NON-TRADITIONAL MACHINING

INTRODUCTION

Non-traditional manufacturing processes is defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp cutting tools as it needs to be used for traditional manufacturing processes.

Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Non traditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below.

- Very hard fragile materials difficult to clamp for traditional machining
- When the workpiece is too flexible or slender
- When the shape of the part is too complex

Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over non-traditional machining processes. The common non-traditional machining processes are described in this section.

Definition:

A machining process is called *non-traditional* if its material removal mechanism is basically different than those in the traditional processes, i.e. a different form of energy (other than the excessive forces exercised by a tool, which is in physical contact with the work piece) is applied to remove the excess material from the work surface, or to separate the workpiece into smaller parts.

Non Traditional Machining (NTM) Processes are characterised as follows:

- Material removal may occur with chip formation or even no chip formation may take place. For example in AJM, chips are of microscopic size and in case of Electrochemical machining material removal occurs due to electrochemical dissolution at atomic level
- In NTM, there may not be a physical tool present. For example in laser jet machining, machining is carried out by laser beam. However in Electrochemical Machining there is a physical tool that is very much required for machining
- In NTM, the tool need not be harder than the work piece material. For example, in EDM, copper is used as the tool material to machine hardened steels.
- Mostly NTM processes do not necessarily use mechanical energy to provide material removal. They use different energy domains to provide machining. For example, in USM, AJM, WJM mechanical energy is used to machine material,

Need for development of Non Conventional Processes

The strength of steel alloys has increased five folds due to continuous R and D effort. In aero-space requirement of High strength at elevated temperature with light weight led to development and use of hard titanium alloys, nimonic alloys, and other HSTR alloys. The ultimate tensile strength has been improved by as much as 20 times. Development of cutting tools which has hardness of 80 to 85 HRC which cannot be machined economically in
conventional methods led to development of non –traditional machining methods.

1.Technologically advanced industries like aerospace, nuclear power, ,wafer fabrication, automobiles has ever increasing use of High –strength temperature resistant (HSTR) alloys (having high strength to weight ratio) and other difficult to machine materials like titanium, SST,nimonics, ceramics and semiconductors. It is no longer possible to use conventional process to machine these alloys.

2.Production and processing parts of complicated shapes (in HSTR and other hard to machine alloys) is difficult , time consuming an uneconomical by conventional methods of machining

3.Innovative geometric design of products and components made of new exotic materials with desired tolerance , surface finish cannot be produced economically by conventional machining.

4.The following examples are provided where NTM processes are preferred over the conventional machining process:

♦ Intricate shaped blind hole – e.g. square hole of 15 mmx15 mm with a depth of 30 mm with a tolerance of 100 microns

♦ Difficult to machine material – e.g. Inconel, Ti-alloys or carbides, Ceramics, composites , HSTR alloys, satellites etc.,

♦ Low Stress Grinding – Electrochemical Grinding is preferred as compared to conventional grinding

♦ Deep hole with small hole diameter – e.g. φ 1.5 mm hole with l/d = 20

♦ Machining of composites

Differences between Conventional and Non conventional machining processes.

Sl No.	Conventional Process	Non Conventional Process
1.	The cutting tool and work piece are always in physical contact with relative motion with each other, which results in friction and tool wear.	There is no physical contact between the tool and work piece, In some non traditional process tool wear exists.
2.	Material removal rate is limited by mechanical properties of work material.	NTM can machine difficult to cut and hard to cut materials like titanium,ceramics,nimonics, SST,composites,semiconducting materials

3.	Relative motion between the tool and work is typically rotary or reciprocating. Thus the shape of work is limited to circular or flat shapes. In spite of CNC systems, production of 3D surfaces is still a difficult task.	Many NTM are capable of producing complex 3D shapes and cavities
4.	Machining of small cavities , slits , blind holes or through holes are difficult	Machining of small cavities, slits and Production of non-circular, micro sized, large aspect ratio, shall entry angle holes are easy using NTM
5.	Use relative simple and inexpensive machinery and readily available cutting tools	Non traditional processes requires expensive tools and equipment as well as skilled labour, which increase the production cost significantly
6.	Capital cost and maintenance cost is low	Capital cost and maintenance cost is high
7.	Traditional processes are well established and physics of process is well understood	Mechanics of Material removal of Some of NTM process are still under research
8.	Conventional process mostly uses mechanical energy	Most NTM uses energy in direct form For example : laser, Electron beam in its direct forms are used in LBM and EBM respectively
9.	Surface finish and tolerances are limited by machining inaccuracies	High surface finish(up to 0.1 micron) and tolerances (25 Microns)can be achieved
10.	High metal removal rate.	Low material removal rate.

SELECTION OF PROCESS:

The correct selection of the non-traditional machining methods must be based on the following aspects.

i) Physical parameters of the process

ii) Shape to be machined

iii) Process capability

iv) Economics of the processes

Physical parameter of the process:

The physical parameters of the different NTM are given in the Table 1.0 which indicates that PAM and ECM require high power for fast machining. EBM and LBM require high voltages and require careful handling of equipment. EDM and USM require medium power . EBM can be used in vacuum and PAM uses oxygen and hydrogen gas.

Shapes cutting capability

The different shapes can be machined by NTM. EBM and LBM are used for micro drilling and cutting. USM and EDM are useful for cavity sinking and standard hole drilling. ECM is useful for fine hole drilling and contour machining. PAM can be used for cutting and AJM is useful for shallow pocketing

Process capability

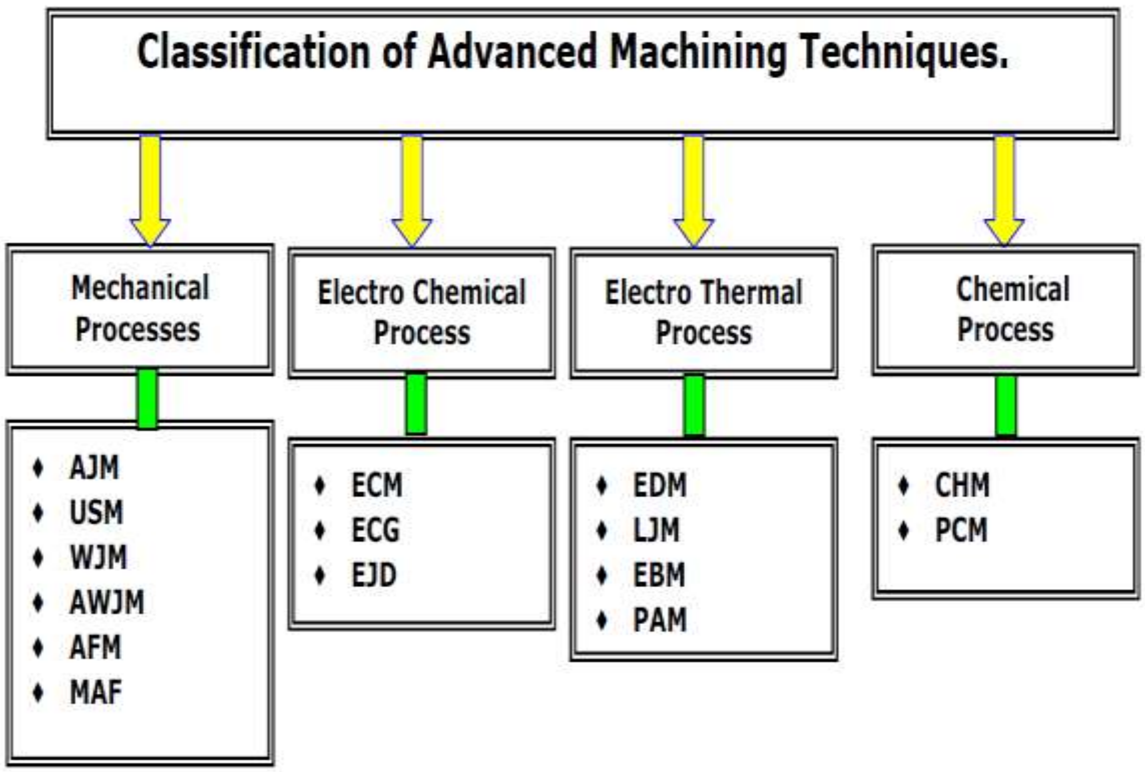
The process capability of NTM is given in Table 2.0 EDM which achieves higher accuracy has the lowest specific power requirement. ECM can machine faster and has a low thermal surface damage depth. USM and AJM have very material removal rates combined with high tool wear and are used non metal cutting. LBM and EBM are, due to their high penetration depth can be used for micro drilling, sheet cutting and welding. CHM is used for manufacture of PCM and other shallow components.

PHYSICAL PARAMETER OF THE PROCESS:

Parameters	NON TRADITIONAL PROCESS							
	USM	AJM	CHM	ECM	EDM	EBM	LBM	PAM
Potential (Volts)	220	220	-	10-30	100-300	150 kV	4.5 kV	100
Current (amps)	12	1	-	10000	50	0.001	2	500
Power (kW)	2.4	0.22	-	100	2.70	0.15	-	50
Gap (mm)	0.25	0.75	-	0.20	0.025	100	150	7.5
Medium	Abrasives In water	Abrasive In gas	Liquid chemical	Electrolyte	Dielectric oil	Vacuum	Air	Argon H_2/O_2

Classification of NTM processes is carried out depending on the nature of energy used for material removal. The broad classification is given as follows:

- **Mechanical Processes**
  - Abrasive Jet Machining (AJM)
  - Ultrasonic Machining (USM)
  - Water Jet Machining (WJM)
- **Electrochemical Processes**
  - Electrochemical Machining (ECM)
  - Electro Chemical Grinding (ECG)
  - Electro Jet Drilling (EJD)
- **Electro-Thermal Processes**
  - Electro-discharge machining (EDM)
  - Laser Jet Machining (LJM)
  - Electron Beam Machining (EBM)
- **Chemical Processes**
  - Chemical Milling (CHM)
  - Photochemical Milling (PCM)


Classification of Advanced Machining Techniques.
Mechanical Processes
AJM
USM
WJM
AWJM
AFM
MAF
Electro Chemical Process
ECM
ECG
EJD
Electro Thermal Process
EDM
LJM
EBM
PAM
Chemical Process
CHM
PCM

ULTRASONIC MACHINING (USM)

INTRODUCTION

USM is mechanical material removal process or an abrasive process used to erode holes or cavities on hard or brittle workpiece by using shaped tools, high frequency mechanical motion and an abrasive slurry. USM offers a solution to the expanding need for machining brittle materials such as single crystals, glasses and polycrystalline ceramics, and increasing complex operations to provide intricate shapes and workpiece profiles. It is therefore used extensively in machining hard and brittle materials that are difficult to machine by traditional manufacturing processes.

Ultrasonic Machining is a non-traditional process, in which abrasives contained in a slurry are driven against the work by a tool oscillating at low amplitude (25-100 μm) and high frequency (15-30 KHz):

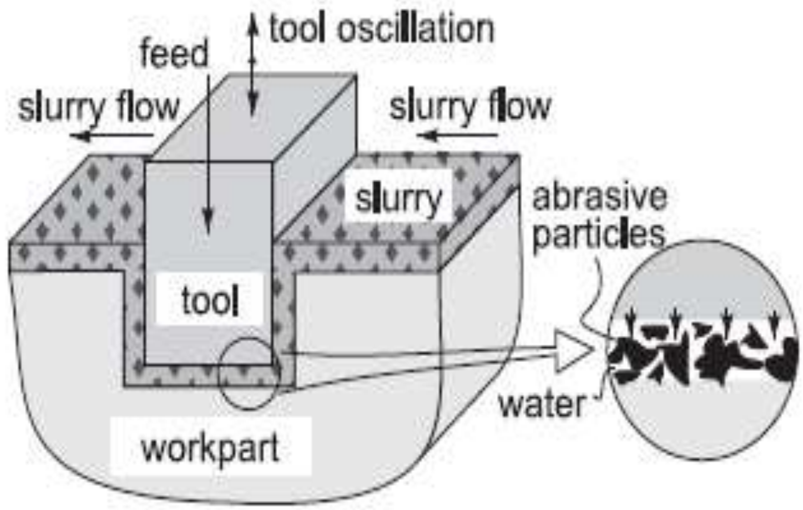
The process was first developed in 1950s and was originally used for finishing EDM surfaces.

The basic process is that a ductile and tough tool is pushed against the work with a constant force. A constant stream of abrasive slurry passes between the tool and the work (gap is 25-40 μm) to provide abrasives and carry away chips. The majority of the cutting action comes from an ultrasonic (cyclic) force applied.

The basic components to the cutting action are believed to be,

- *brittle fracture* caused by impact of abrasive grains due to the tool vibration;
- *cavitation induced erosion*;
- *chemical erosion* caused by slurry.

USM working principle



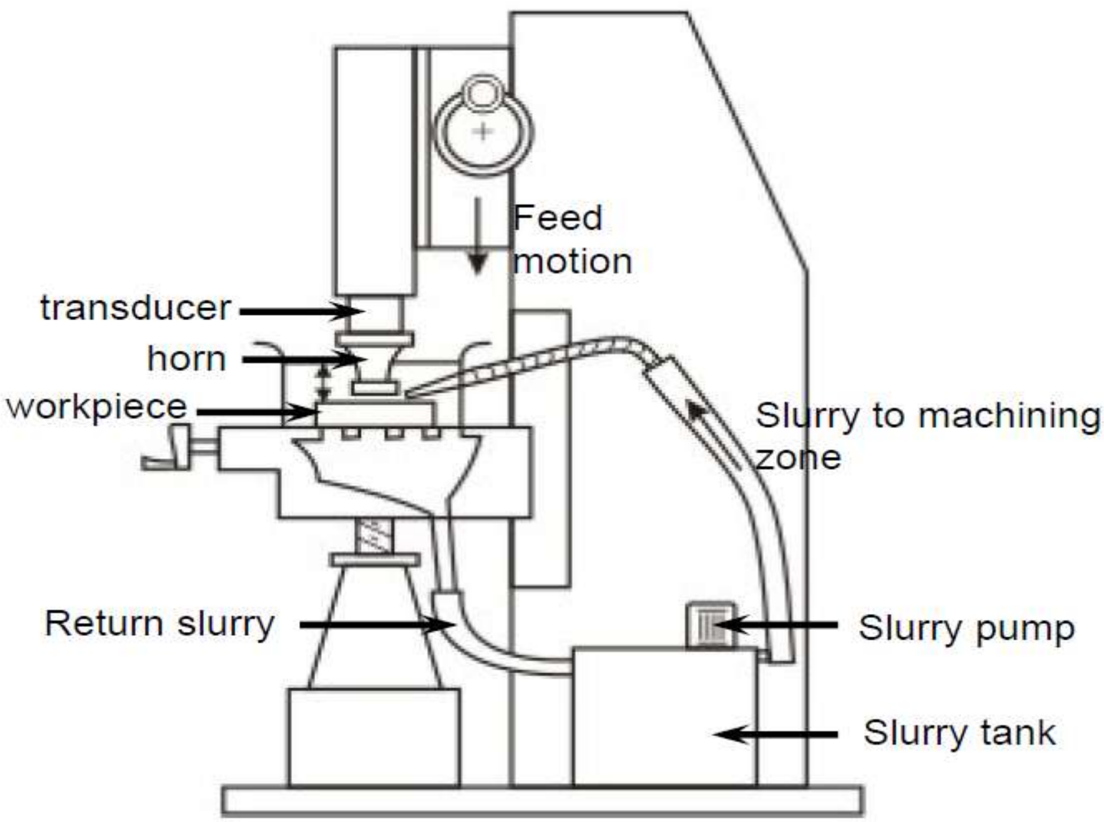
Ultrasonic machining.

- Material removal primarily occurs due to the indentation of the hard abrasive grits on the brittle work material.
- Other than this brittle failure of the work material due to indentation some material removal may occur due to free flowing impact of the abrasives against the work material and related solid-solid impact erosion,
- Tool's vibration – indentation by the abrasive grits.
- During indentation, due to Hertzian contact stresses, cracks would develop just below the contact site, then as indentation progresses the cracks would propagate due to increase in stress and ultimately lead to brittle fracture of the work material

under each individual interaction site between the abrasive grits and the workpiece.

- The tool material should be such that indentation by the abrasive grits does not lead to brittle failure.
- Thus the tools are made of tough, strong and ductile materials like steel, stainless steel and other ductile metallic alloys.

USM Machine



USM Equipment

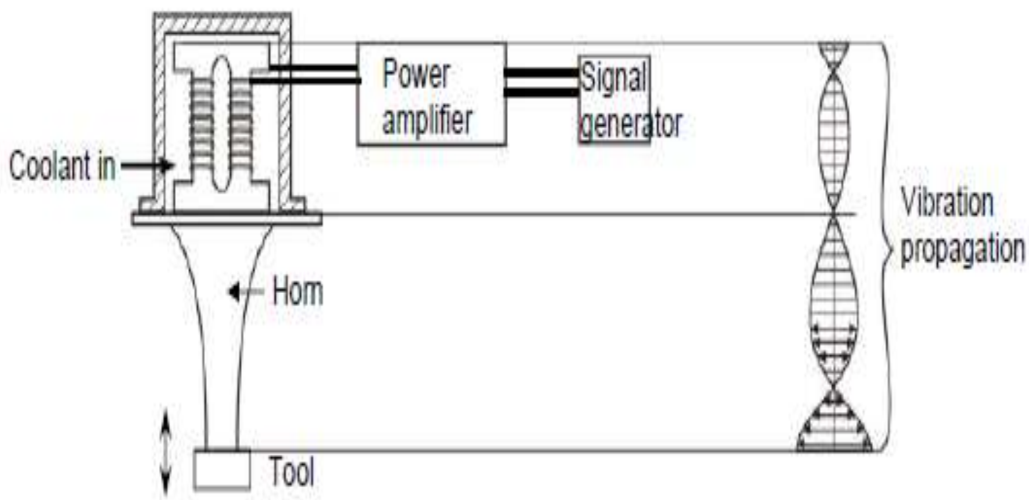
The basic mechanical structure of an USM is very similar to a drill press.

However, it has additional features to carry out USM of brittle work material. The work piece is mounted on a vice, which can be located at the desired position under the tool using a 2 axis table. The table can further be lowered or raised to accommodate work of different thickness.

The typical elements of an USM are

- Slurry delivery and return system
- Feed mechanism to provide a downward feed force on the tool during machining
- The transducer, which generates the ultrasonic vibration
- The horn or concentrator, which mechanically amplifies the vibration to the required amplitude of 15 – 50 μm and accommodates the tool at its tip.

Working of horn as mechanical amplifier of amplitude of vibration



The ultrasonic vibrations are produced by the transducer. The transducer is driven by suitable signal generator followed by power amplifier.

The transducer for USM works on the following principle

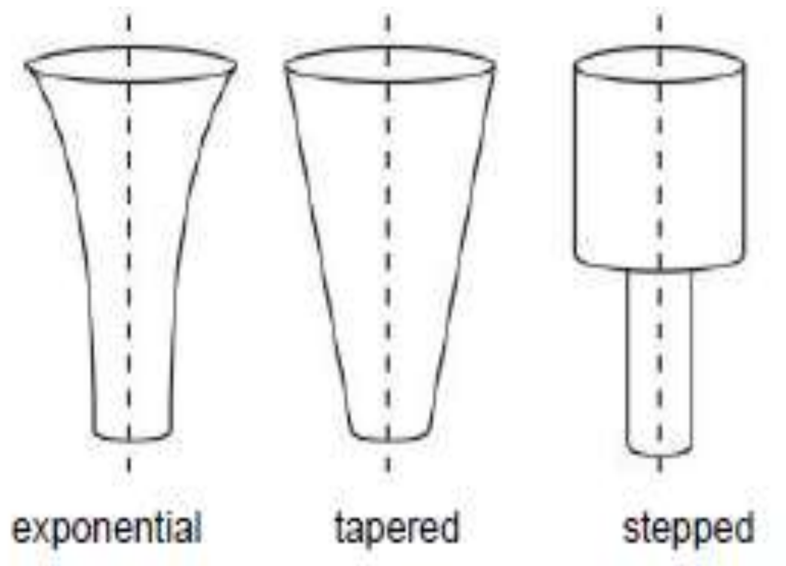
- Piezoelectric effect
- Magnetostrictive effect
- Electrostrictive effect

Magnetostrictive transducers are most popular and robust amongst all. Figure shows a typical magnetostrictive transducer along with horn. The horn or concentrator is a wave guide, which amplifies and concentrates the vibration to the tool from the transducer.

The horn or concentrator can be of different shape like

- Tapered or conical
- Exponential
- Stepped

Machining of tapered or stepped horn is much easier as compared to the exponential one. Figure shows different horns used in USM



PROCESS VARIABLES:

- Amplitude of vibration (a_o) – 15 – 50 μm
- Frequency of vibration (f) – 19 – 25 kHz
- Feed force (F) – related to tool dimensions
- Feed pressure (p)
- Abrasive size – 15 μm – 150 μm

- Abrasive material – Al_2O_3
  - SiC
  - B_4C
  - Boronsilicarbide
  - Diamond
- Flow strength of work material
- Flow strength of the tool material
- Contact area of the tool – A
- Volume concentration of abrasive in water slurry – C

Applications of USM

- Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.
- Used for machining round, square, irregular shaped holes and surface impressions.
- Machining, wire drawing, punching or small blanking dies.

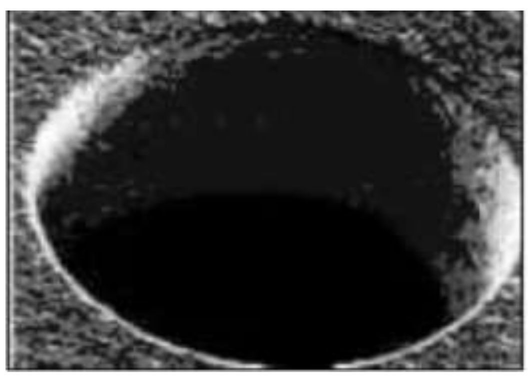


Figure: A non-round hole made by USM

Advantage of USM

USM process is a non-thermal, non-chemical, creates no changes in the microstructures, chemical or physical properties of the workpiece and offers virtually stress free machined surfaces.

The main advantages are;

· Any materials can be machined regardless of their electrical conductivity

· Especially suitable for machining of brittle materials

· Machined parts by USM possess better surface finish and higher structural integrity.

· USM does not produce thermal, electrical and chemical abnormal surface

Some disadvantages of USM

· USM has higher power consumption and lower material-removal rates than traditional fabrication processes.

· Tool wears fast in USM.

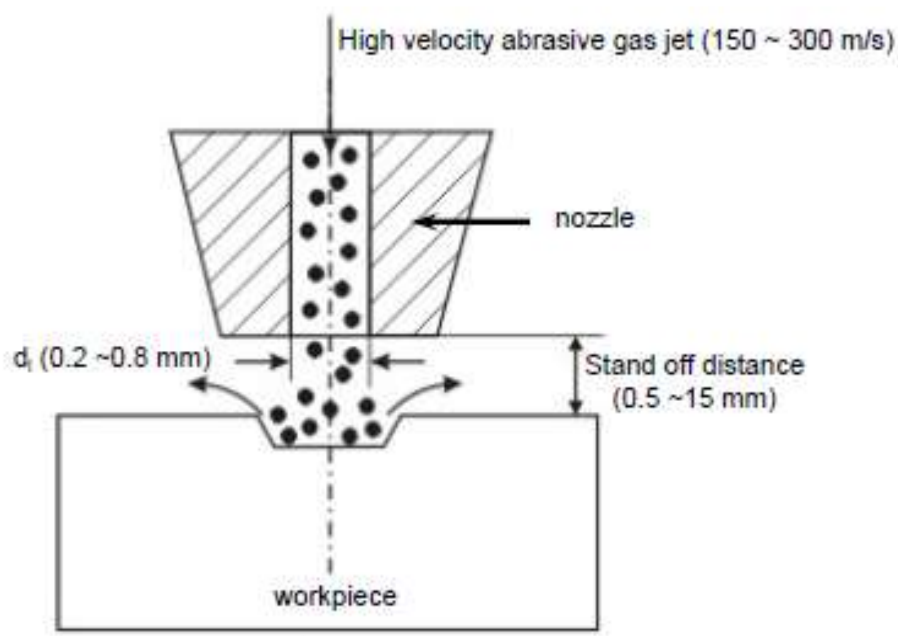
· Machining area and depth is restraint in USM.

ABRASIVE JET MACHINING (AJM)

INTRODUCTION

Abrasive water jet cutting is an extended version of water jet cutting; in which the water jet contains abrasive particles such as silicon carbide or aluminium oxide in order to increase the material removal rate above that of water jet machining. Almost any type of material ranging from hard brittle materials such as ceramics, metals and glass to extremely soft materials such as foam and rubbers can be cut by abrasive water jet cutting. The narrow cutting stream and computer controlled movement enables this process to produce parts accurately and efficiently. This machining process is especially ideal for cutting materials that cannot be cut by laser or thermal cut. Metallic, non-metallic and advanced composite materials of various thicknesses can be cut by this process. This process is particularly suitable for heat sensitive materials that cannot be machined by processes that produce heat while machining.

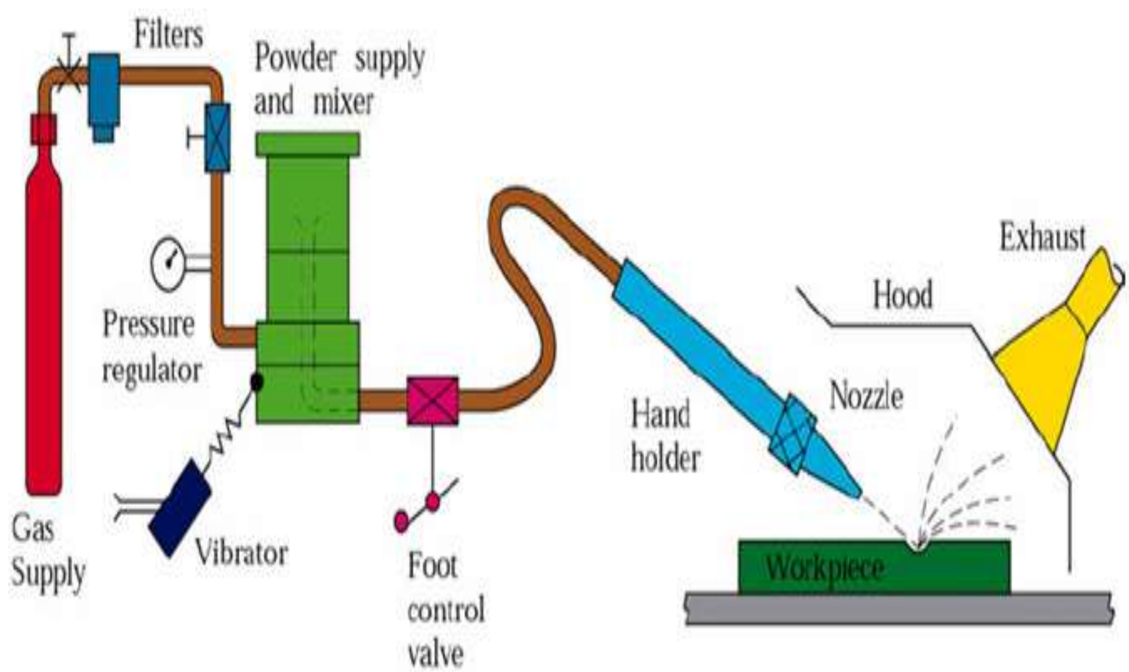
Working principle



AJM

In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on the work material at a high velocity. The jet of abrasive particles is carried by carrier gas or air. The high velocity stream of abrasive is generated by converting the pressure energy of the carrier gas or air to its kinetic energy and hence high velocity jet. The nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the work piece and the impingement angle can be set desirably. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.

AJM Equipment



In AJM, air is compressed in an air compressor and compressed air at a pressure of around 5 bar is used as the carrier gas. Figure also shows the other major parts of the AJM system. Gases like CO_2, N_2 can also be used as carrier gas which may directly be issued from a gas cylinder. Generally oxygen is not used as a carrier gas. The carrier gas is first passed through a pressure regulator to obtain the desired working pressure. To remove any oil vapour or particulate contaminant the same is passed through a series of filters. Then the carrier gas enters a closed chamber known as the mixing chamber. The abrasive particles enter the chamber from a hopper through a metallic sieve. The sieve is constantly vibrated by an electromagnetic shaker. The mass flow rate of abrasive (15 gm/min) entering the chamber depends on the amplitude of vibration of the sieve and its frequency. The abrasive particles are then carried by the carrier gas to the machining chamber via an electro-magnetic on-off valve. The machining enclosure is essential to contain the abrasive and machined particles in a safe and eco-friendly manner. The machining is carried out as high velocity (200 m/s) abrasive particles are issued from the nozzle onto a work piece traversing under the jet.

Process Parameters and Machining Characteristics.

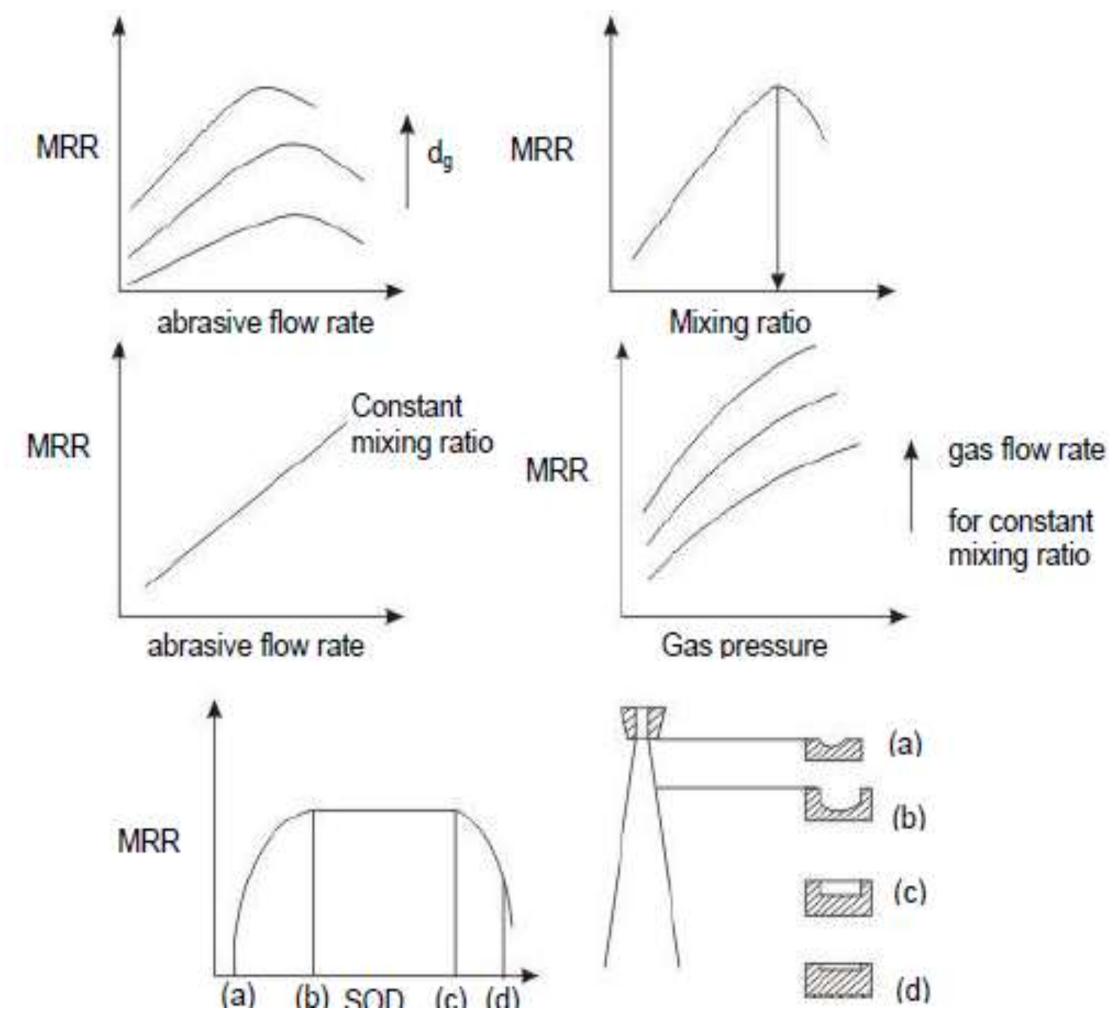
The process parameters are listed below:

- Abrasive
    - Material – Al_2O_3 / SiC / glass beads
    - Shape – irregular / spherical
    - Size – 10 ~ 50 μm
    - Mass flow rate – 2 ~ 20 gm/min
- Carrier gas
    - Composition – Air, CO_2, N_2
    - Density – Air ~ 1.3 kg/m^3
    - Velocity – 500 ~ 700 m/s
    - Pressure – 2 ~ 10 bar
    - Flow rate – 5 ~ 30 lpm
- Abrasive Jet
    - Velocity – 100 ~ 300 m/s
    - Mixing ratio – mass flow ratio of abrasive to gas
    - Stand-off distance – 0.5 ~ 5 mm
    - Impingement Angle – 60^0 ~ 90^0

- Nozzle
  - Material – WC / sapphire
  - Diameter – (Internal) 0.2 ~ 0.8 mm
  - Life – 10 ~ 300 hours

The important machining characteristics in AJM are

- The material removal rate (MRR) mm^3/min or gm/min
- The machining accuracy
- The life of the nozzle



Effect of process parameters MRR

Parameters of Abrasive Jet Maching (AJM) are factors that influence its Metal Removal Rate (MRR). In a machining process, Metal Removal Rate (MRR) is the volume of metal removed from a given work piece in unit time. The following are some of the important process parameters of abrasive jet machining:

1. Abrasive mass flow rate
2. Nozzle tip distance
3. Gas Pressure
4. Velocity of abrasive particles
5. Mixing ratio
6. Abrasive grain size

Abrasive mass flow rate:

Mass flow rate of the abrasive particles is a major process parameter that influences the metal removal rate in abrasive jet machining.

In AJM, mass flow rate of the gas (or air) in abrasive jet is inversely proportional to the mass flow rate of the abrasive particles.

Due to this fact, when continuously increasing the abrasive mass flow rate, Metal Removal Rate (MRR) first increases to an optimum value (because of increase in number of abrasive particles hitting the work piece) and then decreases.

However, if the mixing ratio is kept constant, Metal Removal Rate (MRR) uniformly increases with increase in abrasive mass flow rate.

Nozzle tip distance:

Nozzle Tip Distance (NTD) is the gap provided between the nozzle tip and the work piece.

Up to a certain limit, Metal Removal Rate (MRR) increases with increase in nozzle tip distance. After that limit, MRR remains constant to some extent and then decreases.

In addition to metal removal rate, nozzle tip distance influences the shape and diameter of cut.

For optimal performance, a nozzle tip distance of 0.25 to 0.75 mm is provided.

Gas pressure:

Air or gas pressure has a direct impact on metal removal rate.

In abrasive jet machining, metal removal rate is directly proportional to air or gas pressure.

Velocity of abrasive particles:

Whenever the velocity of abrasive particles is increased, the speed at which the abrasive particles hit the work piece is increased. Because of this reason, in abrasive jet machining, metal removal rate increases with increase in velocity of abrasive particles.

Mixing ratio:

Mixing ratio is a ratio that determines the quality of the air-abrasive mixture in Abrasive Jet Machining (AJM).

It is the ratio between the mass flow rate of abrasive particles and the mass flow rate of air (or gas).

When mixing ratio is increased continuously, metal removal rate first increases to some extent and then decreases.

Abrasive grain size:

Size of the abrasive particle determines the speed at which metal is removed.

If smooth and fine surface finish is to be obtained, abrasive particle with small grain size is used.

If metal has to be removed rapidly, abrasive particle with large grain size is used.

Applications

- Abrasive water jet cutting is highly used in aerospace, automotive and electronics industries.
- In aerospace industries, parts such as titanium bodies for military aircrafts, engine
- components (aluminium, titanium, heat resistant alloys), aluminium body parts and interior cabin parts are made using abrasive water jet cutting.
- In automotive industries, parts like interior trim (head liners, trunk liners, door panels) and fibre glass body components and bumpers are made by this process. Similarly, in electronics industries, circuit boards and cable stripping are made by abrasive water jet cutting.

Figure: Steel gear and rack cut with an abrasive water jet

Advantages of abrasive water jet cutting

- In most of the cases, no secondary finishing required
- No cutter induced distortion
- Low cutting forces on workpieces
- Limited tooling requirements
- Little to no cutting burr
- Typical finish 125-250 microns
- Smaller kerf size reduces material wastages

- No heat affected zone
- Localises structural changes
- No cutter induced metal contamination
- Eliminates thermal distortion
- No slag or cutting dross
- Precise, multi plane cutting of contours, shapes, and bevels of any angle.

Limitations of abrasive water jet cutting

- Cannot drill flat bottom
- Cannot cut materials that degrades quickly with moisture
- Surface finish degrades at higher cut speeds which are frequently used for rough cutting.
- The major disadvantages of abrasive water jet cutting are high capital cost and high
- noise levels during operation.

WATER JET MACHINING (WJM)

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The schematic of abrasive water jet cutting is shown in Figure which is similar to water jet cutting apart from some more features underneath the jewel; namely abrasive, guard and mixing tube. In this process, high velocity water exiting the jewel creates a vacuum which sucks abrasive from the abrasive line, which mixes with the water in the mixing tube to form a high velocity beam of abrasives.

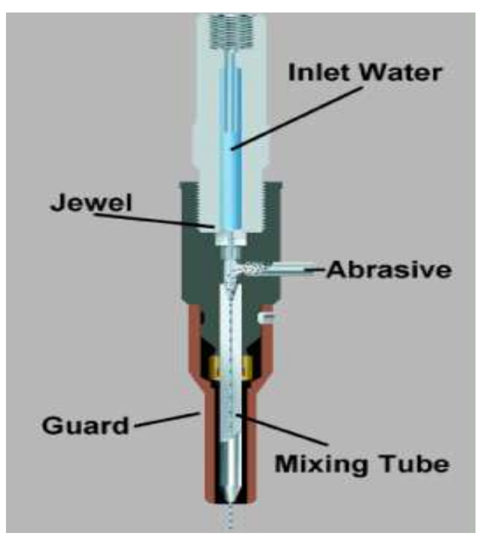

Figure: Abrasive water jet machining

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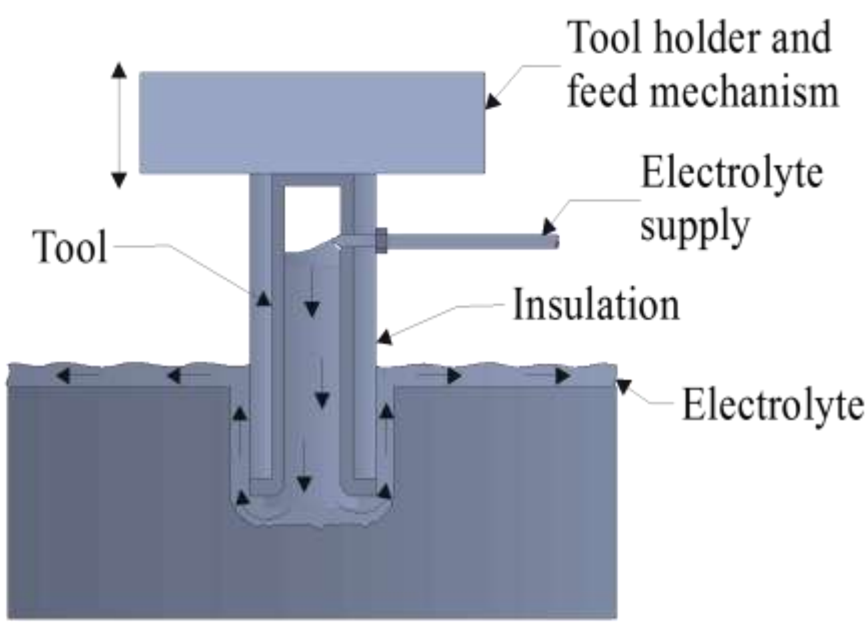
ELECTROCHEMICAL MACHINING (ECM)

INTRODUCTION

Electrochemical machining (ECM) is a metal-removal process based on the principle of reverse electroplating. In this process, particles travel from the anodic material (workpiece) toward the cathodic material (machining tool). A current of electrolyte fluid carries away the deplated material before it has a chance to reach the machining tool. The cavity produced is the female mating image of the tool shape.



ECM process

Similar to EDM, the workpiece hardness is not a factor, making ECM suitable for machining difficult-to –machine materials. Difficult shapes can be made by this process on materials regardless of their hardness. A schematic representation of ECM process is shown in Figure 8. The ECM tool is positioned very close to the workpiece and a low voltage, high amperage DC current is passed between the workpiece and electrode. Some of the shapes made by ECM process is shown in Figure.

Material removal rate, MRR, in electrochemical machining:

$MRR = C .I. h \quad (cm^3/min)$

C: specific (material) removal rate (e.g., 0.2052 cm^3/amp-min for nickel);

I: current (amp);

h: current efficiency (90–100%).

The rates at which metal can electrochemically remove are in proportion to the current passed through the electrolyte and the elapsed time for that operation. Many factors other than current influence the rate of machining. These involve electrolyte type, rate of electrolyte flow, and some other process conditions.

Parts made by ECM

Advantages of ECM

- The components are not subject to either thermal or mechanical stress.
- No tool wear during ECM process.
- Fragile parts can be machined easily as there is no stress involved.
- ECM deburring can debur difficult to access areas of parts.
- High surface finish (up to 25 µm in) can be achieved by ECM process.
- Complex geometrical shapes in high-strength materials particularly in the aerospace industry for the mass production of turbine blades, jet-engine parts and nozzles can be machined repeatedly and accurately.
- Deep holes can be made by this process.

Limitations of ECM

- ECM is not suitable to produce sharp square corners or flat bottoms because of the tendency for the electrolyte to erode away sharp profiles.
- ECM can be applied to most metals but, due to the high equipment costs, is usually used primarily for highly specialised applications.

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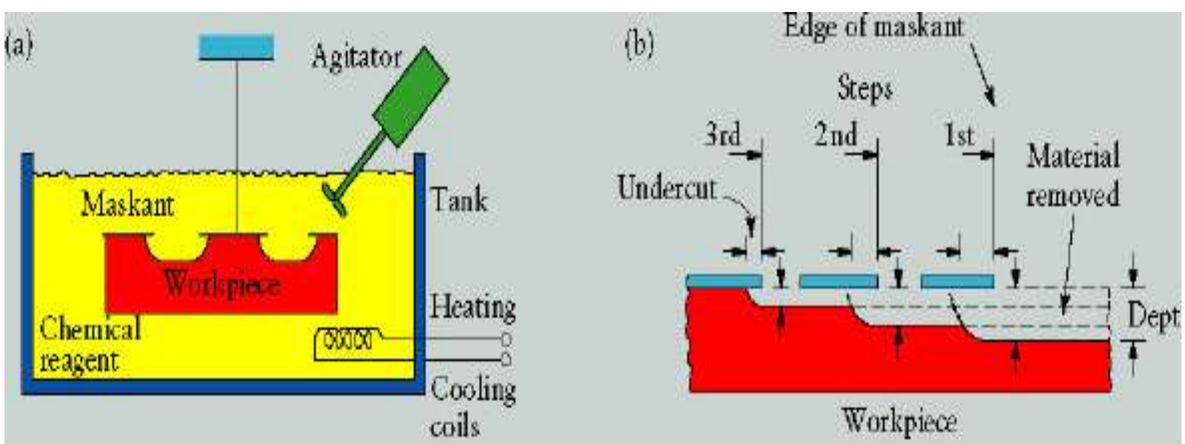
CHEMICAL MACHINING (CHM)

INTRODUCTION

Chemical machining (CM) is the controlled dissolution of workpiece material (etching) by means of a strong chemical reagent (etchant). In CM material is removed from selected areas of workpiece by immersing it in a chemical reagents or etchants; such as acids and alkaline solutions. Material is removed by microscopic electrochemical cell action, as occurs in corrosion or chemical dissolution of a metal. This controlled chemical dissolution will simultaneously etch all exposed surfaces even though the penetration rates of the material removal may be only 0.0025–0.1 mm/min. The basic process takes many forms: chemical milling of pockets, contours, overall metal removal, chemical blanking for etching through thin sheets; photochemical machining (pcm) for etching by using of photosensitive resists in microelectronics; chemical or electrochemical polishing where weak chemical reagents are used (sometimes with remote electric assist) for polishing or deburring and chemical jet machining where a single chemically active jet is used. A schematic of chemical machining process is shown in Figure.



(a) Schematic of chemical machining process (b) Stages in producing a profiled cavity by chemical machining (Kalpakjain & Schmid)

CHEMICAL MILLING

In chemical milling, shallow cavities are produced on plates, sheets, forgings and extrusions. The two key materials used in chemical milling process are etchant and maskant. Etchants are acid or alkaline solutions maintained within controlled ranges of chemical composition and temperature. Maskants are specially designed elastomeric products that are hand strippable and chemically resistant to the harsh etchants.

Steps in chemical milling

- Residual stress relieving: If the part to be machined has residual stresses from the previous processing, these stresses first should be relieved in order to prevent warping after chemical milling.
- Preparing: The surfaces are degreased and cleaned thoroughly to ensure both good adhesion of the masking material and the uniform material removal.
- Masking: Masking material is applied (coating or protecting areas not to be etched).
- Etching: The exposed surfaces are machined chemically with etchants.
- Demasking: After machining, the parts should be washed thoroughly to prevent further reactions with or exposure to any etchant residues. Then the rest of the masking material is removed and the part is cleaned and inspected.

Applications:

Chemical milling is used in the aerospace industry to remove shallow layers of material from large aircraft components missile skin panels (Figure), extruded parts for airframes.

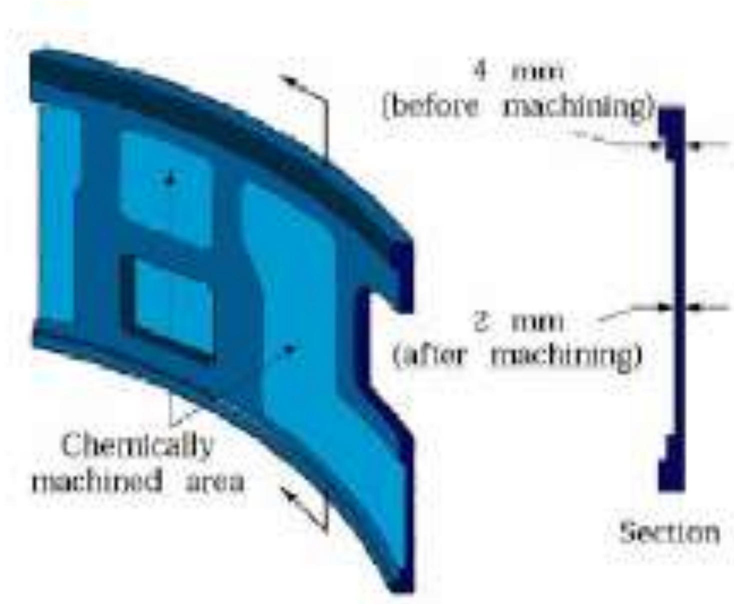


Figure : Missile skin-panel section contoured by chemical milling to improve the stiffness- to- weight ratio of the part (Kalpakjain & Schmid)

ELECTRICAL DISCHARGE MACHINING (EDM)

INTRODUCTION

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 utilises thermoelectric process to erode undesired materials from the workpiece by a series of discrete electrical sparks between the workpiece and the electrode. A picture of EDM machine in operation is shown in Figure.

Figure : Electrical discharge machine

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.

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 discharges 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} to 10^{-6} mm^3.

The material removal rate, MRR, in EDM is calculated by the following foumula:

$MRR = 40\ I / T_m^{\ 1.23} \quad (cm^3/min)$

Where, *I* is the current amp,

T_m is the melting temperature of workpiece in ^0C

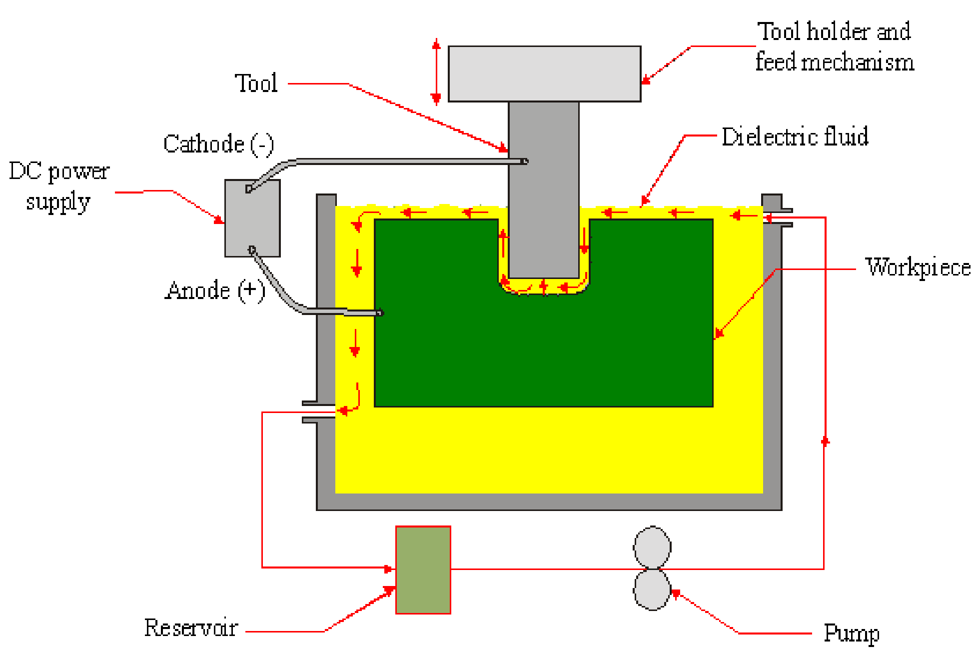


Figure: Schematic of EDM process

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 the order of 50 volts/10amps.

Dielectric fluids

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

- Act as an insulator between the tool and the workpiece.
- Act as coolant.
- 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.

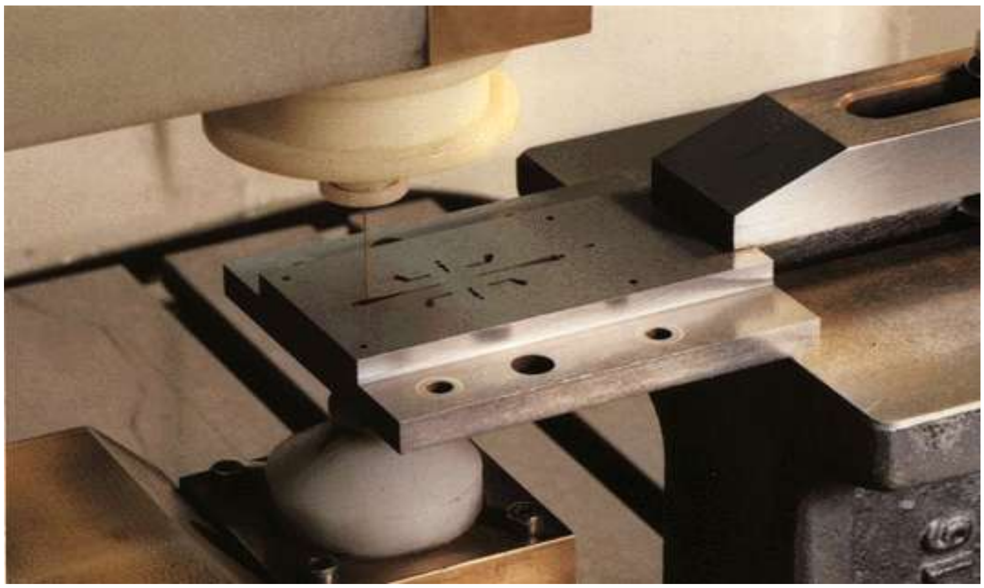
Design considerations for EDM process are as follows:

- Deep slots and narrow openings should be avoided.
- 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 low.

Wire EDM

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 dieelectirc 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 removed particles are flushed away by the flowing dielectric fluids.

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.



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.

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Sparked eroded extrusion dies

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.

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.

Figure: Difficult internal parts made by EDM process

Advantages of EDM

The main advantages of DM are:

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

Limitations of EDM

The main limitations of this process are:

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

LASER–BEAM MACHINING (LBM)

INTRODUCTION

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.

Different types of lasers are available for manufacturing operations which are as follows:

- CO_2 (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 ($Y_3Al_5O_{12}$) laser is a solid-state laser which can deliver light through a fibre-optic cable. It can provide up to 50 kW power in pulsed mode and 1 kW in continuous-wave mode.

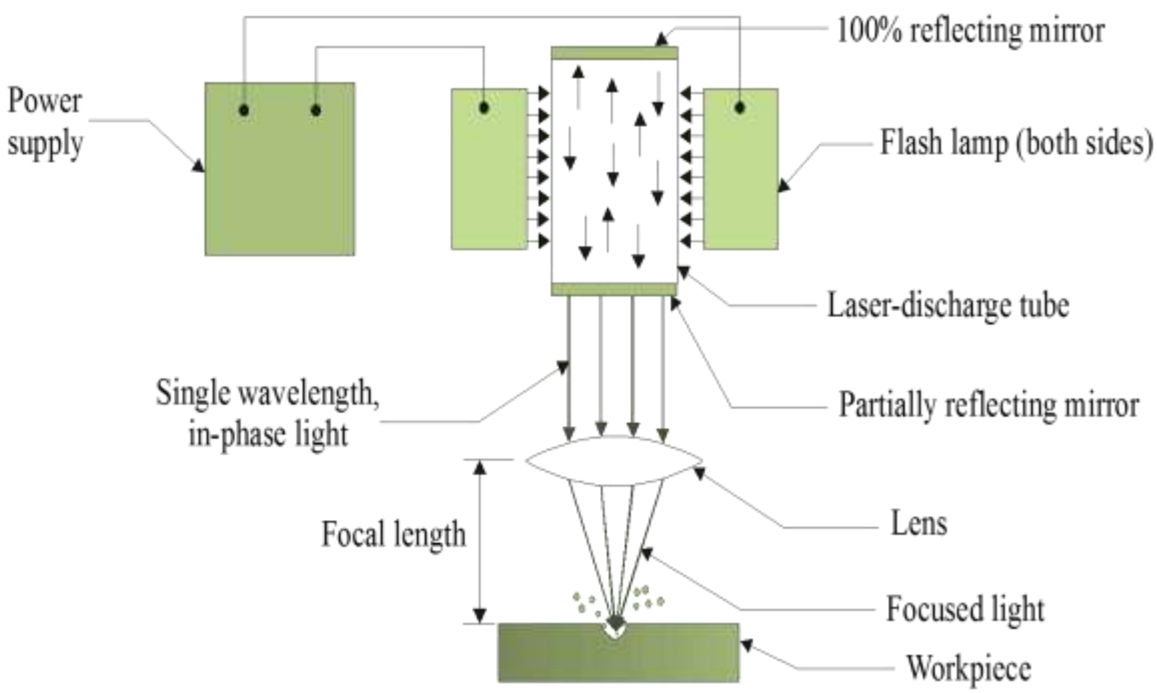

Figure: Laser beam machining schematic

Laser beam cutting (drilling)

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

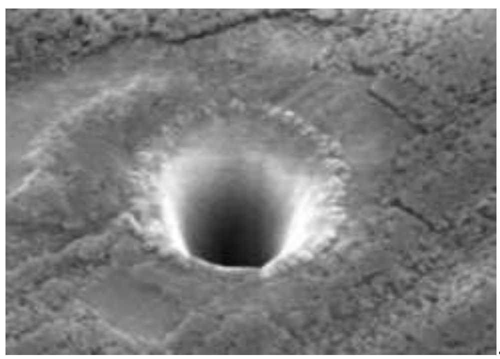.

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

Laser beam cutting (milling)

- A laser spot reflected onto the surface of a workpiece travels along a prescribed trajectory and cuts into the material.
- Continuous-wave mode (CO_2) 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

- No limit to cutting path as the laser point can move any path.
- The process is stress less allowing very fragile materials to be laser cut without any support.
- Very hard and abrasive material can be cut.
- Sticky materials are also can be cut by this process.
- It is a cost effective and flexible process.
- High accuracy parts can be machined.
- No cutting lubricants required
- No tool wear
- Narrow heat effected zone

Limitations of laser cutting

- Uneconomic on high volumes compared to stamping
- Limitations on thickness due to taper
- High capital cost
- High maintenance cost
- Assist or cover gas required