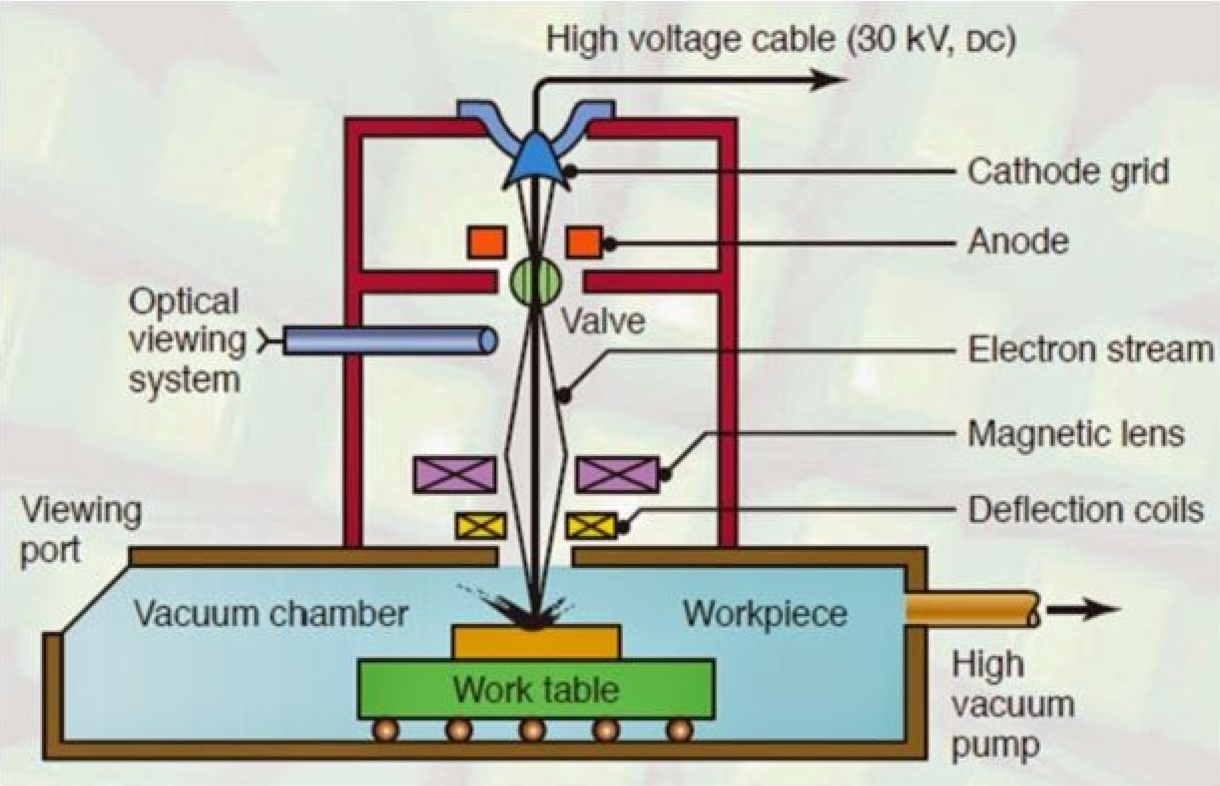
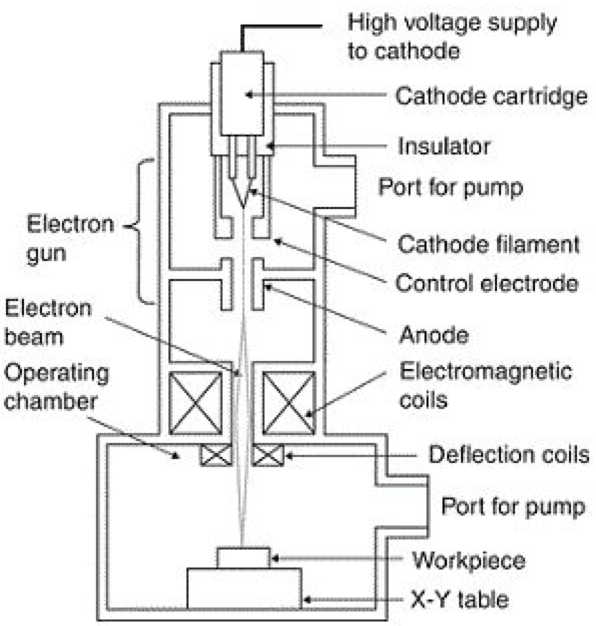
ELECTRON BEAM MACHINING (EBM)

Basic Introduction

EBM is a process where a narrow beam of high-velocity electrons are directed toward the workpiece, creating heat & vaporizing the material.

- Energy domain: Thermal
- Beam current: No of electrons crossing any section per second.
- Vacuum is compulsory to reduce contamination by electron collisions with air molecules.





Working principle

A pulsating stream of high-speed electrons carry immense kinetic energy.

- When they impinge on workpiece generates very high temperatures.
    - Kinetic energy converts to thermal energy.
- Due to this the metal melts / vapourises & results in metal cutting / machining.
- Vacuum is required to avoid contamination of electrons by collision with air molecules.

Equipment

- Electron gun: It generates high velocity concentrated electron beam. It consists of
    - Cathode: Negatively charged electrode that emits electrons.
        - is made of tantalum or tungsten material
    - Bias grid: It is also known as grid cup.
        - It is a negatively charged with respect to the filament.
    - Anode: Positive electrode in the shape of a ring that converges the beam.
- Electromagnetic lens: Consists of Electromagnetic coils that generates electric field to deflect / focus electron beam.
- telescope, vacuum gauge, throttle valve, diffusion pump.
- EBM equipment in construction is similar to electron beam welding machines.

Process Description

- Electron gun emits a pulsed beam of electrons which are diverging initially.
    - DC voltage of about 150kV applied.
    - The cathode filaments get heated to 2500°C to 3000°C.
    - It leads to thermo-ionic emission of electrons.
    - The cathode controls the flow of the electrons.
    - The solidities lies between 5 Ac to 15 Ac.
- Bias grid: The electrons emitted from cathode will directly flow towards the anode.
    - During the flow of the electrodes no diversions are seen.
    - The grid cup is used to operate the gun in pulsed mode only.
- The anode attracts the electrons & accelerates them to a high velocity.
- The beams pass through electromagnetic lens & get focussed suitably.
    - Computers / numerical control is employed for precise control.
    - Spot size is controlled by the degree of focusing of the electromagnetic lenses.
    - the apertures are connected in series.
    - It shapes the electron beam & reduce the diversion factor.
    - The apertures allow the convergent electrons & stop the low energy divergent electrons from the fringes.
- Vacuum is maintained throughout the path of electron beam.
    - A diffusion pump & rotary pump are used to maintain vacuum.
        - Diffusion pump should act as an oil heater.
        - If the oil is heated then the oil vapor rushes upwards.
        - The nozzle changes the direction of the oil vapor & starts moving in the downward direction at high velocity.
        - The oil vapors are reduces in the diffusion pump; this is because of the presence of the cooling water cover.
    - Vacuum prevents collisions of electrons with gas molecules, which would scatter or diffuse the beam
    - It also protects the workpiece from oxidation and other atmospheric contamination.
- Lead shielding is required to protect the operator from X-ray radiation produced by the electron beam.
- there is a series of rotating disc with slots.

    - The disc allows the electron beam to pass over the material for machining,
    - it also prevents the fumes & vapors generated during the machining.
- Work piece is placed on the bench that is CNC controlled for holes or required shape.

Process Variations

Process Parameters

- Voltages range: 150 to 200 kV
- Cathode current: 25 mA to 100 mA.
- Power range: 0.5kW to 60 kW
    - P = CQ
        - P - Power
        - C - specific power consumption.
        - Q - Material removal rate
- Beam intensity: 1.55×10^5 to 1.55×10^9 W/cm ^{2}
- Beam current: Range is 0.1 mA to 1 mA.
    - Increasing the beam current directly increases the energy per pulse.
- Velocity of electrons: about 200,000 km/s (2/3rd of Light!)
- Pulse duration: Range is from 50 µs to 15 ms.
    - Similarly increase in pulse duration also enhances energy per pulse.
- Power density: 6500 x10^9 W/mm^2.
- Formula for thermal velocity of electrons in the beam:
    - $$V = \sqrt{\frac{2 K_B T}{M}}$$
        - Where, K_B= Boltzmann constant
        - M = mass of one atom of work.
        - T = rise in temperature
- A higher energy density, i.e., for a lower spot size, the material removal would be faster though the size of the hole would be smaller.
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Performance Characteristics

- Focus diameter: 10 – 200 µM diameter.
- Material Removal Rate - MRR = A.V
    - A - area of slot hole
    - V - cutting velocity
- Kerf width (Narrowest cut): 0.03 mm
- Max depth of cut: 15 mm
- penetration rates: up to 0.25 mm/s
- Length to diameter ratio: 10.
    - i.e. Hole depth can be 10 times its diameter.
- In the electron discharge machining Cut formation is not observed
- Materials: stainless steel, aluminum, steel, plastics, ceramics etc.
    - Allows machining of brittle & fragile materials.
- Heat affected zone: 25-50µm.
- Compared to the steels, aluminum & titanium is freely machined.
- Holes can be drilled at an angle of 20 to 30

Advantages

- Very small size holes (0.002 inches) can be drilled with high accuracy.
- Compared to other thermal cutting processes, EBM gives
    - better surface finish
    - narrower kerf width
- Highly reactive metals like Al & Mg can be machined very easily.
- Pulse energy can be adjusted for thicker plates & larger holes.
- There is no direct contact hence all tool related problems do not exist.
    - No cutting forces.
    - No tool replacement required.
- No distortions.
- High accuracy & repeatability.
- Complex contours can be easily obtained deflecting electron beam using electromagnets.
- Small spot size (25-50μm) hence negligible HAZ - Heat Affected Zone.
- EBM can be used for very accurate cutting or boring of a wide variety of metals.
- Reverse tapper can also be performed below the surface of the workpiece material.

Disadvantages

- Low MRR compared to conventional machining processes.
- Produces hazardous x-rays,
- Maintaining perfect vacuum is very difficult.
    - Suitable only for small workpieces.
    - Increases the cost for large workpieces.
- The machining process can't be seen by operator.
- Trained professionals are needed to operate.
- Only electrically conducting materials can be machined.
- Very high equipment cost
- Need for secondary backing materials.

Applications

- Used for producing very small size holes like holes in diesel injection nozzles, Air brakes etc.
    - Used only for circular holes.
- Drilling holes in the aircraft engine, nuclear reactor etc.
- We can see small cross sectional area in the wire drawing die-machines.
- Electron beam is used for annealing, welding or metal removal by heating.

Extra points:

- High-energy pulses (in excess of 100 J/pulse) can machine larger holes on thicker plates.
- The energy density & power density is governed by energy per pulse duration & spot size.
- The plane of focusing would be on the surface of the workpiece or just below the surface of the work piece.