Unit - 5

Thermal Energy Based Processes

5.1 Introduction:

- Heat energy is concentrated on a small area of the w/p to melt and vapourise the tiny bits of work mtl. The required shape is obtained by the continued repetition of this process.

Examples:

1) Electron Beam Machining (EBM)
2) Laser Beam Machining (LBM)
3) Plasma Arc Machining (PAM)

5.1 Electron Beam Machining (EBM)

Introduction:

- In EBM process, ~~high~~ a beam of high velocity electrons are focussed on the workpiece to remove the metal. These electrons are travelling at half the velocity of light (ie) 1.6×10^8 m/s. This process is best suited for micro-cutting of materials.

5.1.2 Principle:

When the high velocity beam of electrons strike the workpiece, its kinetic energy is converted into heat. This concentrated heat raises the temperature of workpiece mtl and vapourises a small amount of it, resulting in removal of material from the workpiece.

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5.1.3 Types of EBM Process:

1. Machining inside the vacuum chamber
2. Machining outside the vacuum chamber

5.1.4 Construction and working of EBM (Machining inside Vacuum Chamber)

Construction:

- It consists of electron gun, diaphragm, focusing lens, deflector coil, work table etc...
- In order to avoid collision of accelerated electrons with air molecules, vacuum is required. So, the entire EBM set up is enclosed in a vacuum chamber, which carries vacuum of the order 10^{-5} to 10^{-6} mm of Hg. This chamber carries a door, through which the w/p is placed over the table. The door is then closed and sealed.

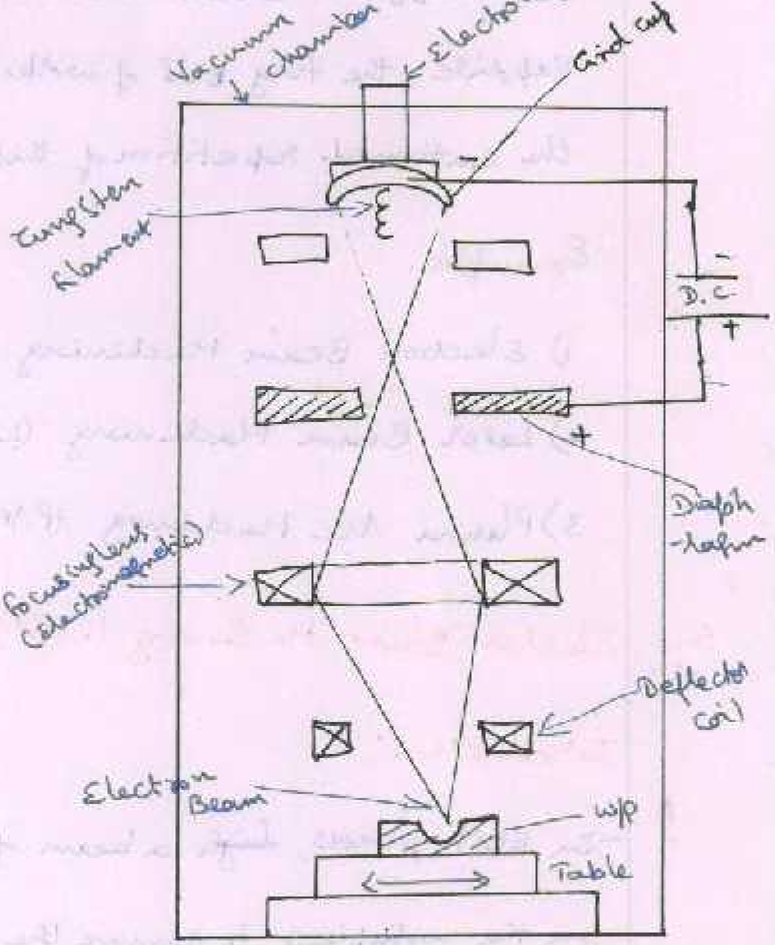

fig. Arrangement of EBM

- The electron gun is responsible for the emission of electrons, which consists of the following 3 parts

1. Tungsten Filament: - connected to the negative terminal of DC power supply and acts as cathode
2. Grid cup - which is negatively biased with respect to filament
3. Anode - connected to the +ve terminal of the DC power supply

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Hg - Mercury

- The focussing lens is used to focus the electrons at a point and reduces the electron beam upto the cross sectional area of 0.01 to 0.02 dia.
- The electromagnetic deflector coil is used to deflect the electron beam to different spot on the w/p. It can also be used to control the path of cut.

Working:

- When high voltage DC source is given to ~~the~~ electron gun, tungsten filament wire gets heated and the temperature raises upto 2500°C
- Due to this high temperature, electrons are emitted from tungsten filament.
- These electrons are directed by grid cup to ~~travel towards~~ travel vertically downwards and they are attracted by anode.
- The electrons passing through the anode are accelerated to achieve high velocity as half the velocity of light by applying 50 to 200 kV at the anode
- The high velocity of these electrons are maintained till they strike the workpiece, since the electrons travel through the vacuum.
- This high velocity electron beam, after leaving the anode, passes through the tungsten diaphragm and then through the electromagnetic focussing lens which is used to focus the electron beam on the
- desired spot of the workpiece
- When the electron beam impacts on the workpiece surface, the kinetic energy of high velocity electrons is ~~immediately~~ immediately converted into heat energy. This high intensity heat melts and vaporises the work material at the spot of beam impact

- Since the power density is very high (about 6500 billion w/mm^2), it takes few micro seconds to melt and vaporise the work material at the spot of beam

- This process is carried out in repeated pulses of short duration. The pulse frequency may range from 1 to 1,6000Hz and duration may range from 4 to 65,000 microseconds
- By alternately focussing and turning off the electron beam, the cutting process can be continued as long as it is needed.
- A suitable viewing device is always incorporated with the m/c, and thus it becomes easy for the observer to observe the progress of machining operation.

5.1.5 Machining outside the vacuum chamber

- Since the fully vacuum system is more costly, the recent development have made it possible to machine outside the vacuum chamber. In this arrangement, the necessary vacuum is maintained within the electron gun and the gases are removed as soon as they enter into the system.

5.1.6 Mechanisms of EBM:

- Electrons are the smallest stable elementary particles with a mass of 9.109×10^{-31} kg with a negative charge of 1.602×10^{-9} coulomb. If it is assumed that the initial velocity of emitting electrons to be negligible then the electron velocity at the striking is given by,

$$V_s = 600\sqrt{E_s} \text{ km/s} \quad \text{------} \rightarrow (1)$$

where E_s – Voltage of the electric field, volt

The power of the electron beam is given by,

$$P_b = E_s I_b ; \text{ Watts} \quad \text{------} \rightarrow (2)$$

where I_b – Beam current, A

The electron beam pressure is given by,

$$F_b = 0.34 \times I_d \sqrt{E_s} \text{, dyne/cm}^2 \quad \text{----} \to (3)$$

where, I_d - Current density, A/cm^2

The thermal velocity acquired by an electron is given by,

$$V_a = \sqrt{\frac{2K\theta}{M_a}} \text{ m/s} \quad \text{--------} \to (4)$$

where, K - Boltzmann's Constant = 1.38×10^{-23} J/K/atom

θ - temperature raised, K

M_a - Mass of one atom of workpiece, Kg

5.1.7 Process Parameters:

The parameters which have significant influence on the beam intensity and MRR are given below.

1. Control of current
2. Control of spot diameter
3. Control of focal distance of magnetic lens

1. Control of current:

- The heated tungsten filament cathode emits electrons depending upon the thermionic emission capability of the filament. It is gn, by Richardson - Dushman equation

$$J = AT^2 e^{-(EW/KT)}$$

where, J - Current density of emitted current (A/cm^2)

A - constant ($120 \; A/cm^2 \cdot degree^2$)

W - Work function of the material of the filament, (V)

T - absolute temperature of the filament (K)

E - electron charge (e-unit)

K - Boltzmann constant (1.3×10^{-23} J/K)

The above mentioned eqn is valid only when the tungsten filament (cathode) is in free space. But the presence of electric field around the filament, alters this current density very much

- The grid bias voltage is used to control the beam current. The more -ve grid with respect to the cathode, the restriction of electron emission will be more.

2. Control of spot diameter.

The diameter of the spot depends upon beam current, accelerating voltage, magnetic lens, distance b/w gun and w/p. The most important three factors which contribute to change in spot diameter are given below,

(i) Effect of Thermal Velocities:

WKT, different electrons converging at different points along the longitudinal axis of the beam. So, the spot size will get spread out and the minimum spot diameter is given by,

$$\delta D_t = \frac{2 r_c}{r_i} \cdot x \cdot \sqrt{\frac{KT}{EV}}$$

where,

δD_t - Minimum spot diameter

r_c - Cathode (tungsten filament) spot radius

r_i - Radius of beam at magnetic lens

x - Distance b/w gun and workpiece

E - Electronic charge

V - Anode Voltage

K - Boltzmann constant (1.3×10^{-23} J/K)

T - Absolute temperature of cathode

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(ii) Spherical deviation of the focusing lens:

The spherical deviation results in the marginal rays causing the axis at a different position from the rays. So, it leads to an ideal point image to be confused in a disc whose diameter is given by,

$$\delta D_s = 2.5\, \alpha_i^3 \left[x / f(S+D)^2 \right]$$

where, S - Lens pole piece separation of the magnetic lens

D - Bore diameter of the magnetic lens

f - focal length of the magnetic lens

(iii) Space charge spreading of target:

The minimum spot size is limited when the electrons converging in a conical beam to a point as the target is subjected to mutual repulsion and the equ is given as,

$$\delta D_c = 11.8 \times 10^4 \times x^{5/2}\, I^{5/4}\, V^{-15/8}\, \alpha_i^{-3/2}$$

3. control at focal distance of magnetic lens:

The focal distance at magnetic lens is given by,

$$\frac{f}{S+D} = \frac{25V}{(NT)^2}$$

where, V - Electron accelerating voltage

NT - Ampere turns in the lens winding

5.1.8. Applications of EBM:

1. EBM is mainly used for micromachining operations on thin materials including drilling, slotting, scribing and perforating

2. Drilling of holes in pressure differential devices used in nuclear reactors, aircraft engines, etc ..

3. It is used for removing small broken taps from holes

4. Micro-drilling operations for thin orifices, dies for wire drawing, parts of electron microscopes, injector nozzles for diesel engines, etc...

5) A micromachining technique known as "Electron beam lithography" is being used in the manufacture of field emission cathodes, I.C. and computer memories

6) It is particularly useful for machining of materials of low thermal conductivity and high melting point

5.1.9 Characteristics of EBM process:

Accelerating Voltage	: 50 to 200 kV
Beam Current	: 100 to 1000 μA
Electron Velocity	: 1.6×10^8 m/s
Power density	: 6500 billion W/mm^2
Medium	: Vacuum (10^{-5} to 10^{-6} mm of Hg)
Workpiece materials	: All materials
Depth of Cut	: upto 6.5 mm
Material Removal Rate	: upto 40 mm^3/s
Specific power consumption	: 0.5 to 50 KW

5.1.10 Advantages of EBM Process:

1. It is an excellent process for micromachining
2. Very small holes can be machined in any type of material to high accuracy
3. Holes of different sizes and shapes can be machined
4. There is no mechanical contact between the tool and workpiece
5. It is a quicker process. Harder materials can also be machined at a faster rate than conventional machining

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6. Electrical conductor materials can be machined
7. The physical and metallurgical damage to the workpiece are very less
8. This process can be easily automated
9. Extremely close tolerances are obtained
10. Brittle and fragile materials can be machined

5.1.10. Disadvantages / Limitations of EBM:

1. The MRR is very low
2. Cost of equipment is very high
3. It is not suitable for large workpieces
4. High skilled operators are required to operate this machine
5. High specific energy consumption
6. A little taper produced on holes
7. Vacuum requirements limits the size of workpiece
8. It is applicable only for thin materials
9. It is not suitable for producing perfectly cylindrical
10. At the spot where the electron beam strikes the material, a small amount of recasting and metal splash can occur on the surface. It has to be removed afterwards by abrasive cleaning

5.2 Laser Beam Machining:

5.2.1 Introduction:

Recent researches in solid state physics have revealed a new device known as 'LASER' which means "Light Amplification by Stimulated Emission of Radiation". It produces a powerful, monochromatic, collimated beam of light in which the waves are coherent.

Like electron beam, the laser beam is also used for drilling microholes upto 25 μm and for cutting very narrow slots, with dimensional accuracy of ±0.025 mm. It is very costly method and can be employed when it is not feasible to machine a w/p through other methods.

5.2.2. Principle of Laser Beam Production:

Laser works on the principle of Quantum theory of radiation.

Consider an atom in the ground state or lower energy state (E_1), when the light radiation falls on the atom, it absorbs a photon of energy $h\nu$ and goes to the exited state E_2.

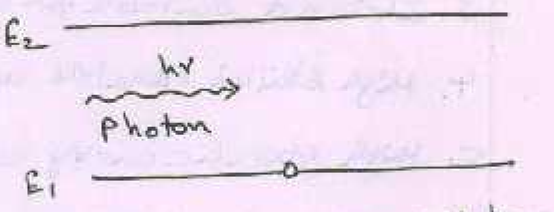

fig (i) Before absorption

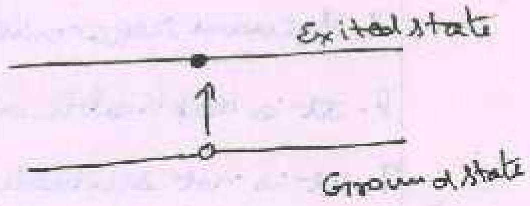

fig (ii) After absorption

Normally, the atoms in the exited state will not stay there for a long time. It comes to the ground state by emitting a photon of energy $E = h\nu$. Such an emission takes place by one of the following two methods

i) Spontaneous Emission:

The atom in the exited state (E_2) returns to the ground state (E_1) by emitting their excess energy ($h\nu$) spontaneously. This process is called as "independent of external radiation".

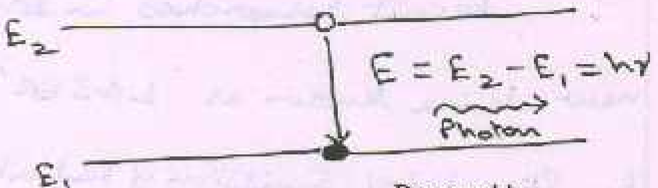

fig Spontaneous Emission

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(c) Stimulated Emission:

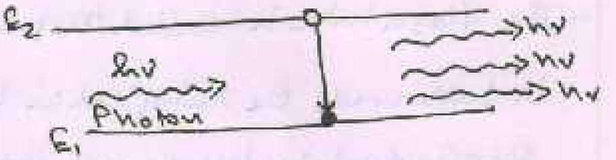

fig Stimulated Emission

In stimulated emission, a photon having energy E_1 equal to the difference in energy between the two levels E_2 and E_1, stimulate an atom in the higher state to make a transition to the lower state with the creation of second photon.

5.2.3. Principle of laser Beam Machining.

In LBM, laser beam (a powerful, monochromatic, collimated beam of light) is focussed on the workpiece by means of lens to give extremely high energy density to melt and vapourise the work material

5.2.4 Construction & working of LBM:

Construction:

There are several types of lasers used for different purposes. eg., Solid state laser, gas laser, liquid laser and semi-conductor laser. In general, only the solid state lasers can provide the required power levels.

- The most commonly used solid state laser is Ruby laser. It is the first successful laser achieved by Maiman in 1960. It consists of ruby rod surrounded by a flash tube
- Synthetic ruby consists of a crystal of Al_2O_3 in which a few of the Aluminium atoms are replaced by chromium atoms. Chromium atoms have the property of absorbing green light
- The end surfaces of the ruby rod is made reflective by mirrors. One end of the ruby rod is highly reflective and the other end is partially reflective

- The flash tube is called the pump and it surrounds the ruby rod in the form of spiral which is filled with noble gases
- Since the ruby rod becomes less efficient at high temperatures, it is continuously cooled with water, air or liquid nitrogen
- Since, the laser beam has no effect on Aluminium, the workpiece to be machined is placed on the Aluminium work table.

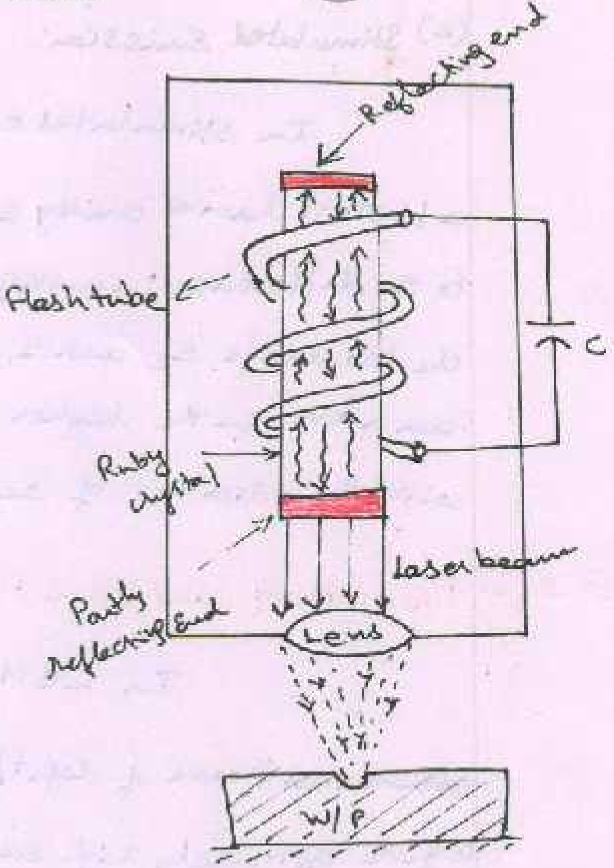

Fig Schematic diagram of LBM

Working:

- The xenon and Argon gas present in the flash tube is fired by discharging a large capacitor through it. The electric power of 250 to 1000 W may be needed for this operation
- This optical energy (ie) light energy from the flash tube is passed into ruby rod
- The chromium atoms in the ruby rod are thus excited to high energy levels. The excited atoms are highly unstable in the higher energy level and it emits energy (photons) when they return to the original levels
- The emitted photons in the axis of ruby rod are allowed to pass back and forth millions of times in the ruby with the help of mirror at two ends. The emitted photons other than the axis will escape out of rod.
- The chain reaction is started and a powerful coherent beam of red light is obtained and it goes out of the partially reflective mirror at one ~~end~~ end of the ruby rod.

- This highly amplified beam of light is focussed through a lens, which converges it to a chosen point on the workpiece
- The high intensity converged laser beam, when falls on the workpiece, melts and vaporises the workpiece material
- The laser head is traversed over the work material by manually adjusting the control board and an operator can visually inspect the machining process.
- The actual profile is obtained from a linked mechanism, made to copy the master drawing of actual profile placed on a nearby bench.

5.2.5 Accuracy.

The laser is used for cutting and drilling. In order to achieve the best possible results in drilling, the material should be placed within a tolerance of ± 0.2 mm focal point.

5.2.6 Lasing Materials:

- Many materials exhibit lasing action. But only a limited number is used in metal working. Solid, gases and semi-conductors can be used as lasing materials.

5.2.7 Solid laser:

- Ruby laser, Neodymium doped Yttrium - Aluminium - Garnet (Nd-YAG) and Neodymium doped glass laser (Nd - glass) are examples of solid state lasers.
- The most commonly used solid state laser is Ruby laser.

5.2.8 Semi conductor laser:

- Lasing action can also be produced in semi-conductors
- It is also called as injection laser.
- In its simplest form, the diode laser consists of a p-n junction doped in a single crystal of a suitable semi conductor Eg: Gallium-Arsenide

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5.2.9 Gas ~~Semiconductor~~ laser:

- The main advantage of gas laser is, it can be operated continuously
- The gas laser produce exceptionally a high monochromaticity and high stability of frequency.
- The output of the laser can be changed to a certain available wavelength which are widely used in industries

Eg: Carbon dioxide (CO_2) laser
Helium-Neon (He-Ne) laser

5.2.10 Processing with laser:

S.NO	Special characteristics of laser beam	Cutting process characteristics
1	It can be focussed to maximum ~~inten~~ intensity or to minimum intensity as needed	Metal removal rate is maximum to minimum
2.	It can be moved rapidly on the w/p	Cutting of complex shapes
3.	It is projected on the w/p at a particular distance from the lens	Remote cutting over long stand-off distances
4.	Dedicated to on-line processes	Re-routing is not necessary
5.	Power is shared on a job	Two or more cuts simultaneously

5.2.11 Machining applications of laser:

Laser in metal cutting:

- Laser beam can be used for cutting metals, plastics, ceramics, textile, cloth and even glass, when its surface is coated with radiation-absorbing material such as carbon
- Normally, it starts by drilling hole through the workpiece, then moving along a pre-determined path of the shape to be cut.

- Steel, Titanium, Nickel and plastics can be cut easily by using laser beam.
- But cutting of Aluminium metal and copper is very difficult, since these metal tends to absorb the applied heat.
- The cutting speed of laser depends on the material being cut, its thickness, physical characteristics and output power of laser beam.
- Laser has an additional advantage in cutting complex shapes with sharp corners and slots.

Laser in drilling:

- The demand for laser drilling is increasing day by day
- Hole drilling by laser is a process of melting and vaporising unwanted mtls. by means of Narrow pulsed laser operating at 3 to 95 pulses/s.
- Due to melting and vaporising, high accuracy is not possible and thus laser drilling is not suited for hole drilling and for producing perfectly cylindrical holes.
- Laser drilling is used in watch jewels, diamond dies and other m/c parts for various industries where a particularly high level of precision is not demanded
- Laser drilling is used widely in aircraft - turbine industry to make holes for air bleeds, air cooling or passage of other fluids.

Laser in welding:

- Here a laser beam is focussed on spot where the two parts are to be welded
- Laser beam welding requires more precise control of the input laser power than in the case of drilling
- Laser welding is especially useful when it is essential to control the size of the heat affected zone, to reduce the roughness of the welded surface and to eliminate mechanical effects. It is generally used for welding multilayer materials

The two types of laser welding are

1) Conduction limited welding

2) Deep penetration welding

Conduction limited welding:

- Here the metal absorbs the laser beam at the work surface, and the area below the surface is heated by conduction
- It is used for welding thin components

Deep penetration welding.

- Here, the metal absorbs the laser beam from top to bottom of the surface
- Thermal conduction doesnot limit the penetration
- This type of welding require greater power and the CO_2 laser is used for the purpose

Basic requirements for laser welding:

1. The focus of the beam should be adjusted to the thickness of mtl.
2. The wavelength of the laser beam must be compatible with the mtl. being welded
3. Pulse waves are normally better than continuous waves
4. A pulse shape of the laser beam should be controlled precisely from weld to weld.

- Many metals and alloys can be welded easily using laser.

Some of the most readily processed mtls are,

low carbon steel
stainless steel
titanium
Zirconium
Silicon bronze

- The two surfaces being welded should remain in close contact with each other. Since, filler mtl is not used in laser welding, there should not be any gap in the joint
- The advantage of laser weld is the elimination of grinding from the entire process

Laser for surface treatment:

Gears, saw teeth, valve seat pads and cylinder lines can be strengthened by using laser beam. The laser is used to deposit a thin layer of cobalt alloy on the turbine blade should contact areas.

- Argon gas is used for shielding during deposition of cobalt alloy and for cooling purposes.
- By using laser, a thin ceramic coating is applied on metal surface for heat and wear resistance.
- Laser can also be used to seal microcracks which are usually present in hard - chromium electroplates

Other Applications:

Other applications include sheet metal trimming, blanking and resistor trimming. Since LBM is not a mass material removal process, it is used in mass micromachining production

5.2.12 Advantages of LBM:

1. Machining of any mtl. including non-metal is possible
2. Micro-sized holes can be machined
3. Soft mtls. like rubber & plastics can be machined
4. There is no tool wear
5. There is no direct contact b/w tool and w/p.
6. Dissimilar mtls can be easily welded

7. Laser can be sent to a long distance without diffraction and thus it can be focussed @ one point thereby generating large amount of heat
8. Process can be easily automated
9. Hardness of the mtl. doesn't affect the process
10. Heat affected zone is small around the machined surface
11. Beam configuration and size of exposed area can be easily controlled
12. Deep holes of very short diameter can be drilled by using unidirectional multiple pulses.

5.2.13 Characteristics of LBM

Material removal technique : Heating, melting & vaporisation of mtl. by using high intensity of laser beam

Work material : All mtls except those having high thermal conductivity and high reflectivity

Tool : Laser beam in wavelength range of 0.3 to 0.6 μm

Power density : Maximum 10^7 W/mm²

O/P energy of laser : 20 J

Pulse duration : one millisecond

MRR : 6 mm³/min

Dimensional accuracy : ±0.025 mm

Medium : atmosphere

Specific power consumption : 1000 W/mm³/min

Efficiency : 10 to 15 %

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5.2.14 Disadvantages / Limitations of LBM:

1. Initial investment is high
2. Operating cost is also quite high
3. Highly skilled operators are needed
4. Rate of production is low
5. Possibility of machining only thin sections and where are a very small amount of metal removal is involved
6. Safety procedures to be followed strictly
7. overall efficiency is extremely low (10 to 15 %)
8. Life of flash lamp is short
9. The machined hole is not round and straight
10. Some materials like fibre glass, reinforced mtl, phenolics etc.., cannot be machined by laser as these mtls. burn, char and bubble.

5.3 Plasma Arc Machining (PAM) [or] Plasma Jet Machining (PJM)

5.3.1 Introduction:

- Solids, liquids and gases are the three familiar state of matter. In general when solid is heated, it turns to liquid and the liquid eventually becomes gas.
- when a gas is heated further to high temperature, the atoms are split into free electrons and ions. The dynamical properties of this gas of free electrons and ions are sufficiently different from the normal unionized gas.
- So, it can be considered considered a fourth state of matter, and is given a new name 'PLASMA'.
- If the gas, or a gas, following gas is heated to a sufficiently high temperature of the order of 11000°c to 28000°c, it becomes

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partially ionised and it is known as PLASMA.

- This is a mixture of free electrons, positively charged ions and neutral atoms and this is used for metal removing process
- PAM process is used for cutting alloy steels, stainless steel, cast iron, copper, Nickel, titanium and Aluminium.

5.3.2 Working principle

In PAM process, material is removed by directing a high velocity jet of high temperature [11,000°C to 28,000°C] ionized gas on the w/P. This high temperature plasma jet melts the mtl. from the workpiece.

5.3.3 Construction and Working of PAM

Construction:

- The plasma arc cutting torch carries a tungsten electrode fitted in a small chamber
- This electrode is connected to the negative terminal of a D.C. power supply and thus it acts as cathode
- The +ve terminal of a D.C. power supply is connected to the nozzle formed near the bottom of the chamber and thus it acts as anode.
- A small passage is provided on one side of the torch for supplying gas into the chamber
- Since there is a water circulation around the torch, the electrode and the nozzle remains water cooled

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Unconventional Machining Processes

Working:

- when a D.C. power is given to the circuit, a strong arc is produced b/w the electrode (cathode) and the nozzle (anode)

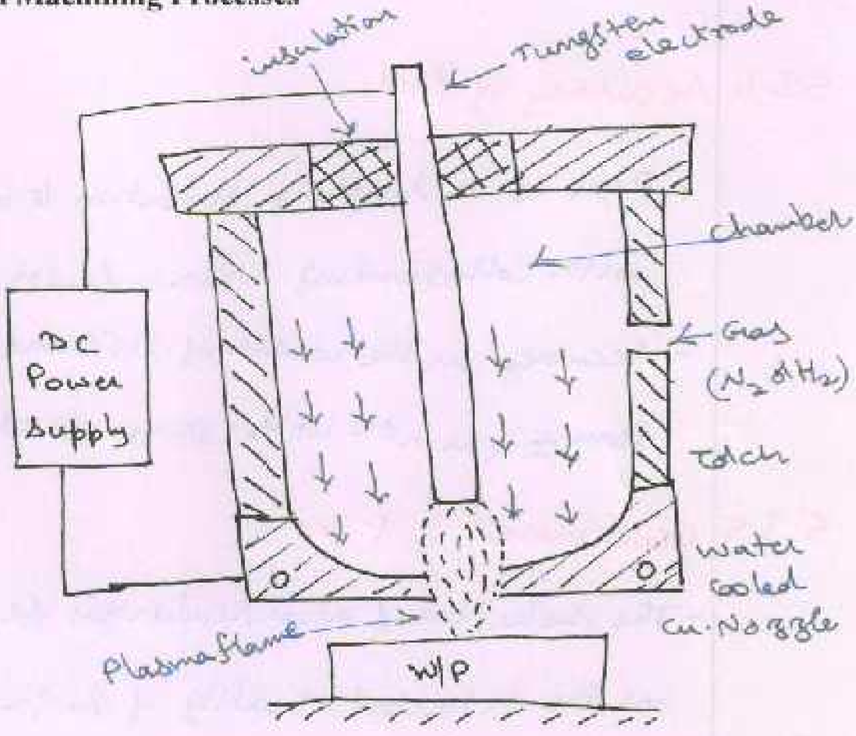

fig Schematic arrangement of PAM

- A gas usually hydrogen (H_2) or Nitrogen (N_2) is passed into the chamber
- This gas is heated to a sufficiently high temperature of the order of 11,000°c to 28000°c by using an electric arc produced b/w the electrode and Nozzle
- @ this temperature, the gases are ionised and large amount of thermal energy is liberated
- This high velocity and high temperature ionised gas (plasma) is directed on the workpiece surface through nozzle.
- This plasma jet melts the metal of the workpiece and the high velocity gas stream effectively blows the molten metal away.
- The heating of w/p mtl. is not due to any chemical reaction, but due to the continuous attack of plasma on the w/p mtl.
- So, it can be safely used for machining of any metal including those which can be subjected to chemical reaction

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5.3.4 Accuracy of PAM:

- PAM is a roughing operation to an accuracy of around 1.4 mm with corresponding surface finish.
- Accuracy on the width of slots and diameter of holes is ordinarily from ± 4 mm on 100 to 150 mm thick plates.

5.3.5 Gases used in PAM:

- The selection of a particular gas for use in this process mainly depends on the expected quality of surface finish on the work mtl. and economic consideration.
- The gases used in this process, should not affect the electrode or w/p to be machined
- The commonly used gases & gas mixtures are listed in table below

S.No	Gas or Gas Mixture	Material to be machined
1	Nitrogen - Hydrogen, Argon - Hydrogen	Stainless steel, Nonferrous mtls.
2	Nitrogen - Hydrogen, compressed air	Carbon & alloy steels, Cast iron
3	Nitrogen, Nitrogen - Hydrogen, Argon - Hydrogen	Aluminium, Magnesium

5.3.6 Types of Plasma arc torches (PLASMATRON)

There are two types of Plasma arc torches. They are

1) Direct arc plasma torches (or) Transferred arc types

2) Indirect arc plasma torches (or) Non-transferred arc type

Direct arc plasma torches:

In direct arc plasma torches, electrode is connected to the -ve terminal (cathode) of a D.C. power supply and w/p is connected to the +ve terminal (anode) of a D.C. power supply. So, more electrical energy is transferred to work, thus giving more heat to work piece.

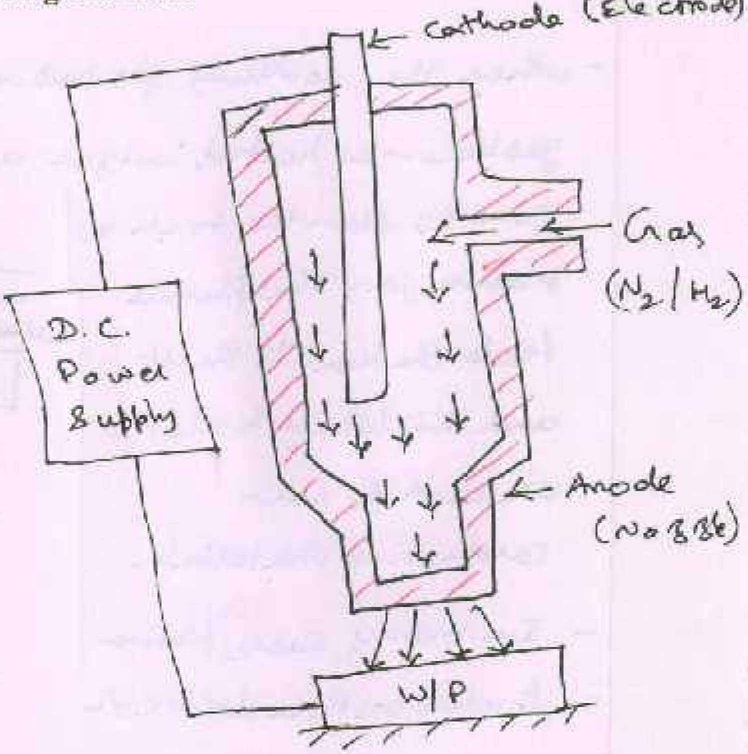

fig Direct arc plasma torch.

- Since it is difficult to strike an arc b/w the electrode and w/p directly through the narrow torch passage, first an auxillary arc is commonly produced b/w the electrode and nozzle.
- when the flame reaches the w/p, it automatically strikes the main arc b/w the electrode and the w/p and the auxillary arc is switched off
- Direct arc torches has higher efficiency and this type of arc is preferred for cutting, welding, depositing etc...

Indirect arc plasma torches

Here, the electrode is connected to -ve terminal (cathode) of a D.C. power supply and nozzle is connected to +ve terminal (anode) of a D.C. supply.

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- when the working gas passing through the nozzle, a part of the working gas becomes heated, ionized and emerges from the torch as plasma jet. This plasma feeds the heat to the w/p and this type of torches are used for non-conducting materials.

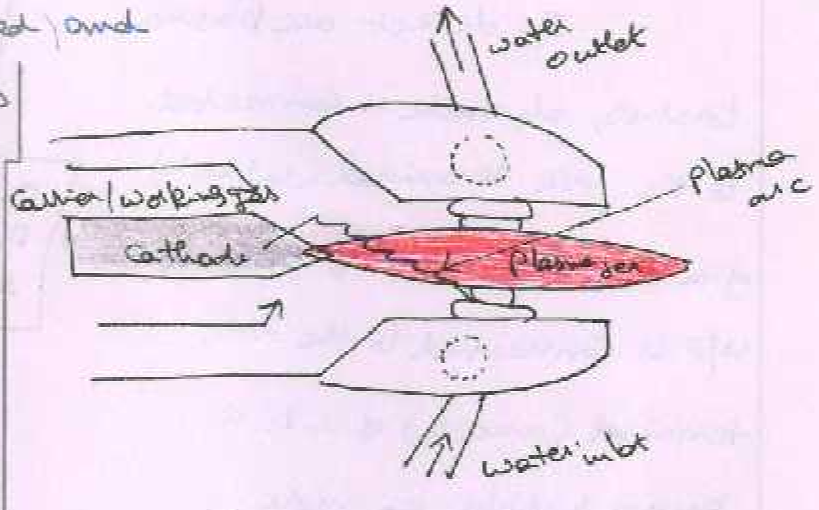

fig Indirect arc plasma torch

- In many cases, plasma torches with a double or combined gas flow are used for welding and cutting. Primary & secondary gases can differ in the designation, composition & flow rate.
- In cutting process the primary gas (inert gas) protects the tungsten electrode from the environment.
- The secondary gas (active gas) is used for forming plasma

5.3.7 Characteristics of PAM:

Metal Removal Technique	: Heating, melting and vaporising by using plasma
Work material	: All metals which conduct electricity
Tool	: Plasma jet
Velocity of Plasma jet	: 500 m/s
Power range	: 2 to 220 KW
Current	: As high as 600 amp
Voltage	: 40 to 280 V
Cutting speed	: 0.1 to 7 m/min
Metal Removal Rate	: 145 cm^3/min

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5.3.8 Stand off distance

- It is the distance b/w nozzle tip & w/p. When the stand off distance increases, the depth of penetration is reduced
- Also, with an excessive reduction of the stand off distance, the plasma torch can be damaged by the metal spatter.
- The optimum stand of distance depends on the thickness of metal being machined and varies from 6 to 10 mm.

5.3.9 Factors affecting the cutting process (or) Process Parameters of PAM:

- MRR depends on thermophysical and metallurgical properties of plasma forming gases like argon, Nitrogen, hydrogen and oxygen
- Since, hydrogen has high heat conductivity, it is possible to achieve the best conditions for the transfer of plasma power to metal. Due to high cutting speed of H_2, smooth surface is obtained
- H_2 containing mixtures are used for cutting thick, high alloy steel plates and good heat conductors such as Cu and Al.
- Gas mixture containing H_2 & Argon (maximum of 20%) is allowed for forming plasma to protect the tungsten electrode from the environment.
- But the protection is not sufficiently reliable, since even the small deviation on the column from the axis of the nozzle causes the damage of tungsten electrode. Besides, Argon is a scare and expensive gas.
- Carbon and alloy steels, Cast iron, Stainless Steel and Aluminium are machined by using N_2. The quality of plasma machining by using N_2 is poor and the cutting speed is considerably less compared to hydrogen containing gases
- Air plasma is simplest and most economical method for machining.
- The air contains N_2 & O_2 and its heat conductivity is less than that of H_2.
- The speed of cutting steels with the air plasma is 1.5 to 2 times greater than the use of N_2 as the cutting gas.
- Non-ferrous alloys can be machined by using air plasma but the quality of surface finish is bad.

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SS - Stainless Steel
H_2 - Hydrogen
N_2 - Nitrogen
O_2 - Oxygen
Ar - Argon

Unconventional Machining Processes

5.3.10 Applications of PAM:

- used to cut alloy steels, SS, Cast iron, Cu, Ni, Titanium, Al & alloy of Cu & Ni
- used for profile cutting
- successfully used for turning and milling of hard to machine materials
- It can be used for stack cutting, shape cutting, piercing and underwater cutting
- Uniform thin film spraying of refractory mtls. on different metals, plastics, ceramics is also done by plasma arcs.

5.3.11 Advantages of PAM:

- Can be used to cut any metal
- cutting rate is high
- As compared to ordinary flame cutting process, it can cut plain carbon steel four times faster
- It is used for rough turning of very difficult mtls.
- Due to high speed cutting, the deformation of sheet metal is reduced while the width of the cut is minimum and the surface quality is high.

5.3.12 Disadvantages of PAM

- It produces tapered Surface
- Protection of noise is necessary
- Equipment cost is high
- Protection of eyes is necessary for the ~~operator and those~~ operator and persons working in nearby areas
- oxidation & scale formation takes place so it requires shielding
- work surface may undergo metallurgical changes.

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