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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

SPR1403 – MODERN MANUFACTURING PROCESSES

COURSE MATERIAL

UNIT – I – SPR1403 – MECHANICAL PROCESSES

Ultrasonic Machining- Elements of process, cutting tool system design, effect of parameters, economic considerations, applications, limitations of the process, advantages and disadvantages. Abrasive Jet Machining-Variables in AJM, metal removal rate in AJM. Water Jet Machining- Jet cutting equipments, process details, advantages and applications

COURSE OBJECTIVES:
To understand the necessity, role in modern industries, working principles, constructional details and performance characteristics of various non-traditional machining processes.

COURSE OUTCOMES:
On completion of the course, student will be able to
CO1: Analyse the fundamentals of the non-traditional machining processes.
CO2: Explain the working principle of chemical metal removal processes.
CO3: Choose a suitable nontraditional machining process for electrochemical metal removal Processes.
CO4: Compare the construction and working of electrical metal removal processes.
CO5: Categorize the EBM, LBM, PAM and USM processes.
CO6: Apply a suitable nontraditional machining process for hybrid metal removal processes.

ULTRASONIC MACHINING

Ultrasonic machining is a non-traditional machining process. USM is grouped under the mechanical group Non Traditional Machining processes.

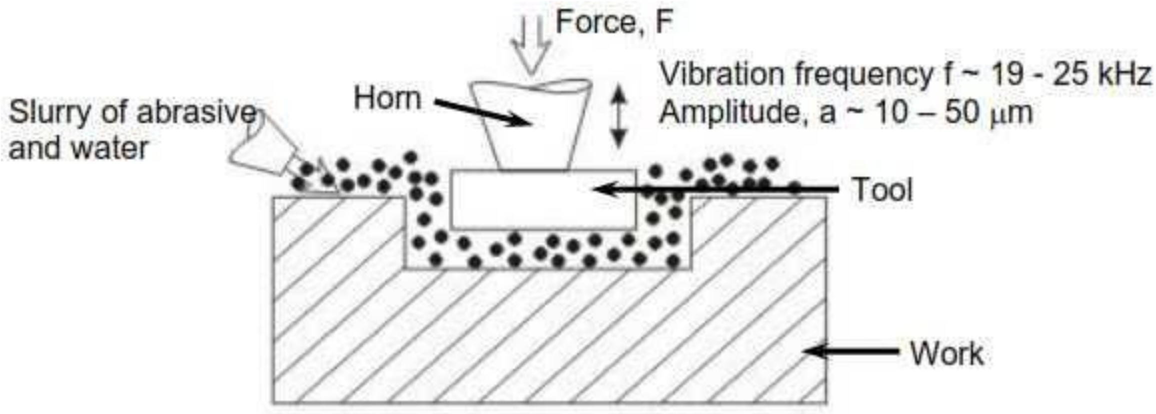


Figure 1.1 Schematic Representation of Material Removal Mechanism

In ultrasonic machining, a tool of desired shape vibrates at an ultrasonic frequency (19000 ~ 25000 Hz) with an amplitude of around 15 – 50 μm over the workpiece. Generally the tool is pressed downward with a feed force, F. Between the tool and workpiece, the machining zone is flooded with hard abrasive particles generally in the form of a water based slurry. As the tool vibrates over the workpiece, the abrasive particles act as the indenters and indent both the work material and the tool. The abrasive particles, as they indent, the work material, would remove the same, particularly if the work material is brittle, due to crack initiation, propagation and brittle fracture of the material. Hence, USM is mainly used for machining brittle materials which are poor conductors of electricity and thus cannot be processed by Electrochemical and Electro-discharge machining.

Effect of Process Parameters

The process parameters which govern the ultrasonic machining process are

- Amplitude of vibration (ao) 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 – Aluminium Oxide (Al2O3), Silicon Carbide (SiC), Boron Carbide (B4 C) and 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

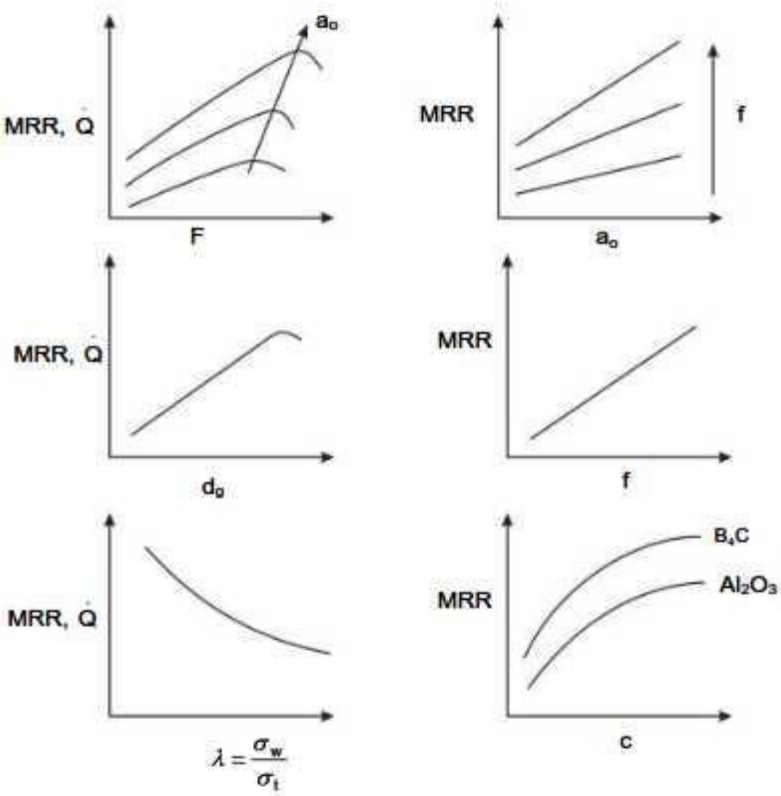


Figure 1.2 Effect of Machining Parameters on MRR

Ultrasonic Machining Equipment

The basic mechanical structure of an USM is very similar to a drill press. It has additional features to carry out USM of brittle work material. The workpiece 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.

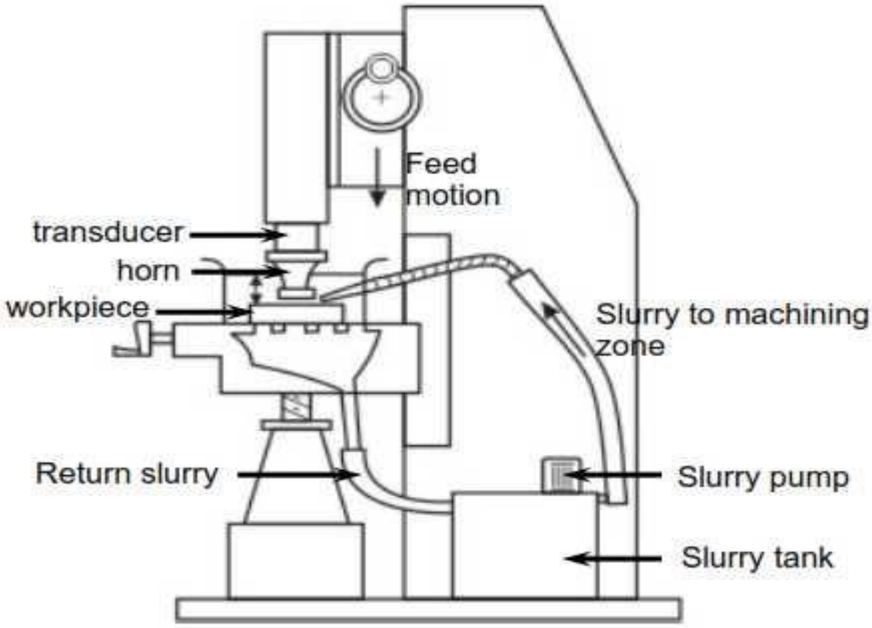


Figure 1.3 Typical Elements of an USM

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. The horn or concentrator of the Magnetostrictive transducers is a wave-guide, which amplifies and concentrates the vibration to the tool from the transducer. The horn or concentrator can be of different shapes like

- Tapered or conical
- Exponential
- Stepped

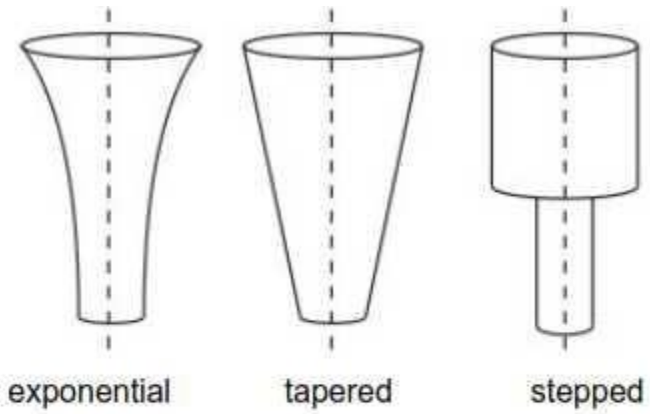


Figure 1.4 Different Shape of Horns Used in an USM

Applications

- Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.
- USM is used in machining round, square, irregular shaped holes and surface impressions.
- Wire drawing, punching or small blanking dies can be fabricated by ultrasonic machining.

Limitations

- Low Material Removal Rate, which results in higher time for machining
- Rather high tool wear hence increased setup time and tool cost
- Low depth of hole. Cannot be used for producing high depth holes.

ABRASIVE JET MACHINING

In abrasive jet machining (AJM), a focused stream of abrasive particles, carried by high-pressure air or gas is made to impinge on the work surface through a nozzle and the work material is made to impinge on the work surface through a nozzle and work material is removed by erosion by high velocity abrasive particles.

Process:

Abrasive particles of around 50 microns grit size are made to impinge on work material at high velocity (200 m/s or more) with a stand-off distance of about 2 - 3mm between nozzle and work. Jet of abrasive particles is carried by carrier gas or air. The high velocity stream of abrasives is generated by converting the pressure energy of carrier gas or air into Kinetic energy and thereby producing a high velocity jet. The Nozzle directs abrasive jet in a controlled manner onto work material. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.

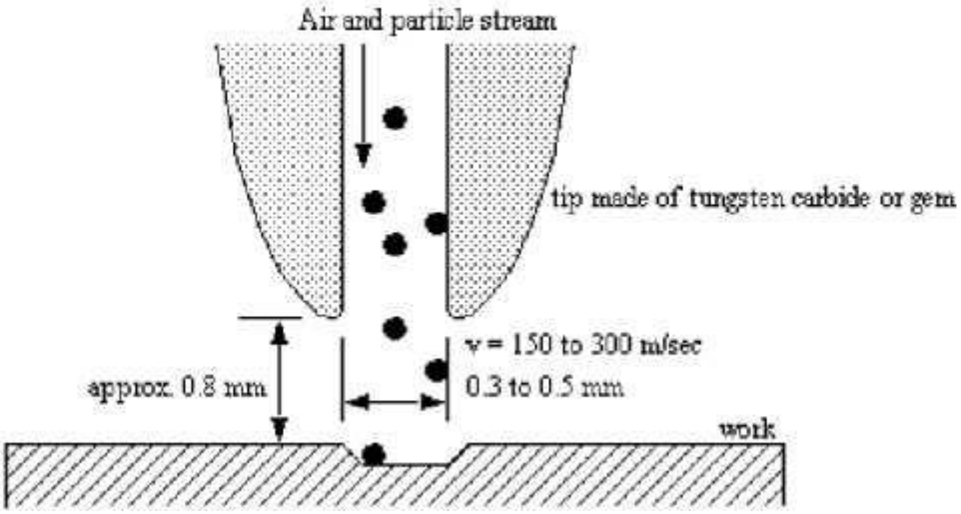


Figure 1.5 Abrasive Particles are made to Impinge on Work Material

Equipment:

A schematic layout of AJM is shown below. The gas stream is passed to the nozzle through a connecting hose. The velocity of the abrasive stream ejected through the nozzle is generally of the order of 330 m/sec.

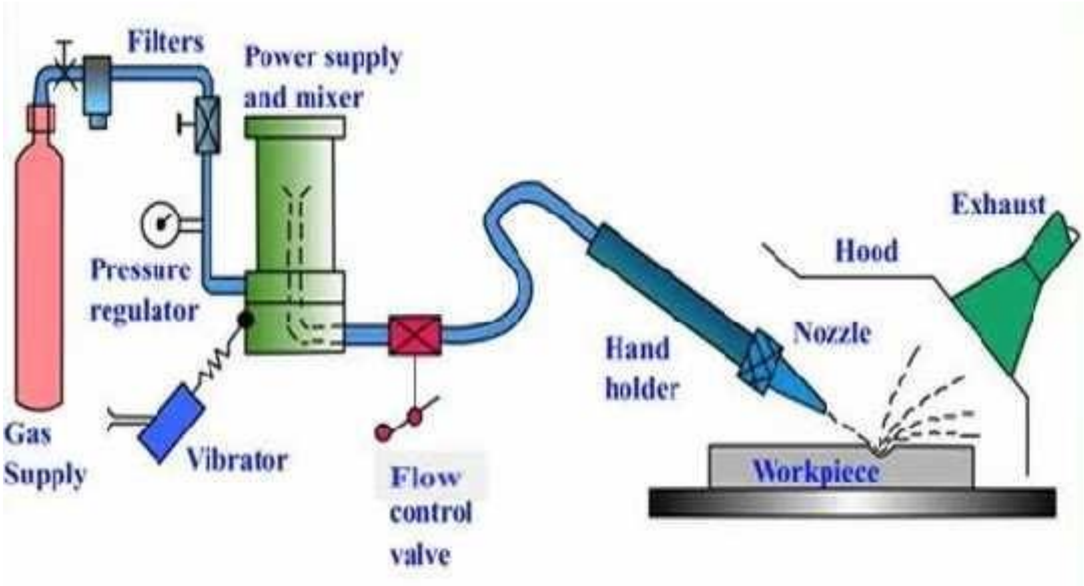


Figure 1.6 Schematic Layout of Abrasive Jet Machining

Abrasive jet machining consists of

- Gas propulsion system
- Abrasive feeder
- Machining Chamber (Mixing)
- AJM Nozzle
- Abrasives

Gas Propulsion System

Supplies clean and dry air. Air, Nitrogen and carbon dioxide to propel the abrasive particles. Gas may be supplied either from a compressor or a cylinder. In case of a compressor, air filter cum drier should be used to avoid water or oil contamination of abrasive powder. Gas should be non-toxic, cheap, and easily available. It should not excessively spread when discharged from nozzle into atmosphere. The propellant consumption is of order of 0.008 m^3/min at a nozzle pressure of 5 bar and abrasive flow rate varies from 2 to 4 gm/min for fine machining and 10 to 20 gm/min for cutting operation.

Abrasive Feeder

Required quantity of abrasive particles is supplied by abrasive feeder. The filleted propellant is fed into the mixing chamber where in abrasive particles are fed through sieve. The sieve is made to vibrate at 50-60 Hz and mixing ratio is controlled by the amplitude of vibration of sieve. The particles are propelled by carrier gas to a mixing chamber. Air abrasive mixture moves further to nozzle. The nozzle imparts high velocity to mixture which is directed at work piece surface.

Machining chamber

It is well closed so that concentration of abrasive particles around the working chamber does not reach to the harmful limits. Machining chamber is equipped with vacuum dust collector. Special consideration should be given to dust collection system if the toxic material (like beryllium) are being machined.

AJM nozzle

AJM nozzle is usually made of tungsten carbide or sapphire (usually life – 300 hours for sapphire, 20 to 30 hours for WC) which has resistance to wear. The nozzle is made of either circular or rectangular cross section and head can be head can be straight, or at a right angle. It is so designed that loss of pressure due to the bends, friction etc is minimum possible. With increase in wear of a nozzle, the divergence of jet stream increases resulting in more stray cutting and high inaccuracy.

Abrasives

Aluminum oxide (Al_2O_3), Silicon carbide (SiC) Glass beads, crushed glass and sodium bicarbonate are some of abrasives used in AJM. Selection of abrasives depends on MRR, type of work material, machining accuracy.

Abrasives	Grain Sizes	Application
Aluminum oxide(Al_2O_3)	12, 20, 50 microns	Good for cleaning, cutting and deburring
Silicon carbide (SiC)	25,40 micron	Used for similar application but for hard material
Glass beads	0.635 to 1.27mm	Gives matte finish
Dolomite	200 mesh	Etching and polishing
Sodium bi carbonate	27 micros	Cleaning, deburring and cutting of soft material Light finishing below 50°C

Process parameters

The following are the process criteria for abrasive jet machining.

1. Mass flow rate
2. Abrasive grain size
3. Velocity of abrasive particles
4. Mixing ratio
5. Nozzle pressure

Process criteria are generally influenced by the process parameters as detailed below:

Abrasives

- Material – Al_2O_3, SiC, Glass beads Crushed glass Sodium bi carbonate
- Shape – irregular/regular
- Size – 10 to 50 microns
- Mass flow – 2 – 20 gm/min

Carrier Gas

- Composition – Air, CO_2, N_2
- b) Density – 1.3 kg/m^3
- c) Velocity - 500 to 700 m/s
- d) Pressure - 2 to 10 bar
- e) Flow rate - 5 to 30 microns

Abrasive Jet

- Velocity - 100 to 300 m/s
- Mixing ratio – Volume flow rate of abrasives/Volume flow rate of gas
- Stand-off distance – 0.5 to 15mm.
- Impingement angle – 60° to 90°

Nozzle

- Material – WC/Sapphire
- Diameter – 0.2 to 0.8 mm
- Life – 300 hours for sapphire, 20 to 30 hours for WC

Process Capability

- Material removal rate – 0.015 cm^3/min
- Narrow slots – 0.12 to 0.25mm± 0.12mm
- Surface finish -0.25 micron to 1.25 micron
- Sharp radius up to 0.2mm is possible
- It is possible to cut Steel up to 1.5mm, Glass up to 6.3mm thick

Effect of abrasive flow rate and grain size on MRR

It is clear from the figure that at a particular pressure MRR increase with increase of abrasive flow rate and is influenced by size of abrasive particles. But after reaching optimum value, MRR decreases with further increase of abrasive flow rate. This is owing to the fact that Mass flow rate of gas decreases with increase of abrasive flowrate and hence mixing ratio increases causing a decrease in material removal rate because of decreasing energy available for erosion.

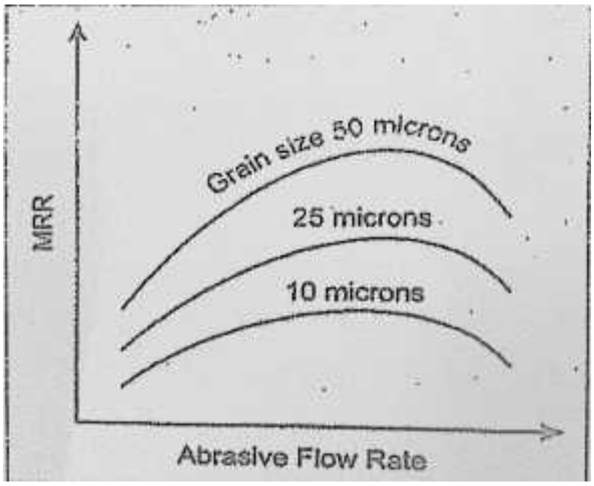


Figure 1.7 Metal Removal Rate increase with Abrasive Flow Rate

Effect of exit gas velocity and abrasive particle density

The velocity of carrier gas conveying the abrasive particles changes considerably with the change of abrasive particle density. The exit velocity of gas can be increased to critical velocity when the internal gas pressure is nearly twice the pressure at exit of nozzle for the abrasive particle density is zero. If the density of abrasive particles is gradually increased exit velocity will go on decreasing for the same pressure condition. It is due to fact that Kinetic energy of gas is utilized for transporting the abrasive particle

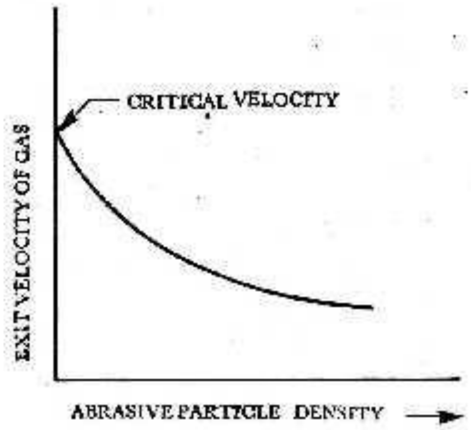


Figure 1.8 The Velocity of Abrasive Particles Changes Considerably With the Change of Abrasive Particle Density

Effect of mixing ratio on MRR

Increased mass flow rate of abrasive will result in a decreased velocity of fluid and will thereby decrease the available energy for erosion and ultimately the MRR. It is convenient to explain to this fact by term MIXING RATIO. Which is defined as

Mixing ratio = Volume flow rate of carrier gas / Volume flow rate of carrier gas

The effect of mixing ratio on the material removal rate is shown below.

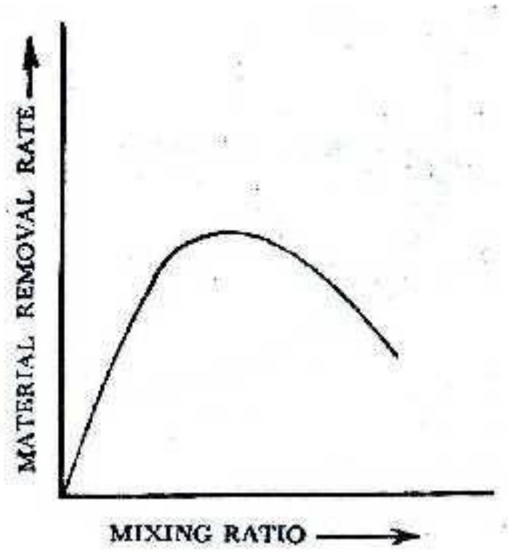


Figure 1.9 The Effect of Mixing Ratio on the Material Removal Rate

The material removal rate can be improved by increasing the abrasive flow rate provided the mixing ratio can be kept constant. The mixing ratio is unchanged only by simultaneous increase of both gas and abrasive flow rate.

Effect of nozzle pressure on MRR

The abrasive flow rate can be increased by increasing the flow rate of the carrier gas. This is only possible by increasing the internal gas pressure as shown in the figure. As the internal gas pressure increases abrasive mass flow rate increase and thus MRR increases.

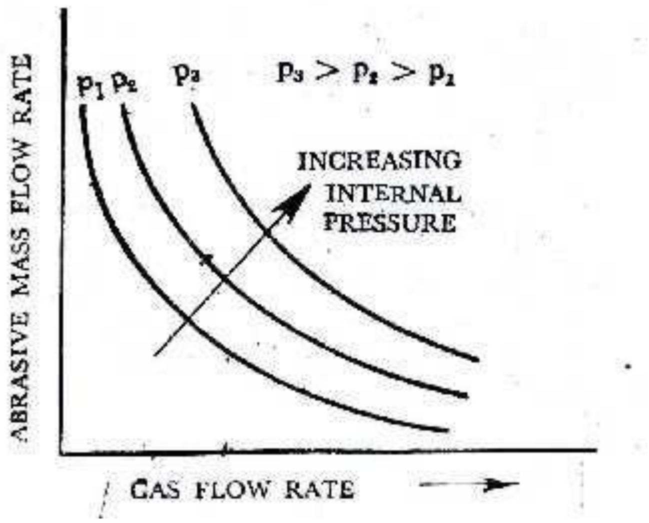


Figure 1.10 The Abrasive Flow Rate can be Increased by Increasing the Flow Rate of the Carrier Gas

Applications

- This is used for abrading and frosting glass more economically as compared to etching or grinding

- Cleaning of metallic smears on ceramics, oxides on metals, resistive coating etc.
- AJM is useful in manufacture of electronic devices , drilling of glass wafers, deburring of plastics, making of nylon and Teflon parts permanent marking on rubber stencils, cutting titanium foils
- Deflashing small castings, engraving registration numbers on toughened glass used for car windows
- Used for cutting thin fragile components like germanium, silicon etc.
- Used for drilling, cutting, deburring etching and polishing of hard and brittle materials
- Most suitable for machining brittle and heat sensitive materials like glass, quartz, sapphire, mica, ceramics germanium, silicon and gallium.
- It is also good method for deburring small hole like in hypodermic needles and for small milled slots in hard metallic components.

Advantages

- High surface finish can be obtained depending upon the grain sizes
- Depth of damage is low (around2.5 microns)
- It provides cool cutting action, so it can machine delicate and heat sensitive
- Material
- Process is free from chatter and vibration as there is no contact between the tool
- and work piece
- Capital cost is low and it is easy to operate and maintain AJM.
- Thin sections of hard brittle materials like germanium, mica, silicon, glass and ceramics can be machined.
- It has the capability of cutting holes of intricate shape in hard materials.

Limitations

- Limited capacity due to low MRR. MRR for glass is 40 gm/minute
- Abrasives may get embedded in the work surface, especially while machining soft material like elastomers or soft plastics.
- The accuracy of cutting is hampered by tapering of hole due to unavoidable flaring of abrasive jet.
- Stray cutting is difficult to avoid
- A dust collection system is a basic requirement to prevent atmospheric pollution and health hazards.
- Nozzle life is limited (300 hours)
- Abrasive powders cannot be reused as the sharp edges are worn and smaller particles can clog the nozzle.
- Short stand-off distances when used for cutting, damages the nozzle.

WATER JET MACHINING

Water Jet Machining (WJM) and Abrasive Water Jet Machining (AWJM) are two non-traditional or non-conventional machining processes. They belong to mechanical group of non-conventional processes like Ultrasonic Machining (USM) and Abrasive Jet Machining (AJM). In these processes the mechanical energy of water and abrasive phases are used to achieve material removal or machining.

WJM and AWJM can be achieved using different approaches and methodologies as enumerated below:

- WJM - Pure
- WJM - with stabilizer
- AWJM – entrained – three phase – abrasive, water and air
- AWJM – suspended – two phase – abrasive and water

However in all variants of the processes, the basic methodology remains the same. Water is pumped at a sufficiently high pressure, 200-400 MPa using intensifier technology. An intensifier works on the simple principle of pressure amplification using hydraulic cylinders of different cross sections as used in "**Jute Bell Presses**". When water at such pressure is issued through a suitable orifice (generally of 0.2- 0.4 mm dia), the potential energy of water is converted into kinetic energy, yielding a high velocity jet (1000m/s). Such high velocity water jet can machine thin sheets/foils of aluminium, leather, textile, frozen food etc.

In pure WJM, commercially pure water (tap water) is used for machining purpose. However as the high velocity water jet is discharged from the orifice, the jet tends to entrain atmospheric air and flares out decreasing its cutting ability. Hence, quite often stabilisers (long chain polymers) that hinder the fragmentation of water jet are added to the water.

In AWJM, abrasive particles like sand (SiO), glass beads are added to the water jet to enhance its cutting ability by many folds. AWJ are mainly of two types – entrained and suspended type as mentioned earlier. In entrained type AWJM, the abrasive particles are allowed to entrain in water jet to form abrasive water jet with significant velocity of 800 m/s. Such high velocity abrasive jet can machine almost any material.

Process parameters

The following are the process criteria for abrasive jet machining.

1. Material removal rate
2. Geometry and surface finish of work piece
3. Wear rate of the nozzle

- Material removal rate is directly proportional to the reactive force (F) of the jet.
- MRR α F

  MRR αm x v

  Where m – Mass flow rate and

  v – Jet velocity
- Geometry and surface finish of work material is affected by nozzle design, jet velocity, cutting speed and depth of cut.
- Wear rate of the nozzle depends upon hardness of nozzle material, pressure exerted by the water jet, velocity of the jet and nozzle design.

Figure 1.11 Commercial CNC Water Jet Machining System and Cutting Heads

Materials that can be processed by WJM

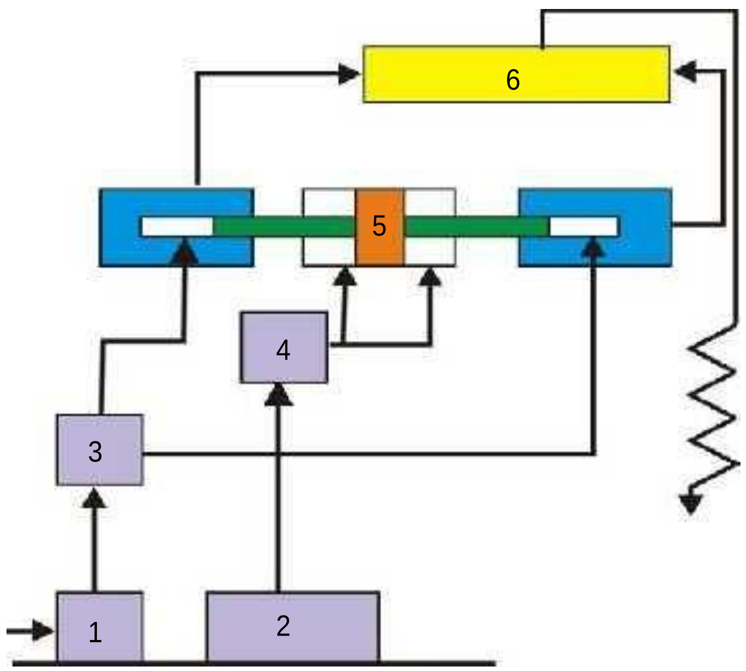
- Steels
- Non-ferrous alloys
- Ti alloys, Ni- alloys
- Polymers
- Metal Matrix Composite
- Ceramic Matrix Composite
- Metal Polymer Laminates
- Glass Fibre Metal Laminates

Machine

Any standard abrasive water jet machining (AWJM) system using entrained AWJM methodology consists of following modules.

- LP booster pump
- Orifice

- Hydraulic unit
- Mixing Chamber
- Additive Mixer
- Focussing tube or inserts
- Accumulator
- Intensifier
- On-off valve
- Catcher
- CNC table
- Abrasive metering device



1. LP Booster
2. Hydraulic drive
3. Additive mixer
4. Direction control
5. Intensifier
6. Accumulator

Figure 1.12 Modules of Abrasive Water Jet Machining (AWJM)

Mechanism of material removal

The general domain of parameters in entrained type AWJ machining system is given below:

- Orifice – Sapphires – 0.1 to 0.3 mm
- Focussing Tube – WC – 0.8 to 2.4 mm
- Pressure – 2500 to 4000 bar
- Abrasive – garnet and olivine - #125 to #60
- Abrasive flow - 0.1 to 1.0 Kg/min
- Stand-off distance – 1 to 2 mm
- Machine Impact Angle – 60° to 90°
- Traverse Speed – 100 mm/min to 5 m/min
- Depth of Cut – 1 mm to 250 mm

Mechanism of material removal in machining with water jet and abrasive water jet is rather complex. In AWJM of ductile materials, material is mainly removed by low angle impact by abrasive particles leading to ploughing and micro cutting. In case of AWJM of brittle materials, other than the above two models, material would be removed due to crack initiation and propagation because of brittle failure of the material.

Applications

- Paint removal
- Cleaning
- Cutting soft materials
- Cutting frozen meat
- Textile, Leather industry
- Mass Immunization
- Surgery
- Turning
- Nuclear Plant Dismantling

Advantages

- Extremely fast set-up and programming
- Machine virtually any 2D shape on any material
- Very low side forces during the machining
- Almost no heat generated on the part
- Machining thick plates is possible

Limitations

- Initial cost is high
- Difficult to machine hard material
- Noisy operation

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UNIT – II – SPR1403 – ELECTROCHEMICAL MACHINING AND METAL REMOVAL PROCESSES

Electrochemical Machining- Elements of ECM process, tool work gap, chemistry of the process, metal removal rate, accuracy, surface finish and other work material characteristics, economics, advantages, applications, limitations. Electrochemical Grinding – Material removal, surface finish, accuracy, advantages, applications.

Instructional Objectives

- Identify electro-chemical machining (ECM) as a particular type of non-tradition processes
- Describe the basic working principle of ECM process
- Draw schematically the basics of ECM
- Draw the tool potential drop
- Describe material removal mechanism in ECM
- Identify the process parameters in ECM
- Develop models for material removal rate in ECM
- Analyse the dynamics of ECM process
- Identify different modules of ECM equipment
- List four application of ECM
- Draw schematics of four such ECM applications

1. Introduction

Electrochemical Machining (ECM) is a non-traditional machining (NTM) process belonging to Electrochemical category. ECM is opposite of electrochemical or galvanic coating or deposition process. Thus ECM can be thought of a controlled anodic dissolution at atomic level of the work piece that is electrically conductive by a shaped tool due to flow of high current at relatively low potential difference through an electrolyte which is quite often water based neutral salt solution.

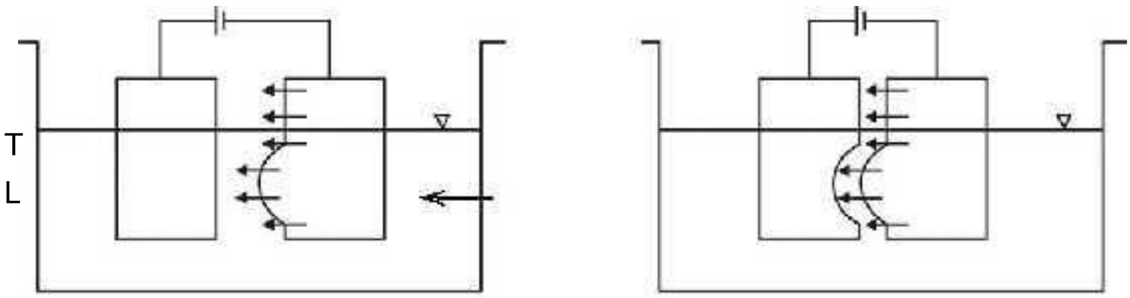


Figure 2.1Basic Principle of Electro Chemical Machining (ECM)

2. Process

During ECM, there will be reactions occurring at the electrodes i.e. at the anode or workpiece and at the cathode or the tool along with within the electrolyte.
Let us take an example of machining of low carbon steel which is primarily a ferrous alloy mainly containing iron. For electrochemical machining of steel, generally a neutral salt solution of sodium chloride (NaCl) is taken as the electrolyte. The electrolyte and water undergoes ionic dissociation as shown below as potential difference is applied

$$NaCl \leftrightarrow Na^+ + Cl^-$$

$$H_2O \leftrightarrow H^+ + (OH)^-$$

As the potential difference is applied between the work piece (anode) and the tool (cathode), the positive ions move towards the tool and negative ions move towards the workpiece. Thus the hydrogen ions will take away electrons from the cathode (tool) and from hydrogen gas as:

$$2H^+ + 2e^- = H_2 \uparrow \text{ at cathode}$$

Similarly, the iron atoms will come out of the anode (work piece) as: $Fe = Fe^{++} + 2e^-$

Within the electrolyte iron ions would combine with chloride ions to form iron chloride and similarly sodium ions would combine with hydroxyl ions to form sodium hydroxide

$$Na^+ + OH^- = NaOH$$

In practice $FeCl_2$ and $Fe(OH)_2$ would form and get precipitated in the form of sludge. In this manner it can be noted that the work piece gets gradually machined and gets precipitated as the sludge. Moreover there is not coating on the tool, only hydrogen gas evolves at the tool or cathode. Fig. 2 depicts the electro-chemical reactions schematically. As the material removal takes place due to atomic level dissociation, the machined surface is of excellent surface finish and stress free.

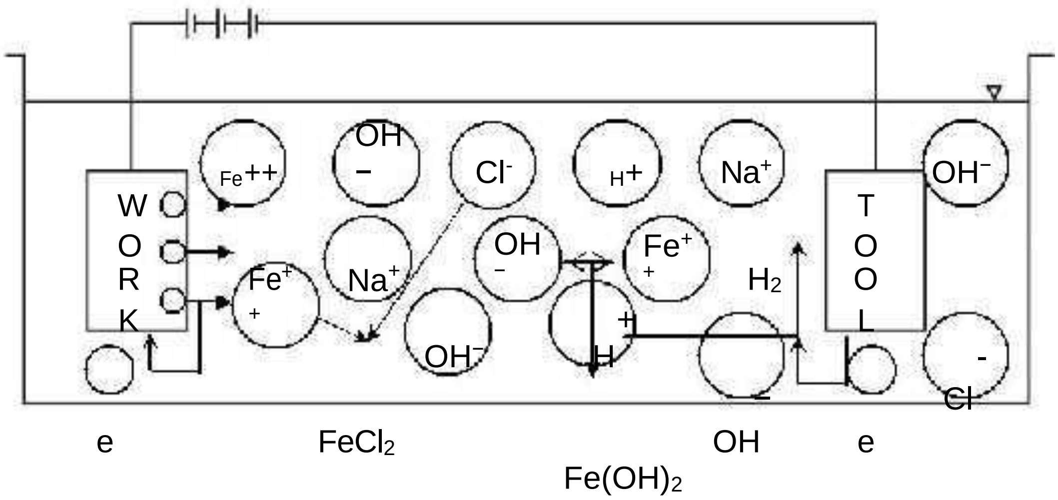


Figure 2.2 Schematic Representation of Electro-Chemical Reactions

The voltage is required to be applied for the electrochemical reaction to proceed at a steady state. That voltage or potential difference is around 2 to 30 V. The applied potential difference, however, also overcomes the following resistances or potential drops. They are:

- The electrode potential
- The activation over potential
- Ohmic potential drop
- Concentration over potential
- Ohmic resistance of electrolyte

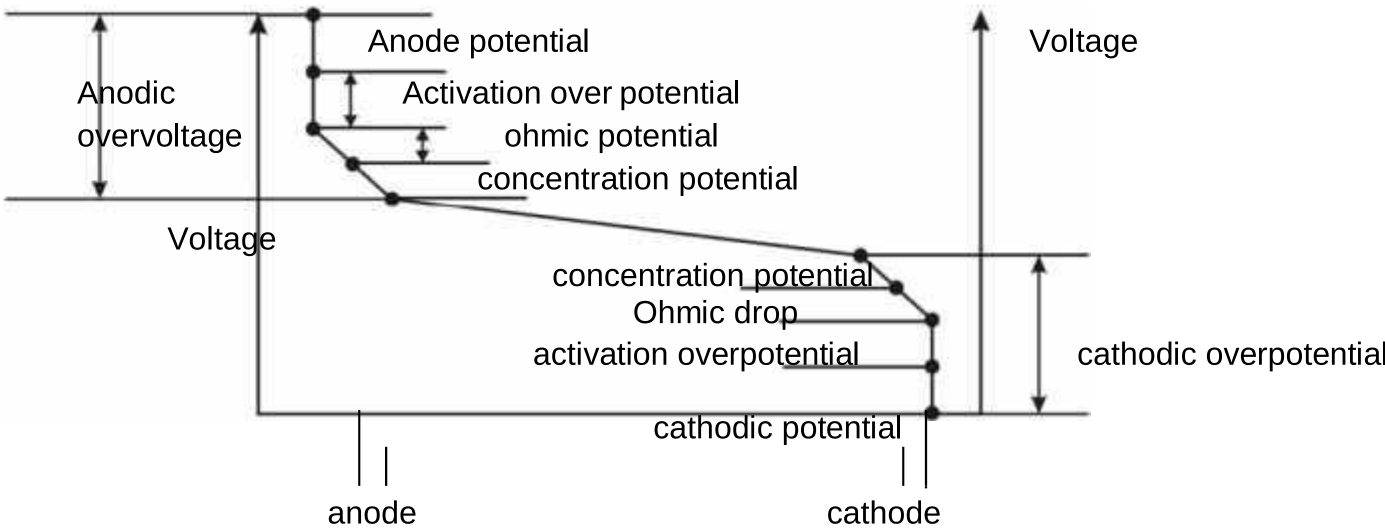


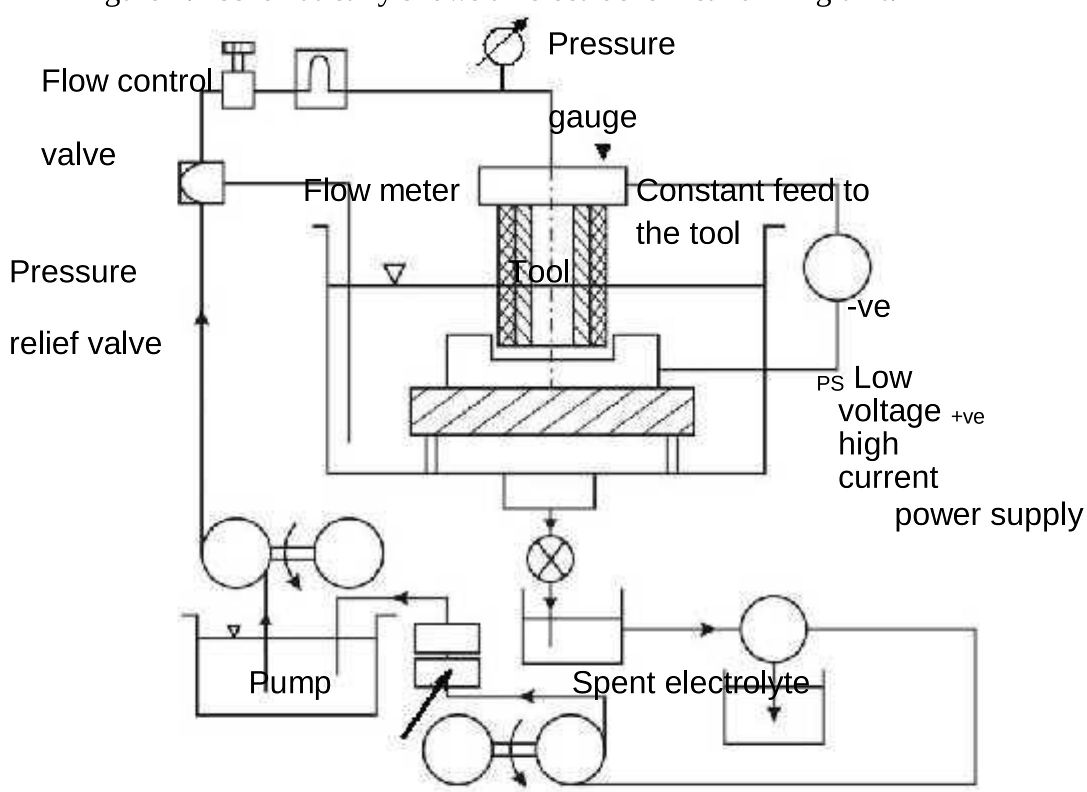
Figure 2.3 Shows the Total Potential Drop in ECM cell

3. Equipment

The electrochemical machining system has the following modules:

- Power supply
- Electrolyte filtration and delivery system
- Tool feed system
- Working tank

Figure 2.4 schematically shows an electrochemical drilling unit.



Material removal rate (MRR) is an important characteristic to evaluate efficiency of a non-traditional machining process.

In ECM, material removal takes place due to atomic dissolution of work material. Electrochemical dissolution is governed by Faraday's laws.
The first law states that the amount of electrochemical dissolution or deposition is proportional to amount of charge passed through the electrochemical cell, which may be expressed as:

$m \propto Q$,

where m = Mass of material dissolved or deposited Q = Amount of charge passed
The second law states that the amount of material deposited or dissolved further depends on Electrochemical Equivalence (ECE) of the material that is again the ratio of the atomic weight and valency. Thus

$m \; \alpha \; ECE \; \alpha \; \overline{A/V}$

Thus $m \; \alpha \; {}^{QA}/_{v}$

where F = Faraday's constant
= 96500 coulombs

$\therefore \quad m = ItA / Fv$

$\therefore \quad MRR = {}^{m}/_{t\rho}$

where I = Current
ρ = Density of the material
The engineering materials are quite often alloys rather than element consisting of different elements in a given proportion.

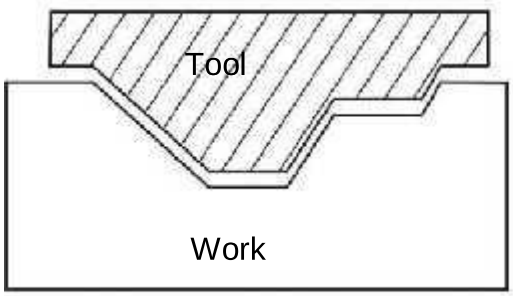
6. Applications

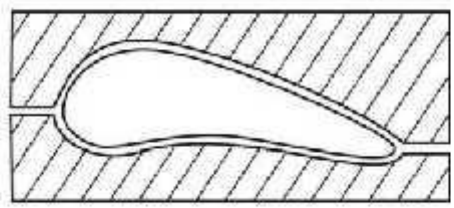
ECM technique removes material by atomic level dissolution of the same by electrochemical action. Thus the material removal rate or machining is not dependent on the mechanical or physical properties of the work material. It only depends on the atomic weight and valency of the work material and the condition that it should be electrically conductive. Thus ECM can machine any electrically conductive work material irrespective of their hardness, strength or even thermal properties. Moreover as ECM leads to atomic level dissolution, the surface finish is excellent with almost stress free machined surface and without any thermal damage.

ECM is used for

- Die sinking
- Profiling and contouring
- Trepanning

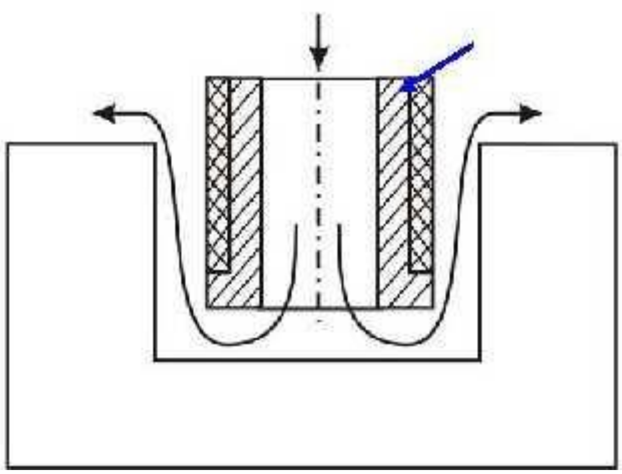
- Grinding
- Drilling
- Micro-machining





3D profiling

Figure 2.5 Different Applications of Electro Chemical Machining



(Drilling)

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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICALENGINEERING

SPR1403 – MODERN MANUFACTURING PROCESS

COURSE MATERIAL

UNIT – III – SPR1403 –THERMAL METAL REMOVAL PROCESSES

Electric Discharge Machining (EDM) or spark erosion machining processes, mechanism of metal removal,spark erosion generators, electrode feed control, dielectric fluids, flushing. Electrodes for spark erosion, selection of electrode material, tool electrode design, surface finish, machining accuracy, machine tool selection and applications. Wire cut EDM. Laser beam machining (LBM) - Apparatus, material removal, cutting speed and accuracy of cut, metallurgical effects, advantages and limitations

ELECTRIC DISCHARGE MACHINING (EDM)

It is also known as spark erosion machining or spark machining**.** Material of work piece removed due to erosion caused by electric spark. Working principle is described below.

Working Principle of Electric Discharge Machining

Electric discharge machining process is carried out in presence of dielectric fluid which creates path for discharge. When potential difference is created across the two surfaces of die electric fluid, it gets ionized. An electric spark/discharge is generated across the two terminals. The potential difference is developed by a pulsating direct current power supply connected across the two terminals. One of the terminal is positive terminal given to work piece and tool is made negative terminal. Two third of the total heat generated is generated at positive terminal so work piece is generally given positive polarity. The discharge develops at the location where two terminals are very close. So tool helps in focusing the discharge or intensity of generated heat at the point of metal removal. Application of focused heat raises the temperature of work piece locally at a point, this way two metal is melted and evaporated.

Electric Discharge Machining Process Details

The working principle and process of EDM is explained with the help of line diagram in Figure 3.1. The process details and components are explained below serially.

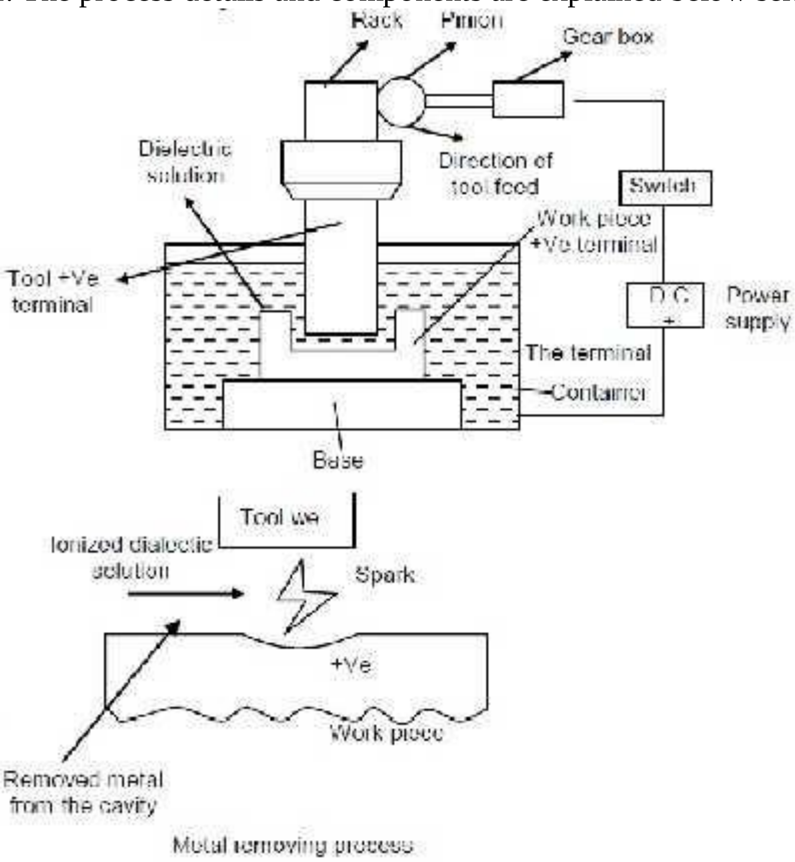

Figure 3.1 Line Diagram Indicating Working Principle and Process Details of EDM

Base and Container

A container of non-conducting, transparent material is used for carrying out EDM. The container is filled with dielectric solution. A base to keep work piece is installed at the bottom of container. The base is made of conducting material and given positive polarity.

Tool

Tool is given negative polarity. It is made of electrically conducting material line brass, copper or tungsten. The tool material selected should be easy to machine, high wear resistant. Tool is made slightly under size for inside machining and over sized for cut side machining. Tool is designed and manufactured according to the geometry to be machined.

Dielectric Solution

Dielectric solution is a liquid which should be electrically conductive. This solution provides two main functions, firstly it drive away the chips and prevents their sticking to work piece and tool. It enhance the intensity of discharge after getting ionized and so accelerates metal removal rate.

Power Supply

A DC power supply is used, 50 V to 450 V is applied. Due to ionization of dielectric solution an electrical breakdown occurs. The electric discharge so caused directly impinges on the surface of work piece. It takes only a few micro seconds to complete the cycle and remove the material. The circuit cam be adjusted for auto off after pre-decided time interval.

Tool Feed Mechanism

In case of EDM, feeding the tool means controlling gap between work piece and the tool. This gap is maintained and controlled with the help of servo mechanism. To maintain a constant gap throughout the operation tool is moved towards the machining zone very slowly. The movement speed is towards the machining zone very slowly. The movement speed is maintained by the help of gear and rack and pinion arrangement. The servo system senses the change in gap due to metal removal and immediately corrects it by moving the tool accordingly. The spark gap normally varies from 0.005 mm to 0.50 mm.

Work piece and Machined Geometry

The important point for work piece is that any material which is electrical conductor can be machined through this process, whatever be the hardness of the same. The geometry which is to be machined into the work piece decides the shape and size of the tool.

Application of Electric Discharge Machining

This process is highly economical for machining of very hard material as tool wear is independent of hardness of work piece material. It is very useful in tool manufacturing. It is also used for broach making, making holes with straight or curved axes, and for making complicated cavities which cannot be produced by conventional machining operations. EDM is widely used for die making as complex cavities are to be made in the die making. However, it is capable to do all operations that can be done by conventional machining.

Advantages of EDM

- This process is very much economical for machining very hard material.
- Maintains high degree of dimensional accuracy so it is recommended for tool and die making.
- Complicated geometries can be produced which are very difficult otherwise.
- Highly delicate sections and weak materials can also be processed without any risk of their distortion, because in this process tool never applies direct pressure on the work piece.
- Fine holes can be drilled easily and accurately.
- Appreciably high value of MRRR can be achieved as compared to other non-conventional machining processes.

Disadvantages and Limitations of EDM Process

There are some limitations of EDM process as listed below:

- This process cannot be applied on very large sized work pieces as size of work piece is constrained by the size of set up.
- Electrically non-conducting materials cannot be processed by EDM.
- Due to the application of very high temperature at the machining zone, there are chances of distortion of work piece in case of this section.
- EDM process is not capable to produce sharp corners.
- MRR achieved in EDM process is considerably lower than the MRR in case of conventional machining process so it cannot be taken as an alternative to conventional machining processes at all.

Process Parameters

The following factors influences the process parameters in EDM processes

1. Operating parameters:

   Operating process involves the removal of metal from the work piece and tool as a measure of electrical energy input.

2. Taper:

   Tapering Effect is observed due to the side sparks .under high dielectric pollution, side sparks are more pronounced as compared to frontal sparks.

3. Surface finish:

   The surface finish of the material depends upon the following factors

   i. Energy of the pulse and
   ii. Frequency of operation

WIRE CUT ELECTRIC DISCHARGE MACHINING (WCEDM)

This is a special type of electric discharge machining that uses a small diameter wire as a cutting tool on the work. Working a principle of wire cut electric discharge machining is same as that of electric discharge machining.

Process Details of WCEDM

Process details of WCEDM are almost similar to EDM with slight difference. The details of the process are indicated in the line diagram shown in Figure 5.2. Its major difference of process details with EDM process details are described below.

Tool Details

The tool used in WCEDM process is a small diameter wire as the electrode to cut narrow kerfs' in the work piece. During the process of cutting the wire is continuously advanced between a supply spoil and wire collector. This continuous feeding of wire makes the machined geometry insensitive to distortion of tool due to its erosion. Material of wire can be brass, copper, tungsten or any other suitable material to make EDM tool. Normally, wire diameter ranges from 0.076 to 0.30 mm depending upon the width of kerf.

Tool Feed Mechanism

Two type of movements are generally given to the total (wire). One is continuous feed from wire supply spoil to wire collector. Other is movement of the whole wire feeding system, and wire along the kerf to be cut into the work piece. Both movements are accomplished with ultra accuracy and pre-determined speed with the help of numerical control mechanism.

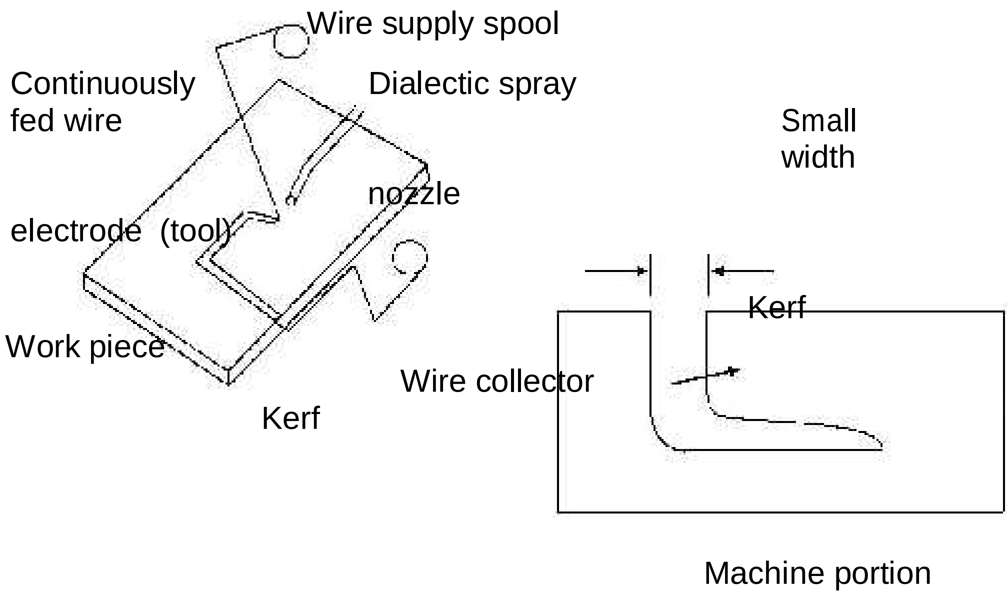

Figure 3.2 Line Diagram for Process Details of Working of Wire Cut Electric Discharge Machining

Dielectric Fluid and Spray Mechanism

Like EDM process dielectric fluid is continuously sprayed to the machining zone. This fluid is applied by nozzles directed at the tool work interface or work piece is submerged in the dielectric fluid container. (*Rest of the process details in* *case of WCEDM process are same as that in case of EDM process*).

Applications of WCEDM

WCEDM is similar to hand saw operation in applications with good precision. It is used to make narrow kerf with sharp corners. It does not impose any force to workpiece so used for very delicated and thin work pieces. It is considered ideal for making components for stamping dies. It is also used to make intricate shapes in punch, dies and other tools.

Advantages of WCEDM

Advantages are listed below:

- Accuracy and precision of dimensions are of very good quality.
- No force is experienced by the work piece.
- Hardness and toughness of work piece do not create problems in machining operation.

Disadvantages and Limitations of WCEDM

The major disadvantages of this process are that only electrically conducting materials can machine. This process is costly so recommended for use specifically at limited operations.

LASER BEAM MACHINING (LBM)

Laser beam have wide industrial applications including some of the machining processes. A laser is an optical transducer that converts electrical energy into a highly coherent light beak. One must know the full name o amplification of stimulated emission of radiation" specific property, if it is focused by conventional optical lenses can generate high power density.

Working Principle of LBM

LBM uses the light energy of a laser beam to remove material by vaporization and ablation. The working principle and the process details (setup) are indicated in Figure 5.6. In this process the energy of coherent light beam is focused optically for pre decided longer period of time. The beam is pulsed so that the released energy results in an impulse against the work surface that does melting and evaporation. Here the way of metal removing is same as that of EDM process but method of generation of heat is different. The application of heat is very finely focused in case of LBM as compared to EDM.

Process Details of LBM

Process details of LBM are shown in line diagram shown in Figure 5.6, description of the details is given below.

Laser Tube and Lamp Assembly

This is the main part of LBM setup. It consists of a laser tube, a pair of reflectors, one at each end of the tube, a flash tube or lamp, an amplification source, a power supply unit and a cooling system. This whole setup is fitted inside a enclosure, which carries good quality reflecting surfaces inside. In this setup the flash lamp goes to laser tube, that excites the atoms of the inside media, which absorb the radiation of incoming light energy. This enables the light to travel to and fro between two reflecting mirrors. The partial reflecting mirror does not reflect the total light back and apart of it goes out in the form of a coherent stream of monochromatic light. This highly amplified stream of light is focused on the work piece with the help of converging lens. The converging lens is also the part of this assembly.

Work piece

The range of work piece material that can be machined by LBM includes high hardness and strength materials like ceramics, glass to softer materials like plastics, rubber wood, etc. A good work piece material high light energy absorption power, poor reflectivity, poor thermal conductivity, low specific heat, low melting point and low latent heat.

Cooling Mechanism

A cooling mechanism circulates coolant in the laser tube assembly to avoid its over heating in long continuous operation.

Tool Feed Mechanism

There is no tool used in the LBM process. Focusing laser beam at a pre- decided point in the work piece serve the purpose of tool. As the requirement of being focused shifts during the operation, its focus point can also be shifted gradually and accordingly by moving the converging lens in a controlled manner. This movement of the converging lens is the tool feed mechanism in LBM process.

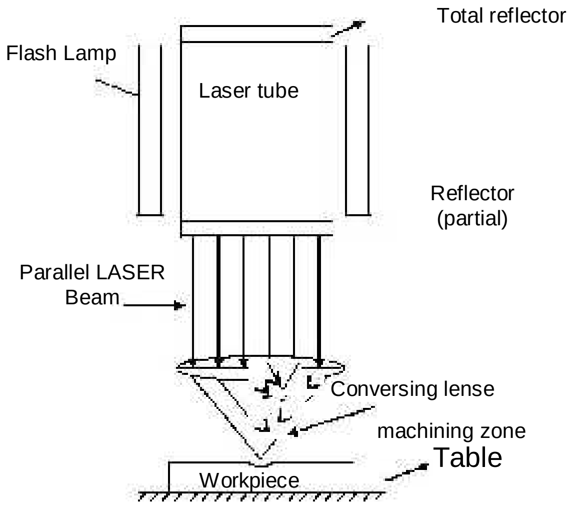

Figure 3.3 Working Principle and Process Details of LBM

Applications of LBM

LBM is used to perform different machining operations like drilling, slitting, slotting, scribing operations. It is used for drilling holes of small diameter of the order of 0.025 mm. It is used for very thin stocks. Other applications are listed below:

- Making complex profiles in thin and hard materials like integrated circuits and printed circuit boards (PCBS).

- Machining of mechanical components of watches.
- Smaller machining of very hard material parts.

Advantages of LBM

- Materials which cannot be machined by conventional methods are machined by LBM.
- There is no tool so no tool wear.
- Application of heat is very much focused so rest of the workpiece is least affected by the heat.
- Drills very find and precise holes and cavities.

Disadvantages of LBM

Major disadvantages of LBM process are given below:

- High capital investment is involved. Operating cost is also high.
- Recommended for some specific operations only as production rate is very slow.
- Cannot be used comfortably for high heat conductivity materials light reflecting materials.
- Skilled operators are required.

QUESTIONS:

1. Explain the principle of working of EDM process with sketch.
2. What are the advantages and disadvantages of the EDM process?
3. Explain the principle of working of wire cut EDM process with a sketch.
4. What are the tools(electrodes) used in EDM process?
5. What are the function of dielectric fluids used in EDM process?
6. Explain the principle of working of LBM process with sketch.
7. What are the advantages and disadvantages of the LBM process?

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SPR1403 – MODERN MANUFACTURING PROCESS

COURSE MATERIAL

UNIT – IV – SPR1403 –PLASMA ARC MACHINING

Plasma, non thermal generation of plasma, mechanism of metal removal, PAM parameters, equipments for D.C. plasma torch unit, safety precautions, economics, other applications of plasma jets - Electron Beam Machining(EBM)– Generation and control of electron beam, theory of electron beam machining, process capabilities and limitations..

Plasma Arc Machining (PAM)

Plasma arc machining is a nontraditional thermal process. *Plasma* is defined as a gas that has been heated to a sufficiently high temperature to become partially ionized and therefore electrically conductive. The term plasma, as employed in physics, means ionized particles. The temperature of plasma may reach as high as 28000°C. Various devices utilizing an electric arc to heat gas to the Plasma State have been in existence since the early 1900's. However, the development of such apparatus into commercial plasma arcs equipment for metal cutting applications dates back to only about 1955.

The plasma arc produced by modern equipment is generated by a plasma torch that is constructed in such a manner as to provide an electric arc between an electrode and workpiece, as shown in Figure 4.1. A typical plasma torch consists of an *electrode holder*, an electrode, a *device to swirl the gas,* and a *water-cooled nozzle*. The geometry of the torch nozzle is such that the hot gases are constricted in a narrow column.

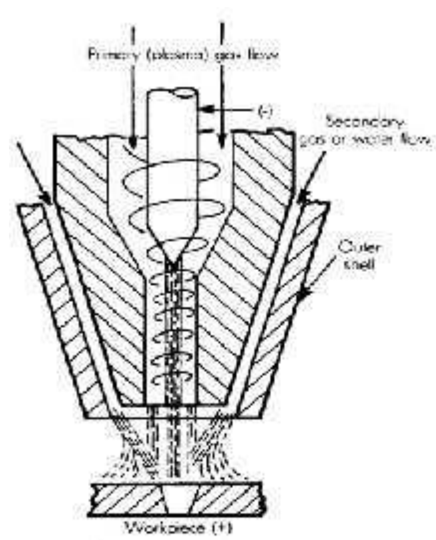

Figure 4.1 Plasma Torch

Primary gasses, such as nitrogen, argon-hydrogen, or air, are forced through the nozzle and arc and become heated and ionized. Secondary gases or water flow are often used to help clean the kerf of molten metal during cutting.

The stream of ionized particles from the nozzle can be used to perform a variety of industrial jobs. The plasma arc, as an industrial tool, is a most heavy employed in sheet and plate cutting operations as an alternative to more conventional oxy-fuel torches or other cutting tools. Plasma arc is routinely used as an integral component of some modern punching machines. Plasma arc methods are also employed in special applications to replace conventional machining operations such as lathe turning, milling and planning, heat treatment and metal deposition operations, and plasma arc welding.

Principle of operation

In PAM, constricting an electric arc through a nozzle, as shown in Fig. 1 generates the basic plasma jet. Instead of diverging into an open arc, the nozzle constricts the arc into a small cross section. This action greatly increases the power of the arc so that both temperature and voltage are raised. After passing through the nozzle, the arc exists in the form of a high-velocity, well-columnated and intensely hot plasma jet.

The basic heating phenomenon that takes place at the workpiece is a combination of heating due to energy transfer of electrons, recombination of dissociated molecules on the workpieces, and connective heating from the high-temperature plasma that accompanies the arc. In some cases, it is desirable to achieve a third source of heating by injecting oxygen into the work area and taking advantage of the exothermic oxidation reaction. Once the material has been raised to the molten point, the high-velocity gas stream effectively blows the material away.

For an optimized PAM cutting or machining operation, up to 45% of the electrical power delivered to the torch is used to remove metal from the workpiece. Of the remaining power, approximately 10% go into the cooling water in the plasma generator and the rest is wasted in the hot gas and in heating the workpiece.

The jet stream of ionized gases exits at sonic speed and tends to maintain a slightly diverging columnar shape until deflected by solid material. This ionized jet serves as a conductor for the arc; it provides directional stability. The ionized gas may be further shielded from dispersion and heat loss, which result from impacting air molecules, as it exits from the nozzle by means of another annular stream of gas that surrounds the plasma as it leaves the orifice nozzle.

The ionized plasma gas is usually inactive to protect the electrode from combustion and ensure long life. When oxygen is added as either the plasma ionized gas or the secondary enveloping gas, the speed of cutting steel is increased. Use of a secondary envelope of gas improves the kerf wall appearance on certain metals. This envelope also acts as a protective shield for the nozzle during extensive piercing operations.

A major improvement in mechanized plasma arc cutting occurred in recent years with the development of so-called "*water injection*". Figure 4.2 illustrates the principle of water swirl injection. When the water injection technique is employed, the arc is constricted by a flow of water around the arc. This injection of water has many advantages, including:

1. A square cut can be made.
2. Arc stability is increased.
3. Cutting speed can be increased.
4. Workpieces are heated less.
5. Less smoke and fumes are generated.
6. Nozzle life is increases.

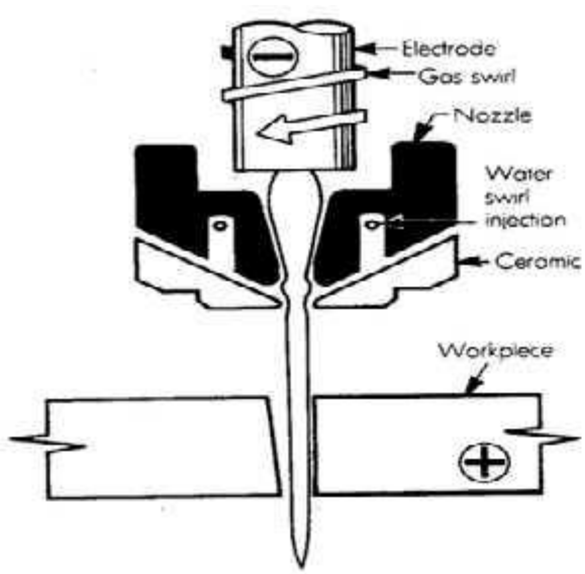

Figure 4.2 Water Swirl Injection

Applications

Cutting: With appropriate equipment and techniques, the plasma arc can be successfully employed to make cuts in electrically conductive metals. Figure 4.3 illustrates the general setup for cutting using a plasma arc torch.

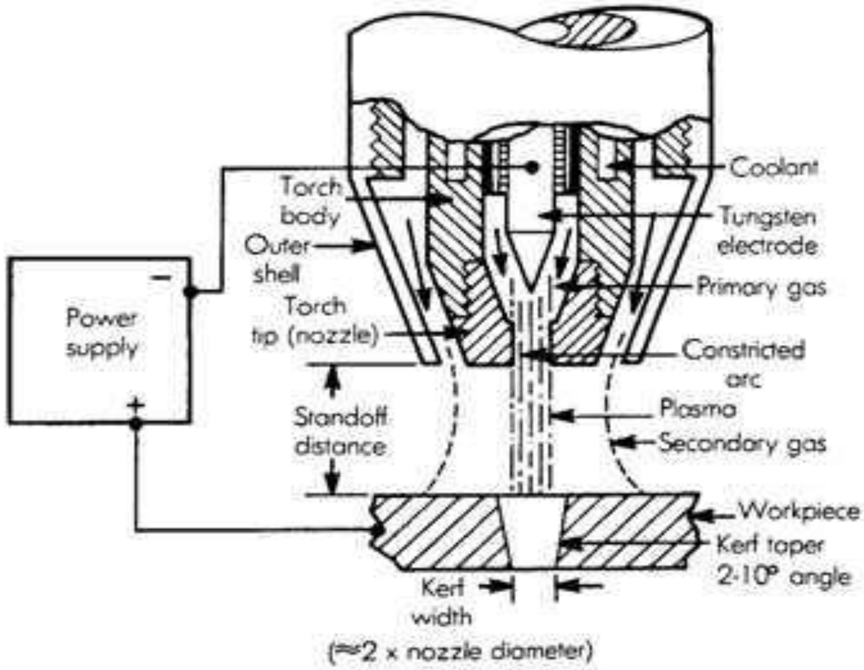

Figure 4.3 Cutting using Plasma Arc Torch

In ***hole piercing***, reproducible and high-quality holes are made rapidly in a variety of materials with the plasma arc. Holes can be pierced much faster than they can be drilled. Plasma arc hole piercing is performed with conventional plasma arc cutting equipment that has been modified to produce a short, carefully controlled arc operating time, suitable arc current programming during the short operating cycle, and effective slag ejection.

Almost instantly after ignition the arc rapidly penetrates through the plate forming a hole approximately the same size as the diameter of the arc stream. Continued plasma exposure increases the size of the hole to 4 or 5 times the arc stream diameter. Moving the torch or workpiece in a circular motion can produce larger holes.

In ***stack cutting***, Plasma is effectively stack-cut stainless steel and aluminum. Plasma stack-cutting of thin carbon steel tends to weld the layers making them difficult to separate after cutting. During cutting, the layers should be clamped firmly enough to minimize gaps, but loose enough to permit slippage between layers due to differential expansion. The upper layer may buckle if clamping does not allow slippage.

Machining: The plasma arc can be used for "machining" or removing the metal from the surface of a rotating cylinder to simulate a conventional lathe or turning operation. The process is shown schematically in Figure 4.4

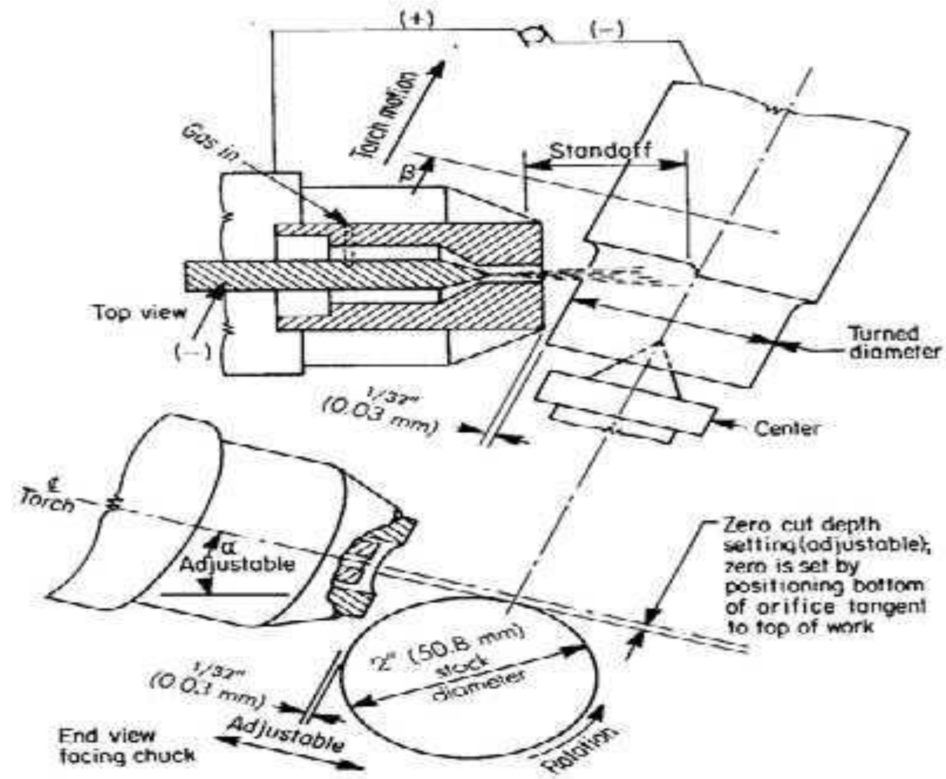

Figure 4.4 Metal Removing in a rotating cylinder

As the work piece is turned, the torch is moved parallel to the axis of the work. The torch is positioned so the arc will impinge tangentially on the workpiece and remove the outer layer of metal. Cutting can be accomplished with the workpiece rotating in either direction relative to the torch, but best results are obtained when the direction of rotation permits use of the shortest arc length for cutting. The flow of molten metal being removed must be in such a direction that it does not tend to adhere to the hot surface that has just been machined.

Generally, the plasma-arc metal removal process has little if any advantage on easy-to-machine metals, but it has considerable economic advantage for rough metal removal of hard-to-machine metals. The process is generally considered to be a roughing operation, which should be followed by a conventional machine finishing cut. Metal removal rates with the plasma arc process on hard-to-machine metals are up to ten times faster than those achieved on a lathe using a tungsten carbide cutting tool. The principal disadvantages are the metallurgical alteration of the characteristic of the surface profile produced.

Operating Parameters

Cutting: Quality of cut and metal removal rate are largely dependent upon proper attention to operating variables. Several factors contribute to the quality and speed of cuts made by the plasma arc process, including cutting-tip nozzle selection, power level, gas type and mixture, gas flow rate, traverse speed, standoff distance, thickness of material, type of materials, impingement angle, and equipment design.

Nozzle size: The highest quality plasma cut is usually obtained when maximum thermal intensity is used. To achieve this, the smallest, or next to the smallest, nozzle size that is capable of operating at a power level suitable for the speed and thickness involved is used. Nozzle size for cutting usually ranges from 0.80 to 6.30 mm in diameter.

Power: Direct current up to 200 kW and 50-1000 A is employed in plasma arc cutting operations.

Gas mixture composition: A proportion of 10% hydrogen and 90% nitrogen or argon usually gives good general-purpose results. Choice of plasma gas composition can have considerable effect on the plasma flame since the ionized gas is the conductive path. The shielding gas or secondary gas can be nitrogen, oxygen, air, or carbon dioxide. Water is sometimes used as a shield.

Gas flow rate: For any particular nozzle size, an increase in plasma gas (primary) flow permits an increase in current. This increases the power density of the flame and permits greater speed with less taper on the kerf walls. Primary gas flow rates usually range between 0.40-5.60 m^3/hr. Secondary gasses are pressurized to flow at up to 11.3 m^3/hr.

Standoff distance: Due to the columnar shape of the plasma jet, a wide range of tip-to-workpiece spacing is allowable. This permits machine cutting along warped or irregular surfaces. General consideration includes:

- Better quality cuts usually result from a short standoff distance since arc divergence is less and the thermal intensity of the arc is greater.
- Excessively close standoff distance can promote arcing due to the accumulation of slag drops on the tip.
- Increased power input is necessary when the standoff distance is great.
- Standoff distance can range from 6.5-76.2 mm.

Machining: In turning operations, torch variables include the electrical power delivered, the gases used to form the plasma, the flow rate of the gases through the torch, the orifice diameter through the nozzle duct, and any secondary gas streams. In general, there is an optimum exit-orifice size for operation at a particular power level that produces a well-controlled, high-velocity plasma jet with maximized capacity for performing the material removal operation. Thus gas flow rate, orifice size, and power level are intimately related.

Metal removal rate: In the physical orientation of PAM operations, such variables as torch standoff, angle to work, depth of cut, feed into the work, and speed of the work toward the torch are involved. Feed and depth of cut determine the volume of metal removed. Since the torch carriage speed and direction are not normally coupled to the work spindle, as they might be on an ordinary lathe, it is necessary to calculate the carriage speed in order to produce a turned piece with a predetermined pitch (pitch-feed). When a 50kW power level on 50 mm rods is used, the maximum metal removal rate for satisfactory surface finish is about 114 cm^3/min.

Surface finish: Surface finish can vary anywhere from helical ridges along the surface to a completely smooth surface with approximately 0.75 µm R_a finish, depending upon the feed into the work optimization of the process. Plasma arc machining for maximum removal rate does produce a slight helical ridge as the cut progresses.

Surface characteristics: One characteristics of the workpiece surface when it is not cooled during an operation is a gradual inward taper in the direction of the cut. This is believed to be due to accumulated heating of the workpiece as the cut progresses and should be minimized or eliminated by appropriate cooling methods. An oxidation scale normally forms behind the cut on an unprotected specimen, but this can be minimized or eliminated by proper shielding.

Metallurgical effects

Metallurgical effects of the PAM process are as widely varied as the materials used and there respective metallurgical histories. In general, the depth of the heat-affected zone is approximately 0.75 mm. For some operations, this hardened material may have to be removed; for other applications, a hardened surface such as this may be desirable. The nature of individual applications of the PAM process determines the metallurgical effects that can be tolerated.

Advantages of PAM Process

- It gives faster production rate.
- Very hard and brittle metals can be machined.
- Small cavities can be machined with good dimensional accuracy.

Disadvantages of PAM Process

- Its initial cost is very high.
- The process requires over safety precautions which further enhance the initial cost of the setup.
- Some of the workpiece materials are very much prone to metallurgical changes on excessive heating so this fact imposes limitations to this process.
- It is uneconomical for bigger cavities to be machined.

ELECTRON BEAM MACHINING

Electron beam machining is a thermal process used for the metal removal during the machining process. In the electrical beam machining, electrical energy is used to generate the electrons with high energy.

Electron Beam Machining Process:

In the electron beam gun the electric beam is generated. Electron beam consists of a small spot size, from which it provides the high velocity electrons. The electron beam machining process is carried out in the vacuum as shown in Figure 4.5. This is due to the electrons present in the process react with the air molecules so they lose the energy and ability of cutting. The work piece material must be placed under the electron beam, and where the equipment is placed under the vacuum. With the spot size of 10 to 100 , the high energy absorbed electron beam is ready to show impact on the work piece material. The high velocity electron consists of kinetic energy, the energy is converted into the heat energy, where the electrons strikes the work material. Because of the high energy present in the electrons it starts to melting and vaporization of the work piece material. The process is done from top to the bottom of the work piece material. In the electrical beam machining the gun is used in the pulsed mode. By using the single pulse holes, and is drilled on the thin sheets. Multiple passes are required for the thicker plates.

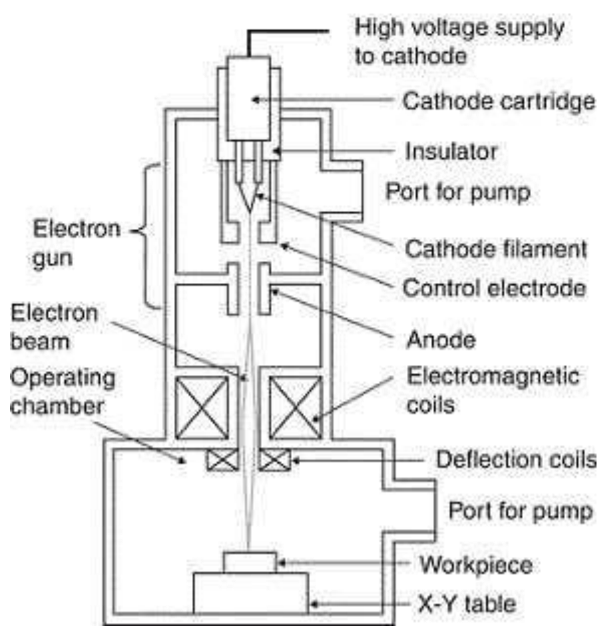

Figure 4.5 Electron Beam Machining

- Cathode, Bias grid, anode, electromagnetic lens, electromagnetic coils, deflector coils, telescope, vacuum gauge, throttle valve, diffusion pump.

- The electron beam machine consists of an electron beam gun used to produce free electrons at the cathode. The high velocity particles are moving through the small spot size. The cathode (tool) is made of tantalum or tungsten material. The cathode filaments are heated to a temperature of 2500to 3000and the heating leads to thermo – ionic emission of electrons. The magnitude varies from the 25 mA to 100 mA. The solidities lies between 5 Ac to 15 Ac .The emission current is influenced by the voltage that is nearly 150kV, and the current is applied between the anode and cathode to release the electrons in the direction of work piece.

- **Bias grid:** It is also known as grid cup. The grid cup is a negative that is subjected with respect to the filament. So, the electrons generated with the help of the cathode will directly flow towards the anode. During the flow of the electrodes no diversions are seen. The anode attracts the electrons and gets accelerated; the electrons will gain a high velocity.
- The cathode controls the flow of the electrons, and the grid cup used to operate the gun in pulsed mode only.
- After the anode the electron beam passing through the magnetic lens and the apertures are connected in series. The magnetic lens is used to shape the electron beam and reduce the diversion factor.
- The apertures allow the convergent electrons to permit and caught the low energy divergent electrons from the fringes.
- Finally the electron beam passes through the electromagnetic lens and deflection coil. Then the deflection coil sends the electron beam through the hole, to improve the shape to machine a hole.
- The vacuum is created between the work piece and the electron beam gun, and there is a series of rotating disc with slots.
- The disc allows the electron beam to pass over the material for machining, and it prevents from the fumes and vapors generated during the machining.
- Work piece is placed on the CNC bench. Then holes of any shape are made on the work piece material. In the gun beam deflection and CNC control are used to shape.
- Vacuum is maintained in gun, and the vacuum ranges from Suitable vacuum are maintained because the electron as it does not lose their energy, and where the life of the cathode is obtained. By using the diffusion pump and rotary pump the vacuum is maintained.
- Diffusion pump should act as an oil heater. If the oil is heated then the oil vapor rushes upwards. The nozzle changes the direction of the oil vapor and starts moving in the downward direction at high velocity. The oil vapors are reduces in the diffusion pump; this is because of the presence of the cooling water cover.

Parameters in the Electron discharge machining:

- We already know that the electron gun is works within the pulse mode. The bias grid is located after the cathode. Then pulse is given to the grid cup, where the pulse duration ranges from 50to 15 ms.

- Beam current is related to the electrons that are emitted from the cathode or available in the beam. Beam current is ranges from the 200micro amps to 1 amp. If the beam current increases, simultaneously there is also an increase in the energy per pulse. High pulse energy is used to machine thicker plates and make the holes larger.
- The power and energy density is ruled by the energy per pulse and the nozzle spot size. With the help of the electromagnetic lens the spot size is controlled. For lower spot size they require a high energy density. The metal removal must be high; this is when compared to the holes size where the hole must be similar.
- The plane of focusing must be above or below the surface of the work piece material.

Capability of Electron Beam machining process

- Electrical beam machining makes a hole ranges from 100 to 2 mm.
- The depth of cut must be 15 mm with a length to diameter ratio of nearly 10.
- Holes can be elongated along with the barrel shape or depth.
- Reverse tapper can also be performed below the surface of the work piece material.
- In the electron discharge machining Cut formation is not observed
- With the help of the electron discharge machining we can machine the wide range of materials like stainless steel, aluminum, steel, plastics, ceramics etc.
- In EBM the heat affected zone is narrow; this is because of the short pulse occurrence. The heat affected zone is nearly 20 to 30
- Compares to the steels aluminum and titanium is freely machined.
- Based upon the type of the material, power density, depth of cut holes diameter, which are the reasons for the number of holes drilled per second on the material.
- The EBM does not apply any cutting forces on the material.
- During the process very simple investment is required for work
- EBM process allows machining of brittle and fragile materials.
- Holes are drilled at an angle of 20 to 30

Advantages of Electron beam machining

- There is no contact between the tool material and work piece material
- Very small holes are also machined on different type of work piece materials with high accuracy
- Drilling is also done on the work piece material with a diameter of nearly 0.002 inches
- Drilling parameters are changed automatically during the machining
- Distortions are not observed to the work piece material
- This process is proficient in attaining high accuracy along with repeatability.
- Compare with the other process, formation of holes is easy with the other process.

Disadvantages:

- The cost of the equipment is very high
- Metal removal rate during the process is low
- Small cut operations are performed on the work piece material with the help of EBM machine
- Vacuum requirements boundaries the dimensions of the work piece material
- Need for secondary backing materials.

Applications of EBM:

- EBM is mainly used for micro machining operations on thin materials. These operations include drilling, perforating, slotting and scribing etc.
- Drilling of holes in pressure differential devices used in nuclear reactors, air craft engines etc.
- It is used for removing small broken taps from holes.

PROCESS PARAMETERS:

The process parameters, which directly affect the machining characteristics in Electron Beam Machining, are:

- The accelerating voltage
- The beam current
- Pulse duration
- Energy per pulse
- Power per pulse
- Lens current
- Spot size
- 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 μ amp 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.

QUESTIONS:

1.Explain plasma arc machining process with sketch.

2.Discuss about PAM process parameters.

3. List the advantages, disadvantages and applications of PAM.

4. Explain EBM process with sketch.

5.Discuss about EBM process parameters.

6. List the advantages, disadvantages and applications of EBM.

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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

SPR1306 – PRODUCTION PLANNING AND CONTROL

COURSE MATERIAL

UNIT – V – SPR1306 – ULTRASONIC MACHINING AND HYBRID PROCESSES

Ultrasonic machining system, mechanics of cutting, process parameters, analysis, capability, grain growing model, grain hammering model, limitations and applications Introduction, working principle, equipment, process parameters, process capabilities and applications of electro chemical grinding (ECG), electrical discharge grinding(EDG), electro chemical discharge grinding (ECDG).

ULTRASONIC MACHINING

Ultrasonic machining is a non-traditional machining process. USM is grouped under the mechanical group Non Traditional Machining processes.

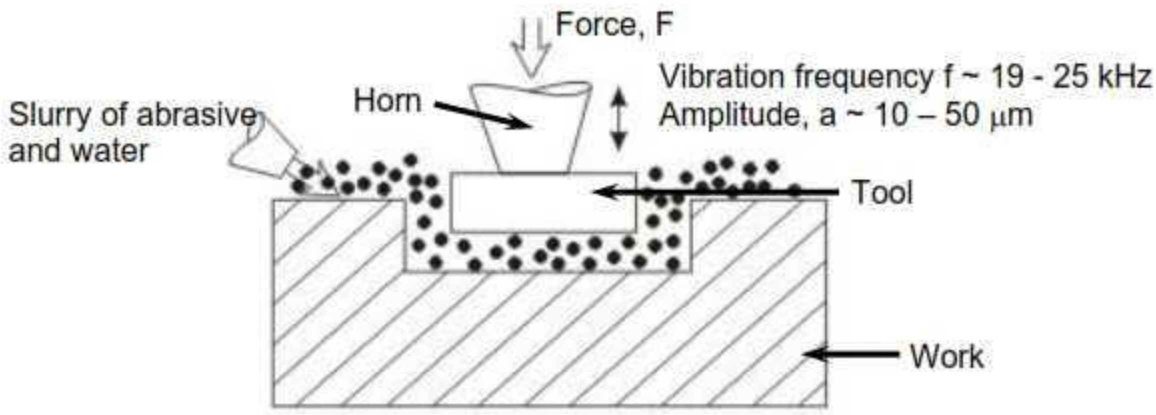

Figure 5.1 Schematic Representation of Material Removal Mechanism

In ultrasonic machining, a tool of desired shape vibrates at an ultrasonic frequency (19000 ~ 25000 Hz) with an amplitude of around 15 – 50 μm over the workpiece. Generally the tool is pressed downward with a feed force, F. Between the tool and workpiece, the machining zone is flooded with hard abrasive particles generally in the form of a water based slurry. As the tool vibrates over the workpiece, the abrasive particles act as the indenters and indent both the work material and the tool. The abrasive particles, as they indent, the work material, would remove the same, particularly if the work material is brittle, due to crack initiation, propagation and brittle fracture of the material. Hence, USM is mainly used for machining brittle materials which are poor conductors of electricity and thus cannot be processed by Electrochemical and Electro-discharge machining.

Effect of Process Parameters

The process parameters which govern the ultrasonic machining process are

- 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 – Aluminium Oxide (Al_2O_3), Silicon Carbide (SiC), Boron Carbide (B_4C), Boronsilicarbide and 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

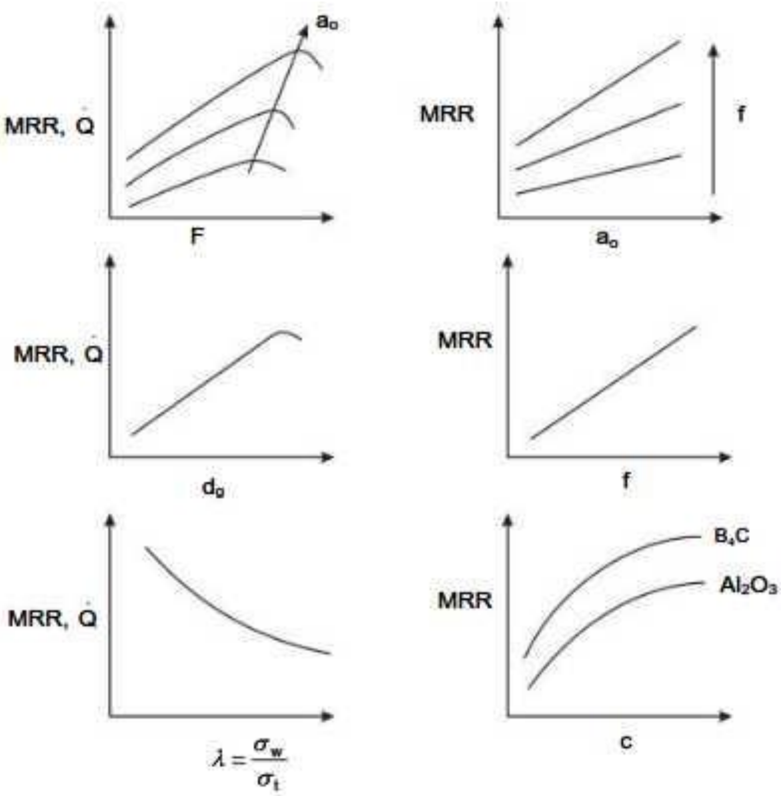

Figure 5.2 Effect of machining parameters on MRR

Ultrasonic Machining Equipment

The basic mechanical structure of an USM is very similar to a drill press. It has additional features to carry out USM of brittle work material. The workpiece 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.

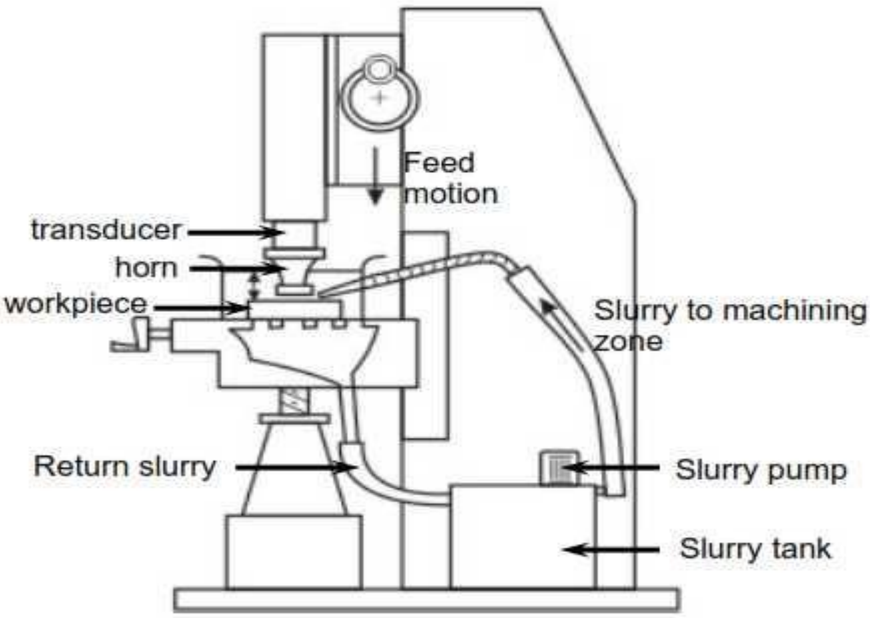

Figure 5.3 Typical Elements of an USM

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. The horn or concentrator of the Magnetostrictive transducers is a wave-guide, which amplifies and concentrates the vibration to the tool from the transducer. The horn or concentrator can be of different shapes like

- Tapered or conical
- Exponential
- Stepped

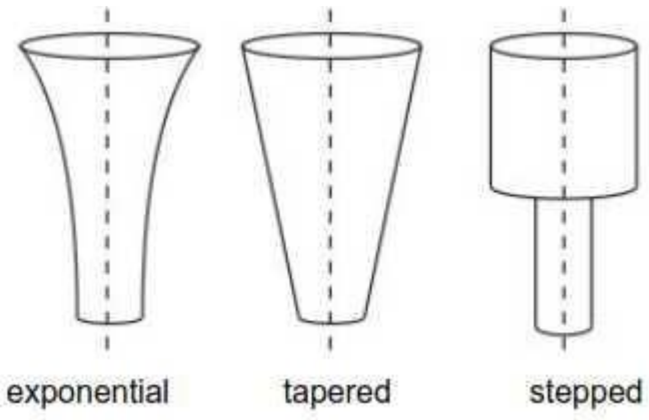

Figure 5.4 Different Shape of Horns Used in an USM

Applications

- Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc. USM is used in machining round, square, irregular shaped holes and surface impressions.
- Wire drawing, punching or small blanking dies can be fabricated by ultrasonic machining.

Limitations

- Low Material Removal Rate, which results in higher time for machining
- Rather high tool wear hence increased setup time and tool cost
- Low depth of hole. Cannot be used for producing high depth holes.

ELECTROCHEMICAL GRINDING (ECG)

Electrochemical Grinding, or ECG, is a variation of ECM (Electrochemical Machining) that Combines electrolytic activity with the physical removal of material by means of charged grinding wheels. Electrochemical Grinding (ECG) can produce burr free and stress free parts without heat or other metallurgical damage caused by mechanical grinding, eliminating the need for secondary machining operations. Like ECM, Electrochemical Grinding (ECG) generates little or no heat that can distort delicate components.

Electrochemical Grinding (ECG) can process any conductive material that is electrochemically reactive. The most common reason customers choose Electrochemical Grinding (ECG) is for the burr free quality of the cut. If a part is difficult or costly to deburr, then Electrochemical Grinding (ECG) is the best option. Materials that is difficult to machine by conventional methods that work harden easily or are subject to heat damage are also good candidates for the stress free and no heat characteristics of Electrochemical Grinding (ECG). The stress free cutting capability of the process also makes it ideal for thin wall and delicate parts.

The real value of Electrochemical Grinding (ECG) is in metalworking applications that are too difficult or time-consuming for traditional mechanical methods (milling, turning, grinding, deburring etc.). It is also effective when compared to non-traditional machining processes such as wire and sinker EDM. Electrochemical Grinding (ECG) is almost always more cost effective than EDM.

Electrochemical Grinding (ECG) differ from conventional grinding Conventional surface grinding typically uses shallow reciprocating cuts that sweep across the work surface to create a flat plane or groove. Another conventional surface grinding process, creep feed grinding, typically uses slower feeds than conventional surface grinding and removes material in deep cuts. Because of the abrasive nature of these processes, the equipment used must be rigid and this is especially true of creep feed grinding.

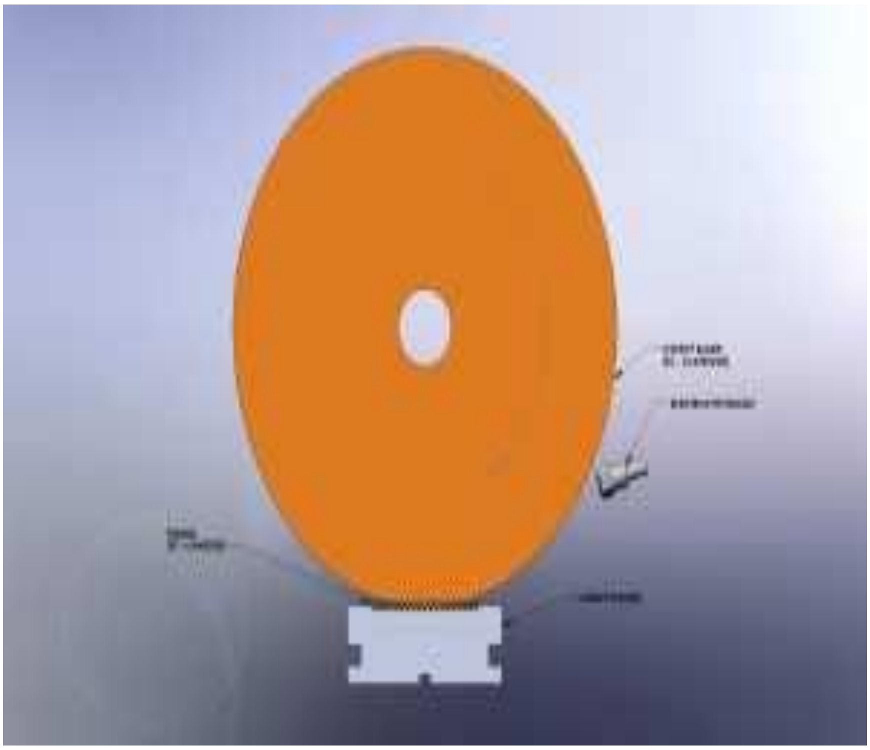

Figure 5.5 Electro Chemical Grinding

Quality Electrochemical Grinding (ECG) machines must also be rigid for close tolerance results but since very little of the material removed is done so abrasively the machines do not have to be as massive as their conventional counterparts. To a user familiar with creep feed grinding Electrochemical Grinding (ECG) will appear to be very similar, that is, relatively slow feeds (as compared to conventional surface grinding) and deep cuts as opposed to shallow reciprocating cuts. Electrochemical Grinding (ECG) is a combination of electrochemical (Anodic) dissolution of a material, according to Faraday’s Law, and light abrasive action.

The metal is decomposed to some degree by the DC current flow between the conductive grinding wheel (Cathode) and the work piece (Anode) in the presence of an electrolyte solution. Unlike conventional grinding techniques, Electrochemical Grinding (ECG) offers the ability to machine difficult materials independent of their hardness or strength. Electrochemical Grinding (ECG) does not rely solely on an abrasive process; the results are precise burr free and stress free cuts with no heat and mechanical distortions.

Figure 5.6 ECG and Traditional Grinding Tool

Electrochemical Grinding (ECG) compare to EDM, laser, water-jet and other non-traditional technologies EDM and laser both cut metal by vaporizing the material at very high temperatures. This results in a re-cast layer and a heat affected zone on the material surface. Electrochemical Grinding (ECG) is a no heat process that never causes metallurgical damage. Electrochemical Grinding (ECG) is usually much faster than EDM but typically is less accurate.

Laser cutting can be very fast and accurate but it is normally limited to thin materials. Water-jet cutting can be quite fast and usually leaves no metallurgical damage but the consumable costs can be very high and the cuts are limited to jigsaw type cuts much like Wire EDM. In most cases, Electrochemical Grinding (ECG)is a more accurate process than water-jet. Another difference between water jet and laser machining compared to electrochemical grinding (ECG) is laser and water jet can both process materials that are not conductive. EDM and electrochemical grinding (ECG) processes can only work on materials that are conductive.

Tolerances can be achieved with electrochemical grinding (ECG) the tolerances that can be achieved using electrochemical grinding (ECG) depend greatly on the material being cut, the size and depth of cut and ECG parameters being used. on small cuts, tolerances of .0002” (.005mm) can be achieved with careful control of the grinding parameters.

Surface Finishes Can Be Achieved With Electrochemical Grinding (ECG)

The Electrochemical Grinding (ECG) process does not leave the typical shiny finish of abrasive grinding. This is because there is no smearing of the metal as in conventional grinding. A 16 micro inch finish or better can be achieved but it will have a matte (dull) rather than a polished look.

Materials Can Be Cut With Electrochemical Grinding (ECG)

Almost any conductive metal can cut with Electrochemical Grinding (ECG). Steel, Aluminum, Copper, Stainless Steels, Inconel and Hastelloy cut very freely with Electrochemical Grinding (ECG). Nickel/Titanium, Cobalt alloys, Amorphous metals, Berilium, Berilium Copper, Iridium Neodymium Iron Boron, Titanium, Nickel/Titanium, Nitinol, Powdered Metals, Rene 41, Rhenium, Rhodium, Stelllite, Vitalium, Zirconium and Tungsten can also be cut effectively.

Advantages of Electrochemical Grinding (ECG)

- Improved wheel life
- Burr free
- No work hardening
- Stress free
- Better finis
- No cracking
- Less frequent wheel dressing
- No metallurgical damage from heat
- Faster for tough materials
- No wheel loading or glazing
- More precise tolerances

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