UNIT-V
THERMAL ENERGY BASED PROCESSES
PART - A (2 MARKS)

1.Name the beam control techniques of EBM.

The following are the beam control techniques in EBM,

- Electromagnetic focusing
- Electro static focusing

2.What is meant by Laser beam drilling?

In laser beam drilling process, laser beam is focused on the work piece by means of lens to give extremely high energy density to melt and vaporize the work piece to make drilling process.

3.Contrast LBM and EBM.

In laser beam machining process, laser beam is focused on the work piece by means of lens to give extremely high energy density to melt and vaporize the work material.

In EBM the high velocity beam of electrons strikes the work piece, its kinetic energy is converted into heat. This concentrated heat raises the temperature of work material and vaporizes a small amount of it, resulting in removal of metal from the work piece.

4.Write the advantages of PAM?

The following are the advantages of PAM,

- It can be used to cut any type of metal
- Cutting rate is high
- As compared to ordinary flame cutting process, it can cut plain carbon steel four times faster.

5.What is meant by Transferred type Plasma Arc Machining process?

In transferred arc type process, electrode is connected to the negative terminal of the D.C. power supply and work piece is connected to the positive terminal of a D.C. power supply. So more electrical energy is transferred to the work, thus giving more heat to the work.

6.What are the limitations of EBM?

- The metal removal rate is very slow.
- It is not suitable for large work pieces.
- Cost of equipment is very high.
- A little taper produced on holes.
- It is applicable only for thin materials.

7.What is the acronym of LASER?

Light Amplification by Stimulated Emission of Radiation is known as LASER. IT is an electromagnetic radiation. It produces a powerful, monochromatic, collimated beam of light in which the waves are coherent.

8.List any two gases used in plasma arc machining?

The commonly used gases in PAM are,

- nitrogen,
- hydrogen,
- Air, mixture of nitrogen-hydrogen and argon-hydrogen, etc.

9.What are the principles of LBM?

In laser beam machining process, laser beam is focused on the work piece by means of lens to give extremely high energy density to melt and vaporized the work material.

10. What is the purpose of vacuum chamber in EBM process?

a. To avoid collision of accelerated electrons with air molecules.
b. Protect the cathode from chemical contamination and heat losses.
c. The possibility of an arc discharge between the electrons is prevented.

11. Define Electron Beam.

It is the thermo-electrical material removal process on which the material is removed by the high velocity electron beam emitted from the tungsten filament made to impinge on the work surface, where kinetic energy of the beam is transferred to the work piece material, producing intense heat, which makes the material to melt or vaporize it locally.

12. Contrast LBM and EBM.

In chemical machining process, material is removed from the work piece through a controlled etching or chemical attack of the work piece material.

It carries current between the tool and the work piece. It cools the cutting zone which becomes hot due to the flow of high current.

13. State the characteristics of laser beam.

a. Special Characteristics of laser beam:
   (i) It can be focused to maximum intensity or to minimum intensity as needed.
   (ii) It can be moved rapidly on the work piece.
b. Cutting process characteristics:
   (i) Metal removal rate is maximum to minimum.
   (ii) Cutting of complex shapes.

14. What are the parameters that govern the performance of plasma arc machining?

- Rate of gas flow.
- Current density.
- Stand-off distance.
- Thermal conductivity of work.

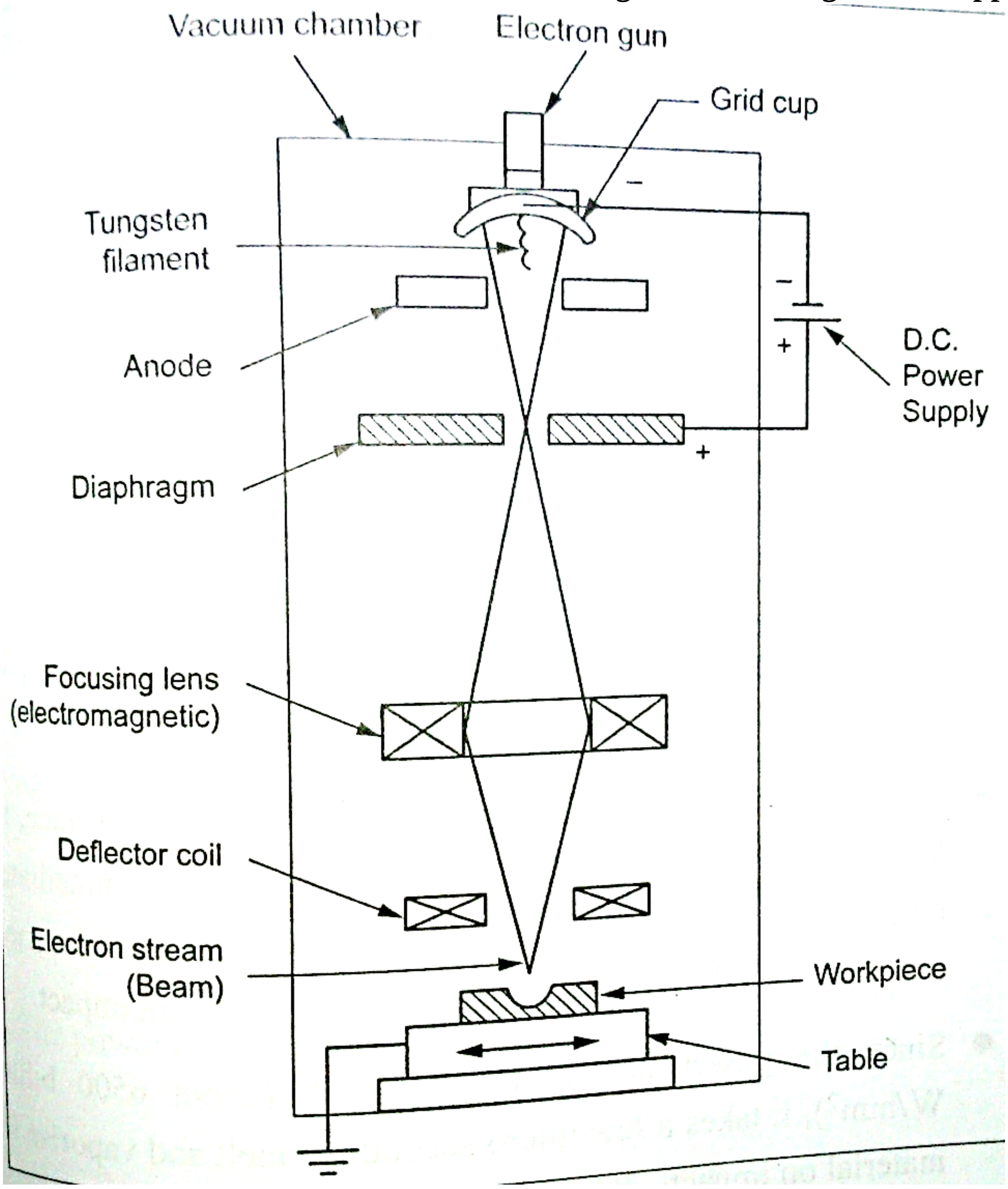
15. How EBM is different from PAM?

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

In plasma arc machining process, material is removed by directing a high velocity jet of high temperature ($11{,}000^0$c to $28{,}000^0$c) ionized gas on the work piece. This high temperature plasma jet melts the material of the work piece.

PART –B (16 MARKS)

1. **Explain the principle, construction and working of Electron beam machining (EBM) with a neat sketch. Also, State some of the advantages, disadvantage and its application.**



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 material and vaporises a small amount of it, resulting in removal of material from the workpiece.

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 setup is enclosed in a vacuum chamber, which carries vacuum of the order 10^{-5} to 10^{-6} mm of mercury. This chamber carries a door, through which the workpiece is placed over the table. The door is then closed and sealed.
- The electron gun is responsible for the emission of electrons, which consists of the following three main parts.
  1. *Tungsten Filament* – which is connected to the negative terminal of the DC power supply and acts as cathode.
  2. *Grid cup* – which is negatively based with respect to the filament.
  3. *Anode* – which is connected to positive terminal of the DC power supply.
- The focusing 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 mm diameter.
- The electromagnetic deflector coil is used to deflect the electron beam to different spot on the workpiece. It can also be used to control the path of the cut.

Working:

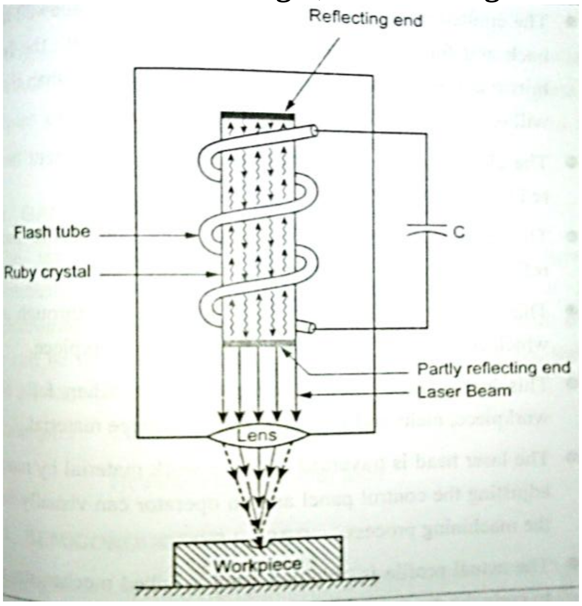
- When the high voltage DC source is given to the electron gun, tungsten filament wire gets heated and the temperature raises upto 2500°C.

- Due to this high temperature, electrons are emitted from tungsten filament. These electrons are directed by grid cup to travel towards 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 (*i.e.*, 1.6×10^8 m / s) by applying 50 to 200 kV at the anode.
- The high velocity of these electrons are maintained till they strike the workpiece. It becomes possible because 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 focusing lens.
- Focusing lens are 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 converted into the 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 a few micro seconds to melt and vaporise the material on impact.
- This process is carried out in repeated pulses of short duration. The pulse frequency may range from 1 to 16,000 Hz and duration may range from 4 to 65,000 microseconds.
- By alternately focusing 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 machine. So, it becomes easy for the operator to observe the progress of machining operation.

Machining outside the vacuum:

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.

2. Explain the principle, construction and working of Laser beam machining (LBM) with a neat sketch. Also, State some of the advantages, disadvantage and its application.



Principle:

In laser beam machining process, laser beam (a powerful, monochromatic, collimated beam of light) is focused on the workpiece by means of lens to give extremely high energy density to melt and vaporise the work material.

Construction:

- There are several types of lasers used for different purposes. *e.g.*, 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 aluminium oxide in which a few of the aluminium atoms are replaced by chromium atoms. Chromium atoms have the property of absorbing green

- 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 as shown in Fig.5.5. This tube is filled with xenon, argon or krypton gas.
- 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.

Working:

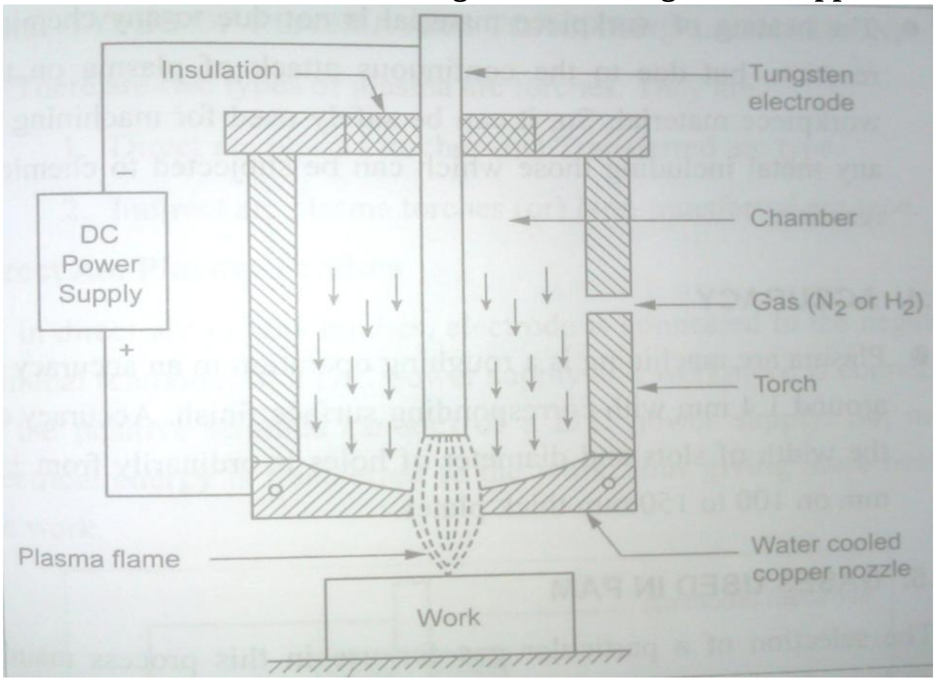
- The xenon or argon gas present in the flash tube is fired by discharging a large capacitor through it. The electric power of 250 to 1000 watts may be needed for this operation.
- This optical energy *i.e.*, light energy from the flash tube is passed into the ruby rod.
- The chromium atoms in the ruby rod are thus excited to high energy levels. The excited atoms are highly unstable in the higher energy levels 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 the 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.
- This powerful beam of red light goes out of the partially reflective mirror at one end of the ruby rod.
- This highly amplified beam of light is focused through a lens, which converges it to a chosen point on the workpiece.
- This high intensity converged laser beam, when falls on the workpiece, melts and vapourise the workpiece material.
- The laser head is traversed over the work material by manually adjusting the control panel and an operator can visually inspect the machining process.
- The actual profile is obtained from a linked mechanism, made to copy the master drawing or actual profile placed on a near-by bench.

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.

3. Explain the principle, construction and working of Plasma arc machining (PAM) with a neat sketch. Also, State some of the advantages, disadvantage and its application.



Principle:

In plasma arc machining process, material is removed by directing a high velocity jet of high temperature (11,000°C to 28,000°C) ionized gas on the workpiece. This high temperature plasma jet melts the material of the workpiece.

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 DC power supply. So it acts as a cathode.
- The positive terminal of a D.C power supply is connected to the nozzle formed near the bottom of the chamber. So, nozzle act as an 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.

Working:

- When a D.C power is given to the circuit, a strong arc is produced between the electrode (cathode) and the nozzle (anode).
- 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 28,000°C by using an electric arc produced between the electrode and the nozzle.
- In this high temperature, the gases are ionized and large amount of thermal energy is liberated.
- This high velocity and high temperature ionized 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 workpiece material is not due to any chemical reaction, but due to the continuous attack of plasma on the workpiece material. So, it can be safely used for machining of any metal including those which can be subjected to chemical reaction.

Accuracy:

- Plasma arc machining 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.

Plasma Arc Machining (PAM):

Plasma-arc machining (PAM) employs a high-velocity jet of high-temperature gas to melt and displace material in its path called PAM, this is a method of cutting metal with a plasma-arc, or tungsten inert-gas-arc, torch. The torch produces a high velocity jet of high-temperature ionized gas called plasma that cuts by melting and removing material from the work piece. Temperatures in the plasma zone range from 20,000° to 50,000° F (11,000° to 28,000° C). It is used as an alternative to oxyfuel-gas cutting, employing an electric arc at very high temperatures to melt and vaporize the metal.

Equipment:

A plasma arc cutting torch has four components:

1. The electrode carries the negative charge from the power supply.
2. The swirl ring spins the plasma gas to create a swirling flow pattern.
3. The nozzle constricts the gas flow and increases the arc energy density.
4. The shield channels the flow of shielding gas and protects the nozzle from metal spatter.

Principle of operation:

PAM is a thermal cutting process that uses a constricted jet of high-temperature plasma gas to melt and separate metal. The plasma arc is formed between a negatively charged electrode inside the torch and a positively charged work piece. Heat from the transferred arc rapidly melts the metal, and the high-velocity gas jet expels the molten material from the cut.

4. i) Explain the process parameters 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 material	:	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

ii) List out its advantages, disadvantages and application of EBM process.

Advantages:

Electron beam machining has the following advantages :

1. It is an excellent process for microfinishing (milligram / s).
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.
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.

Disadvantages:

1. The metal removal rate is very slow.
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. 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.
10. It is not suitable for producing perfectly cylindrical deep holes.

Applications:

1. EBM is mainly used for micro-machining operations on thin materials. These operations include drilling perforating, slotting, and scribing, *etc*.
2. Drilling of holes in pressure differential devices used in nuclear reactors, air craft engines, *etc*.
3. It is used for removing small broken taps from holes.
4. Micro-drilling operations (upto 0.002 mm) 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, integrated circuits and computer memories.
6. It is particularly useful for machining of materials of low thermal conductivity and high melting point.

5. What are the various machining applications of laser?

A laser has a wide range of machining applications.

Laser in Metal Cutting

A 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, laser cutting starts by drilling a 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 the laser depend on the material being cut, its thickness, physical characteristics and the output power of the laser beam. Laser has an additional advantage in cutting complex shapes with sharp corners and slots.

Laser in Drilling

Laser drilling was one of the first practical applications of laser technology in industry and the demand for laser drilling is increasing.

Hole drilling by laser is a process of melting and vaporising unwanted materials by means of narrow pulsed laser operating at 3 to 95 pulses/s. Due to melting and vaporization process, high accuracy is not possible in laser drilling. So, laser drilling is not suited for deep hole drilling and for producing perfectly cylindrical holes.

Laser drilling is used in watch jewels, diamond dies and other machine parts for various industries where a particularly high level of precision is not demanded.

Laser drilling is used in aircraft-turbine industry to make holes for air bleeds, air cooling or the passage of other fluids. It is also used for making holes in hypodermic needles, automotive fuel plates, various lubrication devices, holes in tungsten-carbide tool plate, holes in baby bottle nipples, relief holes in pressure plugs, *etc.*

Laser in Welding

In this process, a laser beam is focused 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.

There are two different types of laser welding. They are :

1. Conduction limited welding.
2. Deep penetration welding.

Conduction Limited Welding

In this method, 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

In this method, the metal absorbs the laser beam from top to bottom of the work surface. Thermal conduction does not limit the penetration. This type of welding require greater power and the CO_2 laser is used for this purpose.

Basic Requirements for Laser Welding

1. The focus of the beam should be adjusted to the thickness of the material.
2. The wavelength of the laser beam must be compatible with the material 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 laser welded. Some of the most readily processed are : low carbon steel, stainless steel, titanium, zirconium, silicon bronze and some nickel alloys.

One of the major factor for laser welding is the proper joint preparation. The two surfaces being welded should remain in close contact with each other. Since filler material is not used in laser welding, there should not be any gap in the joint.

The advantage of the laser weld is the elimination of grinding from the entire process. In conventional welding process, electron beam welding process and plasma welding process excess filler material is removed by grinding.

Laser for Surface Treatment

Gears, saw teeth, valve wear pads, and cylinder liners can be strengthened by using laser beam. The laser is used to deposit a thin layer of cobalt alloy on the turbine blade shroud-contact areas. Argon gas is used for shielding during deposition of the cobalt alloy and for cooling purposes. By using laser, a thin ceramic coatings 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 steel metal trimming, blanking and resistor trimming. Since laser beam machining is not a mass material removal process, it is used in mass micromachining production.

6. i) Explain the characteristics of Laser beam machining process.

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

Work material : All materials 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/mm^2.

Output energy of laser : 20 J

Pulse duration : One millisecond.

Material removal rate : 6 mm^3/min

Dimensional accuracy : ± 0.025 mm

Medium : Atmosphere

Specific power consumption : 1000 W/mm^3/min

Efficiency : 10 to 15%

ii) List out its advantages, disadvantages and application of LBM process.

Advantages:

1. Machining of any material including non-metal is possible.
2. Micro-sized holes can be machined.
3. Soft materials like rubber and plastics can be machined.
4. Unlike conventional machining, there is no direct contact between tool and workpiece.
5. There is no tool wear.
6. Laser beam can be sent to long distance without diffraction. It can also be focused at one point thereby generating large amount of heat.
7. Process can be easily automated.
8. Hardness of the material does not affect the process.
9. Dissimilar materials can be easily welded.
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.

Disadvantages:

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 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. Some materials like fibre glass, reinforced material, phenolics, *etc.*, cannot be machined by laser as these materials burn, char and bubble.
9. Life of flash lamp is short.
10. The machined hole is not round and straight.

Applications:

Refer Question No.5

7. i) Explain the process parameters of PAM process.

PROCESS PARAMETERS OF PAM

The metal removal rate mainly depends on thermo-physical and metallurgical properties of the plasma-forming gases. The most commonly used gases are 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 the metal. Due to high cutting speed of hydrogen, smooth surface is obtained. Hydrogen containing mixtures are used for cutting thick, high alloy steel plates and good heat conductors such as copper and aluminium.

Gas mixture containing hydrogen and argon (Maximum of 20%) is also used for forming plasma. Argon gas is used 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 nitrogen. The quality of plasma machining by using nitrogen is poor and the cutting speed is considerably less compared to hydrogen-containing gases.

Air plasma is simplest and most economical method for machining. Air contains nitrogen and oxygen. The heat conductivity of air is higher than that of hydrogen. The speed of cutting steels with the air plasma is 1.5 to 2 times greater than the use of nitrogen as the cutting gas. Non-ferrous alloys can be machined by using air plasma. But the quality of the surface finish is poor.

5.3.8. STAND OFF DISTANCE

Stand-off distance is the distance between the nozzle tip and workpiece. When the stand-off distance increases, depth of penetration is reduced. With an excessive reduction of the stand-off distance, the plasma torch can be damaged by the metal spatter. The optimum stand-off distance depends on the thickness of the metal being machined and varies from 6 to 10 mm.

ii) List out its advantages, disadvantages and application of PAM process.

Advantages:

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

Disadvantages:

1. It produces tapered surface.
2. Protection of noise is necessary.
3. Equipment cost is high.
4. Protection of eyes is necessary for the operator and persons working in nearby areas.
5. Oxidation and scale formation takes place. So, it requires shielding.
6. Work surface may undergo metallurgical changes.

Applications:

1. It is used for cutting alloy steels, stainless steel, cast iron, copper, nickel, titanium, aluminium and alloy of copper and nickel, *etc.*
2. It is used for profile cutting.
3. It is successfully used for turning and milling of hard to machine materials.
4. It can be used for stack cutting, shape cutting, piercing and underwater cutting.
5. Uniform thin film spraying of refractory materials on different metals, plastics, ceramics is also done by plasma arcs.

8. i) Explain the principle of laser beam production.

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 o energy $h\nu$ and goes to the excited state (E_2).

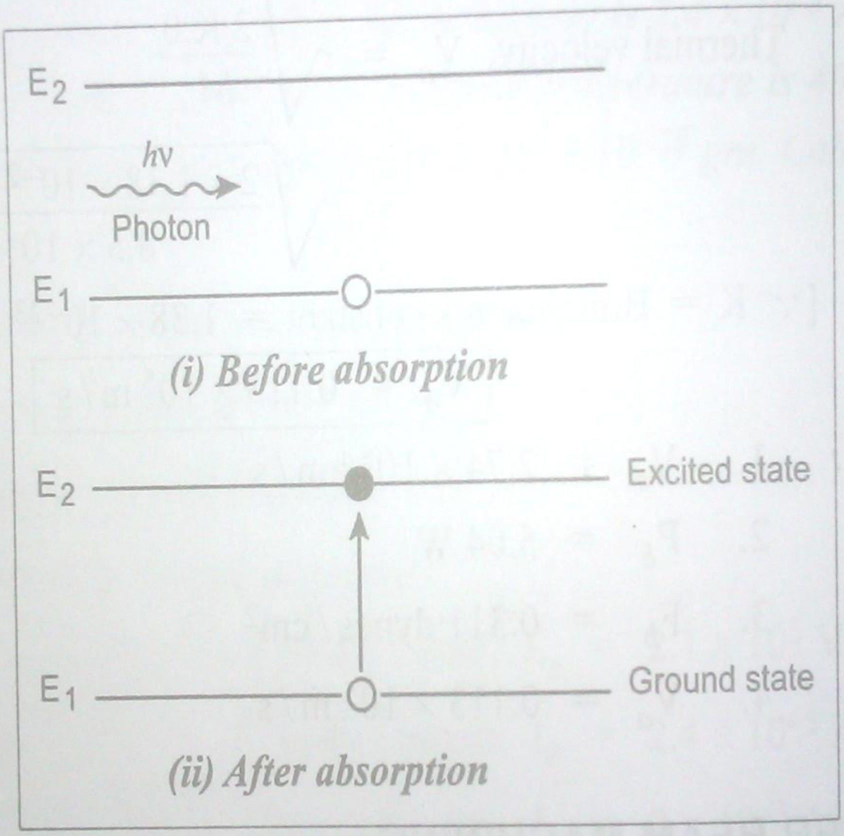


Fig. 5.2.

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

(1) Spontaneous Emission

The atom in the excited state (E_2) returns to the ground state (E_1) by emitting their excess energy ($h\nu$) spontaneously. This process is independent of external radiation. It is shown in Fig.5.3.

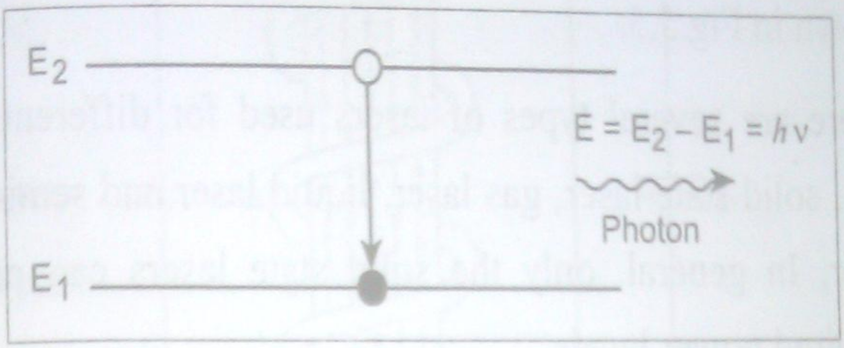


Fig. 5.3. Spontaneous emission

(2) Stimulated Emission

In stimulated emission, a photon having energy E, 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 as shown in Fig.5.4.

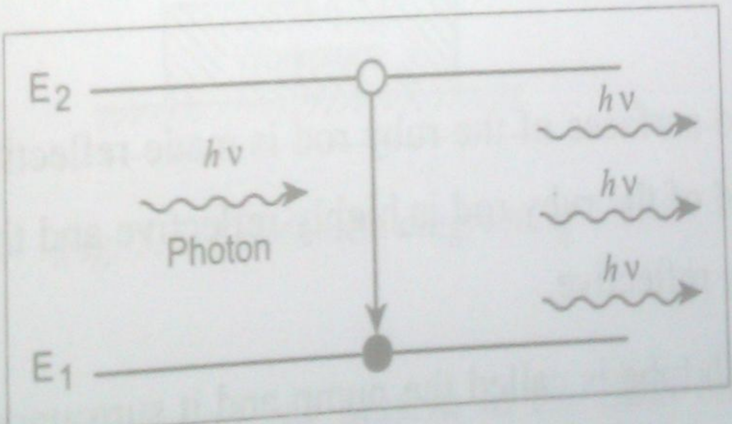


Fig. 5.4. Stimulated emission

ii) Write short notes on the following.

a. Lasing materials
b. Solid state laser
c. Gas laser
d. Semiconductor laser

a. Lasing materials

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

b. Solid state laser

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

c. Gas 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. So, the gas lasers are widely used in industries.

Examples : Carbon dioxide (CO_2) laser

Helium-Neon (He-Ne) laser

d. Semiconductor laser

Lasing action can also be produced in semi-conductors. The most compact type of laser is semiconductor laser. It is also known 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.

Example : Gallium-arsenide.

9. Explain the two types of Plasma arc machining (PAM) with a neat sketch. List out the advantages, disadvantages and application of PAM Process.

Types of Plasma arc machining (PAM)

There are two types of plasma arc torches. They are,

1. Direct arc plasma torches (or) Transferred arc type.
2. Indirect arc plasma torches (or) Non-transferred arc type.

Direct Arc Plasma Torches

In direct arc plasma torches, electrode is connected to the negative terminal (cathode) of a D.C power supply and workpiece is connected to the positive terminal (anode) of a D.C power supply. So, more electrical energy is transferred to the work, thus giving more heat to the work.

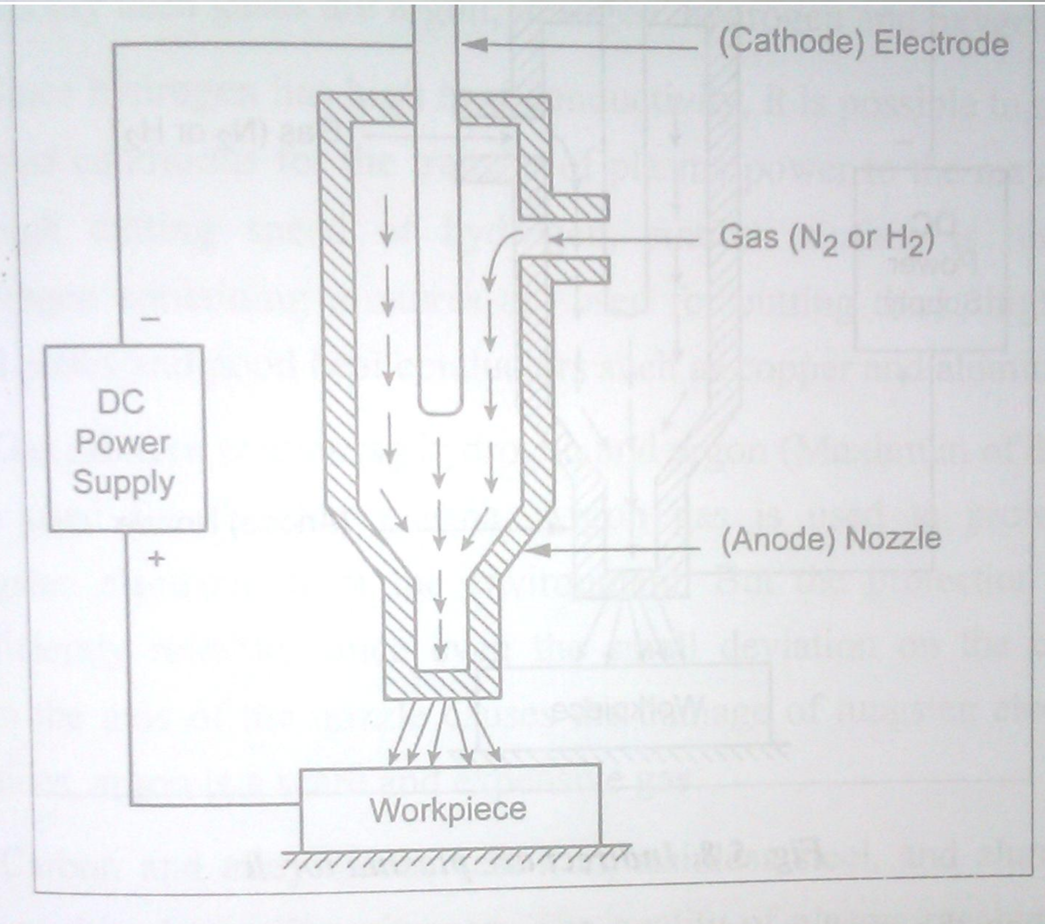


Fig. 5.7. Direct arc plasma torch

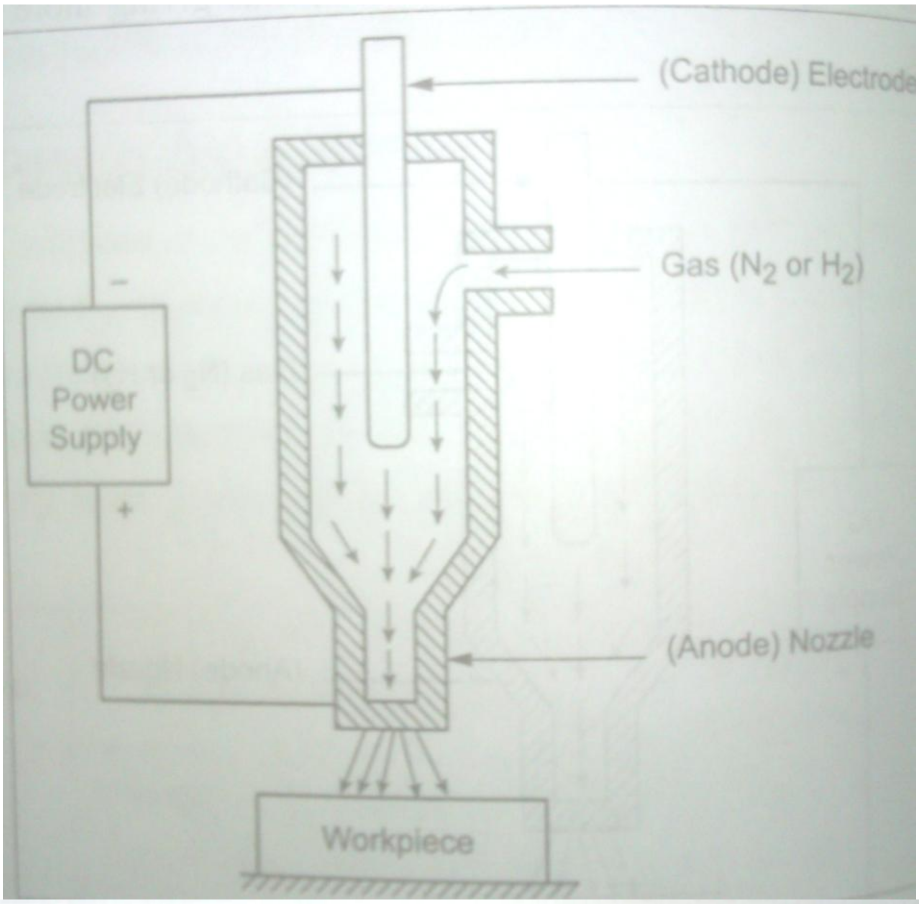
Since it is difficult to strike an arc between the electrode and workpiece directly through the narrow torch passage, first an auxiliary arc is commonly produced between the electrode and the nozzle.

When the arc flame reaches the workpiece, it automatically strikes the main arc between the electrode and the workpiece and the auxiliary 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

In these type of torches, electrode is connected to the negative terminal (cathode) of a D.C power supply and nozzle is connected to the positive terminal (anode) of a D.C power supply.



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

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

Plasma arc welding machine is used for several purposes and in various fields. The common application areas of the machine are:

1. Single runs autogenous and multi-run circumferential pipe welding.
2. In tube mill applications.
3. Welding cryogenic, aerospace and high temperature corrosion resistant alloys.
4. Nuclear submarine pipe system (non-nuclear sections, sub assemblies).
5. Welding steel rocket motor cases.
6. Welding of stainless steel tubes (thickness 2.6 to 6.3 mm).
7. Welding of carbon steel, stainless steel, nickel, copper, brass, monel, inconel, aluminium, titanium, etc.
8. Welding titanium plates up to 8 mm thickness.
9. Welding nickel and high nickel alloys.
10. or melting, high melting point metals.
11. Plasma torch can be applied to spraying, welding and cutting of difficult to cut metals and alloys.

10. Explain the two types of Electron beam machining (EBM) with a neat sketch. List out the advantages, disadvantages and application of EBM Process.

Refer Question No.1