UNCONVENTIONAL MACHINING PROCESS – UNIT 1
INTRODUCTION

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INTRODUCTION

• Conventional machining process
  – Metal is removed by means of tool which is harder than work piece and they both are in contact with each other

• Demerits of conventional machining process
  – Disposal and recycling of the chips are difficult and tedious process
  – Large cutting forces are involved in this process
NEED FOR UCM

• Unconventional manufacturing process
  – Unconventional machining process
  – Unconventional forming process

• Need for unconventional machining process
  – Harder and difficult to machine materials, can be machined easily and precisely
CLASSIFICATION OF UCM

• Classification of UCM
  – Based on type of energy required to shape the material
    • Thermal energy methods
    • Electrical energy methods
    • Electro chemical energy methods
    • Chemical energy methods
    • Mechanical energy methods
  – Based on mechanisms involved
    • erosion
    • Ionic dissolution
    • vaporization
– Based on the source of energy required for material removal
  • Hydrostatic pressure
  • High current density
  • High voltage
  • Ionized material

– Based on medium of transfer of energies
  • High voltage particles
  • Electrolyte
  • Electron
  • Hot gases
Process Selection

• Points to be considered for correct selection of UCM are
  – Physical parameters
  – Shapes to be machined
  – Process capability or machining characteristics
  – Economic consideration
# Physical parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ECM</th>
<th>EDM</th>
<th>EBM</th>
<th>LBM</th>
<th>PAM</th>
<th>USM</th>
<th>AJM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential, V</td>
<td>5 – 30</td>
<td>50 – 500</td>
<td>$200 \times 10^3$</td>
<td>$4.5 \times 10^3$</td>
<td>250</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>Current, A</td>
<td>40,000</td>
<td>15 – 500</td>
<td>0.001</td>
<td>2</td>
<td>600</td>
<td>12</td>
<td>1.0</td>
</tr>
<tr>
<td>Power, KW</td>
<td>100</td>
<td>2.70</td>
<td>0.15</td>
<td>20</td>
<td>220</td>
<td>2.4</td>
<td>0.22</td>
</tr>
<tr>
<td>Gap, mm</td>
<td>0.5</td>
<td>0.05</td>
<td>100</td>
<td>150</td>
<td>7.5</td>
<td>0.25</td>
<td>0.75</td>
</tr>
<tr>
<td>Medium</td>
<td>Electrolyte</td>
<td>Dielectric Fluid</td>
<td>Vacuum</td>
<td>Air</td>
<td>Argon or hydrogen or nitrogen</td>
<td>Abrasive grains &amp; water</td>
<td>N$_2$ or CO$_2$ or Air</td>
</tr>
<tr>
<td>Work Material</td>
<td>Difficult to machine materials</td>
<td>Tungsten Carbides and electrically conductive materials</td>
<td>All materials</td>
<td>All materials</td>
<td>All materials which conduct electricity</td>
<td>Tungsten Carbide, Glass, Quartz</td>
<td>Hard and brittle materials</td>
</tr>
</tbody>
</table>
## Shapes to be machined

<table>
<thead>
<tr>
<th>Shape Description</th>
<th>Suitable Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>For producing micro holes</td>
<td>LBM is best suited</td>
</tr>
<tr>
<td>For producing small holes</td>
<td>EBM is well suited</td>
</tr>
<tr>
<td>For deep holes (L/D &gt; 20) and contour machining</td>
<td>ECM is best suited</td>
</tr>
<tr>
<td>For shallow holes</td>
<td>USM and EDM are well suited</td>
</tr>
<tr>
<td>For precision through cavities in work pieces</td>
<td>USM and EDM are best suited</td>
</tr>
<tr>
<td>For honing</td>
<td>ECM is well suited</td>
</tr>
<tr>
<td>For etching small portions</td>
<td>ECM and EDM are well suited</td>
</tr>
<tr>
<td>For grinding</td>
<td>AJM and EDM are best suited</td>
</tr>
<tr>
<td>For deburring</td>
<td>USM and AJM are well suited</td>
</tr>
<tr>
<td>For threading</td>
<td>EDM is best suited</td>
</tr>
<tr>
<td>For clean, rapid cuts and profiles</td>
<td>PAM is well suited</td>
</tr>
<tr>
<td>For shallow pocketing</td>
<td>AJM is well suited</td>
</tr>
</tbody>
</table>
## Process capability

<table>
<thead>
<tr>
<th>Process</th>
<th>Material Removal Rate (mm³/s) MRR</th>
<th>Process Capability</th>
<th>Accuracy</th>
<th>Specific Power (KW/cm³/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBM</td>
<td>0.10</td>
<td>0.4 to 6.0</td>
<td>25</td>
<td>2700</td>
</tr>
<tr>
<td>EBM</td>
<td>0.15 to 40</td>
<td>0.4 to 6.0</td>
<td>25</td>
<td>450</td>
</tr>
<tr>
<td>EDM</td>
<td>15 to 80</td>
<td>0.25</td>
<td>10</td>
<td>1.8</td>
</tr>
<tr>
<td>ECM</td>
<td>27</td>
<td>0.2 to 0.8</td>
<td>50</td>
<td>7.5</td>
</tr>
<tr>
<td>PAM</td>
<td>2500</td>
<td>Rough</td>
<td>250</td>
<td>0.90</td>
</tr>
<tr>
<td>USM</td>
<td>14</td>
<td>0.2 to 0.7</td>
<td>7.5</td>
<td>9.0</td>
</tr>
<tr>
<td>AJM</td>
<td>0.014</td>
<td>0.5 to 1.2</td>
<td>50</td>
<td>312.5</td>
</tr>
</tbody>
</table>
## Process economy

<table>
<thead>
<tr>
<th>Process</th>
<th>Capital Cost</th>
<th>Tooling and requirement</th>
<th>Power requirement</th>
<th>Efficiency</th>
<th>Total Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDM</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>CHM</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Very low</td>
</tr>
<tr>
<td>ECM</td>
<td>Very High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Very Low</td>
</tr>
<tr>
<td>AJM</td>
<td>Very Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>USM</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>EBM</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Very High</td>
<td>Very Low</td>
</tr>
<tr>
<td>LBM</td>
<td>Medium</td>
<td>Low</td>
<td>Very Low</td>
<td>Very High</td>
<td>Very Low</td>
</tr>
<tr>
<td>PAM</td>
<td>Very Low</td>
<td>Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
</tr>
<tr>
<td>Conventional Machining</td>
<td>Very low</td>
<td>Low</td>
<td>Low</td>
<td>Very Low</td>
<td>Low</td>
</tr>
</tbody>
</table>
• Advantages of UCM
  – Increases productivity
  – Reduces no. of rejected components
  – Close tolerance is possible
  – Toll material need not be harder than work piece
  – Machined surface does not have residual stress

• Limitations of UCM
  – More expensive
  – MRR is slow
UNCONVENTIONAL MACHINING PROCESS – UNIT 2
Mechanical Energy Based process

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Mechanical Energy Based process

• Material is removed by mechanical erosion of work piece material
  – Abrasive Jet Machining (AJM)
  – Water Jet Machining (WJM)
  – Ultrasonic Machining (USM)
ABRASIVE JET MACHINING (AJM)

• Principle
  – A high speed stream of abrasive particles mixed with high pressure air or gas are injected through a nozzle on the workpiece to be machined.
AJM

• Construction and working principle
AJM

• Process parameters
  – Mass Flow rate
  – Abrasive grain size
  – Gas pressure
  – Velocity of abrasive particles
  – Mixing ratio
  – Nozzle tip clearance
## AJM

### Characteristics

<table>
<thead>
<tr>
<th><strong>Work material</strong></th>
<th>Hard and brittle materials</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abrasive</strong></td>
<td>Al₂O₃, SiC, glass powder</td>
</tr>
<tr>
<td><strong>Size of abrasive</strong></td>
<td>Around 25 microns</td>
</tr>
<tr>
<td><strong>Flow rate</strong></td>
<td>2 to 20 g/min</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>N₂, CO₂ or air</td>
</tr>
<tr>
<td><strong>Velocity</strong></td>
<td>125 to 300 m/s</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>2 to 8 kg/centimetre square</td>
</tr>
<tr>
<td><strong>Nozzle material</strong></td>
<td>Tungsten carbide or synthetic sapphire</td>
</tr>
<tr>
<td><strong>Life of nozzle</strong></td>
<td>WC – 12 to 12 hrs</td>
</tr>
<tr>
<td></td>
<td>Sapphire – 300 hrs</td>
</tr>
<tr>
<td><strong>Nozzle tip clearance</strong></td>
<td>0.25mm to 15mm</td>
</tr>
<tr>
<td><strong>Tolerance</strong></td>
<td>±0.05 mm</td>
</tr>
<tr>
<td><strong>Machining operation</strong></td>
<td>Drilling, deburring, cleaning</td>
</tr>
</tbody>
</table>
AJM

• Applications
  – To machine hard and brittle materials
  – Fine drilling and micro welding
  – Machining of semiconductors
  – Machining of intricate profiles
  – Surface etching
  – Surface preparation
  – Cleaning and polishing of plastics, nylon and teflon
AJM

• Advantages
  – Process is suitable to cut all materials
  – Even diamond can be machined using diamond abrasives
  – No direct contact between tool and workpiece
  – Low initial investment
  – Good surface finish
  – Used to cut intricate hole shapes
AJM

• Disadvantages
  – MRR is slow
  – Soft material cannot be machined
  – Machining accuracy is poor
  – Nozzle wear rate is high
  – Abrasive powder once used can never be used again
  – Requires some kind of dust collection system
  – Cleaning is essential after the operation
**WATER JET MACHINING (WJM)**

- **Principle**
  - When high velocity of water jet comes out of the nozzle and strikes the material, its kinetic energy gets converted into pressure energy inducing a high stress in the work material. When this stress exceeds the ultimate shear stress of the material, small chips of the material get loosened and fresh surface is exposed.

- Used to cut paper boards, plastics, wood, fibre glass, leather.
WJM

• Construction and working

Accumulator → Control Valve

Intensifier → Flow Regulator

Pump

Reservoir

Nozzle

Water Jet

Workpiece
WJM

• Process parameters
  – Material removal rate
  – Geometry and surface finish of work material
  – Wear rate of nozzle

• Disadvantages
  – Initial cost is high
  – Noisy operation
  – Difficult to machine hard material
WJM

- **Characteristics**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Work material</strong></td>
<td>Soft and non-metallic materials</td>
</tr>
<tr>
<td><strong>Tool</strong></td>
<td>Water or water with additives</td>
</tr>
<tr>
<td><strong>Additives</strong></td>
<td>Glycerin, polyethylene oxide</td>
</tr>
<tr>
<td><strong>Pressure of water</strong></td>
<td>100 to 1000 Mpa</td>
</tr>
<tr>
<td><strong>Mass flow rate</strong></td>
<td>8 lit/min</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>45 KW</td>
</tr>
<tr>
<td><strong>MRR</strong></td>
<td>0.6 Cu.m/S</td>
</tr>
<tr>
<td><strong>Feed rate</strong></td>
<td>1 to 4 mm/s</td>
</tr>
<tr>
<td><strong>Nozzle material</strong></td>
<td>Tungsten Carbide, synthetic sapphire</td>
</tr>
<tr>
<td><strong>Stand off distance</strong></td>
<td>2 to 50 mm</td>
</tr>
</tbody>
</table>
WJM

• Advantages
  – Water is used as energy medium and hence it is cheap, non-toxic and easy to dispose
  – Low operating cost
  – Low maintenance cost
  – Work area remains clean and dust free
  – Easily automated
  – No thermal damage to work
ULTRASONIC MACHINING (USM)

• Principle
  – A slurry of small abrasive particles are forced against the work piece by means of a vibrating tool and it causes the removal of metal from the work piece in the form of extremely small chips

  – Also known as ultrasonic grinding or impact grinding

  – Ultrasonic refers to high frequency – above 20khz
USM

• Construction and working
USM

- Process parameters
  - MRR
  - Tool material
  - Work material
  - Surface finish
  - Tool wear rate
  - Abrasive material & abrasive slurry
# USM

## Characteristics

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abrasive</strong></td>
<td>Boron carbide, silicon carbide, diamond, aluminum oxide</td>
</tr>
<tr>
<td><strong>Abrasive slurry</strong></td>
<td>Abrasive grains + water (20 – 30 %)</td>
</tr>
<tr>
<td><strong>Vibration frequency</strong></td>
<td>20 to 30 KHz</td>
</tr>
<tr>
<td><strong>Amplitude</strong></td>
<td>25 to 100 microns</td>
</tr>
<tr>
<td><strong>Wear ratio</strong></td>
<td>1.5:1 for tungsten carbide, 100:1 for glass, 50:1 for quartz, 75:1 for ceramics, 1:1 for steel</td>
</tr>
<tr>
<td><strong>Tool material</strong></td>
<td>Low carbon steel, stainless steel</td>
</tr>
<tr>
<td><strong>Work material</strong></td>
<td>WC, Germanium, glass, quartz</td>
</tr>
<tr>
<td><strong>Surface finish</strong></td>
<td>0.2 to 0.7 micron</td>
</tr>
</tbody>
</table>
USM

• Advantages
  – Extremely hard and brittle materials can be machined easily
  – Noiseless operation
  – Cost of metal removal is low
  – No heat generation on this process
  – Equipments are safe to operate
  – No conductive materials can easily be machined
USM

- Disadvantages
  - MRR is slow
  - Softer materials are difficult to machine
  - Wear rate of tool is high
  - Initial setup cost is high
  - High power consumption
  - Tool cost is high
  - Abrasive should be replaced periodically
USM

• Applications
  – Holes as small as 0.1 mm can be drilled
  – Precise and intricate shaped articles can be machined
  – Efficiently applied to machine glass, ceramics, tungsten
  – Used for making tungsten carbide and diamond wire drawing dies and dies for forging and extrusion process
USM

• Limitations
  – Under ideal conditions
    • Penetration rate – 5 cu.m/min
    • Power – 500 to 1000 W
  – MRR on brittle materials – 0.18 cu.m/J
  – Hole Tolerance – 25 microns
  – Surface finish – 0.2 to 0.7 microns

• Recent developments
  – Instead of using slurry, the tool is impregnated with diamond dust
  – In some cases it is impossible to rotate the tool, so the work piece will be rotated in some cases
Electrical Energy based processes

• Electrical energy is directly used to cut the material to get the final shape and size

  – Electrical discharge machining (EDM)
  – Wire cut Electrical Discharge Machining (WC EDM)
Electrical Discharge Machining (EDM)

• Principle
  – Metal is removed by producing powerful electric spark discharge between the tool (cathode) and the work material (anode)

  – Also known as Spark erosion machining or electro erosion machining
EDM

• Construction and Working
EDM

• Dielectric Fluid
  – Fluid medium which doesn’t conduct electricity
  – Dielectric fluids generally used are paraffin, white spirit, kerosene, mineral oil
  – Must freely circulate between the work piece and tool which are submerged in it
  – Eroded particles must be flushed out easily
  – Should be available @ reasonable price
  – Dielectric fluid must be filtered before reuse so that chip contamination of fluid will not affect machining accuracy
EDM

• Functions of dielectric fluid
  – Acts as an insulating medium
  – Cools the spark region & helps in keeping the tool and work piece cool
  – Carries away the eroded material along with it
  – Maintains a constant resistance across the gap
  – Remains electrically non-conductive
EDM

• Tool materials and tool wear
  – Metallic materials
    • Copper, Brass, Copper-tungsten
  – Non metallic materials
    • graphite
  – Combination of metallic and non metallic
    • Copper – graphite
  – Three most commonly used tool materials are
    • Copper, graphite, copper-tungsten
EDM

• Tool materials
  – Graphite
    • Non-metallic
    • Can be produced by molding, milling, grinding
    • Wide range of grades are available for wide applications
    • It is abrasive and gives better MRR and surface finish
    • But costlier than copper
  – Copper
    • Second choice for tool material after graphite
    • Can be produced by casting or machining
    • Cu tools with very complex features are formed by chemical etching or electroforming
  – Copper-tungsten
    • Difficult to machine and also has low MRR
    • Costlier than graphite and copper
EDM

• Selection of cutting tool is influenced by
  – Size of electrode
  – Volume of material to be removed
  – Surface finish required
  – Tolerance allowable
  – Nature of coolant application

• Basic requirement of any tool materials are
  – It should have low erosion rate
  – Should be electrically conductive
  – Should have good machinability
  – Melting point of tool should be high
  – Should have high electron emission
EDM

• Tool wear
  – Tool does not come in contact with the work
  – So, life of tool is long and less wear takes place

\[
\text{Wear ratio} = \frac{\text{vol. of work material removed}}{\text{vol. of electrode consumed}}
\]

• Tool wear ratio for
  – Brass electrode is 1:1
  – Copper of 2:1
  – Copper tungsten is 8:1
  – Graphite varies between 5 and 50:1
EDM

• Metal Removal Rate (MRR)
  – Defined as volume of metal removed per unit time
  – Depends upon current intensity and it increases with current
  – Usually a rough cut with heavy current and finishing cut with a less current is performed
  – MRR up to 80Cu.mm/S, can be obtained
  – Surface finish of 0.25 microns is obtained
  – Tolerances of the order of ±0.05 to 0.13 mm are commonly achieved
EDM

• Factors affecting MRR
  – Increases with forced circulation of dielectric fluid
  – Increases with capacitance
  – Increases up to an optimal value of work-tool gap, after that it drops suddenly
  – Increases up to an optimum value of spark discharge time, after that it decreases
  – MRR is maximum, when the pressure is below atmospheric pressure
EDM

- Power generating circuits
  - Resistance capacitance circuit (RC Circuit)
  - R-C-L Circuit
EDM

– Rotary pulse generator circuit

[Diagram of a rotary impulse generator for EDM]

– Controlled pulse generator circuit

[Diagram of a controlled pulse circuit for EDM]
EDM

• Process Parameters
  – Operating parameters
    • Electrical energy
    • Voltage
    • Time interval
    • Instantaneous current
    • Torque
    • Pulse width
  – Taper
  – Surface finish
    • Energy of the pulse
    • Frequency of operation
  – Current density
### EDM

#### Characteristics of EDM

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal removal technique</td>
<td>By using powerful electric spark</td>
</tr>
<tr>
<td>Work material</td>
<td>Electrically conductive materials</td>
</tr>
<tr>
<td>Tool material</td>
<td>Copper, alloy of Zinc, yellow brass, Copper-Tungsten</td>
</tr>
<tr>
<td>MRR</td>
<td>15 to 80 Cu.mm/S</td>
</tr>
<tr>
<td>Spark gap</td>
<td>0.005 to 0.05 mm</td>
</tr>
<tr>
<td>Spark frequency</td>
<td>200 to 500 KHz</td>
</tr>
<tr>
<td>Volts</td>
<td>30 to 250 V</td>
</tr>
<tr>
<td>Current</td>
<td>5 to 60 A</td>
</tr>
<tr>
<td>Temperature</td>
<td>10,000 degree celcius</td>
</tr>
<tr>
<td>Dielectric fluid</td>
<td>Petroleum based HC fluids, Paraffin, White Spirit</td>
</tr>
</tbody>
</table>
EDM

• Applications
  – Production of complicated and irregular profiles
  – Thread cutting in jobs
  – Drilling of micro holes
  – Helical profile drilling
  – Curved hole drilling
  – Re-sharpening of cutting tool and broaches
  – Re-machining of die cavities without annealing

• Recent developments
  – EDM change from using relaxation circuit to faster and more efficient impulse circuits
  – Instead of using Cu; WC is used as electrode
EDM

• Advantages
  – Can be used to machine various conductive materials
  – Gives good surface finish
  – Machining of very thin section is possible
  – Does not leave any chips or burrs on the workpiece
  – High accuracy is obtained
  – Fine holes can be easily drilled
  – Process once started does not need constant operators attention
  – It is a quicker process
  – Well suited to machine complicated components
EDM

• Disadvantages
  – Used to machine only electrically conductive materials
  – Non-metallic compounds such as plastics, ceramics or glass can never be machined
  – Suitable for machining small work pieces
  – Electrode wear and overcut are serious problems
  – Perfect square corners can not be machined
  – MRR is slow
  – Power requirement is high
  – The surface machined has been found to have micro holes
Wire Cut Electro-Discharge Machining (WC EDM)
WC EDM

[Diagram showing a wire EDM process with labeled parts such as filter, pump, workpiece, wire guide, wire pulley, spark gap, wire diameter, and slot (kerf).]
WC EDM

• Applications
  – Best suited for production of gears, tools, dies, rotors, turbine blades and cams

• Disadvantages
  – Capital cost is high
  – Cutting rate is slow
  – Not suitable for large work pieces
WC EDM

- Features / Advantages of WC EDM
  - Manufacturing electrode
  - Electrode wear
  - Surface finishing
  - Complicated shapes
  - Time utilization
  - Straight holes
  - Rejection
  - Economical
  - Cycle time
  - Inspection time
## Difference between EDM & WC EDM

<table>
<thead>
<tr>
<th>S. No</th>
<th>Wire Cut EDM</th>
<th>EDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very thin wire made of brass is used as tool</td>
<td>Expensive alloy of silver and tungsten are used as electrode</td>
</tr>
<tr>
<td>2</td>
<td>Whole work piece is not submerged in dielectric medium</td>
<td>Whole work piece is submerged in dielectric medium</td>
</tr>
<tr>
<td>3</td>
<td>Easy to machine complex two dimensional profiles</td>
<td>Difficult to cut complex two dimensional profiles</td>
</tr>
</tbody>
</table>