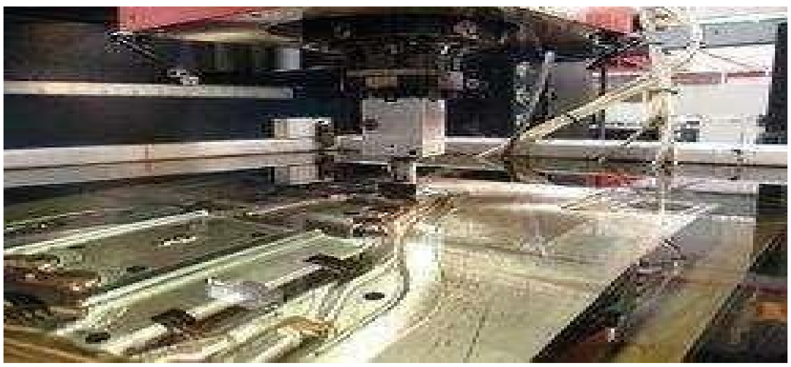
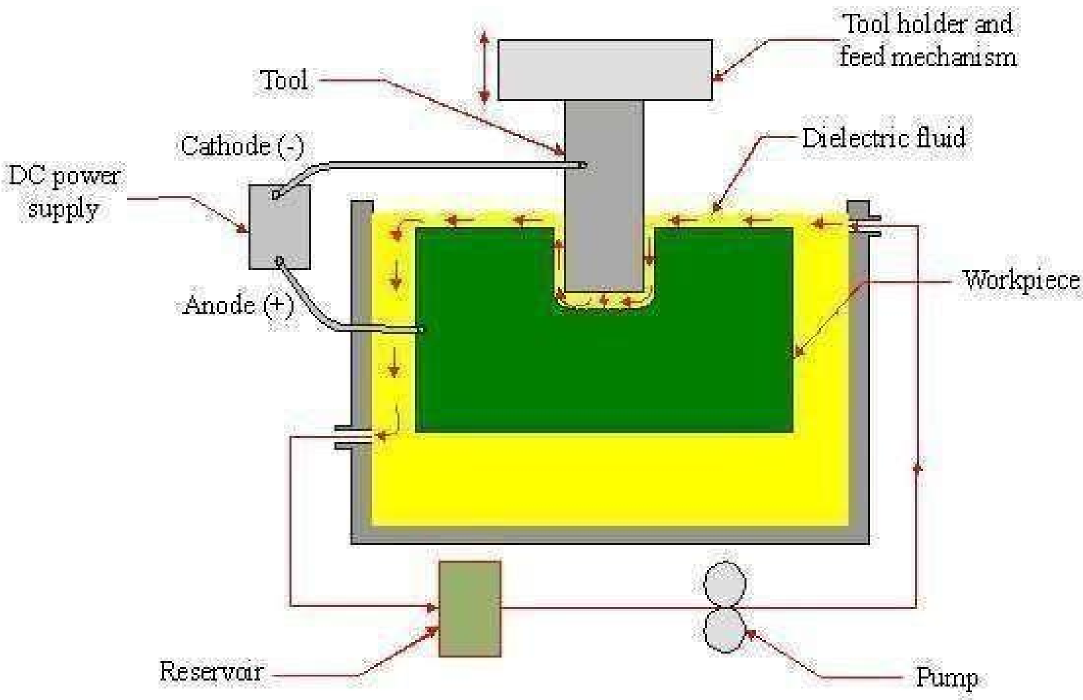
Electrical Discharge Machining (EDM)

Electrical discharge machining (EDM) is one of the most widely used non-traditional machining processes. The main attraction of EDM over traditional machining processes such as metal cutting using different tools and grinding is that this technique utilizes thermoelectric process to erode undesired materials from the work piece by a series of discrete electrical sparks between the work piece and the electrode. A picture of EDM machine in operation



The traditional machining processes rely on harder tool or abrasive material to remove the softer material whereas non-traditional machining processes such as EDM uses electrical spark or thermal energy to erode unwanted material in order to create desired shape. So, the hardness of the material is no longer a dominating factor for EDM process. A schematic of an EDM process is shown in Figure 2, where the tool and the workpiece are immersed in a dielectric fluid.

Figure 2: Schematic of EDM process



EDM removes material by discharging an electrical current, normally stored in a capacitor bank, across a small gap between the tool (cathode) and the workpiece (anode) typically in order

Application of EDM

The EDM process has the ability to machine hard, difficult-to-machine materials. Parts with complex, precise and irregular shapes for forging, press tools, extrusion dies, difficult internal shapes for aerospace and medical applications can be made by EDM process. Some of the shapes made by EDM process are shown in Figure 3.

Figure 3: Difficult internal parts made by EDM process working

Principle Of EDM

As shown in Figure 1, at the beginning of EDM operation, a high voltage is applied across the narrow gap between the electrode and the workpiece. This high voltage induces an electric field in the insulating dielectric that is present in narrow gap between electrode and workpiece. This cause conducting particles suspended in the dielectric to concentrate at the points of strongest electrical field. When the potential difference between the electrode and the workpiece is sufficiently high, the dielectric breaks down and a transient spark is charges through the dielectric fluid, removing small amount of material from the workpiece surface.

The volume of the material removed per spark discharge is typically in the range of $10^{-6} mm^3$.

The material removal rate, MRR, in EDM is calculated by the following formula: $MRR = 40\ I / Tm^{1.23}$ (cm^3/min)

Where, I is the current amp, Tm is the melting temperature of workpiece in ^0C

Advantages of EDM

The main advantages of DM are:

a. By this process, materials of any hardness can be machined;
b. No burrs are left in machined surface;
c. One of the main advantages of this process is that thin and fragile/brittle components can be machined without distortion;

d. Complex internal shapes can be machined

Limitations of EDM

The main limitations of this process are:

a) This process can only be employed in electrically conductive materials;
b) Material removal rate is low and the process overall is slow compared to conventional machining processes;
c) Unwanted erosion and over cutting of material can occur;
d) Rough surface finish when at high rates of material removal.

Dielectric fluids

Dielectric fluids used in EDM process are hydrocarbon oils, kerosene and deionised water. The functions of the dielectric fluid are to:

a) Act as an insulator between the tool and the workpiece.
b) Act as coolant.
c) Act as a flushing medium for the removal of the chips.

The electrodes for EDM process usually are made of graphite, brass, copper and copper-tungsten alloys.

Design considerations for EDM process are as follows:

a) Deep slots and narrow openings should be avoided.
b) The surface smoothness value should not be specified too fine.

Rough cut should be done by other machining process. Only finishing operation should be done in this process as MRR for this process is slow.

Wire Cut Electrical Discharge Machining (WCEDM)

EDM, primarily, exists commercially in the form of die-sinking machines and wire-cutting machines (Wire EDM). The concept of wire EDM is shown in Figure 4. In this process, a slowly moving wire travels along a prescribed path and removes material from the workpiece. Wire EDM uses electro-thermal mechanisms to cut electrically conductive materials. The material is removed by a series of discrete discharges between the wire electrode and the workpiece in the presence of dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The area where discharge takes place is heated to extremely high temperature, so that the surface is melted and removed.

The wire EDM process can cut intricate components for the electric and aerospace industries. This non-traditional machining process is widely used to pattern tool steel for die manufacturing.

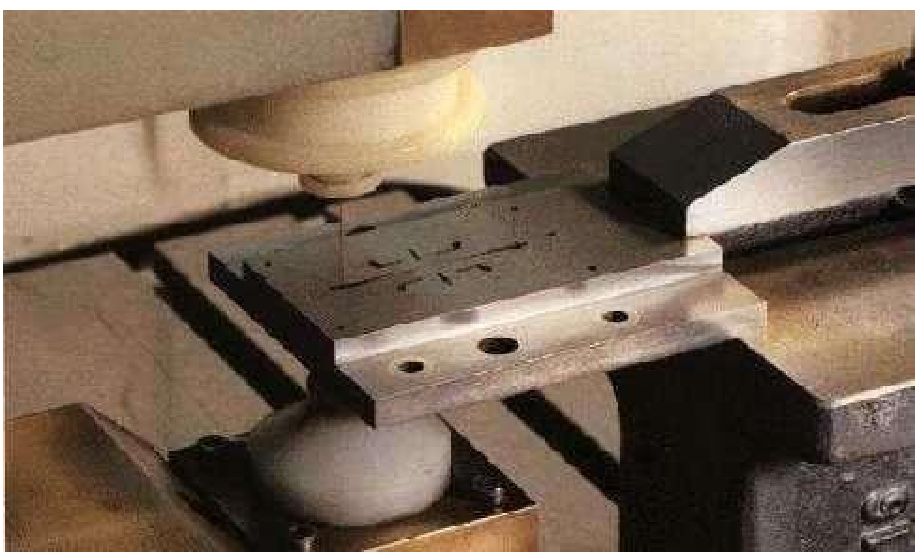


Figure 4: Wire erosion of an extrusion die

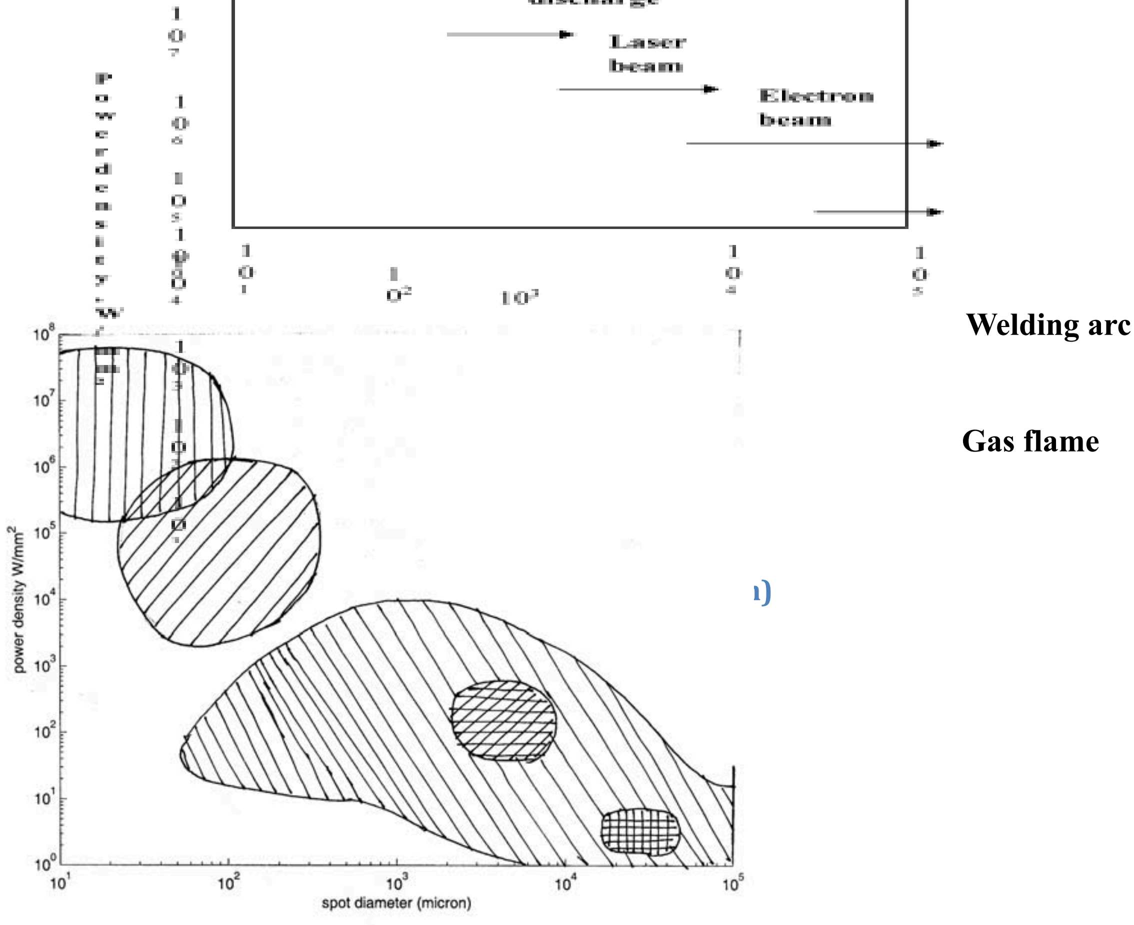
The wires for wire EDM is made of brass, copper, tungsten, molybdenum. Zinc or brass coated wires are also used extensively in this process. The wire used in this process should posses high tensile strength and good electrical conductivity. Wire EDM can also employ to cut cylindrical objects with high precision. The sparked eroded extrusion dies are presented in Figure 5.

This process is usually used in conjunction with CNC and will only work when a part is to be cut completely through. The melting temperature of the parts to be machined is an important parameter for this process rather than strength or hardness. The surface quality and MRR of the machined surface by wire EDM will depend on different machining parameters such as applied peak current, and wire materials.

Introduction

Electron Beam Machining (EBM) and Laser Beam Machining (LBM) are thermal processes considering the mechanisms of material removal. However electrical energy is used to generate high-energy electrons in case of Electron Beam Machining (EBM) and high-energy coherent photons in case of Laser Beam Machining (LBM). Thus these two processes are often classified as electro-optical-thermal processes.

There are different jet or beam processes, namely Abrasive Jet, Water Jet etc. These two are mechanical jet processes. There are also thermal jet or beams. A few are oxyacetylene flame, welding arc, plasma flame etc. EBM as well as LBM are such thermal beam processes. Fig. 9.6.1 shows the variation in power density vs. the characteristic dimensions of different thermal beam processes. Characteristic length is the diameter over which the beam or flame is active. In case of oxyacetylene flame or welding arc, the characteristic length is in mm to tens of mm and the power density is typically low. Electron Beam may have a characteristic length of tens of microns to mm depending on degree of focusing of the beam. In case of defocused electron beam, power density would be as low as 1 Watt/mm^2. But in case of focused beam the same can be increased to tens of kW/mm^2. Similarly as can be seen in Fig. 9.6.1, laser beams can be focused over a spot size of 10 – 100 μm with a power density as high as 1 MW/mm^2. Electrical discharge typically provides even higher power density with smaller spot size.

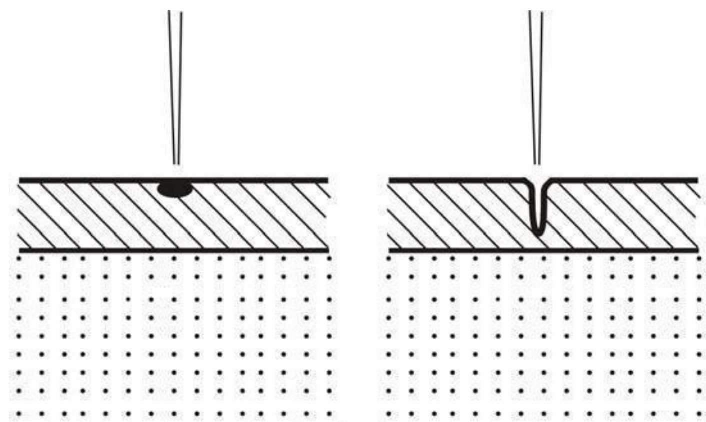


Laser beam
Electron beam
Welding arc
Gas flame
power density W/mm^2
spot diameter (micron)

EBM and LBM are typically used with higher power density to machine materials. The mechanism of material removal is primarily by melting and rapid vaporisation due to intense heating by the electrons and laser beam respectively.

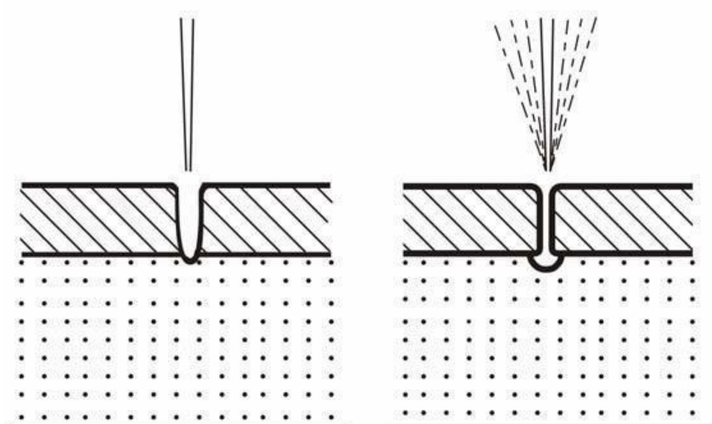
Electron Beam Machining – Process

Electron beam is generated in an electron beam gun. The construction and working principle of the electron beam gun would be discussed in the next section. Electron beam gun provides high velocity electrons over a very small spot size. Electron Beam Machining is required to be carried out in vacuum. Otherwise the electrons would interact with the air molecules, thus they would lose their energy and cutting ability. Thus the workpiece to be machined is located under the electron beam and is kept under vacuum. The high-energy focused electron beam is made to impinge on the workpiece with a spot size of 10 – 100 μ m.The kinetic energy of the high velocity electrons is converted to heat energy as the electrons strike the work material. Due to high power density instant melting and vaporization starts and "melt – vaporization" front gradually progresses, as shown in Fig. 9.6.2. Finally the molten material, if any at the top of the front, is expelled from the cutting zone by the high vapor pressure at the lower part. Unlike in Electron Beam Welding, the gun in EBM is used in pulsed mode. Holes can be drilled in thin sheets using a single pulse. For thicker plates, multiple pulses would be required. Electron beam can also be manoeuvred using the electromagnetic deflection coils for drilling holes of any shape.



Localized heating by focused electron beam

Gradual formation of hole



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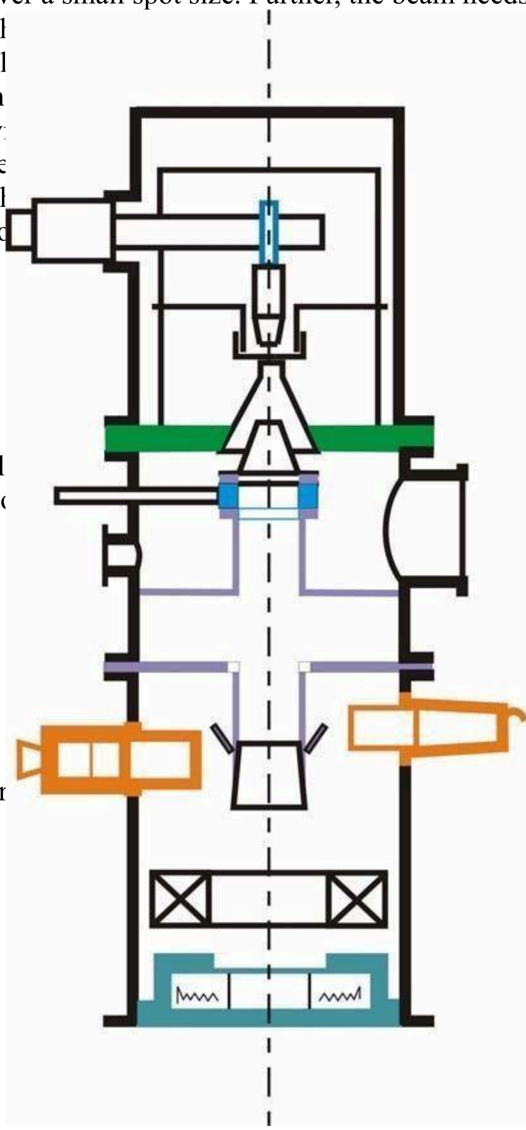
Electron Beam Machining – Equipment

Fig. 9.6.3 shows the schematic representation of an electron beam gun, which is the heart of any electron beam machining facility. The basic functions of any electron beam gun are to generate free electrons at the cathode, accelerate them to a sufficiently high velocity and to focus them over a small spot size. Further, the beam needs to be manoeuvred if required by thegun.

Tl nerally made of tungsten or tantalum. Such cathode fil mperature of around 2500^0C. Such heating leads to th further enhanced by maintaining very low vacuum w gun. Moreover, this cathode cartridge is highly ne ctrons are strongly repelled away form the cathode. Tl ge so that it can be changed very quickly to reduce do



coils

deflector coils

Just after the cathode, there is an annular bias grid. A high negative bias is applied to this grid so that the electrons generated by this cathode do not diverge and approach the next element, the annular anode, in the form of a beam. The annular anode now attracts the electron beam and gradually gets accelerated. As they leave the anode section, the electrons may achieve a velocity as high as half the velocity of light.

The nature of biasing just after the cathode controls the flow of electrons and the biased grid is used as a switch to operate the electron beam gun in pulsed mode.

After the anode, the electron beam passes through a series of magnetic lenses and apertures. The magnetic lenses shape the beam and try to reduce the divergence. Apertures on the other hand allow only the convergent electrons to pass and capture the divergent low energy electrons from the fringes. This way, the aperture and the magnetic lenses improve the quality of the electron beam.

Then the electron beam passes through the final section of the electromagnetic lens and deflection coil. The electromagnetic lens focuses the electron beam to a desired spot. The deflection coil can manoeuvre the electron beam, though by small amount, to improve shape of the machined holes.

Generally in between the electron beam gun and the workpiece, which is also under vacuum, there would be a series of slotted rotating discs. Such discs allow the electron beam to pass and machine materials but helpfully prevent metal fumes and vapour generated during machining to reach the gun. Thus it is essential to synchronize the motion of the rotating disc and pulsing of the electron beam gun.

Electron beam guns are also provided with illumination facility and a telescope for alignment of the beam with the workpiece.

Workpiece is mounted on a CNC table so that holes of any shape can be machined using the CNC control and beam deflection in-built in the gun.

One of the major requirements of EBM operation of electron beam gun is maintenance of desired vacuum. Level of vacuum within the gun is in the order of 10^{-4} to 10^{-6} Torr. *{1 Torr = 1mm of Hg}* Maintenance of suitable vacuum is essential so that electrons do not lose their energy and a significant life of the cathode cartridge is obtained. Such vacuum is achieved and maintained using a combination of rotary pump and diffusion pump. Diffusion pump, as shown in Fig. is attached to the diffusion pump port of the electron beam gun

Diffusion pump is essentially an oil heater. As the oil is heated the oil vapour rushes upward where gradually converging structure as shown in Fig. 9.6.4 is present. The nozzles change the direction of motion of the oil vapour and the oil vapour starts moving downward at a high velocity as jet. Such high velocity jets of oil vapour entrain any air molecules present within the gun. This oil is evacuated by a rotary pump via the backing line. The oil vapour condenses due to presence of cooling water jacket around the diffusion pump.

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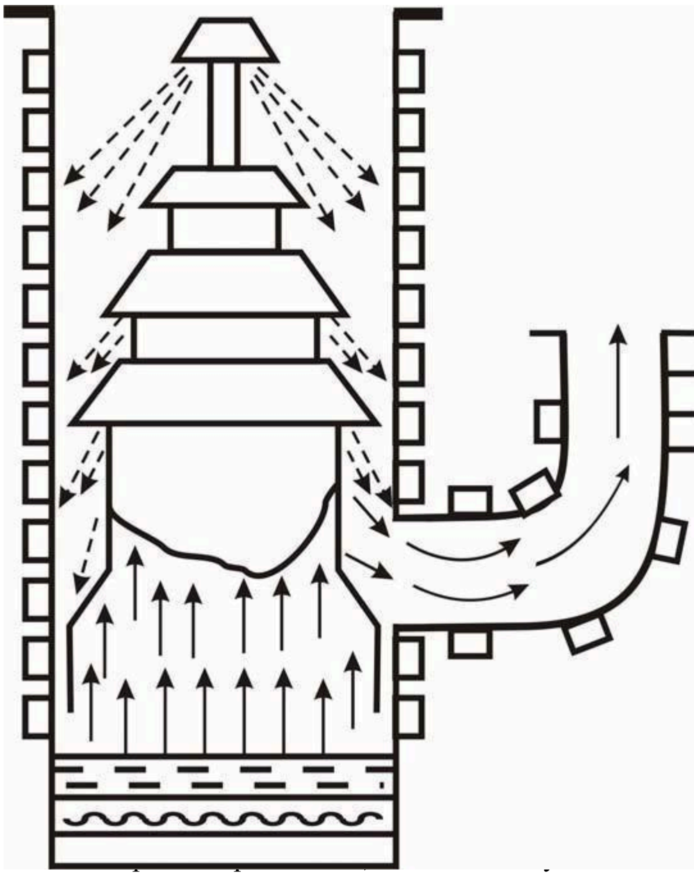

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machining characteristics in Electron Beam Machining, are:

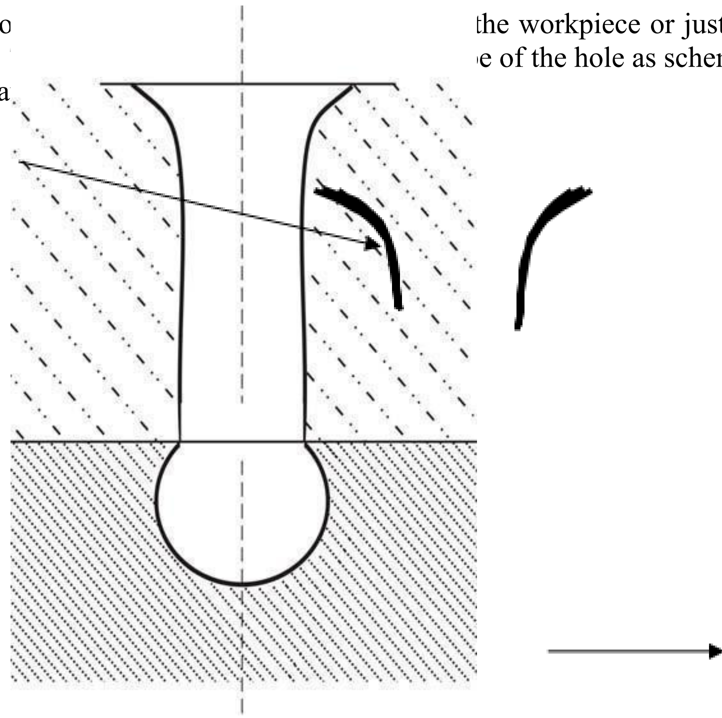
a) The accelerating voltage
b) The beam current
c) Pulse duration
d) Energy per pulse
e) Power per pulse
f) Lens current
g) Spot size
h) Power density

As has already been mentioned in EBM the gun is operated in pulse mode. This is achieved by appropriately biasing the biased grid located just after the cathode. Switching pulses are given to the bias grid so as to achieve pulse duration of as low as 50 μs to as long as 15 ms. Beam current is directly related to the number of electrons emitted by the cathode or available in the beam. Beam current once again can be as low as 200 μamp to 1 amp.

Increasing the beam current directly increases the energy per pulse. Similarly increase in pulse duration also enhances energy per pulse. High-energy pulses (in excess of 100 J/pulse) can machine larger holes on thicker plates.

The energy density and power density is governed by energy per pulse duration and spot size. Spot size, on the other hand is controlled by the degree of focusing achieved by the electromagnetic lenses. 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.

The plane o the workpiece or just below the surface of the workpiece. e of the hole as schematically shown in Fig. re solidified la



Auxiliary support

As has been indicated earlier, the final deflection coil can manoeuvre the electron beam providing holes of non-circular cross-section as required.

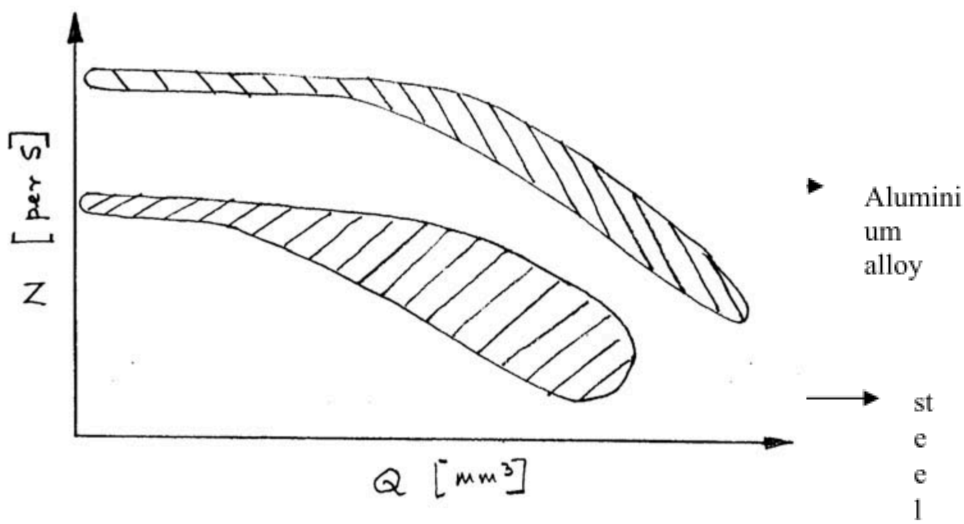
Electron Beam Process Capability

EBM can provide holes of diameter in the range of 100 μm to 2 mm with a depth upto 15 mm, i.e., with a l/d ratio of around 10. Fig. schematically represents a typical hole drilled by electron beam. The hole can be tapered along the depth or barrel shaped. By focusing the beam below the surface a reverse taper can also be obtained. Typically as shown in Fig., there would be an edge rounding at the entry point along with presence of recast layer. Generally burr formation does not occur in EBM.

A wide range of materials such as steel, stainless steel, Ti and Ni super- alloys, aluminum as well as plastics, ceramics, leathers can be machined successfully using electron beam. As the mechanism of material removal is thermal in nature as for example in electro-discharge machining, there would be thermal damages associated with EBM. However, the heat- affected zone is rather narrow due to shorter pulse duration in EBM. Typically the heat- affected zone is around 20 to 30 μm.

Some of the materials like Al and Ti alloys are more readily machined compared to steel. Number of holes drilled per second depends on the hole diameter, power density and depth of the hole as well as material type as mentioned earlier. Fig. 9.6.6 depicts the variation in drilling speed against volume of material removed for steel and Aluminum alloy.

EBM does not apply any cutting force on the workpieces. Thus very simple work holding is required. This enables machining of fragile and brittle materials by EBM. Holes can also be drilled at a very shallow angle of as less as 20 to 30^0.



Electron Beam Machining – Advantages and Limitations

EBM provides very high drilling rates when small holes with large aspect ratio are to be drilled. Moreover it can machine almost any material irrespective of their mechanical properties. As it applies no mechanical cutting force, work holding and fixturing cost is very less. Further for the same reason fragile and brittle materials can also be processed. The heat affected zone in EBM is rather less due to shorter pulses. EBM can provide holes of any shape by combining beam deflection using electromagnetic coils and the CNC table with high accuracy.

However, EBM has its own share of limitations. The primary limitations are the high capital cost of the equipment and necessary regular maintenance applicable for any equipment using vacuum system. Moreover in EBM there is significant amount of non-productive pump down period for attaining desired vacuum. However this can be reduced to some extent using vacuum load locks. Though heat affected zone is rather less in EBM but recast layer formation cannot be avoided.

Laser Beam Machining – Introduction

Laser Beam Machining or more broadly laser material processing deals with machining and material processing like heat treatment, alloying, cladding, sheet metal bending etc. Such processing is carried out utilizing the energy of coherent photons or laser beam, which is mostly converted into thermal energy upon interaction with most of the materials. Nowadays, laser is also finding application in regenerative machining or rapid prototyping as in processes like stereo-lithography, selective laser sintering etc.

Laser stands for light amplification by stimulated emission of radiation. The underline working principle of laser was first put forward by Albert Einstein in 1917 through the first industrial laser for experimentation was developed around1960s.

Laser beam can very easily be focused using optical lenses as their wavelength ranges from half micron to around 70 microns. Focused laser beam as indicated earlier can have power density in excess of 1 MW/mm^2. As laser interacts with the material, the energy of the photon is absorbed by the work material leading to rapid substantial rise in local temperature. This in turn results in melting and vaporisation of the work material and finally material removal.

Laser Beam Machining – the lasing process

Lasing process describes the basic operation of laser, i.e. generation of coherent (both temporal and spatial) beam of light by "light amplification" using "stimulated emission".

In the model of atom, negatively charged electrons rotate around the positively charged nucleus in some specified orbital paths. The geometry and radii of such orbital paths depend on a variety of parameters like number of electrons, presence of neighboring atoms and their electron structure, presence of electromagnetic field etc. Each of the orbital electrons is associated with unique energy levels. At absolute zero temperature an atom is considered to be at ground level, when all the electrons occupy their respective lowest potential energy. The electrons at ground state can be excited to higher state of energy by absorbing energy form external sources like increase in electronic vibration at elevated temperature, through chemical reaction as well as via absorbing energy of the photon. Fig depicts schematically the absorption of a photon by an electron. The electron moves from a lower energy level to a higher energy level.

On reaching the higher energy level, the electron reaches an unstable energy band. And it comes back to its ground state within a very small time by releasing a photon. This is called spontaneous emission. Schematically the same is shown in Fig.. The spontaneously emitted photon would have the same frequency as that of the “exciting” photon.

Sometimes such change of energy state puts the electrons in a meta-stable energy band. Instead of coming back to its ground state immediately (within tens of ns) it stays at the elevated energy state for micro to milliseconds. In a material, if more number of electrons can be somehow pumped to the higher meta-stable energy state as compared to number of atoms at ground state, then it is called “population inversion”. Such electrons,

Laser-beam machining is a thermal material-removal process that utilizes a high-energy, coherent light beam to melt and vaporize particles on the surface of metallic and non-metallic workpieces. Lasers can be used to cut, drill, weld and mark. LBM is particularly suitable for making accurately placed holes. A schematic of laser beam machining is shown in Figure 12.
Different types of lasers are available for manufacturing operations which are as follows:

• CO2 (pulsed or continuous wave): It is a gas laser that emits light in the infrared region. It can provide up to 25 kW in continuous-wave mode.
• Nd:YAG: Neodymium-doped Yttrium-Aluminum-Garnet (Y3Al5O12) laser is a solid- state laser which can deliver light through a fibre-optic cable. It can provide up to50kW power in pulsed mode and 1 kW in continuous-wave mode.

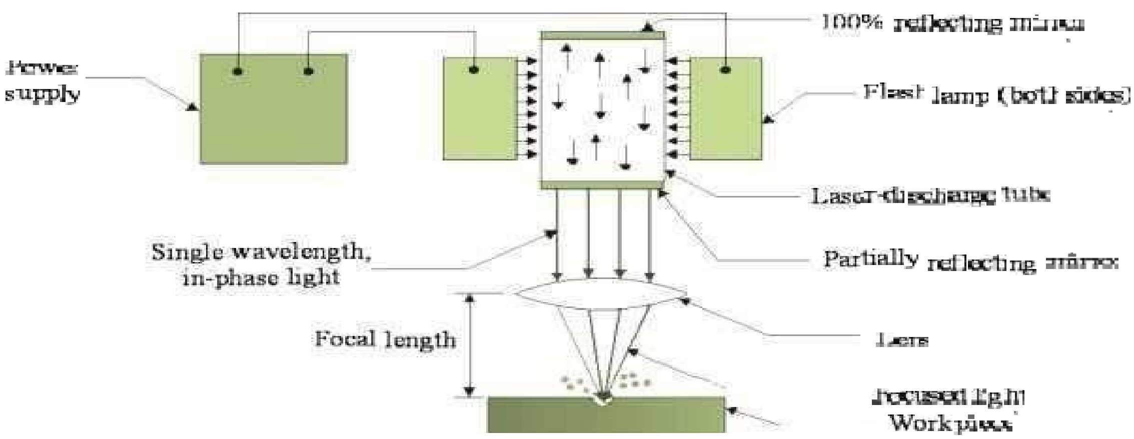


Figure 12: Laser beam machining schematic

Applications

LBM can make very accurate holes as small as 0.005 mm in refractory metals ceramics, and composite material without warping the workpieces. This process is used widely for drilling

Laser beam cutting (drilling)

a) In drilling, energy transferred (e.g., via a Nd:YAG laser) into the workpiece melts the material at the point of contact, which subsequently changes into a plasma and leaves the region.

b) A gas jet (typically, oxygen) can further facilitate this phase transformation and departure of material removed.

c) Laser drilling should be targeted for hard materials and hole geometries that are difficult to achieve with other methods.

A typical SEM micrograph hole drilled by laser beam machining process employed in making a hole is shown in Figure 13.

Figure 13: SEM micrograph hole drilled in 250 micro meter thick Silicon Nitride with 3rd harmonic Nd: YAG laser

Laser beam cutting (milling)

a) A laser spot reflected onto the surface of a workpiece travels along a prescribed trajectory and cuts into the material.

b) Continuous-wave mode (CO2) gas lasers are very suitable for laser cutting providing high-average power, yielding high material-removal rates, and smooth cutting surfaces.

Advantage of laser cutting

a) No limit to cutting path as the laser point can move any path.

b) The process is stress less allowing very fragile materials to be laser cut without any support.

c) Very hard and abrasive material can be cut.

d) Sticky materials are also can be cut by this process.

e) It is a cost effective and flexible process.

f) High accuracy parts can be machined.
g) No cutting lubricants required
h) No tool wear
i) Narrow heat effected zone

Limitations of laser cutting

a) Uneconomic on high volumes compared to stamping
b) Limitations on thickness due to taper
c) High capital cost
d) High maintenance cost
e) Assist or cover gas required

ELECTRON BEAM MACHINING (EBM)

INTRODUCTION

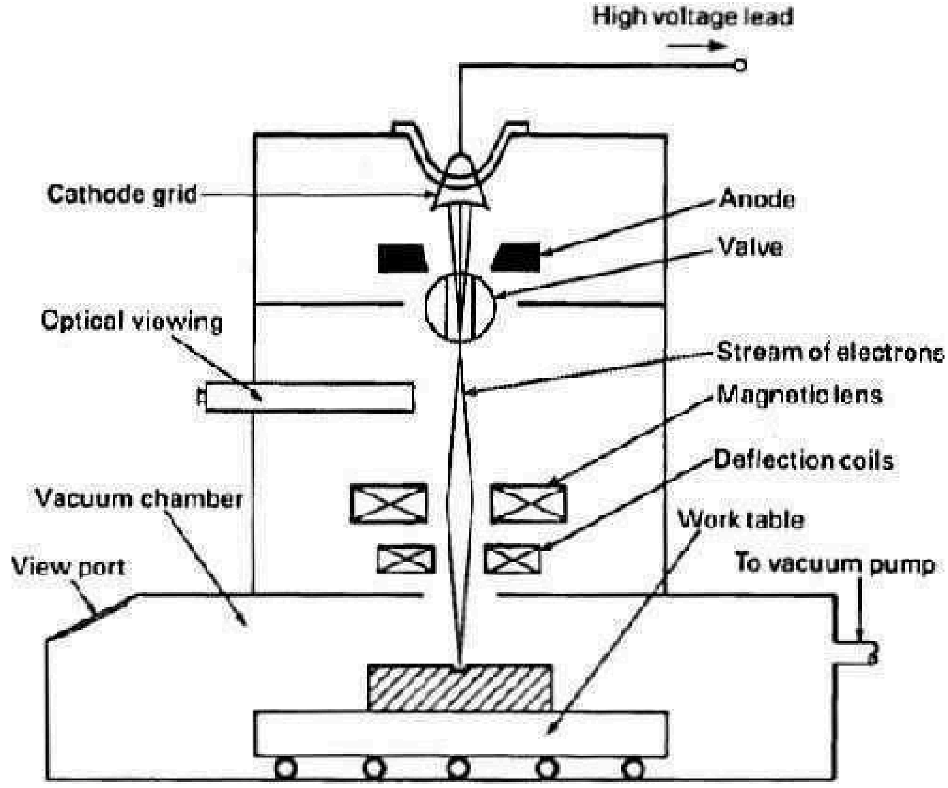
As has already been mentioned in EBM the gun is operated in pulse mode. This is achieved by appropriately biasing the biased grid located just after the cathode. Switching pulses are given to the bias grid so as to achieve pulse duration of as low as 50 μs to as long as 15 ms. Beam current is directly related to the number of electrons emitted by the cathode or available in the beam. Beam current once again can be as low as 200 μamp to 1 amp. Increasing the beam current directly increases the energy per pulse. Similarly increase in pulse duration also enhances energy per pulse. High-energy pulses (in excess of 100 J/pulse) can machine larger holes on thicker plates. The energy density and power density is governed by energy per pulse duration and spot size. Spot size, on the other hand is controlled by the degree of focusing achieved by the electromagnetic lenses. 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. The plane of focusing would be on the surface of the work piece or just below the surface of the work piece.

a) Electrons generated in a vacuum chamber
b) Similar to cathode ray tube
c) 10^{-4} torr
d) Electron gun
e) Cathode - tungsten filament at 2500 – 3000degC
f) Emission current – between 25 and 100mA (a measure of electron beamdensity)

MRR:

In the region where the beam of electrons meets the workpiece, their energy is converted into heat workpiece surface is melted by a combination of electron pressure and surface tension Melted liquid is rapidly ejected and vaporized to effect material removal temperature of the workpiece specimen outside the region being machined is reduced by pulsing the electron beam (10kHz or less)

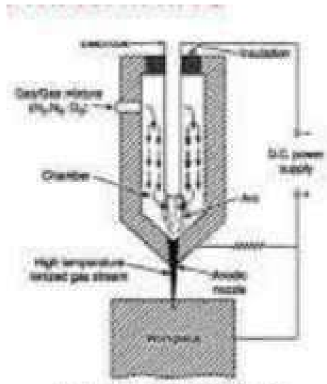
Material	Volumetric removal rate (mm^3s^{-1})
Tungsten	1.5
Aluminum	3.9



ADVANTAGES OF EBM:

Large depth-to-width ratio of material penetrated by the beam with applications of very fine hole drilling becoming feasible. There is a minimum number of pulses n_e associated with an optimum accelerating voltage. In practice the number of pulses to produce a given hole depth is usually found to decrease with increase in accelerating voltage.

PLASMA ARC MACHINING (PAM)



Introduction:

The plasma welding process was introduced to the welding industry in 1964 as a method of bringing better control to the arc welding process in lower current ranges. Today, plasma retains the original advantages it brought to industry by providing an advanced level of control and accuracy to produce high quality welds in miniature or precision applications and to provide long electrode life for high production requirements.

The plasma process is equally suited to manual and automatic applications. It has been used in a variety of operations ranging from high volume welding of strip metal, to precision welding of surgical instruments, to automatic repair of jet engine blades, to the manual welding of kitchen equipment for the food and dairy industry.

Plasma Arc welding (PAW):

Plasma arc welding (PAW) is a process of joining of metals, produced by heating with a constricted arc between an electrode and the work piece (transfer arc) or the electrode and the constricting nozzle (non transfer arc). Shielding is obtained from the hot ionized gas issuing from the orifice, which may be supplemented by an auxiliary source of shielding gas.

Transferred arc process produces plasma jet of high energy density and may be used for high speed welding and cutting of Ceramics, steels, Aluminum alloys, Copper alloys, Titanium alloys, Nickel alloys.

Non-transferred arc process produces plasma of relatively low energy density. It is used for welding of various metals and for plasma spraying (coating). Equipment:

a) Power source. A constant current drooping characteristic power source supplying the dc welding current is required. It should have an open circuit voltage of 80 volts and have a duty cycle of 60 percent.

b) Welding torch. The welding torch for plasma arc welding is similar in appearance to a gas tungsten arc torch but it is more complex.

i. All plasma torches are water cooled, even the lowest-current range torch. This is because the arc is contained inside a chamber in the torch where it generates considerable heat. During the non-transferred period, the arc will be struck between the nozzle or tip with the orifice and the tungsten electrode.

ii. The torch utilizes the 2 percent thoriated tungsten electrode similar to that used for gas tungsten welding.

c) Control console. A control console is required for plasma arc welding. The plasma arc torches are designed to connect to the control console rather than the power source. The console include a power source for the pilot arc, delay timing systems for transferring from the pilot arc to the transferred arc, and water and gas valves and separate flow meters for the plasma gas and the shielding gas. The console is usually connected to the power source. The high-frequency generator is used to initiate the pilot arc.

Principles of Operation:

a) The plasma arc welding process is normally compared to the gas tungsten arc process. But in the TIG-process, the arc is burning free and unchanneled, whereas in the plasma-arc system, the arc is necked by an additional water-cooled plasma-nozzle. A plasma gas – almost always 100 % argon –flows between the tungsten electrode and the plasma nozzle.

b) The welding process involves heating a gas called plasma to an extremely high temperature and then ionizing it such that it becomes electrically conductive. The plasma is used to transfer an electric arc called pilot arc to a work piece which burns between the tungsten electrode and the plasma nozzle. By forcing the plasma gas and arc through a constricted orifice the metal, which is to be welded is melted by the extreme heat of the arc. The weld pool is protected by the shielding gas, flowing between the outer shielding gas nozzle and the plasma nozzle. As shielding gas pure argon-rich gas- mixtures with hydrogen or helium are used.

c) The high temperature of the plasma or constricted arc and the high velocity plasma jet provide an increased heat transfer rate over gas tungsten arc welding when using the same current.

d) This results in faster welding speeds and deeper weld penetration. This method of operation is used for welding extremely thin material and for welding multi pass groove and welds and fillet welds.

Uses & Applications:

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

a) Single runs autogenous and multi-run circumferential pipe welding.

b) In tube mill applications.

c) Welding cryogenic, aerospace and high temperature corrosion resistant alloys.

d) Nuclear submarine pipe system (non-nuclear sections, subassemblies).

e) Welding steel rocket motor cases.

f) Welding of stainless steel tubes (thickness 2.6 to 6.3mm).

g) Welding of carbon steel, stainless steel, nickel, copper, brass, monel, inconel, aluminum, titanium, etc.

h) Welding titanium plates up to 8 mm thickness.

i) Welding nickel and high nickel alloys.

j) or melting, high melting point metals.

k) Plasma torch can be applied to spraying, welding and cutting of difficult to cut metals and alloys.

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.

Temperaturesintheplasmazonerangefrom20,000°to50,000°F(11,000°to28,000°C). It is used as an alternative to oxy fuel-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:

a) The electrode carries the negative charge from the power supply.

b) The swirl ring spins the plasma gas to create a swirling flow pattern.

c) The nozzle constricts the gas flow and increases the arc energy density.

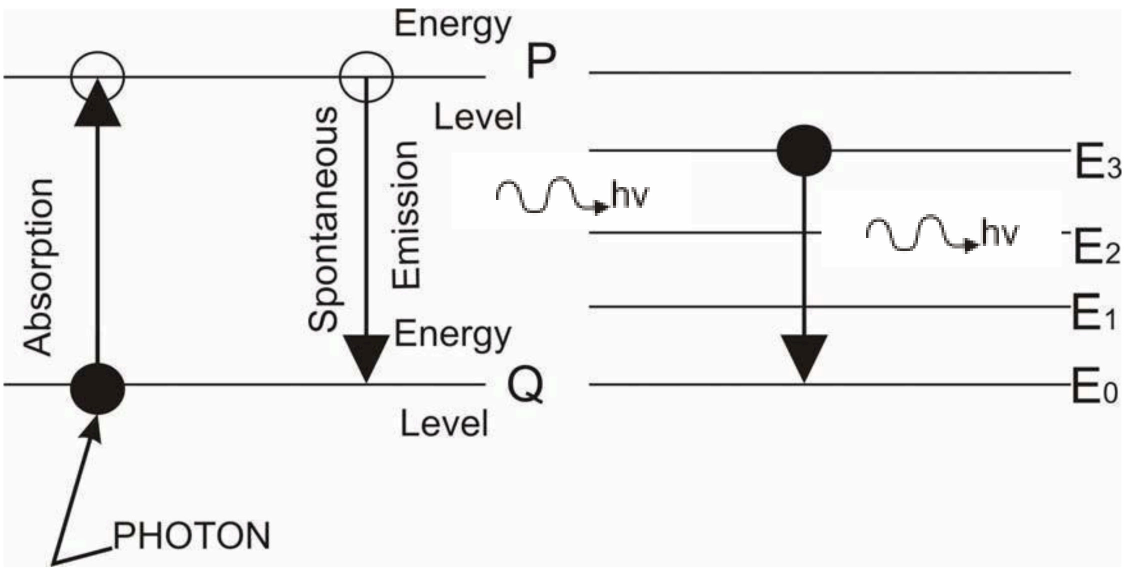
d) The shield channels the flow of shielding gas and protects the nozzle from metal spatter.

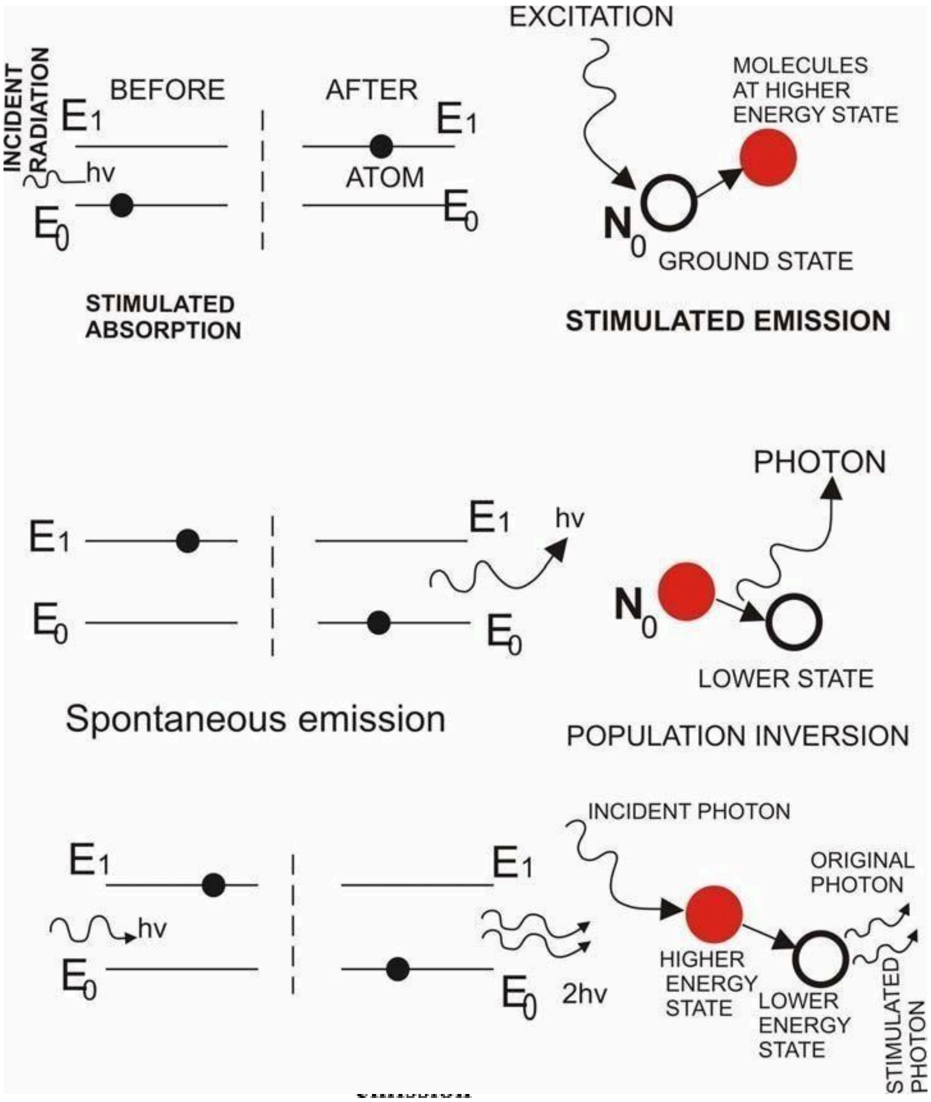
Principle of operation:

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.

The materials cut by PAM are generally those that are difficult to cut by any other means, such as stainless steels and aluminum alloys. It has an accuracy of about 0.008".

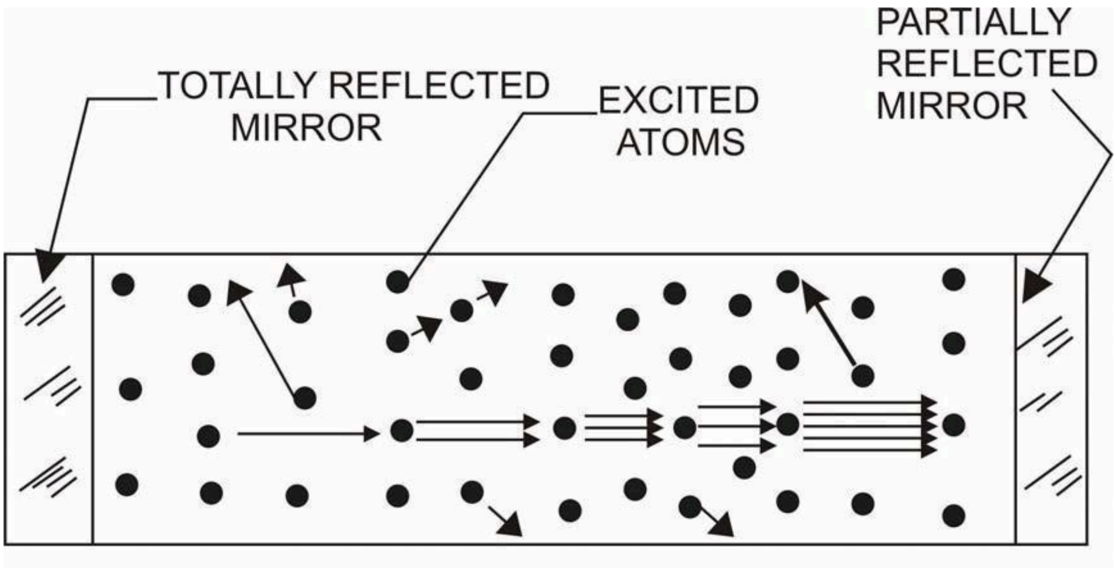
In the latest field of technology respect to welding and machining, plasma arc welding and machining have a huge success. Due to its improved weld quality and increased weld output it is been used for precision welding of surgical instruments, to automatic repair of jet engine blades to the manual welding for repair of components in the tool, die and mold industry. But due to its high equipment expense and high production of ozone, it‟s been outnumbered by other advance welding equipment like laser beam welding and electro beam welding. To overcome the mentioned problem, it is been expected that soon it will fetch with its minimum cons.





at higher energy meta-stable state, can return to the ground state in the form of an avalanche provided stimulated by a photon of suitable frequency or energy. This is called stimulated emission. Fig. shows one such higher state electron in meta-stable orbit. If it is stimulated by a photon of suitable energy then the electron will come down to the lower energy state and in turn one original photon, another emitted photon by stimulation having some temporal and spatial phase would be available. In this way coherent laser beam can be produced.

Fig schematically shows working of a laser. There is a gas in a cylindrical glass vessel. This gas is called the lasing medium. One end of the glass is blocked with a 100% reflective mirror and the other end is having a partially reflective mirror. Population inversion can be carried out by exciting the gas atoms or molecules by pumping it with flash lamps. Then stimulated emission would initiate lasing action. Stimulated emission of photons could be in all directions. Most of the stimulated photons, not along the longitudinal direction would be lost and generate waste heat. The photons in the longitudinal direction would form coherent, highly directional, intense laser beam.



Lasing Medium

Many materials can be used as the heart of the laser. Depending on the lasing medium lasers are classified as solid state and gas laser. Solid-state lasers are commonly of the following type

a) Ruby which is a chromium – alumina alloy having a wavelength of $0.7 \mu m$

b) Nd-glass lasers having a wavelength of $1.64 \mu m$

c) Nd-YAG laser having a wavelength of $1.06 \mu m$ these solid- state

lasers are generally used in material processing.

The generally used gas lasers are

a) Helium –Neon
b) Argon
c) CO_2 etc.

Lasers can be operated in continuous mode or pulsed mode. Typically CO_2 gas laser is operated in continuous mode and Nd – YAG laser is operated in pulsed mode.

Laser Construction

Fig shows a typical Nd-YAG laser. Nd-YAG laser is pumped using flash tube. Flash tubes can be helical, as shown in Fig., or they can be flat. Typically the lasing material is at the focal plane of the flash tube. Though helical flash tubes provide better pumping, they are difficult to maintain.

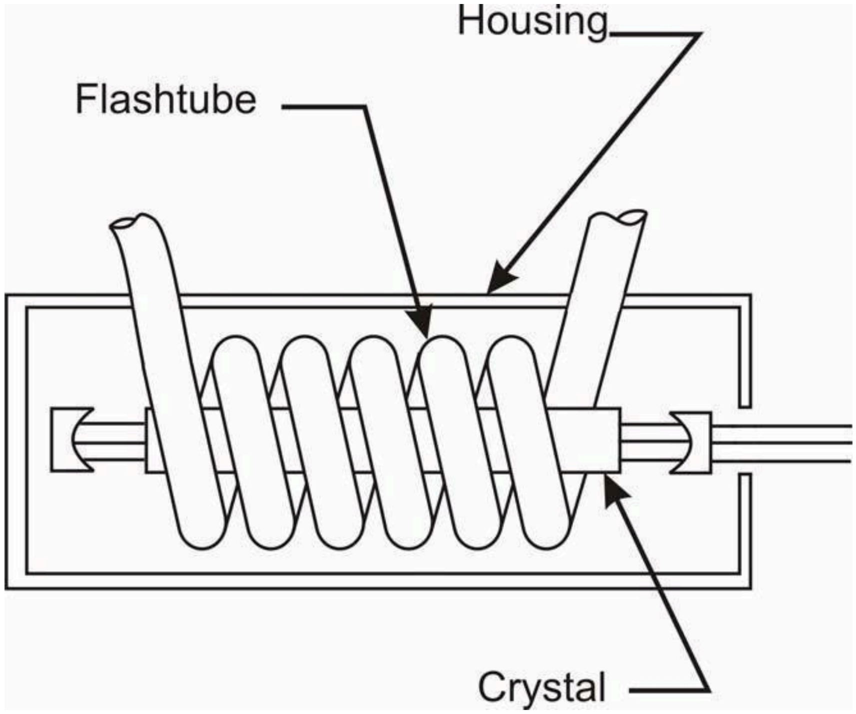


Fig shows the electrical circuit for operation of a solid-state laser. The flash tube is operated in pulsed mode by charging and discharging of the capacitor. Thus the pulse on time is decided by the resistance on the flash tube side and pulse off time is decided by the charging resistance. There is also a high voltage switching supply for initiation of pulses.

Fig shows a CO_2 laser. Gas lasers can be axial flow, as shown in Fig, transverse flow and folded axial flow as shown in Fig.. The power of a CO_2laser is typically around 100 Watt per meter of tube length. Thus to make a high power laser, a rather long tube is required which is quite inconvenient. For optimal use of floor space, high- powered CO_2 lasers are made of folded design.

In a CO_2 laser, a mixture of CO_2, N_2 and He continuously circulate through the gas tube. Such continuous recirculation of gas is done to minimize consumption of gases. CO_2 acts as the main lasing medium whereas Nitrogen helps in sustaining the gas plasma. Helium on the other hand helps in cooling the gases.

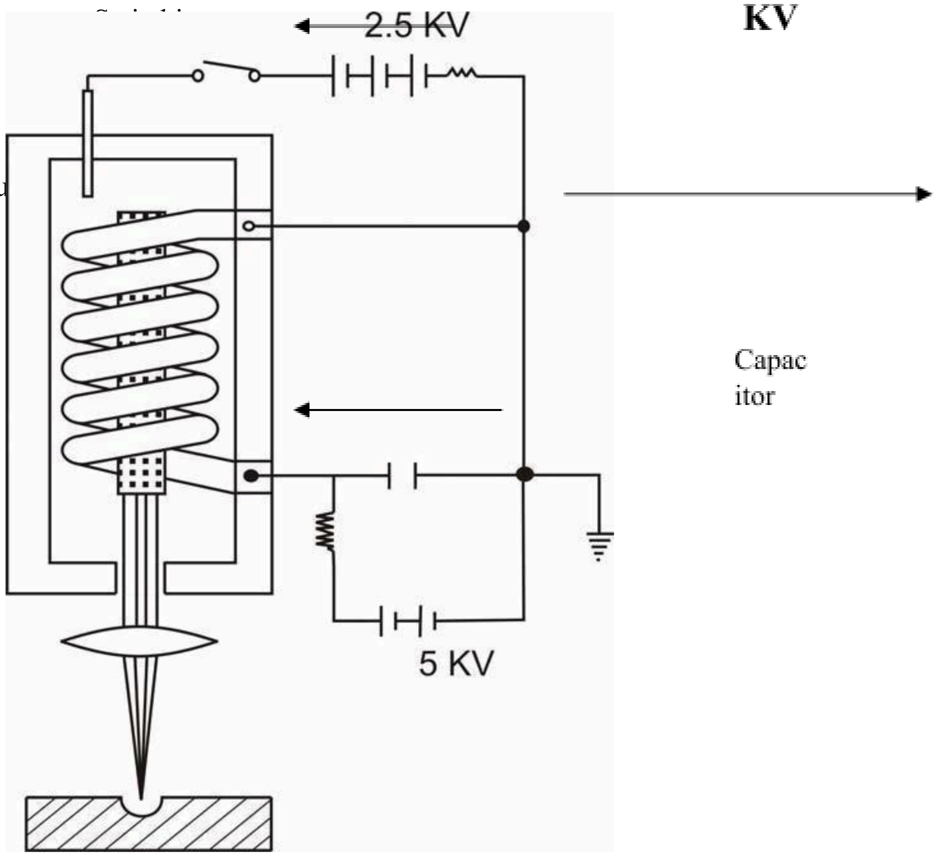
As shown in Fig high voltage is applied at the two ends leading to discharge and formation of gas plasma. Energy of this discharge leads to population inversion and lasing action. At the two ends of the laser we have one 100% reflector and one partial reflector. The 100% reflector redirects the photons inside the gas tube and partial reflector allows a part of the laser beam to be issued so that the same can be used for material processing. Typically the laser tube is cooled externally as well.

As had been indicated earlier CO_2 lasers are folded to achieve high power. Fig shows a similar folded axial flow laser. In folded laser there would be a few 100% reflective turning mirrors for manoeuvring the laser beam from gas supply as well as high voltage supply as shown in Fig.

25

KV

Flash tu



Capac
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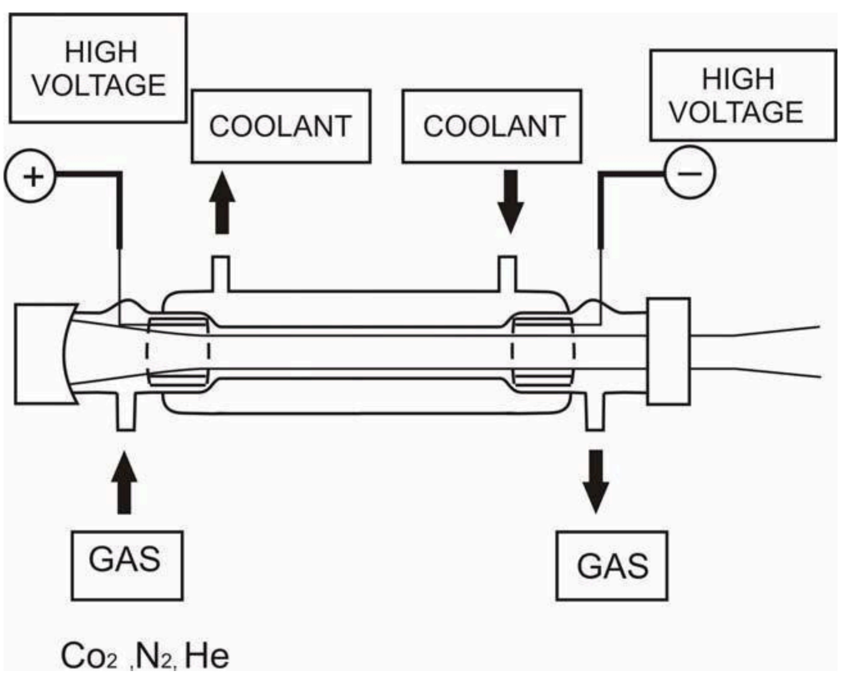

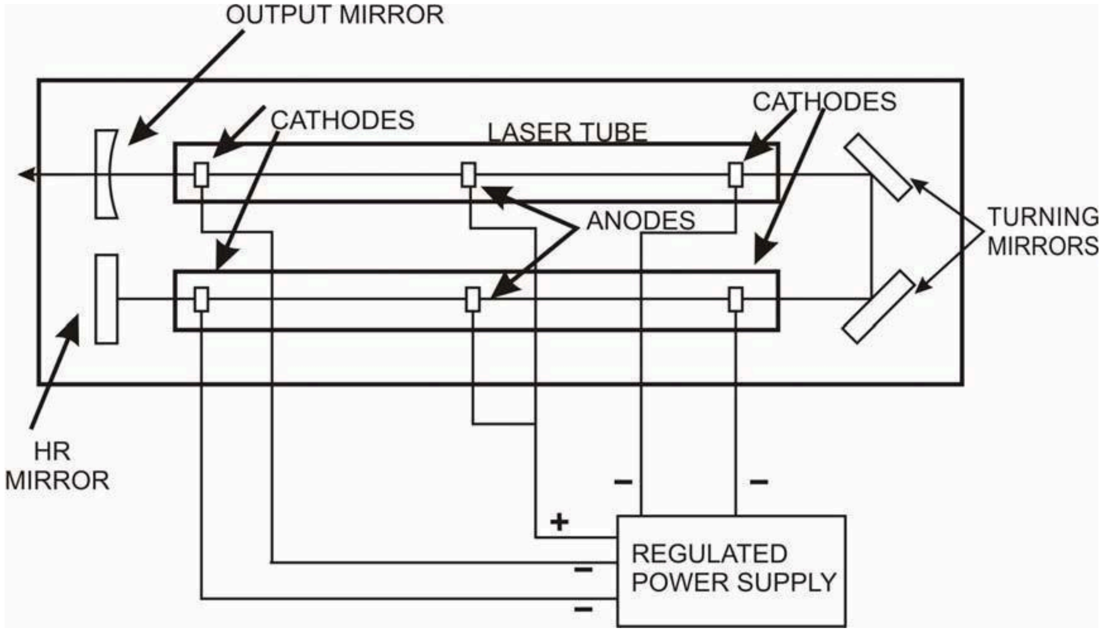
OUTPUT MIRROR
CATHODES
LASER TUBE
CATHODES
ANODES
TURNING
MIRRORS
HR
MIRROR
+
–
–
–
–
REGULATED
POWER SUPPLY

Application	Type of laser
Large holes upto 1.5 mm dia. Large holes (trepanned) Small holes > 0.25 mm dia. Drilling (punching or percussion)	Ruby, Nd-glass, Nd-YAG Nd-YAG, CO_2 Ruby, Nd-glass, Nd-YAG Nd-YAG, Ruby
Thick cutting Thin slitting of metals Thin slitting of plastics	CO_2 with gas assist Nd-YAG CO_2
Plastics Metals Organics, Non-metal Ceramics	CO_2 Nd-YAG, ruby, Nd-glass Pulsed CO_2 Pulsed CO_2, Nd-YAG

Lasing materials	Ruby	**Nd-YAG**	Nd-glass	**CO_2**
Type	Solid state	**Solid state**	Solid state	**Gas**
Composition	0.03 – 0.7% Nd in Al_3O_2	**1% Nd doped Yttrium – Aluminium-Garnet**	2-6% Nd in glass	**CO_2+He+N_2(3 :8:4)**
Wavelength (radiation)	0.69 μm	**1.064 μm**	1.064 μm	**10.6 μm**
Efficiency	1% max.	**2%**	2%	**10-15%**
Beam mode	Pulsed or CW	**Pulsed or CW**	Pulsed	**Pulsed or CW**
Spot size	0.015 mm	**0.015 mm**	0.025 mm	**0.075 mm**
Pulse repetition rate (normal operation).	1-10 pps	**1-300 pps or CW**	1-3 pps	**CW**
Beam output	10-100 W	**10-1000 W**	10 – 100 W	**0.1 – 10 kW**
Peak power	200 kW	**400 kW**	200 kW	**100 kW**

Laser Beam Machining – Application

Laser can be used in wide range of manufacturing applications

a) Material removal – drilling, cutting and tre-panning
b) Welding
c) Cladding
d) Alloying

Drilling micro-sized holes using laser in difficult – to – machine materials is the most dominant application in industry. In laser drilling the laser beam is focused over the desired spot size. For thin sheets pulse laser can be used. For thicker ones continuous laser may be used.

Laser Beam Machining – Advantages

a) In laser machining there is no physical tool. Thus no machining force or wear of the tool takes place.
b) Large aspect ratio in laser drilling can be achieved along with acceptable accuracy or dimension, form or location
c) Micro-holes can be drilled in difficult – to – machine materials
d) Though laser processing is a thermal processing but heat affected zone specially in pulse laser processing is not very significant due to shorter pulse duration.

Laser Beam Machining – Limitations

a) High initial capital cost
b) High maintenance cost
c) Not very efficient process
d) Presence of Heat Affected Zone – specially in gas assist CO2 laser cutting
e) Thermal process – not suitable for heat sensitive materials like aluminum glass fibre laminate as shown in Fig.