and carbon and alloy steels.

Working

- In PAM, a DC power supply generates a strong arc b/w a cathode (electrode) and an anode (nozzle
- Gas, such as hydrogen, nitrogen, argon, or their mixtures is supplied and heated by the arc to extremely high temperatures (11,000 to 28000°C)
- This heat causes the gas molecules to dissociate into atoms, and some atoms are ionized, forming plasma while releasing significant thermal energy.
- The ionized gas is then directed toward the workpiece at high velocity
- The plasma melts the material, and the high-speed gas blows away the molten metal, effectively removing material
- The electric arc enhances the process by increasing the temperature, aligning the gas beam, and boosting gas velocity for efficient machining.

2. What is the safety precaution in PAM? Explain.

⇒ Safety Precautions in PAM:

1. Heat-Affected Zone: Ensure the heat-affected zone

is controlled within 0.25 - 5mm to prevent material damage.

2. Gas Pressure regulation: Maintain proper gas pressure, typically 1-1.4 MPa, to ensure stable operation

3. Torch Positioning: Keep a constant distance between the torch and workpiece for consistent machining.

4. Operator Training: Provide proper training for operators to handle the equipment safely and effectively.

5. Eye and skin protection: Use protective gear to shield against intense glare, sparks & spatter from the plasma

6. Noise Protection: Equip operators with ear protection to mitigate noise exposure during operation

7. Ventilation: Ensure proper ventilation to manage fumes and maintain a safe working environment

8. Fire safety: Keep flamable materials away from the workspace and have fire safety equipment on hand

9. Electrical safety: Regularly check the equipment for proper insulation and grounding

10. Inspection and maintenance: Conduct routine inspections and maintenance to prevent accidents due to equipment failure

11. Proper Shielding: Use protective shields ~~and~~ around the machining area to contain spatter and debris

12. Emergency Shutoff: Ensure the equipment has a readily accessible emergency shutoff mechanism to halt operations in case of malfunction

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3. What are the advantages and limitations of PAM?

⇒ Advantages of PAM

1. High Production rate: Enables faster machining

compared to conventional methods
2. Material versatility: Can machine very hard and brittle metals
3. Precision: Capable of machining small cavities with excellent dimensional accuracy.
4. Non-contact Process: No direct contact with the workpiece minimizes tool wear.
5. versatility: Suitable for variety of materials, including metals and non metals
6. High temperature capability: Handles extremely high temperatures, allowing for efficient machining
7. Reduced mechanical stress: Causes minimal distortion due to non contact operation

Limitations of PAM
1. High initial cost: The setup cost is very high
2. Safety requirements: Extensive safety measures increases operational complexity and cost.
3. Material sensitivity: Some materials are prone to metallurgical changes due to excessive heating
4. Not economical for large cavities: Inefficient for machining larger cavities
5. Limited thickness: Effective only within a specific range of material thickness
6. Energy consumption: High power requirements increase operational costs
7. Skilled labor: Requires highly trained operators for effective use.

4. Explain the neat sketch, working principle of Laser beam machining (LBM) process.

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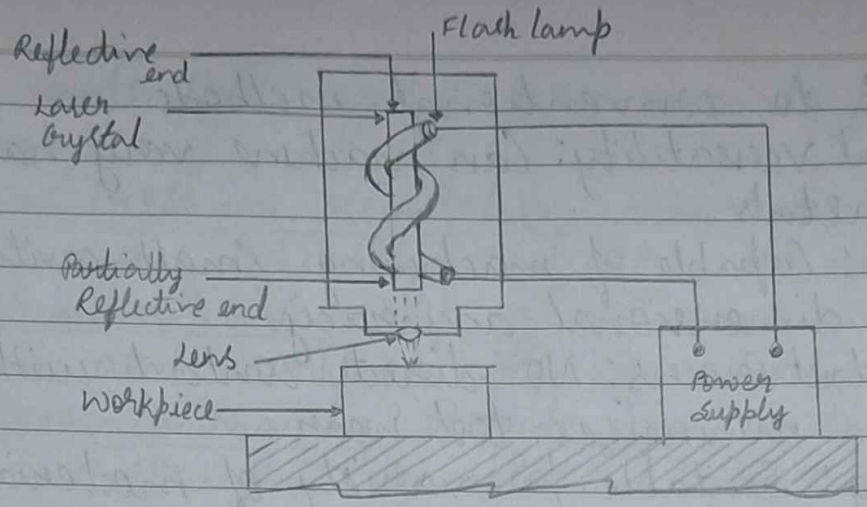

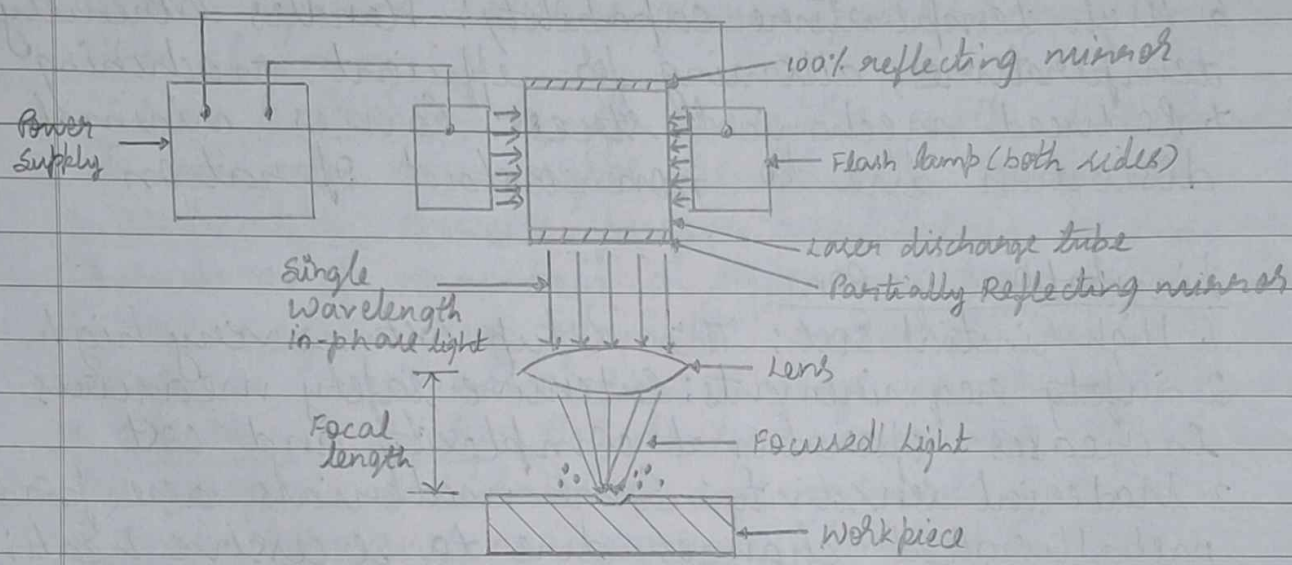

Laser Beam Machining

Equipment:

1. Power supply: The electric current or power is supplied to the system. A high voltage power system is used in laser beam machining. It will give initial power to the system after that reaction starts in a laser that will machine the material

2. Capacitor: During the major portion of the cycle, a capacitor bank charges and releases the energy during the flashing process. This is used for the pulsed mode

for charging & discharging.

3. Flash lamps: It is the electric arc lamp that is used to produce extremely intense production of white light which is a coherent high-intensity beam. It is filled with gases that ionize to form great energy that will melt and vaporizes the material of the workpiece.

4. Reflecting mirror: There are 2 main types: internal & external. Internal mirrors also called as resonator that is used to generate, maintain & amplify the laser beam. It is used to direct the laser beam towards the workpiece.

5. Laser light beam: It is the beam of radiation produced by the laser through the process of amplification based on the coherence of light created by the bombarding of active material.

6. Ruby crystal: Ruby laser produces a series of coherent pulses which is deep red in color. It achieves the concept of population inversion. It is a three-level solid-state laser.

7. Lens: It is used to focus the laser beam onto the workpiece. First laser light will enter into the expanding lens and then into the collimating lens which makes the light rays parallel & the expanding lens expand the laser beams to the desired size

8. Workpiece: It can be metallic or non-metallic.

Working principle

- Laser machining is based on the LASER and conversion or process of electric energy into light energy & into thermal energy
- Negatively charged electrons in the atomic model rotate around the positively charged nucleus in

orbital paths. It depends on the number of electrons, electron structure, neighboring atoms, & the electromagnetic field.

- Every orbital of electrons is associated with different energy levels. An atom is considered to be at ground level at absolute zero temperature at this, all electrons occupy their lowest potential energy
- The electrons at the ground state move to higher state of energy by absorbing energy like an increase in electronic vibration at elevated temperatures.
- High voltage is applied at the ends that leads to discharge and gas ~~palm~~ plasma will be formed. Population inversion & lasing action will take place due to energy transformation.
- The laser has one 100% reflector and the other one is partial reflector. 100% reflector directs the photons inside the gas tube and other reflector will allow only some part of the beam to be used for processing of material.
- The laser beam produced has to be focused on the workpiece. When the laser strikes the workpiece, the thermal energy impinges on the workpiece
- This will heat and then melt, vaporize, and finally the material will be removed from the workpiece

5. What are the characteristics and process of LBM?

⇒ <u>Characteristics</u>

1. <u>Laser Power</u>: Increasing the laser power generally leads to higher metal removal rates (MRR). However, excessively high laser power can cause material melting & vaporization, resulting in poor surface finish & accuracy

2. Beam diameter: It affects the spot size on the workpiece. Smaller beam diameter produce finer details and better surface finish, but they may also result in slower MRR. Larger diameter, achieves higher MRR but may sacrifice surface finish and accuracy.

3. Beam Quality: Higher beam quality, characterized by good focusability & stability, allows for improved accuracy & surface finish. It also influences the depth of focus, which can affect the achievable surface finish & accuracy

4. Pulse duration: In pulsed laser machining, shorter pulse duration tends to minimize heat transfer & reduce the heat affected zone. It results in improved surface finish & accuracy. Extremely short pulse durations may lead to decreased MRR

5. Pulse frequency: The pulse frequency along with pulse duration, determines the average power delivered to workpiece. Higher pulse frequency increases MRR but may affect surface finish & accuracy.

6. Beam scanning speed: Higher scanning speed generally results in higher metal removal rates, but may lead to decreased surface finish and accuracy due to reduced interaction time between the laser and the workpiece

7. Assist gas: Different assist gases can affect the heat transfer and MRR mechanisms. Proper selection and control of the assist gas can help improve the machining process & achieve desired results.

Process

- LBM is a thermal material removal process that

uses a high-energy, coherent laser beam to precisely melt and vaporize material from metallic and non-metallic workpieces.

- The process begins with laser generation, where electrons ~~beam~~ absorb energy, emit photons and amplify light through stimulated emissions
- Equipment includes power supply, capacitors, flash lamps, mirrors, and lenses to direct and focus the beam.
- The laser's energy is concentrated on the workpiece, heating the surface to melt or vaporize material, aided by assist gases like nitrogen or oxygen for improved efficiency.
- LBM is widely used for cutting, drilling and marking in industries like aerospace, electronics and automotive due to its precision & versatility

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6. What are the advantages and limitations of LBM?

⇒ 1. <u>No limit to cutting path</u>: The laser beam can move in any direction, allowing complex and intricate designs to cut easily.

2. <u>Stress-Free process</u>: Fragile materials can be cut without requiring physical contact or mechanical support, preventing damage

3. <u>Cuts hard and abrasive materials</u>: Capable of handling materials that are challenging for traditional cutting methods, such as ceramics & composites

4. <u>Cuts ~~stick~~ sticky materials</u>: Materials like adhesive layers can be cut cleanly without to the cutting tool

5. <u>Cost effective and flexible</u>: Suitable for prototyping

and small batch production, minimizing tooling costs
6. High accuracy: Produces parts with extremely fine tolerances, often without need for secondary finishing
7. No tool wear: Since there is physical contact, there is no wear and tear, ensuring consistent quality over time

Limitations
1. Uneconomical for high volumes: Traditional machining or stamping are more economical than LBM
2. Thickness limitation: Effectiveness decreases for thicker materials due to beam divergence and energy dissipation
3. High initial and maintenance costs: Regular maintenance part replacement, and caliberation add to operational expenses, also it requires significant upfront investment
4. Gas assitance required: Requires assist gases to aid the process, which increases cost
5. Energy intensive: Laser systems consume a significant amount of power compared to some conventional processes.
6. Material reflectivity issues: Struggles with highly reflective metals like gold, silver, or copper without specialized configuration
7. Slow for simple geometries: For straightforward shapes, traditional methods like drilling or punching are faster

7. Explain the working of Electron beam machining process with neat sketch.

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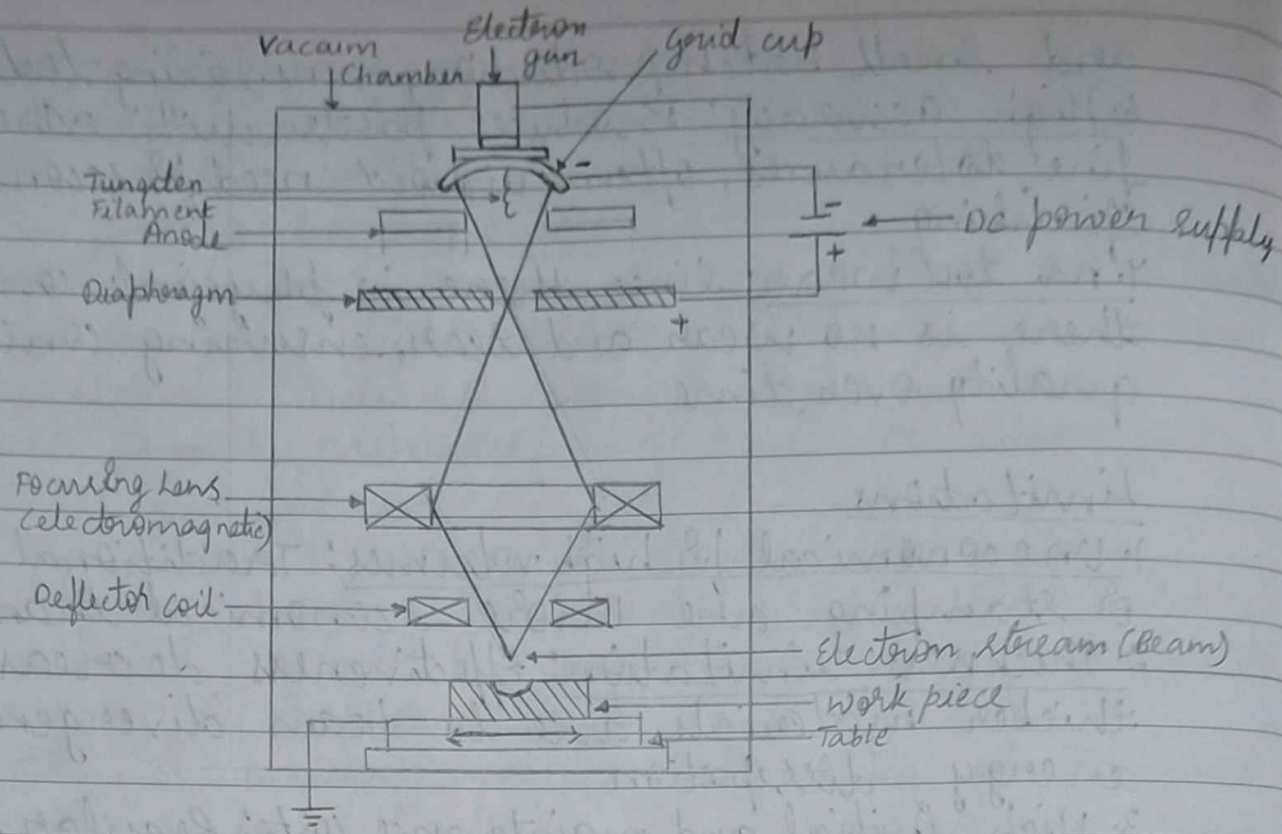

Working

- EBM is a precise, non-contact thermal machining process that uses a high velocity electron beam to remove material by vaporization
- It is performed in a vacuum environment to prevent scattering of the electron beam by air molecules

Steps:

1. Electron generation
   - A tungsten filament is heated to ~2500 °C, generates electrons
   - Electrons are accelerated using a high voltage (50-200kV) applied between the cathode & anode
2. Electron focusing
   - The electron beam passes through electromagnetic focusing lens that condense it into a fine spot with a diameter as small as 0.01 to 0.02 mm.

- The beam's path is controlled using electromagnetic deflector coils.

3. Material Interaction:
   - The high energy electron strikes the workpiece
   - Kinetic energy of electrons is converted into thermal energy, causing localized heating, melting and vaporization of material.
   - The process is repeated in pulses, allowing precise control of material removal

4. Vaccum environment
   - The entire setup is enclosed in a vaccum chamber to prevent collisions with air molecules, ensuring efficient beam propagation and minimizing contamination

Mechanism of material removal
- The concentrated heat energy from the electron beam creates a high power density (~ 6500 kW/mm^2) at the focal point, instantly vaporizing material.
- Machining is typically carried out in short pulses to control heat transfer and material removal rate

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8. Explain the equipment used in the Electron Beam Machining (EBM)

⇒ EBM relies on a sophisticated setup that ensures precision, reliability, and effective material removal

Equipment:

1. Electron gun: It is the core component responsible for generating and accelerating electrons of to high energy levels. It consists of:

• Tungsten Filament (Cathode)
↳ made of tungsten due to its high melting point (~3400°C) and ability to emit electrons efficiently when heated.
↳ It is connected to the negative terminal of DC power supply. when heated to ~2500°C it emits steady stream of electrons
• Grid cup
↳ Positioned near the tungsten filament, it shapes and directs the emitted electrons into a narrow beam
• Anode
↳ Acts as a positively charged electrode, accelerating the electrons towards the workpiece
↳ A high voltage (50-200kV) is applied b/w cathode and anode to give the electrons sufficient kinetic energy.

2. <u>Focusing System</u>: It ensures that the electron beam converges into a fine spot for precise machining.
• Electromagnetic focusing lens
↳ these are magnetic coils that create an electro-magnetic field to focus the electron beam
↳ They condense the beam to a very small diameter (0.01-0.02 mm), enhancing precision
• Adjustable lens system
↳ Allows the beam to be focused at varying depths accomodating different workpiece geometries

3. <u>Deflector coils</u>: Enables precise control over the beam's path and positioning. Features are

· Beam steering
↳ By generating controlled magnetic fields, these coils deflect the electron beam to specific locations on the work piece
↳ This capability allows machining of intricate patterns, holes and shapes with physically moving the workpiece
· Cut path control
↳ The deflection system can be programmed to follow complex paths, ensuring uniform cuts & patterns

4. Vaccum chamber: It is essential for EBM to minimize electron scattering & contamination. Features are.
· High vaccum levels
↳ Typically maintained at pressures of 10^5 to 10^7 torr, ensuring uninterrupted beam propagation.
↳ Prevents electrons from colliding with air molecules, which could scatter the beam and reduce efficiency.
· Sealed door with worktable access
↳ Allows easy placement and removal of workpieces.
↳ The door is equipped with seals to maintain the vaccum integrity during operations
· Integrated gas removal system
↳ Removes gases generated during machining to maintain the required vaccum levels

5. Power supply: It is critical for generating the energy required to produce and control the electron beam. Its components include:
· High voltage generator:
↳ Supplies the voltage (50-200kV) necessary to accelerate electrons in the gun.

↳ Designed to be stable to avoid fluctuations that could affect beam performance

• Beam current control

↳ Adjusts the flow of electrons, controlling the intensity and energy of the beam.

• Auxiliary supplies

↳ Provide power to other components like focusing lenses, deflector coils, and the vaccum system.

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9 Write the advantages and applications of EBM.

⇒ Advantages

1. High precision: EBM provides exceptional precision with the ability to focus the electron beam to a very small spot size (as small as 0.01 mm), enabling intricate machining and fine feature resolution

2. Minimal Heat-Affected zone (HAZ): The high-energy, focused beam minimizes heat diffusion into surrounding areas, reducing material distortion and preserving the mechanical properties of the workpiece

3. Non-contact process: EBM is a non-contact machining process, eliminating tool wear and mechanical stresses on the workpiece. This results in high-quality surfaces without additional finishing.

4. Automation and CNC integration: The process is easily integrated and automated with CNC systems ~~with~~ for precise control, improving productivity and repeatability.

5. Minimal contamination: Conducted in a vaccum

environment, EBM minimizes oxidation and contamination, producing clean surfaces suitable for critical applications.

6. No Tool wear: Since EBM involves no physical contact, there is no wear and tear on cutting tools, reducing costs on maintenance and operations.

7. High-speed drilling: EBM can drill upto 4000 holes per second with precise and consistent diameters

Applications

1. Aerospace industry: Extensively used here for machining critical components like turbine blades, nozzle guide vanes and fuel injection nozzles. Its high precision and ability to work with high-temperature alloys make it suitable for manufacturing aerospace components that require tight tolerances and complex geometries.

2. Medical device manufacturing: In manufacturing components like surgical instruments, implants, orthopedic devices and dental prosthetics. EBM's ability to work with biocompatible materials and produce fine details makes it well-suited for this industry

3. Electronics industry: In manufacturing microelectro-mechanical systems (MEMS) and precision electronic components. It can be employed to create micro-sized holes, slots, and channels in materials like silicon, ceramics, and thin films.

4. Automotive industry: EBM is used for manufacturing components like fuel injectors, turbocharger parts and engine valves. The ability to achieve fine feature resolution and work with high-strength

material makes EBM a prefered choice for creating high-performance automative parts.

5. Tool and die manufacturing: EBM is employed in production of molds, dies, & inserts. It enables machining of complex cavities and features with high precision and minimal distortion.

6. Research and development: For prototyping and exploring novel material designs. It allows researchers to fabricate complex geometries and evaluate the performance of new materials in various industries.