As given in the problem,

$$v_g = 0.785 \times (1.3)^2 \times 0.1 \times 10^{-2}\ cm^3 = 0.001\ cm^3$$

$$E = \frac{4.2 \times 0.001 \times 8[0.11(1808-293)+0.11(3000-1808)+67+1630]}{0.7}$$

$$= \mathbf{95.8\ J}$$

Now, if a short pulse of 10^{-5} sec duration is used, the power required,

$$P_m = \frac{95.8}{10^{-5}}\ W.$$

The power density is, $$\frac{P_m}{A} = \frac{95.8 \times 10^5}{0.785 \times (0.13)^2}$$

$$= 7221 \times 10^5\ W/cm^2$$

Accuracy : The laser is best used for cutting as well as for drilling. In order to achieve the best possible results in drilling, it is imperative that the material be located within a tolerance of ±0.2 mm of focal point. Accuracy in profile cutting with numerical control or photoelectric tracer is about ± 0.1 mm.

Application of LBM : Laser machining process is at present found to be suitable only in exceptional cases like machining very small holes and cutting complex profiles in thin, hard materials like ceramics. It is also used in partial cutting or engraving. Other applications include sheet metal trimming, blanking and resistor trimming. Though LBM is not a mass material removal process, it is possible to use this process in mass micro-machining production.

Off-the-shelf laser systems are now available with NC controls and are being used for applications ranging from cigarette paper cutting to drilling microholes in turbine engine blades. Scattered laser light from laser equipment damages the cornea and optic nerves of the eye and for this reason protective materials are absolutely necessary when working around laser equipment.

Advantages : Any solid material which can be melted without decomposition can be cut with the laser beam. Other major advantages of the laser beam machining include the following :

1. There is no direct contact between the tool and the workpiece.
2. machining of any material including nonmetal is possible.

3. Drilling and cutting of areas not readily accessible are possible.
4. Heat affected zone is small because of the collimated beam.
5. Extremely small holes can be machined.
6. There is no tool wear.
7. Soft materials like rubber and plastics can be machined.

Limitations : One of the main limitations of the laser is that it cannot be used to cut metals that have high heat conductivity or high reflectivity, e.g., Al, Cu, and their alloys. In addition, the process has the following disadvantages :

1. Its overall efficiency is extremely low (10 to 15 per cent).
2. The process is limited to thin sheets.
3. It has very low material removal rate.
4. The machined holes are not round and straight.
5. The laser system is quite troublesome since the life of the flash lamp is short.
6. Cost is high.
7. Output energy from LASER is difficult to control precisely.

20.11 PLASMA ARC MACHINING (PAM)

When a flowing gas is heated to a sufficiently high temperature to become partially ionized, it is known as 'plasma'. This is virtually a mixture of free electrons, positively charged ions and neutral atoms.

Plasma arc machining is a material removal process in which the material is removed by directing a high velocity jet of high temperature (11,000 to 30,000 °C) ionized gas on the workpiece.

The principle of plasma arc machining is shown in Fig.20.15. In a plasma torch, known as the gun or plasmatron, a volume of gas such as H_2, N_2, O_2, etc. is passed through a small chamber in which a high frequency spark (arc) is maintained between the tungsten electrode (cathode) and the copper nozzle (anode), both of which are water cooled. In certain torches an inert gas-flow surface rounding the main flame is provided to shield the gas from atmosphere. The high velocity electrons generated by arc collide with the gas molecules and produce dissociation of diatomic molecules of the gas resulting in ionization of the atoms and causing large amounts of thermal energy to be liberated. The plasma forming gas is forced through a nozzle duct of the torch in such a manner as to stabilize the arc. Much of the heating of the gas takes place in the constricted region of the nozzle duct resulting into relatively high exit gas velocity and very high core temperature upto 30,000°C. The plasma jet melts the workpiece material and the high velocity gas stream effectively blows the molten metal away.

The depth of heat affected zone depends on the work material, its thickness and cutting speed. On a workpiece of 25 mm thickness the heat affected zone is about 4 mm and it is less at high cutting speeds. Table 20.8 shows the typical variation of machining parameters of PAM.

Typical flow rate of the gas is 2 to 11 m^3/hr. Direct current, rated at about 400V and 200kW out put is normally required. Arc current ranges between 150 and 1000 A for a cutting rate of 250 to 1700 mm/min. The gas flow is delivered to the nozzle at pressure up to 1.4 MPa.

Accuracy : This is a roughing operation to an accuracy of about 1.5 mm with corresponding surface finish. Accuracy on the width of slots and diameter of holes is ordinarily from ± 0.8 mm on 6 to 30 mm thick plates, and ± 3.0 mm on 100 to 150 mm thick plates.

Applications of PAM : This is chiefly used to cut stainless steel and aluminum alloys. Profile cutting of metals, particularly of these metals and alloys, has been the most prominent commercial application of PAM. PAM has been used successfully in turning and milling of materials which are hard and difficult to machine.

Advantages and limitations : The principal advantage of this process is that it is almost equally effective on any metal, regardless of its hardness of refractory nature. There being no contact between the tool and workpiece, only a simply supported workpiece structure is enough.

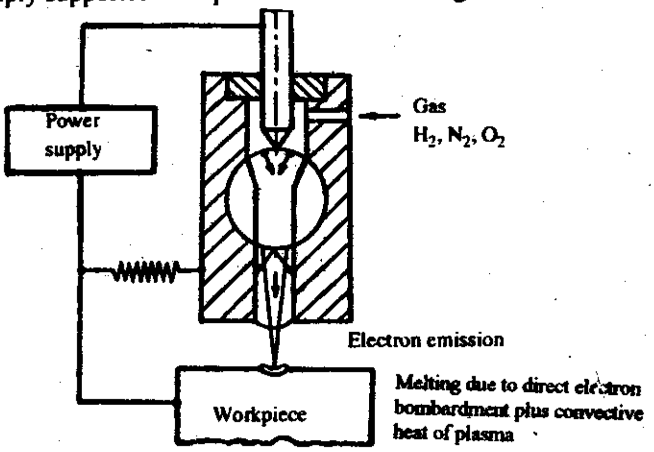

Figure 20.15 Plasma arc machining

The main disadvantages of this process are the metallurgical change of the surface. Safety precautions are necessary for the operator and those in near-by areas. This adds additional cost.

20.12 ION BEAM MACHINING

Ion - beam machining or etching is generally a surface finishing process in which the material removal takes place by *sputtering* of ions.

The process is different from electric discharge, electron beam, laser and plasma arc machining in that the process does not depend on heating of the workpiece to the point of evaporation.

TABLE 20.8 VARIATION OF CUTTING SPEED OF PAM WITH ARC CURRENT

Material	*Thickness (mm)*	*Arc current (A)*	*Cutting speed (mm/min)*
Stainless steel	75	800	380
	130	1000	150
Aluminium	75	900	760
	180	1000	180
Brass	13	400	1780
Titanium	13	400	2300

Source : Fundamentals of machining and machine tools, Boothroyd G. and W.A.Knight, Mercel Dekker, Inc.

This sputter etching mechanism is very simple. It consists in bombarding the work with accelerated ions which collide with the surface atoms of the work. Each bombarding ions, as a result of collisions, dislodges surface layer.

It consists of an electron gun discharging free electrons into a chamber filled with argons gas. The gas is then ionized by electrons. The top of the chamber is known as ion-beam generating apparatus. At the other end, the workpiece is fixed to a table which can be oscillated and rotated so that different points on the work surface can be subjected to ion-beam.

Accuracy : Practical etching rates vary up to 2000 Å (2×10^{-4}) per min. The accuracy of the etching process is considerably high mainly due to the small amount of material removal. Tolerances in the vicinity of ± 50 Å (± 50×10^{-6m}) are possible.

Applications of IBM : It is applied mostly in micro-machining (etching) of electronic components like computer parts, figuring optical surfaces and for the precision fabrication of fine wire dies in refractory materials. Typical materials that can be etched include glass, alumina, quartz, crystal, silica, agates, porcelains, cermets and numerous metals and oxides.

Ion beams can also be used to deposit materials such as platinum, tungsten and silicon oxide insulators on other material substrate. In these applications, the beam parameters and gas flow are optimised for the most efficient equilibrium condition between the cracking of the precursor gases and the milling action of the beam. Fig.20.16 shows the schematic diagram of a ion beam machining process.

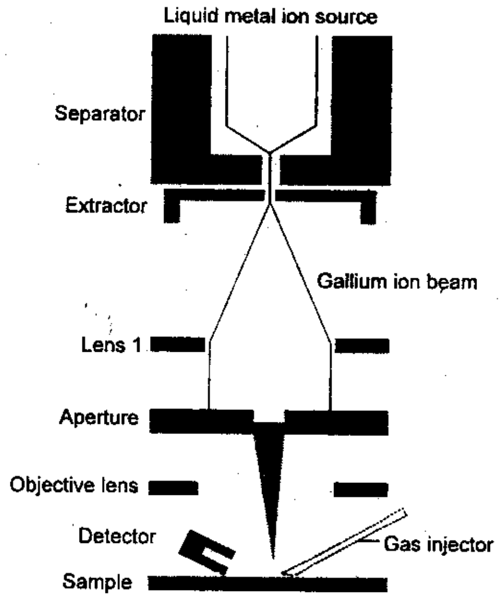

Figure 20.16 Ion beam machining process

Advantages and disadvantages : Ion-beam has many *advantages* which ncludes :

1. The process is almost universal.
2. No chemical reagents or etching are required.
3. There is no undercutting as with other chemical etching process.
4. Etching rates are easily controlled.

However, the process has many *disadvantages* which are as follows :

1. It is relatively expensive.
2. Etching rates are slow.
3. Although virtually no heat is generated there is little possibility of some thermal or radiation damage.

REVIEW QUESTIONS

1. How would you classify the non-traditional machining processes? Explain. State the specific features of these processes.
2. Explain ultrasonic machining processes. Specify some of its process characteristics.
3. List the common materials used for USM tools.
4. List the common abrasive powders used in USM.
5. What is chemical milling? How it is done?
6. Explain the purpose of masking in chemical milling.
7. In what cases is chemical milling advantageous, and when not?
8. What are the materials commonly used for making a tool in ECM?
9. Explain the principle of ECM. List its advantages. Is there any limitation on the type of material that can be machined by ECM? List ECM applications.
10. Describe the operation of electro chemical grinding (ECG) with the help of a heat sketch? What are the differences between ECG and conventional grinding?
11. Briefly describe the principle of electro-discharge machining (EDM) process. What are the advantages and disadvantages?
12. Explain the function of di-electric fluid in EDM. Name the common di-electric fluids used in EDM.
13. What is overcut in EDM?
14. Explain how electron beam machining (EBM) process is carried out. What are the limitations?
15. What is LASER? Explain how LASER is utilized on machining materials. Differentiate LBM and EBM.
16. Explain the principle of plasma arc machining (PAM). What are the various types of PAM.