# Mechanical Engineering

Section A :

## Production Engineering

Section B :

## Maintenance Engineering

**Comprehensive Theory**

with **Solved Examples** and **Practice Questions**

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Section A :

# Production Engineering

Comprehensive Theory

with **Solved Examples** and **Practice Questions**

Chapter 7

# Non Traditional Machining Methods

## 7.1 Unconventional Machining

### 7.1.1 Machining Processes

The machining process described in this section removes material by chip formation, abrasion or microchipping. There are situations, however, where these processes are not satisfactory economical or even possible for the following reasons:

- The hardness and strength of the material is very high or the material is too brittle.
- The workpiece is too flexible, slender or delicate to withstand the cutting or grinding forces, or the parts are difficult to fixture, that is to clamp in work holding devices.
- The shape of the part is complex, including such features as internal and external profiles or small diameter holes in fuel injection nozzle.
- Surface finish and dimensional tolerance requirement are move rigorous than those obtain by other processes.
- Temperature rise and residual stresses in the workpiece are not desirable or acceptable.

The requirement led to the development of chemical, electrical, laser and other means of material removal. Beginning in the 1940's, these advanced methods which in the past have been called unconventional or nontraditional machining when selected and applied properly, advanced machining processes offer major technical and economic advantage over traditional machining method. This chapter describes these processes, including their typical application, limitations and consideration of quality, dimensional accuracy, characteristic of surface produced and economics.

**Table 7.1** Non Traditional Machining Methods

| Energy | Mechanics of Material removal | Source | Process |
|---|---|---|---|
| Mechanical | Plastic shear | Mechanical motion of job/tool | Conventional machining |
| | Erosion | Mechanical/fluid motion | AJM, USM |

| | | | |
|---|---|---|---|
| Electrochemical | Ion displacement | Electric current | ECM |
| Mechanical and Electrochemical | Plastic shear and ionic displacement | Electric current and mechanical motion | ECG |
| Chemical | Corrosive reaction | Corrosive agent | Chemical Machining (CHM) |
| Thermal | Fusion and vapourization | Electric spark | EDM |
| | | High speed electrons | EBM |
| | | Power full radiation | LBM |
| | | Ionized substance | IBM |
| | | High temp. plasma | PAM |

## 7.2 Ultrasonic Machining (USM)

- Ultrasonic means those vibrational waves having a frequency above the normal range.
- In this method a slurry of abrasive grains are hammered on to the work surface by vibrating tool normal to work surface removing work piece material in the form of **extremely small chip**. (as shown in Figure 7.1)
- Tool is fed gradually towards work by feed mechanism.
- In ultrasonic machining the abrasives are suspended in a fluid medium to form a slurry water is the most commonly used fluid. Other liquid used are **benzene**, oils etc.

  The stress produced by impact of abrasive particles on the workpiece surface is high because the time of contact between the particle and the surface is very short and the area of contact is very small.

  In brittle materials, these impact stresses are sufficiently high to cause microchipping and erosion of the workpiece surface. Ultrasonic machining is best suited for material that are holed and brittle such as ceramics, carbides, precious stones and hardened steels.

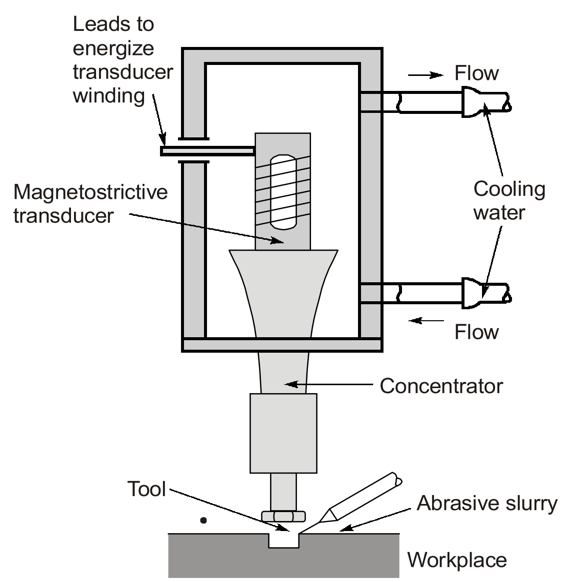


**Figure 7.1** Machining using ultrasonic machining

**Advantages :**

- It operates at very low noise on no noise.
- Equipment used in the operation can be operated by skill as well as unskilled labor.
- Heat generation is negligible.

- Good surface finish and high accuracy.
- Every material can be machined irrespective of conductivity.

**Disadvantages :**

- Material remove is very low.
- Energy require for cutting is very high.
- Softer material is difficult to machine.

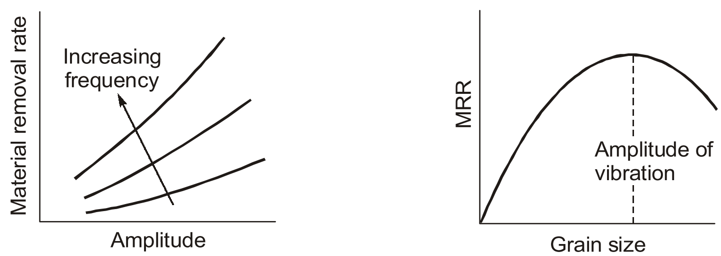


**Figure 7.2 (a)** **Figure 7.2 (b)**

**Application :**

- It is normally used for making dies.
- It is also used for machining hard carbides glasses and precious stones.
- It is also used for dental application.

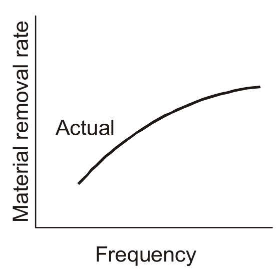


**Figure 7.3**

## 7.3 Abrasive Jet Machining

**Principle**

- The fundamental principle of abrasive jet machining involves the use of high velocity stream of abrasives particles carried by a high pressure gas through nozzle on the work piece.
- Metal removal occurs due to erosion by the abrasive particles impacting the work surface at high speed.

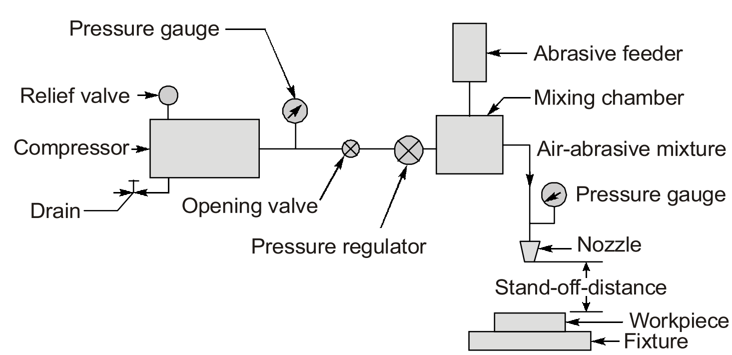


**Figure 7.4** Line diagram of Abrasive Machining

In abrasive jet machining (AJM), a high velocity jet of dry air, nitrogen or carbon dioxide, containing abrasive particles, is aimed at the workpiece under controlled conditions. The impact of the particles develops a sufficiently concentrated force to perform operation such as cutting small holes, slots or intricate patterns in very hard or brittle metallic and nonmetallic material deburring or removing small flash from parts, trimming and beveling, removing oxides and other surface films and general cleaning of components with irregular surfaces.

The gas supply pressure is on the order of 850 kPa and the abrasive jet velocity can be as high as 300 m/s and is controlled by a valve. The hand held nozzles are usually made of tungsten carbide or sapphire. The abrasive size is in the range of from 10 to 50 mm. Because the flow of the free abrasives tends to round off corners design for abrasive jet machining should avoid sharp corners ; also holes made in metals parts tend to be tapered.

There is some hazard involved in using this process because of air borne particulates. This problems can be avoided by using the abrasive water jet machining process.

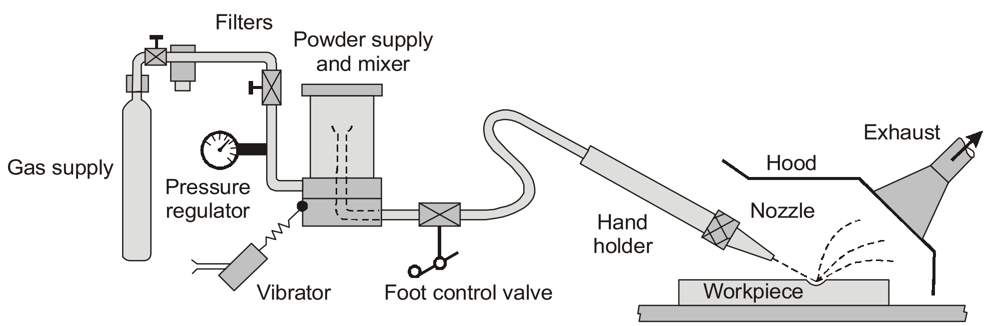


**Figure 7.5** Abrasive-jet machining process

**Abrasive Water Jet Machining**

In abrasive water jet machining (AWJM) the water jet contains abrasive particles [such as silicon carbide or aluminium oxide], which increase the material removal rate about that of water jet machining. Metallic, non metallic and advanced composite material of various thickness can be cut in single or multilayer.

This process is suitable particularly for heat sensitive materials that cannot be machined by processes in which heat produced. Cutting speed can be as high as 7.5 m/min for reinforced Plastic, but much lower for metals consequently, this process may not be acceptable for situations require high production rates.

The minimum hole size that can be produced satisfactory to be about 3 mm and maximum hole depth is on the order of 25 mm. With multiple axis and robotic control machines complex three dimensional parts can be machined to finish dimensions. The optimum level of abrasives in the jet stream is controlled automatically in modern AWJM systems. Nozzle life has been improved by making nozzles from rubies, sapphires and carbide based composite materials.

## 7.4 Nozzle Tip Distance (NTD)

- Distance between work piece and the tip of the nozzle is called nozzle tip distance. It varies from 7 to 13 mm.
- Nozzles are subjected to high degree of wear so they are made or hard material like tungsten carbide or ceramics.

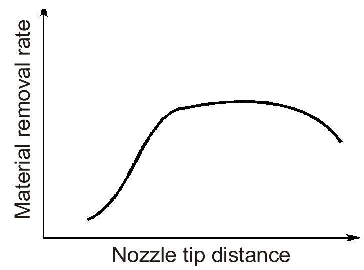


**Figure 7.6** **(a)** Variation of MRR with respect to stand off distance

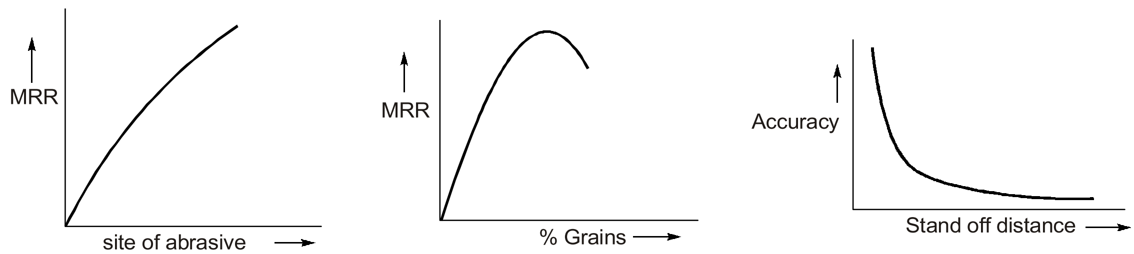


**Figure 7.6** **(b)** Variation of MRR with respect to grain size, % of grains and stand off distance

## 7.5 Electric Discharge Machining (EDM)

The principle of electric discharge machining (EDM) also called electro discharge spark erosion machining, is based on the erosion of metals by sparks discharges. We know that when two current conducting wires are allowed to touch each other, an arc is produced. If we look closely at the point of contact between two wires, we note that a small portion of the metal has been eroded away, leaving a small crater.

Although this phenomenon has been known since the discovery of electricity it was until the 1940's that a machining process based on this principle was developed. This EDM process has become one of the most important and widely accepted production technologies in manufacturing.

**Principle of Operation**

The basic EDM system consists of a shaped tool (electrode) and workpiece (as shown in Figure 1.98 (a)), connected to a *dc* power supply and placed in a dielectric (electrically non conducting) fluid. When the potential difference between the tool and the workpiece is sufficiently high, a transient spark discharges through the fluid, removing a very small amount of metal from the workpiece surface the capacitor discharge is repeated at rate of between 50 kHz and 500 kHz with voltage usually ranging between 50 V and 380 V and current from 0.1 A to 500 A.

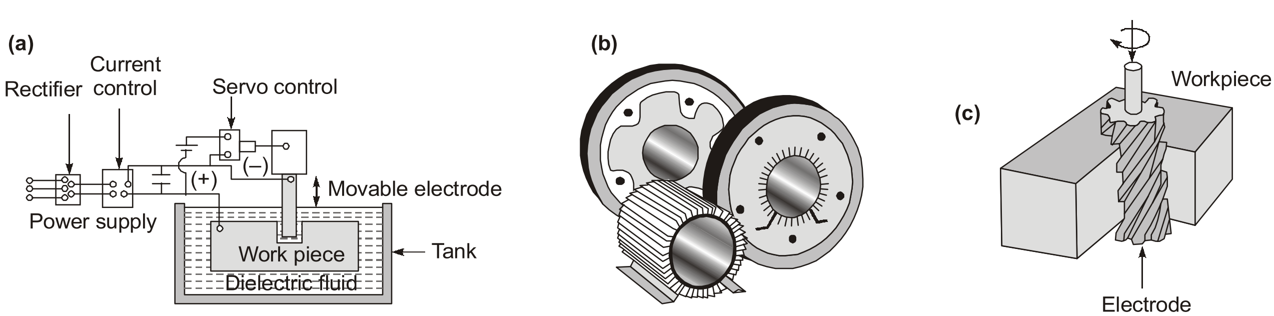


**Figure 7.7** **(a)** The electrical-discharge machining process **(b)** Examples of cavities produced by the electrical-discharge machining process, using shaped electrodes **(c)** A spiral cavity produced by EDM using a slowly rotating electrode, similar to a screw thread

The workpiece is fixtured within the tank containing the dielectric fluid, and its movements are controlled by numerically control system. The gap between the tool and the workpiece is critical; thus the downward feed of the tool is controlled by a **servomechanism**, which automatically maintains a constant gap.

The most common dielectric fluids are minerals oils, although kerosene and distilled and deionized water are also used in specialized applications.

Recent trends involve the use of clear low viscosity fluids ; although more expansive, these fluids make cleaning easier. The machine are equipped with a pump and filtering system for the dielectric fluid.

The EDM process doesn't involve mechanical energy, the hardness, strength and toughness of the workpiece material don't necessarily influence the removed rate. The frequency of discharge or the energy per discharge is usually varied to control the removal rates as are the voltage rate and surface roughness increases with increasing current density and decreasing frequency of sparks.

The EDM process can be used on any material that is an electrical conductor. The melting point and the latent heat of melting are important physical properties that determine the volume of metal removed per discharge. As these quantities increase, the rate of material removal decreases. The volume of material removed per discharge is typically in the range of $10^{-6}$ to $10^{-14}$ $mm^3$.

Tool wear is an important factor because it affects dimensional accuracy and the shape produced. Tool wear is related to the melting points of the materials involved ; the lower the melting point the higher the wear rate.

Consequently, graphite electrode have the highest wear resistance. Tool wear can be minimized by reversing the polarity and using copper tools, a process called No - wear

## 7.6 Process Capabilities

Electrical discharge machining has numerous applications, such as the production of die cavities for large automotive body components (die sinking machining centres) deep small diameter holes with tungsten wire as the electrode, narrow slots in parts, turbine blades and various intricate shapes.

### 7.6.1 Uses of Dielectric Fluid

- It acts as a vehicle to drive away the clips and thus preventing them from sticking to the surface of tool.
- It helps in increasing the MRR by promoting spark between tool and work.
- It also acts as a coolant medium.
- EDM process is also called **spark erosion machining** where the material is removed by erosion or repeated sparks.
- It is high voltage and low current process.

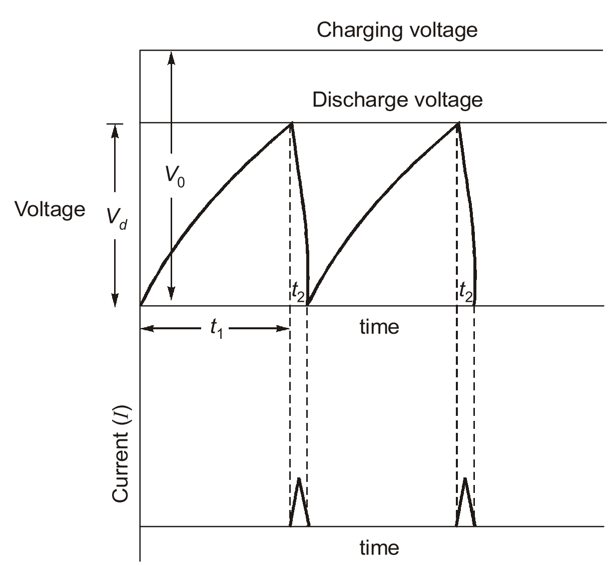


**Figure 7.8** Variation of Current and Voltage

### 7.6.2 Tool Material

- In EDM tool also erodes due to spark hence the selection of tool depends upon wear ratio, ease of tool fabrication and cost of material.
- The most commonly used electrode material are : Cu, Tungsten alloys, Cast iron, Steel etc.

**NOTE**

In electric discharge machining metal is removed due to erosion caused by rapidly occurring discharge between the tool and work. Mechanism of material removal is melting and evaporation. The basic principle is that when a discharge take place two points intense heat is generated near sparking zone. Positive terminal erodes out faster so w/p is made anode. Only good conductor of electricity can be machine irrespective of hardness.

**Advantages**

- MRR is very high as compare to other unconventional machining.
- Surface finish is very good.
- Complex cavities can also be cut by this process.

**Disadvantages**

- Only good conductors material can be machined with this process.
- Tool wears limit the accuracy.
- Tool wear rate is very high.

$R$ = Resistance in relaxation circuit

$V_0$ = Supply voltage

$V_d$ = Discharge voltage

$P$ = Power input in kW

MRR = Metal removal rate

$$E = \frac{1}{2} C \times V^2$$

$$V_d = V_0(1 - e^{-t/Rc}) \qquad \left[\because \frac{t}{RC} = N\right]$$

$$E = \frac{1}{2} CV_0^2 \left(1 - e^{-N}\right)^2$$

$$P = \frac{E}{t} = \frac{RCV_0^2 \left(1 - e^{-N}\right)^2}{R2t} = \frac{V_0^2 \left(1 - e^{-N}\right)^2}{2RN}$$

$$\frac{dP}{dN} = 0$$

$$N = 1.26$$

$$\frac{V_d}{V_0} = 1 - e^{-1.26} = 0.72$$

$$V_d = 0.72\, V_0$$

EDM process is spark erosion machining where the material is removed by the erosion due to repeated sparks. Its high voltage and low current process. [During machining kerosene burns providing solid lubrication] During a major portion of cycle capacitor charges and once voltage reaches a threshold value, all the capacitors will discharge simultaneously providing a spark at the tool tip.

- When spark hits the workpiece a crater will be produced over it. During machining tool material also melts out thus graphite is used for high M.P. Some copper is added to graphite to increase the conductivity.
- If thermal conductivity of workpiece increases then material removal rate decreases.

- If specific heat of the tool is low then tool wear will be high.
- The removed material starts accumulating in the tool work gap and flushing mechanism removes the material by servo-mechanism.
- A mean spark gap voltage at constant value is maintained.

**Application**

- For blind cavities and making slots in dies.
- For machining orifice, airbrake valves, slots in diesel fuel injection nozzle.

**Example 7.1** In an EDM process using RC relaxation circuit, a 12 mm diameter through hole is made in a steel plate of 50 mm thickness using a graphite tool and kerosene as dielectric. Assume discharge time to be negligible. Machining is carried out under the following conditions

Resistance = 40 Ω

Capacitance = 20 μF

Supply voltage = 220 V

Discharge voltage = 110 V

1. The time for one cycle, in milliseconds is
   (a) 0.55 (b) 0.32 (c) 0.89 (d) 0.24
2. Average power input (in kW) is
   (a) 0.373 (b) 0.137 (c) 0.218 (d) 0.5

**Solution:**

1.
$$V_d = V_0\left(1-e^{-t_1/RC}\right)$$
$$110 = 220\left(1-e^{-t_1/40\times20\times10^{-6}}\right)$$
$$0.5 = 1-e^{-t_1/8\times10^{-4}}$$
$$e^{-t_1/8\times10^{-4}} = 0.5$$
$$-\frac{t_1}{8\times10^{-4}} = \ln 0.5$$
$$-\frac{t_1}{8\times10^{-4}} = -0.693$$
$$t_1 = 5.545\times10^{-4}\text{ s}$$
$$= 0.5554\text{ ms}$$

2. Average power,
$$P_{avg} = \frac{E}{t_1} = \frac{\frac{1}{2}CV_d^2}{t_1} = \frac{0.5\times20\times10^{-6}\times110^2}{0.554\times10^{-3}} = 218.4\text{ W} = 0.218\text{ kW}$$

**Example 7.2** In EDM, if the thermal conductivity of tool is high and the specific heat of workpiece is low, then the tool wear rate and material removal rate are expected to be respectively.

(a) High and high (b) Low and low (c) High and low (d) Low and high

**Solution:**

If thermal conductivity of tool is high then its wear will be low. If specific heat of workpiece is low then its will be removed at a higher rate. Thus, answer is (d).

## 7.7 Wire Cut EDM

- Used for cutting sheets into complex shapes.
- Instead of moving electrode - a moving wire is used.
- Work table should have moments in $x$ and $y$-axis to cut the plate in desired shape.

**Example 7.3** A titanium sheet of 8 mm thickness is cut by wire cut EDM process using a wire of 1 mm diameter. A uniform spark gap of 0.4 mm on both sides of the wire is maintained during cutting operation. If the feed rate of the wire into the sheet is 20 mm/min. Material removal rate in ($mm^3$/min)

(a) 150 (b) 288 (c) 300 (d) 400

**Solution : (b)**

Area of slot = gap × thickness

Width of slot = 1 + 0.4 + 0.4 = 1.8 m

$A = 1.8 \times 8 = 14.4 \text{ mm}^2$

$\text{MRR} = 14.4 \times 20 = 288 \text{ mm}^3/\text{min}$

## 7.8 Electric Discharge Grinding (EDG)

- Its similar to EDM except that the electrode is rotating wheel (usually graphite).
- Here also the complete workpiece is immersed in dielectric fluid and is fed past the wheel by servo-controlled machine table.
- Metal chips are flushed among by the dielectric fluid carried through the cutting area by the wheel rotation.

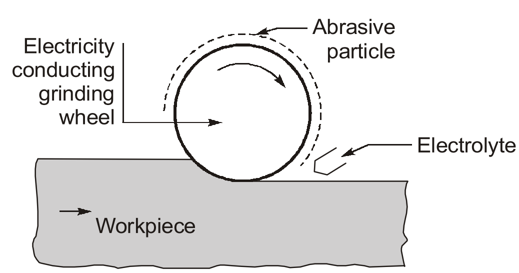


**Figure 7.9**

**Application**

- Grinding carbide and steel workpieces without wheel loading.
- Grinding thin sections without distortion.
- Grinding brittle parts without fracturing.

**NOTE :** No contact between tool and work piece. Specific power consumption is very large. Metal removal rate is low. It is used for machining very hard material for precision work.

## 7.9 Electro Chemical Machining

Electrochemical Machining (ECM) is basically the reverse of electroplating. An electrolyte acts as current carrier and the high rate of electrolyte movement in the tool workpiece gap washes metal ions away from the workpiece before they have a chance to plate onto the tool (cathode). Modification of this process are used for turning facing slotting, trepanning and profiling operations in which the electrode becomes the cutting tool.

### 7.9.1 Main Function of Electrolyte

- Complete the electrical circuit between the tool and the work piece and allow large current to pass through it.
- To carry away the heat and waste product of reactions.
- Allow electro chemical reaction at a faster rate.

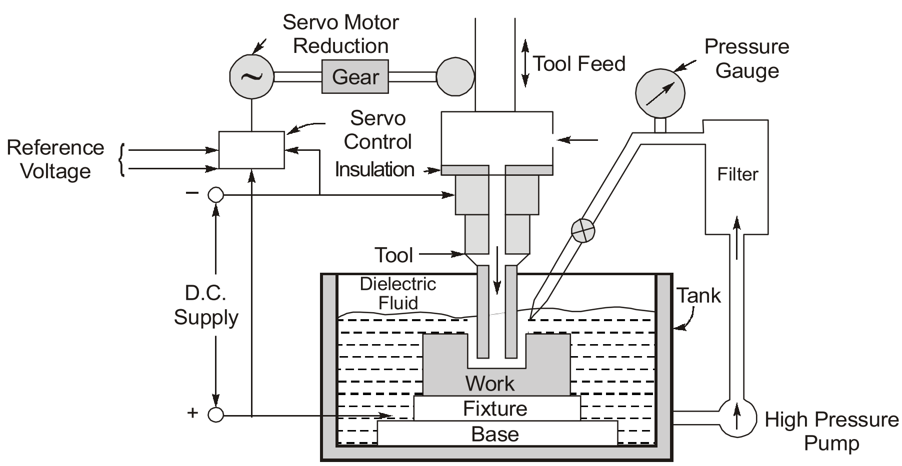


**Figure 7.10** Electrode Discharge Machining

### 7.9.2 Mechanism

Mass of material remove ∝ charge

$$\text{Mass} \propto q \propto It$$

$$M = ZIt$$

we know

$$Z = \frac{e}{F}$$

$Z$ = Electrochemical equivalent

$F$ = Faraday's constant = 96500

$e$ = Chemical equivalent (atomic *wt*/valency)

$I$ = Current passed

$t$ = Time

$$\text{Metal removal rate} = \frac{eI}{F\rho} = sI$$

$\rho$ = density

$$s = \text{specific material removal rate} = \frac{e}{F\rho}$$

$$\text{Electrode feed rate} = s \times S_1$$

$$S_1 = \text{Current density} = \frac{I}{A}$$

$$I = \frac{\Delta V}{R}$$

$$R = \rho_s \frac{L}{A}$$ ($\rho_s$ - electrical resistivity)

$$S_1 = \frac{\Delta V}{\rho_s L}$$ ($L$ - Gap between tool and work piece)

**Example 7.4** Calculate the MMR and electrode feed rate when copper is electrochemically machined. Under following conditions?

$\rho_s = 5\ \Omega$ cm, Tool gap = 0.5 m, $\Delta V = 18$ V, Atomic wt. = 56, $I = 500$ A, Valency = 2, $\rho = 7.8$ g/cm$^3$.

**Solution :**

$$\text{MMR} = \frac{eI}{F\rho}$$

e = chemical equivalent (Atomic wt/ valency)
ρ = density
$I$ = current
F = Faraday's constant (96500)

$$e = \frac{56}{2} = 28$$

$$F = 96500$$

$$\rho = 7.8 \text{ g/cm}$$

$$I = 500 \text{ A, MRR} = \frac{28 \times 500}{96500 \times 7.8}$$

$$\text{MRR} = 0.0186 \text{ cm}^3\text{/s}$$

$$\text{Electrode feed rate} = s \times S_1$$ ($s$ = specific material removal rate (MRR)

$$s = \frac{e}{F \times \rho}$$

$$S_1 = \frac{\Delta V}{\rho_s L} = \frac{18}{5 \times 0.5} = 0.134 \text{ cm/s} = 72 \text{ Amp/m}^2$$

$$\text{Electrode feed rate} = 3.72 \times 10^{-5} \times 72 \text{ cm/s} = 0.0267 \text{ mm/s}$$

**Example 7.5** A researcher conducts ECM on a binary alloy (density 6000 kg/m$^3$) of iron (atomic weight 56, valency 2) and metal $P$ (atomic weight 24, valency 4) Faraday's constant 96500 coulomb/mole. Volumetric material removal rate of the alloy is 50 mm$^3$/s at a current of 2000 A. What is the percentage of metal $P$ in the alloy.

**Solution :**

The chemical equivalent is,
$$\frac{1}{e} = \frac{4}{24}\left(\frac{x}{100}\right) + \frac{2}{56}\left(\frac{100-x}{100}\right) \quad \text{... (i)}$$

where percentage of $P$ in alloy is $x$,
$$\text{MRR} = \frac{eI}{F\rho}$$
$$50 = \frac{e \times 2000}{96500 \times 6000 \times 10^{-6}}$$
$$e = 14.475$$

Now putting value of $e$ in equation (i), $x = 25.482\%$

**Example 7.6** Electro chemical machining is performed to remove material from an iron surface of 20 × 20 mm.

Inter-electrode gap = 0.2 mm

Supply voltage = 12 V

Special resistance of electrolyte = 2 Ω cm

Atomic weight = 55.85

Valency = 2

Faraday's constant = 96540

What is the material removal rate (in gm/s)

**Solution :**

$$\text{MMR} = \frac{eI}{F\rho} = \frac{55.85 \times I}{2 \times 96540 \times \rho} \qquad R = \rho\frac{l}{A} = 2 \times \frac{0.02}{2 \times 2} = 0.01$$
$$I = \frac{12}{0.01} = 1200 \text{ A}$$
$$\frac{\text{cm}^3}{s} \times \frac{\text{gm}}{\text{cm}^3} = \frac{55.85 \times 1200}{2 \times 96540} = 0.3471 \text{ gm/sec}$$

**Example 7.7** Evaluate MRR for Nimonic alloy {CO-Ni-Cr}

| | | |
|---|---|---|
| CO - 18% | 58.93 | 2 |
| Ni - 62% | 58.71 | 2 |
| Cr - 20% | 51.99 | 6 |

$I$ = 500 A; $d_2$ = 8.28 gm/cm$^3$

**Solution :**

$$\frac{1}{e} = \frac{2}{58.93} \times 0.18 + \frac{2}{58.71} \times 0.62 + \frac{6}{51.99} \times 0.2$$
$$= 6.1 \times 10^{-3} + 0.0211 + 0.023$$
$$\frac{1}{e} = 0.05$$
$$l = 19.89$$
$$\text{MRR} = \frac{eI}{F\rho} = \frac{19.89 \times 500}{96500 \times 8.28} = 0.0124 \text{ cm}^3/\text{s}$$

**Example 7.8** In an ECM operation _____ hole of dimensions 3 × 5 mm is drilled in a copper block. The current used in 8000 A. Atomic weight of copper is 63 and valence of dissolution is 1. $F$ = 96500 Coulomb. Material removal rate (gm/s)

(a) 0.522 (b) 5.22 (c) $5.22 \times 10^3$ (d) $5.22 \times 10^5$

**Solution : (b)**

$$\text{MRR} \times \rho = \frac{eI}{F} = \frac{63}{1} \times \frac{8000}{96500} = 5.22$$

## 7.10 Electrochemical Grinding

Work is machined by considered action of electrochemical effect (90%) and conventional grinding (10%). Rotating grinding wheel will be used as a tool.

**Features of ECG process are**

- Tool wear negligible and more tool life.
- No surface stresses and distortion.
- Used for shaping and sharpening of consider cutting tools.

The shaped tool is generally made of brass, copper, bronze or stainless steel. The electrolyte is highly conductive inorganic salt solution, such as sodium chloride mixed in water or sodium nitrate. It is pumped at a high rate through the passages in the tool. A *dc* power supply in the range of 5 - 25 V maintains current densities which for most applications are 1.5 - 8 A/mm$^3$ of active machined surface.

Machines having current capacities as high as 40,000 A and as low as 5 A are available. The penetration rate of the tool is proportional to the current density. Because the metal removal rate is only a function of ions exchange rate, it is not affected by strength hardness or toughness of the workpiece.

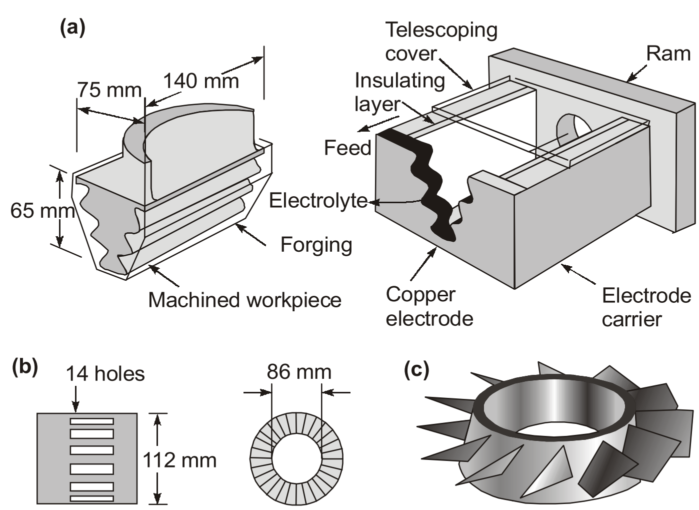


**Figure 7.11** **(a)** Turbine blade made of a nickel alloy **(b)** Thin slots on a 4340-steel roller-bearing cage **(c)** Integral airfoils on a compressor disk

**Process Capabilities :** Electrochemical machining is generally used to machine complex cavities in high strength material, particulars in the aerospace industry for the mass production of turbine blades jet engine parts and nozzle. It is also used to machine forging die cavities and to produce small holes. The ECM process leaves a burr free surface in fact it can also be used as a deburring process. It doesn't cause any thermal damage to the part and the lack of tool forces prevents distortion of parts further more there is not tool wear and the process is capable of producing complex shapes as well as machining hard materials.

However, the mechanical properties of components made by ECM should be compared carefully to those of other material removal methods. Electro chemical machining systems are now available as numerically controlled machining centers with the capability of high production rates, high flexibility and the maintenance of close dimensional tolerance.

**NOTE**

This process is an extension of already known process of electroplating with modification in reverse direction. A shaped tool or electrode is used in the process which form cathode and work piece form anode. A small gap is maintained between the tool and the work piece and electrolyte is pump through it. Low voltage direct current is used which in the presence of electrolyte enables a control removal of metal form work piece by anodic dissolution. Electrolyte is pumped at a high pressure through the small gap between tool and work.

## 7.11 Laser Beam Machining

In laser beam machining (LBM) (as shown in Figure 7.12 (a)) the source of energy is a laser, which forces optical energy on the surface of the workpiece. The highly focused high density energy melts and evaporates portions of the workpiece in a controlled manner. This process, which does not require vacuum is used to machine a variety of metallic and non metallic materials.

There are several type of laser used in manufacturing operations

(a) $CO_2$ (Pushed or continuous wave) laser
(b) Nd:- YAG (neodymium) laser
(c) Nd: Glass, ruby laser
(d) Exclaimer lasers.

Important physical parameter in LBM are the reflectivity and thermal conductivity of the workpiece surface and its specific heat and latent heats of melting and evaporations. The lower these quantities, the move efficient the process. The surface produced by LBM is usually rough and has a heat affected zone which is critical in application and may have to be removed or heat treated. Kerf width is an important consideration, as it is in other cutting process, such as sawing, wire EDM and electron beam machining.

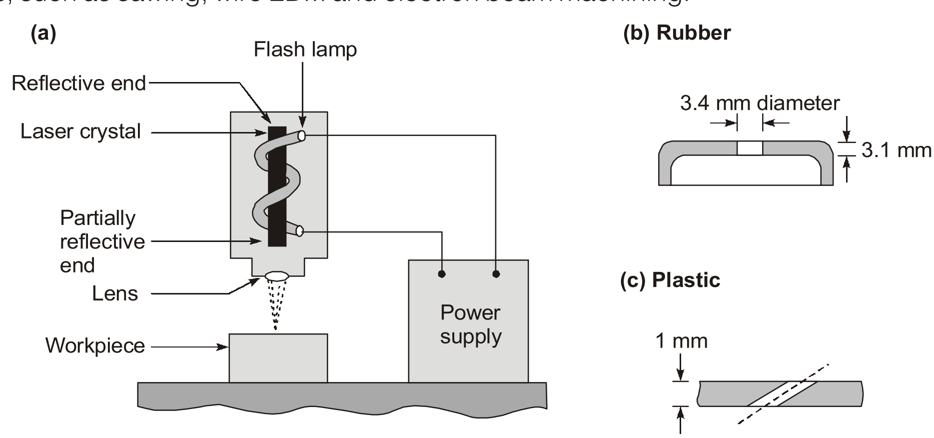


**Figure 7.12** **(a)** Illustration of the laser-beam machining process **(b)** and **(c)** examples of holes produced in nonmetallic parts by LBM

Laser beams may be used in combination with a gas stream such as oxygen, nitrogen or organ (Laser Beam Torch) for cutting thin sheet material. High pressure, insert gas asserted laser cutting is used for stainless steel and aluminium. It leaves an oxide free edge than can improve weldability gas streams also have the important function of blowing away molten and vaporized material from the workpiece material.

Laser beam are also used for following :

1. Welding
2. Small scale and localized heat treating of metals and ceramics to modify their surface mechanical and tribiological properties.
3. The marking of parts such as letters numbers, codes etc. Marking can also be done by processes such as with ink, with mechanical devices such as pins, punches, styles, scroll trimming.

   Although the equipment is more expansive than that used in other methods, marking and engraving with laser has become increasingly common due to its accuracy, reproducibility flexibility, ease of automation and on-line application in manufacturing.

   The cutting process, with its fiber optic beam delivery simple fixturing and low set up times and the availability of multi kW machines and 2 D and 3 D computer controlled laser cutting systems are attractive features. Therefore laser cutting can compete successfully with cutting sheet metal with the traditional punching processes. There are now efforts to combine the two processes for improved over all efficiency.

   Extreme caution should be exercised with lasers. Because power lasers can cause damage to the retina of the worker if proper precautions are not observed.

**NOTE**

In this method focusing of laser on the workpiece result into a very high surface temperature, resulting in metal removal due to melting and evaporation. The rays of laser are perfectly parallel and they can be focused to a very small diameter. It is costly method and is used only when it is not feasible to machine with other process. It is used to dull micro hole, cutting very slots in very hard material like diamond, used for making drawing dies. Heat affected zone in this process is very less.

## 7.12 Electron Beam Machining

The source of energy in electron beam machining (EBM) is high-velocity electrons, which strike the surface of the workpiece utilize voltage in the range of 50 kV-220 kV to accelerate the electrons to speed of 50% to 80% of the speed of light. Its application are similar to those of laser beam machining except that EBM requires a vacuum. Consequently, it is used much less than laser beam machining

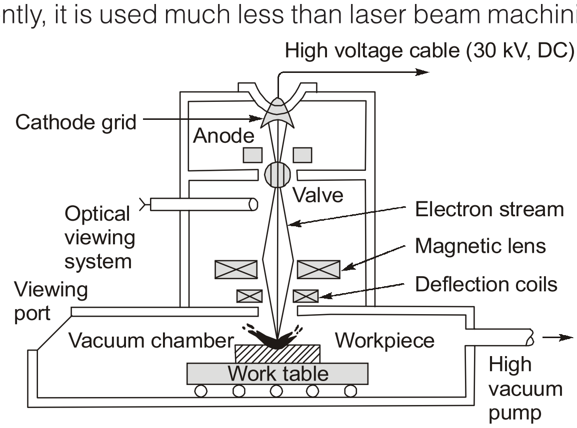


**Figure 7.13** The electron-beam machining process. Unlike LBM, this process requires a vacuum, so workpiece size is limited to the size of the vacuum chamber

Electron beam machining can be used for very accurate cutting of a wide variety of metals. Surface finish is better and Kerf width is narrower than that for other thermal cutting process the interaction of the electron beam with the workpiece surface produces hazardous X-rays ; equipment should therefore, be used only by highly trained personnel.

**NOTE**

Electron beam machining is the process of machining material with the use of very high velocity beam of electrons. The work piece is held in vacuum chamber and the electron beam focused on it. When it strikes the surface of material it result into generation of very high temperature. Leading to metal removal due to melting and evaporation. Used for drilling very fine holes, cutting, contours and very narrow slots. It is also used for producing metering hole in injector nozzle of diesel engines.

MRR : ECM > EDM > USM
Tool Wear : USM > EDM > ECM

**Example 7.9** In an AJM process if $Q$ = flow rate of abrasives MRR is proportional to

(a) $Q/d^2$ (b) $Qd$ (c) $Qd^2$ (d) $Qd^3$

**Ans. (d)**

$$\text{MRR} = KQd^3V^{3/2}\left(\frac{l}{2H}\right)^{3/4}$$

## 7.13 Water Jet Machining

- Water-jet alone (without abrasives) can be used for cutting.
- Thin jets of high pressure and high velocity have been used to cut materials such as wood, coal, textiles, rubber, rocks, concrete, asbestos and leather.
- The mechanism of MRR is by erosion,
- When high pressure water jet emerges from a nozzle,it attains a large kinetic energy.
- When this high velocity jet strikes the workpiece, its kinetic energy is converted into pressure energy inducing high stresses in the work material.
- When the induced stress exceeds the ultimate shear stress, the material removal takes place.

**NOTE**

- No moving parts in the system.
- Less operating and maintenance cost.
- Safe process.
- No thermal damage.
- Convenient process to cut soft material like rubber because teeth logged in conventional methods.

## 7.14 Plasma Arc Machining

A plasma is a high temperature ionized gas. The plasma arc machining is done with a high speed jet of a high temp. plasma. The plasma jet heats up the workpiece where it impinges, causing a quick melting, PAM can be used on all material. Which conduct electricity, inducing those which are resistant to any fuel gas cutting. The process is extensively used for profile cutting of stainless steel, normal and super alloy plates.

A plasma is generated by subjecting a flowing gas to the electron bombardment of an arc. For this, the arc is set up between the electrode and the anodic nozzle; the gas is forced to flow through this arc.

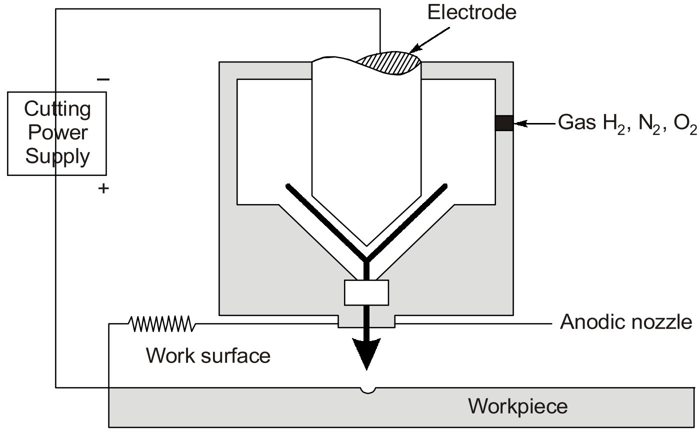


**Figure 7.14**

The high velocity electrons of the arc collide with the gas molecules, causing a dissociation of the diatomic molecules or atoms into ions and electrons resulting in a substantial increase in the conductivity of the gas which is now in plasma state. The free electrons, accelerate and cause more ionization and heating. Afterward a further increase in temp takes place when the ions and free electrons recombine into atoms on molecules following an exothermic process.

So a high temp. plasma is generated which is forced through the nozzle in the form of a jet.

The mechanism of material removal is based on (i) heating and melting (ii) removal of the molten metal by blasting action of plasma jet.

Material application – All conducting materials.

Slope application – Cutting plates

Limitation – Low accuracy.

**Example 7.10** Consider the following statements in relation to the NTM.

1. Different forms of energy directly applied to workpiece to have shape transformation or material removal from work surface.
2. Relative motion between the work and the tool is essential.
3. Cutting tool is not in physical contact with workpiece.

Which of the above statements given above are correct?

(a) 1, 2 and 3 (b) 1 and 2 only (c) 2 and 3 only (d) 1 and 3 only

**Solution: (d)**

Statement 2 is incorrect as relative motion between the work and the tool is not essential in non traditional machining methods.

**Example 7.11** Selection of electrolyte for ECM is as follows:

(a) non-passivating electrolyte for stock removal and passivating electrolyte for finish control.
(b) passivating electrolyte for stock removal and non passivating electrolyte for finish control.
(c) selection of electrolyte is dependent on current density.
(d) electrolyte selection is based on tool work electrodes.

**Ans. (a)**

**Example 7.12** In USM the material removal rate would ________ with increasing mean grain diameter of the abrasive material

(a) increase
(b) decrease
(c) increase and then decrease
(d) decrease and then increase

**Ans. (c)**

## Student's Assignments 1 Unsolved

**Example 7.13** In an ECM operations, 8.5 V d.c. supply is used. The conductivity of the electrolyte is 2 $\Omega^{-1}$ $cm^{-1}$ and fed rate of 1 mm/min. The workpiece is pure iron. Calculate the ______ gap.

Given : for prime iron, Atomic weight : 55.85 g, $\rho$ = 7.86 $gm/cm^3$, _________.

**Example 7.14** A laser beam with a power intensity of $10^5$ $W/mm^2$ is used to drill holes in a tungsten sheet of 0.5 mm thickness. If 3 × $10^4$ $J/cm^3$ are required to vapourize tungsten, estimate the time required to drill a through hole. The efficiency many be taken as 10%.

**Example 7.15** For cutting a 150 μm wide slot in a 1 mm thick tungsten sheet, an electron seam 5 kN power is used. Determine the speed of cutting. Special power consumption of tungsten is 12 $W/mm^3$/min.

■■■■