UNIT – V

HYBRID NON-TRADITIONAL MACHINING PROCESSES

Recent developments in non traditional machining process is the hybrid process. This process was developed by combining the advantages of two non traditional machining processes and eliminating the limitations of those processes.

The various types of hybrid process are

1. Electric discharge diamond grinding (EDDG)
2. Electro chemical spark machining (ECSM)
3. Magneto rheological abrasive flow finishing (MRAFF)

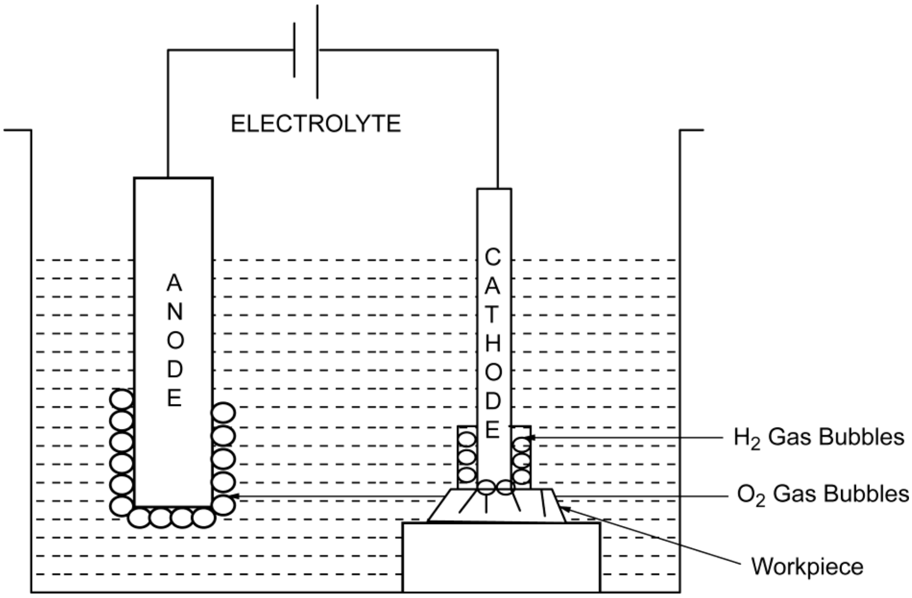
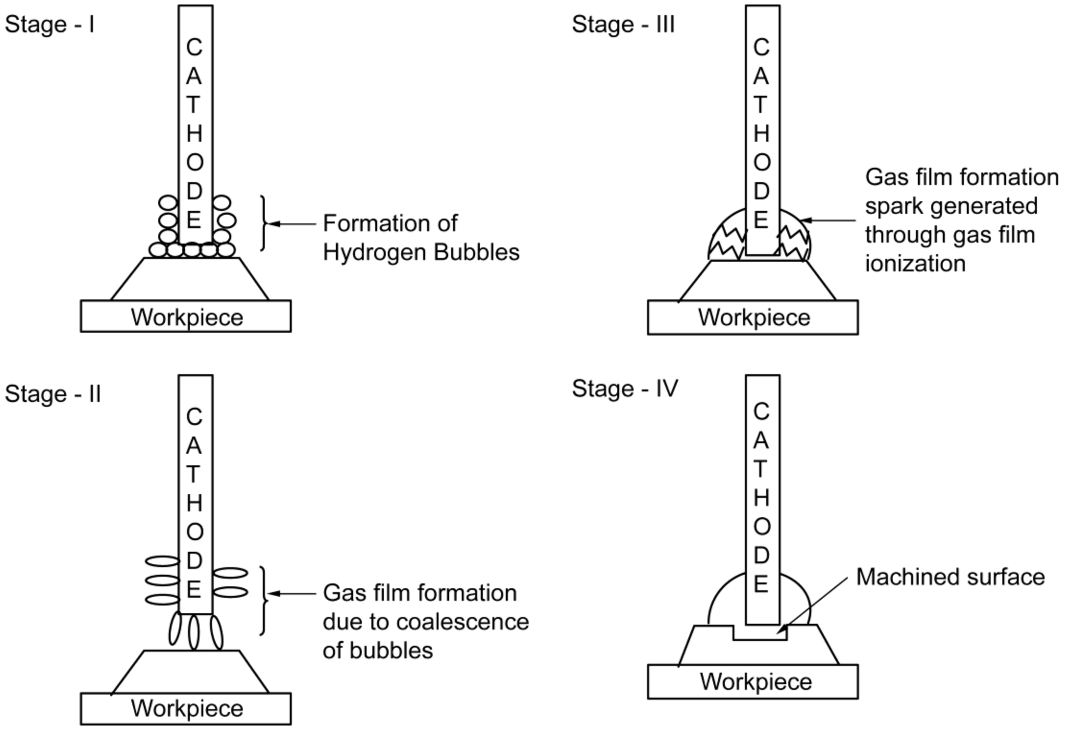


Fig. 5.1. Electro chemical spark machining process

The main purposes of implementing hybrid process are

- ❖ It enhances volumetric material removal rate.
- ❖ Computer controls of the processes have good results and better performance.

- Awareness of capabilities will resolve many problems in machining.Application of adaptive



control machining becomes easier.

Fig. 5.2. Stages in electro chemical spark machining

5.2. ELECTRO CHEMICAL SPARK MACHINING

Introduction

Electro chemical spark machining is a hybrid process of electro chemical machining and electric discharge machining. This process is Unique because it is suitable for both conducting and non conducting material. It is used for selective deposition, microwelding and machining of special non conductive material.

5.2.1. PRINCIPLE

The anode and the cathode are immersed inside the electrolyte. Due to potential difference developed, hydrogen bubbles are generated and thus spark is created between the cathode and workpiece. This produces high energy that helps in material removal or vapourization of material take place as shown in figure 5.3.

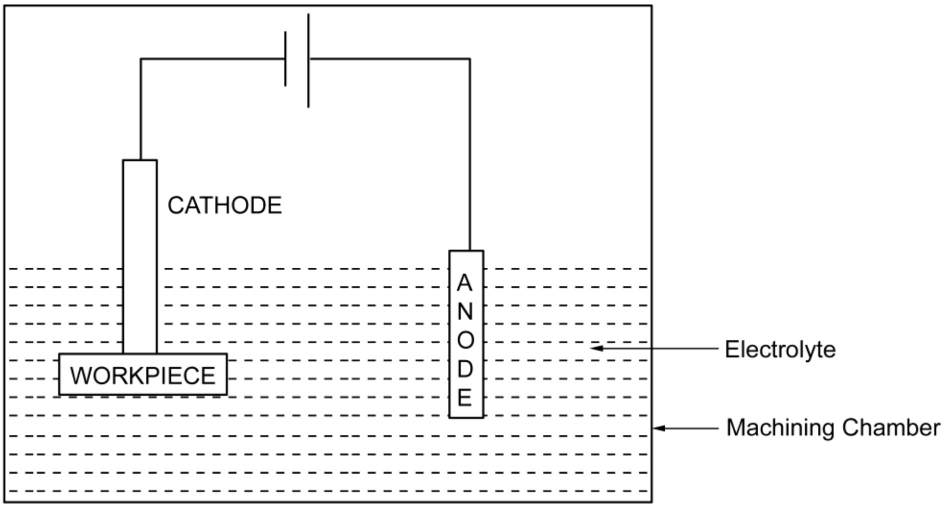


Fig. 5.3. Principle of ECSM

5.2.2. CONSTRUCTION AND WORKING OF ECSM

- ❖ The schematic arrangement of electro chemical spark machining process is as shown in figure 5.1.
- ❖ The electro chemical spark machining process consists of an anode, cathode, electrolyte, workpiece table controlled servometer, exhaust pipes and PC control system.
- ❖ In ECSM process the anode used in graphite and it is immersed in the electrolyte. The anode larger in size compared to cathode.
- ❖ The cathode used in ECSM process is smaller in size. It is placed just above the workpiece at a distance of 500 μm. The cathode and anode with the workpiece are maintained at same distance of 500 μm.
- ❖ The electrolyte connected with this process may be a combination ofwater, hydrochloric acid with sodium chloride.
- ❖ The table in ECSM process has three types of rotation *x*, *y* and *z* axis. The whole experimental setup is placed in the table.
- ❖ Exhaust pipes are provide above the arrangement, which is used in removing poisonous fumes that are released during electrolysis and

  sparking. As these fumes are harmful to the operator and also corrosive in nature.

Working

- ❖ The anode and cathode which are connected to the power supply are immersed inside the electrolyte.
- ❖ When the supply is ON, potential difference is created in the area and hydrogen bubbles are produced near the bubble in between the workpiece

as shown in figure 5.2.

- A huge number of electrons are generated due to discharge accelerated towards the workpiece kept near the cathode tip. The former being at a relatively high potential.
- The flow of huge number of electrons is seen as a current spike for a short duration of a milli seconds.
- The bombardment of electron raises the temperature of the workpieces giving rise to a sharp temperature pulse. This removes the material and vapourise it.
- The material removal in ECSM process is in the form of circular pits.
- The chemical reaction involved in this process are
- At cathode, reduction reaction takes place

$$2\ H_2O + 2\ e^- \rightarrow H_2 \uparrow + 2\ OH^-$$

- At anode, oxidization reaction takes place

$$4\ OH^- \rightarrow 2\ H_2O + O_2 \uparrow + 4\ e^-$$

- The material removal in ECSM process takes place through
  - Melting and vapourisation
  - Chemical reaction when proper electrolyte is not selected.
  - Cracks propagate through random thermal stresses.
  - Due to mechanical shock and cavitations effect.
- As the material removal is due to the heat energy produced by the spark, the workpiece used can be a conductive material or a non conductive material.

5.2.3. THE PROCESS PARAMETERS INVOLVED IN ECSM PROCESS

- A supply voltage ranges between 35 – 50 V.
- Cutting tool has a wire diameter of 200 μm.
- The workpiece used here is soda lime glass.
- The gap to be maintained between the cathode and workpiece is around 50 – 500 μm depending on the type of application.
- The electrolyte solution is 14 – 20% of water and sodium chloride.
- The table speed is 4 rpm.

5.2.4. ADVANTAGES OF ECSM

- No need for vacuum
- Cost effective
- Material removal is in the form of circular pits.

5.2.5. DISADVANTAGES OF ECSM

- The fumes produced due to chemical reaction is harmful to the operator.

- The fumes are more corrosive in nature.

5.2.6. APPLICATION OF ECSM

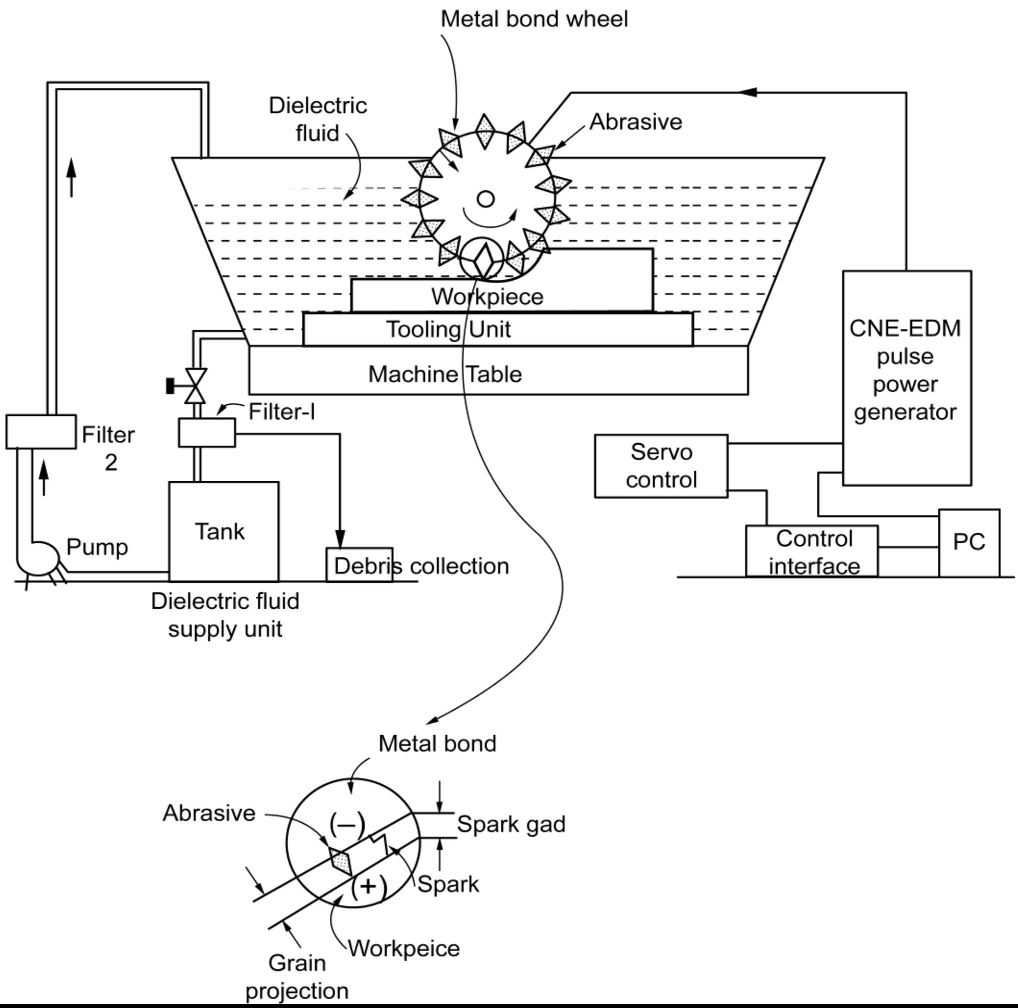
- It is used in machining materials like Alumina, Quartz and composites.
- It is used in preparation of blind holes in quartz material.
- It is used in machining materials like glass, copper, tantalum etc.
- It is used in automobile, electrical and manufacturing fields.

Electrical Discharge Diamond Grinding (EDDG)

5.3. INTRODUCTION

Electric discharge diamond grinding process is a hybrid process of electric discharge machining and diamond grinding. This process eliminates the limitations of EDM and diamond grinding process. The limitations of EDM are low material removal rate and resolidified white layer infected with micro cracks are produced. The limitations of diamond grinding are high cost, high specific material removal energy, due to high temperature strength degradation takes place and due to wheel wear, dressing becomes a problem.

This hybrid process takes the advantages of EDM and diamond grinding such as



grinding of hard materials, increases thermal softening of the workpiece which requires less force and better accuracy with surface dressing.

Fig. 5.4. Schematic Arrangement of Electric Discharge Diamond Grinding

5.3.1. PRINCIPLE

Electric discharge diamond grinding process is a spark erosion process used for precision grinding. Spark is produced between metal bonded grinding wheel and

workpiece. Heat generated during sparking softens the workpieces surface and grinding process is easily abraded using diamond abrasive particles.

5.3.2. CONSTRUCTION AND WORKING OF EDDG

The schematic arrangement of electric diamond grinding process is as shown in figure 5.4.

EDDG process consists of dielectric fluid, metal bonded diamond grit wheel, workpiece, servo control system and CNC-EDM controlled pulse power generator.

Dielectric Fluid: The dielectric fluid used in EDDG may be water or water based cutting fluid such as kerosene, paraffin oil and hydrocarbon oil. The arrangement consists of a tank which receives the dielectric fluid from the bottom of EDDG setup. This fluid is filtered twice and pumped into the arrangement again by using motor. This fluid filtration is done in order to remove the chips and debris formed during grinding.

Tool

The alumina metal bonded diamond grit wheel is used as a tool. This tool is an electrically conductive material. This tool is connected to negative terminal of pulse power generator. The abrasives in the wheel are diamond grits which are arranged on outer surface of grinding wheel which is used for material removal.

Workpiece

The workpiece used in EDDG process is hard material. It is electrically conductive material. The workpiece is connected to the positive terminal of the pulse power generator. The workpiece materials used are high speed steel and cemented carbides.

Servo Control System

The servo control system used in EDDG is used to maintain in a constant gap between the grinding wheel and workpiece during active feeding of the wheel into the workpiece.

The system monitors the desire gap distance in such a way that the wheel feeds into the workpiece will be equal to the rate at which material is being removed.

The circuit senses the gap distance effectively, if the gap is sensed block with particles they get melted out due to high generated.

Pulse Power Generator

The pulse power generator generates the DC power supply to the tool and workpieces. The whole setup in CNC EDM controlled using computer arrangement.

Working

- ❖ An electrically conductive rotating, grinding wheel is used as the electrode and workpiece is used as the anode.
- ❖ The wheel and the workpiece are connected –ve and +ve terminal of pulse power generator.
- ❖ This pulse power generator is in turn connected to the CNC computer.
- ❖ The arrangement is submerged in a big tank filled with dielectric fluid.
- ❖ The pulse power generator generates pulse electrical energy at rates upto 250000 pulse/second.
- ❖ The dielectric fluid flows through a small gap that is maintained continuously and uniformly at the rotational motion of grinding wheel.
- ❖ When the power supply discharges, DC pulse power to the wheel and workpiece, the insulative property of dielectric fluid is broken down and a small spark is produced between the gap as shown in figure 5.5. Due to this heat is generated between the gap and the material removal takes place.
- ❖ A small pool of molten metal is formed in the tool as well as the workpieces. The tool has a smaller pool than the workpiece. Large amountof heat energy is released and forms the pool. This softens the workpieces.
- ❖ The diamond abrasive grits attached an alumina wheel pushes the material in the workpiece surface.
- ❖ The materials removed in the form of chips are washed away and some sticks on the surface of the wheel. As continuously high heat energy is produced, the materials that sticks on the wheel surface get melted.
- ❖ Thus the sharpness of abrasives on the wheel are retained again and again. This continuous dressing and declogging takes place as shown in figure.

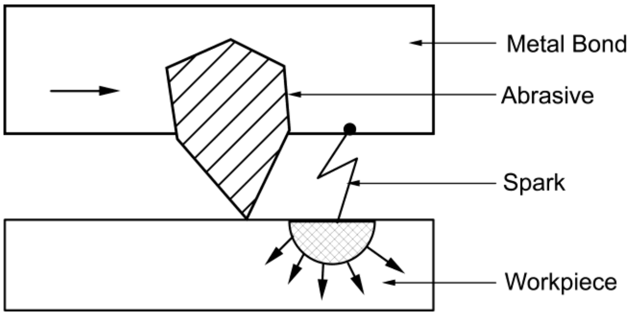


Fig. 5.5. Formation of Spark in an Abrasive

Thus dressing and declogging of the wheel is maintained. The forces acting in this process are normal and tangential force.

Normal force acts on the grinding wheel helps in penetration of the wheel into the workpiece.

Tangential forces are used to remove the material from the workpieces.

5.3.3. BASIC CONFIGURATION OF EDDG

The process of material removal in EDDG is done through two basic configuration. They are

(i) When the workpieces is the electrically conductive material

(ii) When the workpiece is electrically nonconductive material.

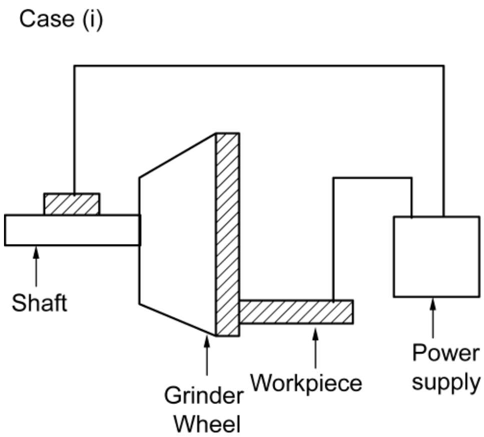


Fig. 5.6. Configuration of electrically conductive workpiece and wheel

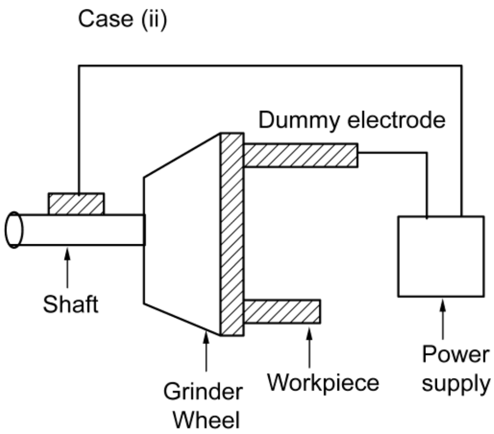


Fig. 5.7. Configuration of electrically conducted wheel and nonconductive workpiece

Case (*i*)

When the workpiece and grinding wheel are electrically conductive materials,they are connected to positive and negative terminal of the power supply. Sparking produces continuously and high heat energy is produced resulting in material removal in workpiece in the form of craters as shown in figure 5.6.

Case (*ii*)

In case (*ii*) as shown in figure 5.7 the grinding wheel is electrically conductive material and workpiece is electrically non conductive material. A dummy electrode is used separately for producing the spark which soften the material and the relative motion between the workpiece and wheel helps in material removal.

The main parameters used in the process are

1. Wheel speed
2. Current
3. Pulse on time

Some of the other parameters are

- ❖ Diamond particle size
- ❖ Bond material
- ❖ Dielectric material
- ❖ Voltage

5.3.4. FACTORS AFFECTING PROCESS PARAMETERS OF EDDG

1. Wheel speed
2. Current
3. Pulse on time

Wheel Speed

- ❖ From the graph 5.8, it is clear that as current increases, the materialremoval rate also increases.
- ❖ In EDDG process, the input current play a major role. When the current is 1 Amps the wheel speed is low and material removal rate is also less.

As the current increases from 1 Amps to 5 Amps there is drasticallyincrease in wheel speed and material removal rate

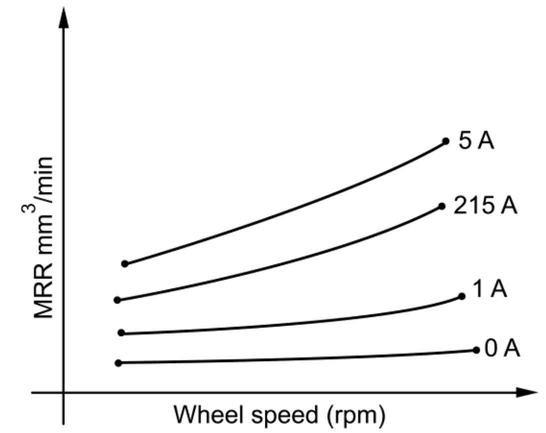


Fig. 5.8.

Current

- From the graph 5.9 it is clear that as current increases, the radial wheel wear rate is also increases.
- The radial wheel wear rate depends or affects the life span of the grinding wheel.

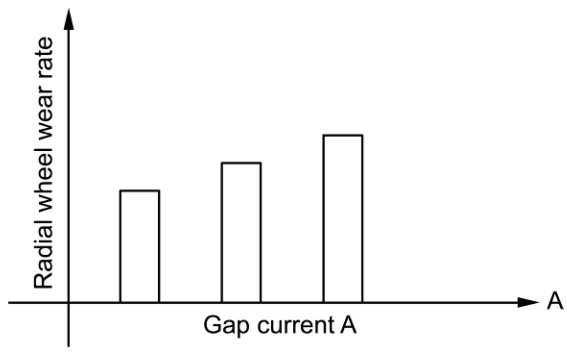


Fig. 5.9.

- In EDDG process, the gap current is influences by the radial wheel wear rate. As gap current increases the radial wheel wear rate also get increased.

Effect of Current on Normal Force

- From the graph 5.10, it is clear that gap current is influenced by the normal force applied.

- When the gap current increases, the heat produced is high and the heat required to soften the workpiece surface is more. Thus the normal force required to penetrate the workpiece surface is less.
- In EDDG process, when the wheel speed is increased from 1.5 m/s to 4.5 m/s, the normal force is higher and there is no significant change in the gap current.

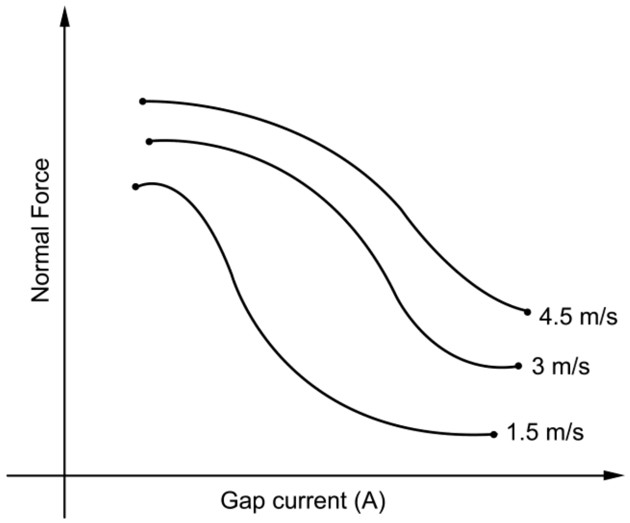


Fig. 5.10.

- The speed of the wheel and normal force should have appropriate values as normal force increases the penetration of the wheel inside the workpieces.

5.3.5. ADVANTAGES OF EDDG

- It can grind any conductive and non conductive materials.
- Less corrosive effect is produced.
- This process involves continuous dressing and declogging of the abrasive wheel and thus increases the wheel life to 25%.
- Higher material removal rate than EDM
- Lower operating cost
- Produces higher accuracy

5.3.6. DISADVANTAGES OF EDDG

- Recast layer is formed after grinding

- ❖ Possibilities of oil fires
- ❖ Wheels are fragile

5.3.7. APPLICATION OF EDDG

- ❖ It is used in grinding of thin sections
- ❖ Grinding of high hardness materials such as cermates, super alloys and metal matrix composites.

Micromachining

Machining processes are carried out at various level, they may be macro, micro and nano level. Recent developments in non traditional machining process has taken place in micro and nano level of machining. In this unit we are going to see some of micromachining processes.

Micromachining is machining of miniature components. It is also defined as removal of material in the form of chips or debris having the size in the range of micron with dimensions greater than or equal to one micro and smaller than or equal to 999 micron.

Micromachining is a precision machine in which the machining error is extremely small.

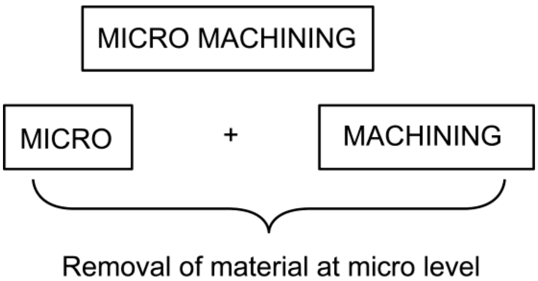


Fig. 5.11.

It is also defined as macro components but material removal is at micro / macro level and also micro / nano components and material removal is at micro / nano level.

The main features of micromachining are

- ❖ Minimising energy and material use

- Faster devices
- Increased selectively and sensitivity
- It has improved accuracy and reliability
- It is basically concern with machining of micro / nano components or material or material removal at micro / nano level.

Classification of Advanced Micro Machining Processes

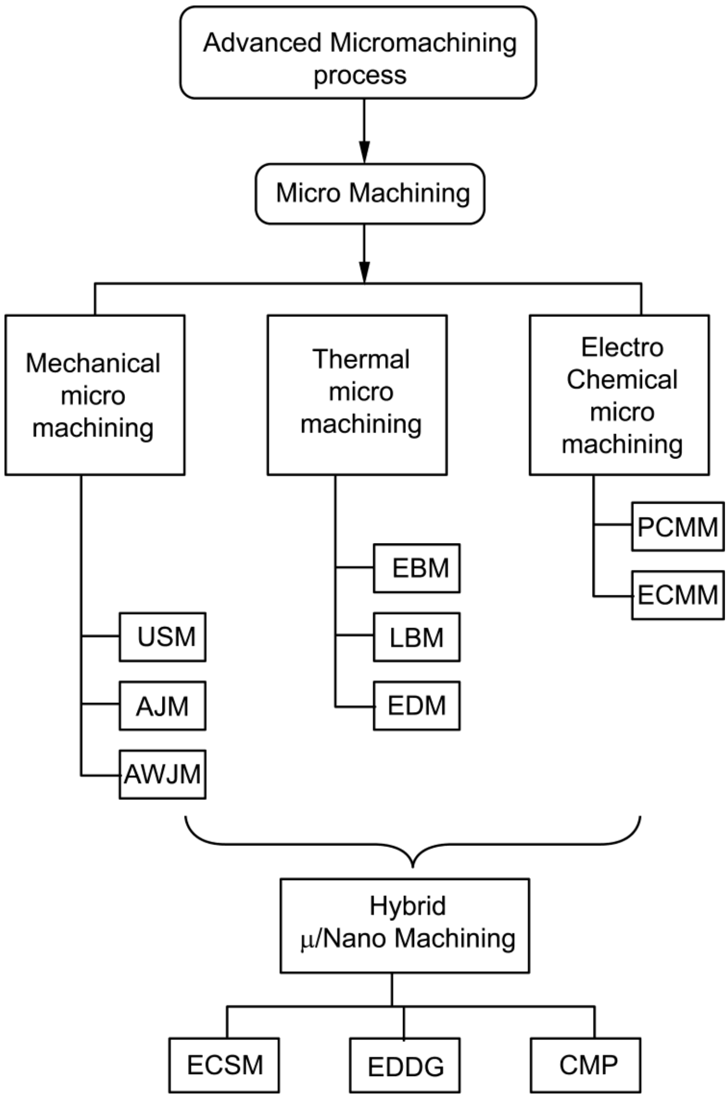


Fig. 5.12.

5.4. MECHANICAL ADVANCED MICROMACHINING PROCESSES

The working principle of advanced mechanical type micro machining processes are fine abrasive particles with high kinetic energy bits the workpiece at an angle.

If the kinetic energy of abrasive particles are high enough, then material removal are high enough, then material removal is done by shear deformation in ductile material and by brittle fracture in brittle materials. The processes involved in mechanical advanced micromachining processes are

- ❖ Abrasive jet micromachining
- ❖ Abrasive waterjet micromachining
- ❖ Ultrasonic micromachining

In these processes, the particle with high kinetic energy hits the workpiece surface at a gap and remove the materials in the form micro / nano chips.

ABRASIVE JET MICROMACHINING

5.4.1. PRINCIPLE

Abrasive jet micromachining works in the same principle of abrasive jet machining (AJM)

A high speed stream of mixture of fluid (air or gas) with abrasive particle is injected through the nozzle on the workpiece to be machined.

5.4.2. CONSTRUCTION AND WORKING OF AJMM

- ❖ The schematic arrangement of abrasive jet micromachining is as shown in figure 5.13.
- ❖ The main components of abrasive jet micromachining (AJMM) are pressurized powder feed system, nozzle, mask, abrasives pressure gauge and regulators.

Pressurized Powder Feed System

- ❖ Compressed air is used along with the abrasives.
- ❖ The abrasives used here are blocky shaped aluminium oxide particle ofsize 10-25 μm.

Powder flowability and compactability depends on

- Particle size
- Size distribution
- Moisture content and
- Surface texture

The powder is fed into the air stream from a pressurized reservoir through a orifice and mixing chamber as shown in figure 5.14.

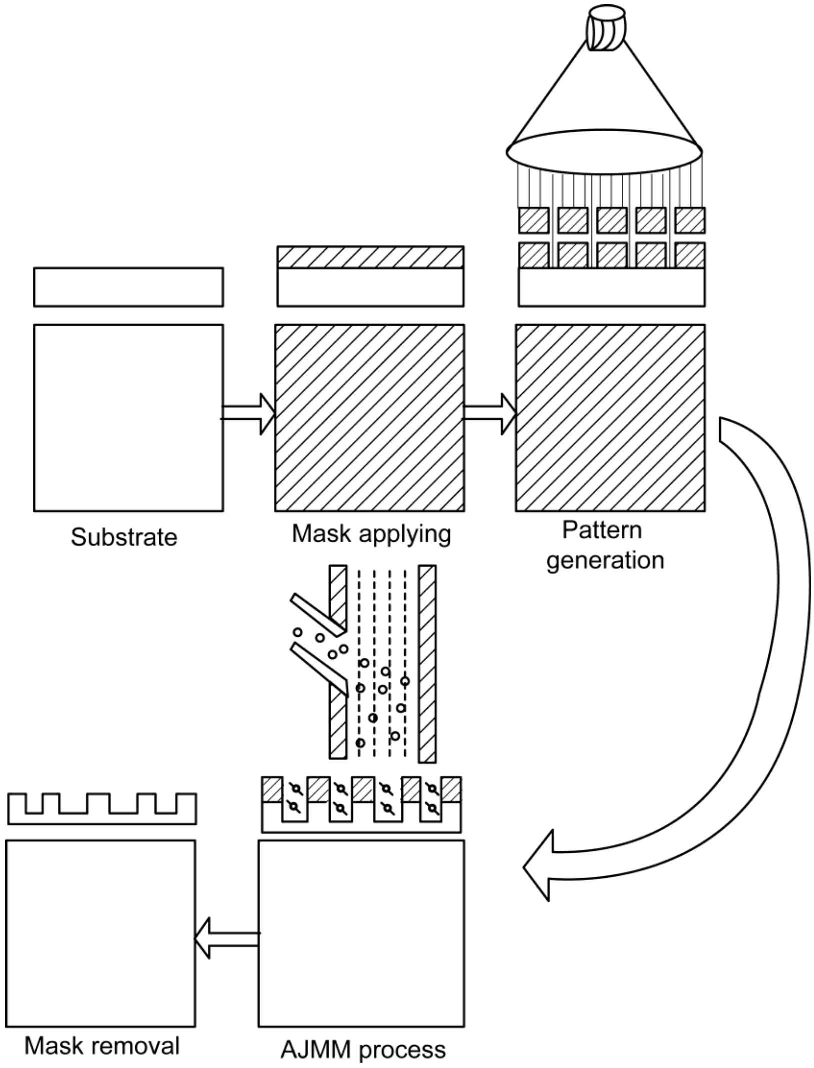


Fig. 5.13. Steps involved in abrasive jet micro machining

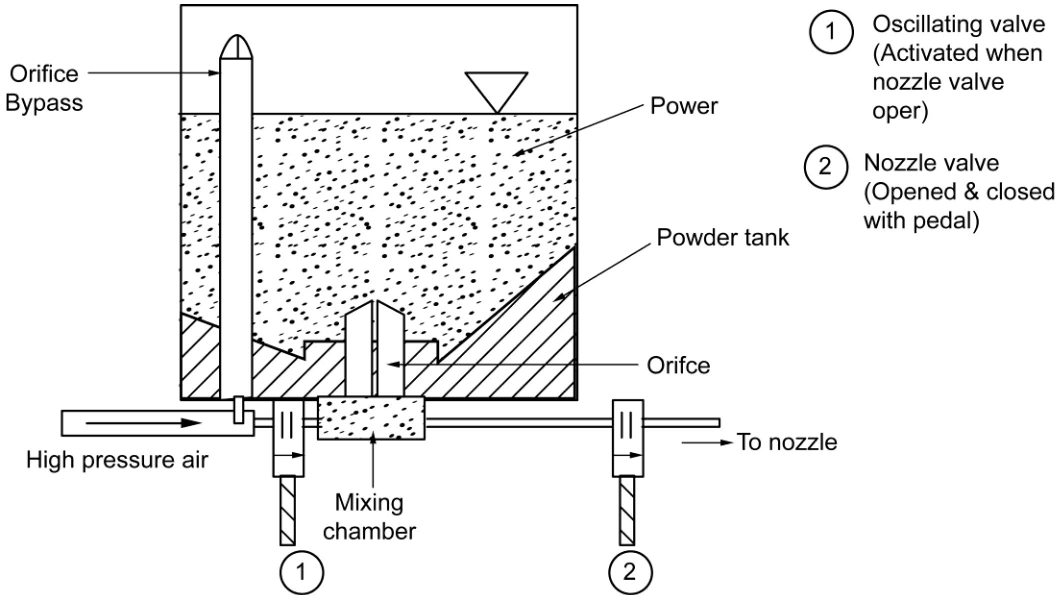


Fig. 5.14. Pressurized powder feed system

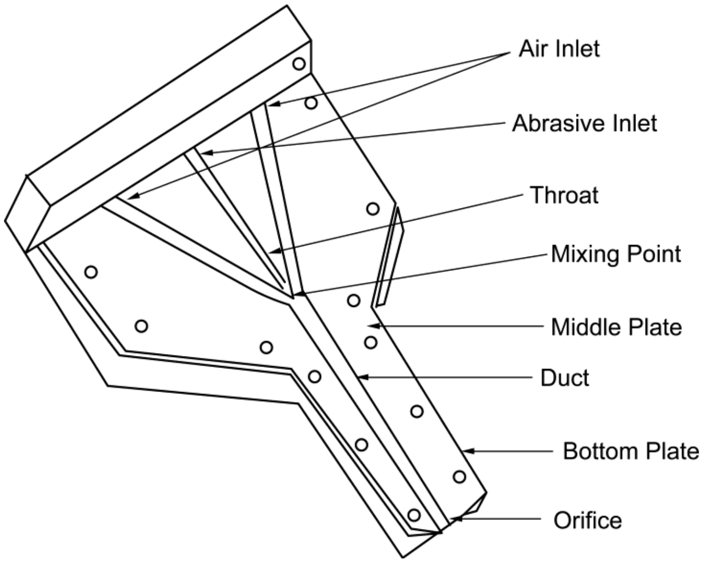


Fig. 5.15. Laval nozzle – Inner view

- ❖ The feed system utilizes an oscillating valve that splits the operation cycle into too halves.
- ❖ The operation cycle is activated by a switch, when the entire system including the reservoir has been pressurized by closing the nozzle end and opening the oscillating valve to the main air supply.

- During the 1st half of the cycle, the oscillating valve is opened. The air flows from the pressure regulators to the mixing chamber.
- Some air enters the powder reservoir and others flow out to the opened nozzle.
- Here any powder that has entered the mixing chamber is forced out of the nozzle.
- Here any powder that has entered the mixing chamber is forced out of the nozzle.
- In 2nd half of the cycle, the oscillating valve is closed and stops the air flow. Now the reservoir is still pressurized, but the mixing chamber is at normal pressure due to open nozzle.
- Due to pressure difference between the reservoir and mixing chamber, the powder force down through the orifice at the bottom of reservoir and into the mixing chamber.

The Oscillating valve is open again and the cycle is repeated again.

In pressurized reservoir of the system, the powder becomes firmly compacted during the AJMM process is as shown in figure.5.15.

Nozzle

- It is an integral part of AJMM process. It focus and accelerates the abrasive stream generated by the baster.
- The nozzle is made of tungsten carbide to resist wear.
- The nozzle used in laval type. Laval nozzle has a converging –diverging geometry with a throat and minimum nozzle diameter as shown in figure 5.16.
- The internal laval geometry is able to increase the air flow velocity to 1 mach.
- Laval type nozzle allows to create a vacuum pressure in the duct and enables a suction feeding system for abrasive.
- To avoid disturbance in flow of the abrasive particle enters in centre and the air inlets are on both sides of the particle inlet.

- Also the nozzle duet is coated with a ceramic layer.
- The nozzle flow achieve a supersonic flow beyond inlet pressure 0.55 MPa without wave in the duet.

Mask

A good quality mesh have the following

- Low erosion rate
- Requires the capabilities of air accurate and easy pattern transfer.
- The ability to retain their resistance in discontinuous layer.

There are 3 types of masks based on the material available. They are

- Ductile material for metal mask
- Elastic material for elastomers
- Photo resists used in IC industry

Working

- Abrasive jet micromachining process is based on the erosion of a brittle substrate by high velocity particle beam.
- When the velocity of abrasive flowing exceeds the material resistance energy brittle material erodes by propagation and interaction of cracks.

In the initial stage, the abrasives that flow from the nozzle at normal impact angle just stick on to the material and again in weight of the workpiece.

On continuous steady state flow of abrasive jet, there is mass loss from the eroded material is proportional to the amount of abrasive particles.

After this incubation time steady state erosion is established and mass loss from the eroded material is proportional to the amount of abrasive particles.

Harder surfaced angular abrasive particle bits the ductile material in an angle of 90° and causes plastic deformation.

The substrate are shielded by a wear resistance mask that is pattern with desired contour.

During blasting, the workpiece is exposed to an abrasive – laden air jet with pressure of 0.2 and 0.8 MPa and hard angular particles with diameter between 10 to 100 μm.

The mass loss of the erodent is proportional to the amount of abrasives

$$\text{mass loss} = \frac{k\,l}{H} \times \frac{1}{2} mv^2$$

k - dimensionless factor

m & *v* - amount and velocity of particles

ρ & H - density and hardness of the eroded material

5.4.3. EFFECT OF PROCESS PARAMETER IN AJMM

The parameter that affects the AJMM process are constant powder feeding. The factors that affect constant powder feeding are

- Powder compaction
- Powder stratification
- Powder humidity

Powder Compaction

The powder becomes firmly compacted or densed during AJMM process. The sticking of powder to the surface of reservoir can be reduced by mounting a variable speed rotator electric mixer at reservoir cap or a stirring blade is fixed on top of reservoir.

Powder Stratification

Powder stratify as they flow and it depends on particle size. On blasting, the small size particles eject first and larger ones settle down.

This can be avoided by using small amount of powder during machining or the powder reservoir should be emptied and refilled with fresh powder repeatedly.

Powder Humidity

Due to increase in humidity in the powder, it results in decrease in the fracture toughness and produce larger effect on solid particle erosion rate. It also affects the powder flowability.

To minimize this effect, dessicant a drying agent is used inside the sealed powder storage and dessicant based refrigeration air dryer is used to dry compressed air.

5.4.4. ADVANTAGES OF AJMM

- Shallow holes can be accurately machined.
- Machining of grooves with the use of mask pattern or target material can be done.

5.4.5. DISADVANTAGES OF AJMM

- Low erosion rate
- Minimum thickness of the substrate should be 0.3 mm or otherwise buckling of the plate occurs.
- Constant powder feeding is affected due to compaction, stratification and humidity.

5.4.6. APPLICATIONS OF AJMM

AJMM process is used in fabrication

- Micro accelerometer beam
- Matrix of micro E-cores
- Capillary electro phores is chips
- 3D suspended microstructures
- 3D passive glass micro mixer.

5.5. ABRASIVE WATERJET MICRO MACHINING PROCESS

5.5.1. PRINCIPLE

Abrasive waterjet micromachining works in the same principle of abrasive waterjet machining.

Abrasive waterjet cut by erosion. A million of such particles impact on a workpiece per second travelling with 2 times the speed of sound for machining the work surface.

5.5.2. CONSTRUCTION AND WORKING OF AWJMM

The schematic arrangement of abrasive waterjet micro machining is a s shown in figure.

The main components of AWJMM are

1. Abrasive water jet generation
2. Abrasive waterjet subsystem
3. Abrasive waterjet machining centers.

5.5.2.1. ABRASIVE WATERJET GENERATION

Abrasive particles are suspended in pressurized water to form slurry and this slurry passes through a cutting nozzle.

The pressurized water passes through the orifice or nozzle to generate a high speed water jet and abrasive particles are induced into the jet as shown in figure 5.16.

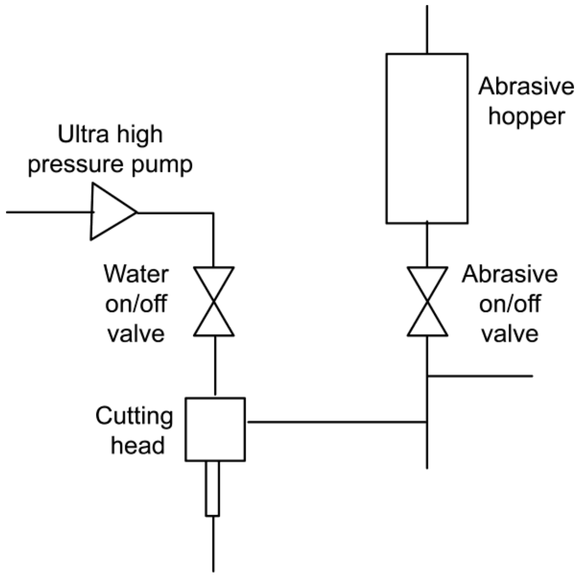


Fig. 5.16. Entrainment method of generating abrasive waterjets

There are two methods of generating abrasive water jets.

(i) Abrasive suspension jet method

(ii) Entrainment abrasive water jets

❖ Entrainment abrasive water jets are in abrasive waterjet micro machining process.

- The cutting operation is carried out by using ultra high pressure water is turn ON and it establishes air flow through the tubing to a cutting head as shown in figure 5.17.

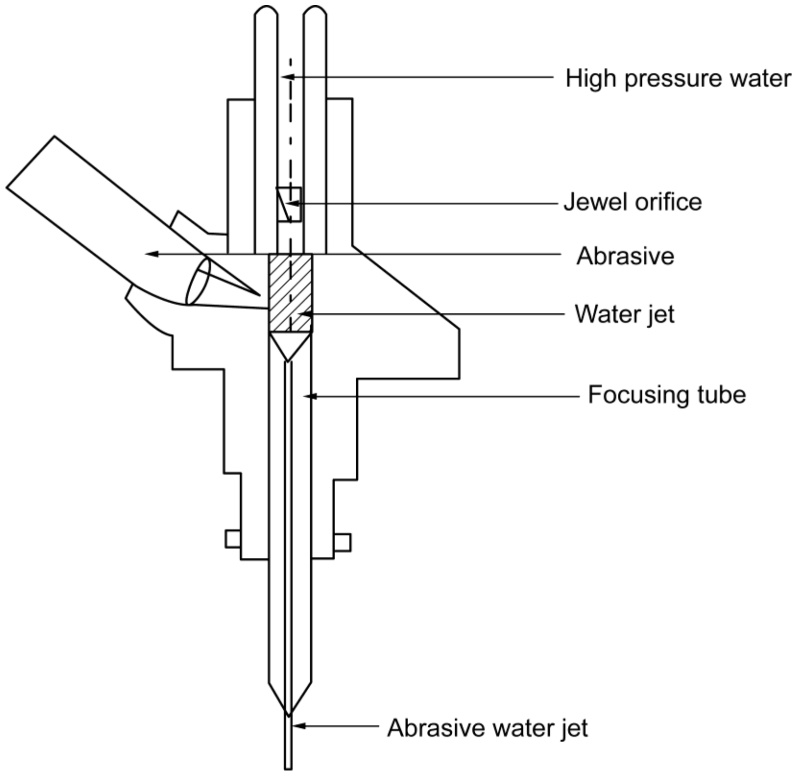


Fig. 5.17. Cutting head of abrasive waterjet

- An entrainment abrasive waterjet generates a ultra high pressure water at 3000 to 6000 bar through jewel orifice.
- The water speed is 750 m/s and abrasives are allowed into the air flow to allow cutting process.
- The waterjet transverse a chamber and passes into the bore of a focusing tube and cutting action takes place.

The cutting head has three phases such as abrasive particles, water and air.

The important parameter is the ratio of focus tube diameter to waterjet orifice diameter as this determines the cutting ratio.

The abrasive cutting head generates and also focuses the cutting jet.

To step cutting, the abrasives feed is stopped and after a short delay the water flow is stopped. This is done in order to clear the abrasive particles from the cutting head.

5.5.2.2. Abrasive Water Jet Subsystem

The main subsystem are

- ❖ Ultra high pressure water feed system
- ❖ The cutting head
- ❖ Abrasive feed system

Ultra High Pressure Water Feed System

Water flows into a plunger head on the suction stroke through a non return valve and is discharged from a plunger head through a second non return valve on the delivery stroke.

Non return valve seals on a metal seat or take the form of flat metal disc sealing on to a flat metal seat. The value is made of ceramic ball.

There are two forms of plunger pump

- ❖ Intensifer
- ❖ Direct driven

The type of pump used in abrasive water jet subsystem is direct driven pump.

The plunger of a direct driven pump is driven by crank. These pumps have 3 plunger that are 8 mm diameter and makes multistroke per second.

Seal life and loads on bearing limits to a pressure of 4000 bar.

Direct driven pumps regains the water energy during compression to start the plunger return stroke. These pumps are more energy efficient.

5.5.2.3. Entrainment Cutting Heads

The major components of cutting heads are (*i*) Water jet jewel orifice (*ii*) focus tube.

These components have important effect on the operation of AWJMM.

Waterjet Jewel Orifice

The waterjet travels a distance between a waterjet orifice and focus tube as shown in figure. 5.17.

This orifice is given a inner edge radius of 0 to 20μm. It should be high wear resistance and withstand impact load.

The orifice edge are made of super hard materials such as sapphire, ruby and diamond.

Deterocation at the edges are due to erosion by microscopic particle present in water.

This leads to waterjet spreading and reduction in cutting efficiency.

Focus Tubes

These tubes focuses the abrasive waterjet into the work surface for machining purpose.

These focus tubes are made of tungsten carbide, poly crystalline diamond and chemical vapour deposition diamond.

The bore diameter is less than 100 μm.

5.5.2.4. Abrasive Feed System

Abrasive particles flows from a hopper and they are carried away by air to cutting head.

They are entrained by a waterjet into a focus tube.

A small hopper is located near the cutting head filled up with abrasives.

The cutting jet diameter is reduced to 400 μm.

The abrasive particles are suspended in water in form of slurry and then feed into cutting heads to generate cutting jets.

5.5.2.5. Abrasive Water Jet Micro Machining Centre

The machining centre consists of

- Motion system
- Machine structure
- Workpiece holding
- Human machine interface and control system

Motion System

AWJMM require a motion system with high performance ball screw and linear motors.

Non contact machine tools do not have high machining forces. The arrangement is linear motors on X and Y axis and high precision ball screw on Z axis.

The linear motors provide high acceleration and transverse speed with long term precision reliability and life.

A precision ball screw on Z axis avoids problems of cutting head movement after loss of power.

Machine Structure

- ❖ A rigid machine frame of high precision machine tools are used in advanced machining centers to which the motion system and workpiece support is attached.
- ❖ A cutting jet catcher tank is separated from the machine structure to prevent disturbances from dissipation of jet energy that is transmitted to machine structure.
- ❖ The catcher tanks are clean repeatedly after sufficient cycles of machining and automatic clearing of used abrasives from the catcher tank.
- ❖ Small size catcher tanks are used for efficient recovery of high valve materials such as gold with spent abrasives.
- ❖ Floor space are compact and fully closed in machining centers.
- ❖ The pumps are located separately from the machine structure, but having its control on machining centers.

Workpiece Holding

To machine the workpiece to close tolerance, workpiece fixtures are required.

Simple fixtures are used for low cutting force.

jigs are used to prevent losing the machine reference during worktransfer.

Human Machine Interface and Control System

- ❖ Human machine interface (HMI) makes the successful link with micro abrasive water jet machining centre. By interacting with and programming the machining center.
- ❖ Also the manufacturer and the control system supplier can access and operate the machine remotely over the internet.
- ❖ Due to this highly skilled operators has a very high level support from experts in AWJMM and control system.
- ❖ The operators can access to updates to HMI and control system.

The design of HMI provides

- ❖ Initiative to learn programming
- ❖ Touch screen programming
- ❖ Facilities to easily correct mistakes.

Working

- ❖ The working of abrasive waterjet micro machining is similar to abrasive jet micro machining.

- ❖ The material removal in AWJMM is in the form of erosion action by high velocity waterjet with abrasive particles.
- ❖ The entrainment abrasive waterjets produces the pressurized water which is mixture with abrasive particles and water to form a slurry.
- ❖ This slurry then passes through the abrasive waterjet subsystem. In this system abrasive particles mixes with ultra pressurized water. The abrasives are fed through the abrasive feed system through the hopper.
- ❖ The pressure of water is around 6000 bar and velocity of slurry is around 750 m/s.
- ❖ The abrasive cutting head regulates the slurry through the jewel orifice and focus the jet using the focus tube.
- ❖ The focusing tube focuses the slurry to workpiece to be machined.
- ❖ When the high velocity jet comes out from the focusing tube and hits the work surface, its kinetic energy is converted to pressure energy including high stresses.
- ❖ When the induced stress exceeds the ultimate shear stress, material removal takes places in the form of debris.
- ❖ The movements of the pumps and the workpiece are controlled by the abrasive waterjet micro machining centers.
- ❖ The human machine interface system and control system controls the flow of slurry and water jets.

5.5.3. ADVANTAGES OF AWJMM

- ❖ Alloy steel and all grades of stainless steel can be machined.
- ❖ Machining of layered materials such as rubber or polymer bonded to metal can be cut.
- ❖ It can cur thicker material than a laser.

5.5.4. DISADVANTAGE OF AWJMM

- ❖ Difficult to machine metals like armour plating, titanium and copper base alloys.
- ❖ High residual stresses are produced in thin and toughened glass during machining.

5.5.5. APPLICATION OF AWJMM

- ❖ Used in jewellery and craft markets
- ❖ Used in precision cleaning, peening to remove and dismantle nuclearplants
- ❖ Used in cutting precision pocket milling, turning and drilling.

5.6. ULTRA SONIC MICRO MACHINING PROCESS

5.6.1. PRINCIPLE

Ultrasonic micromachining process works in the same principle of ultrasonic machining process.

Ultrasonic micromachining produces ultrasonic vibration, when combined with a abrasive slurry to create a accurate cavity of any shape through the impact of fine grains. Ultrasonic micromachining is a mechanical process that it produces high quality surface.

5.6.2. CONSTRUCTION AND WORKING OF USMM

- The schematic arrangement of ultrasonic micromachining is as shown in figure 5.18.

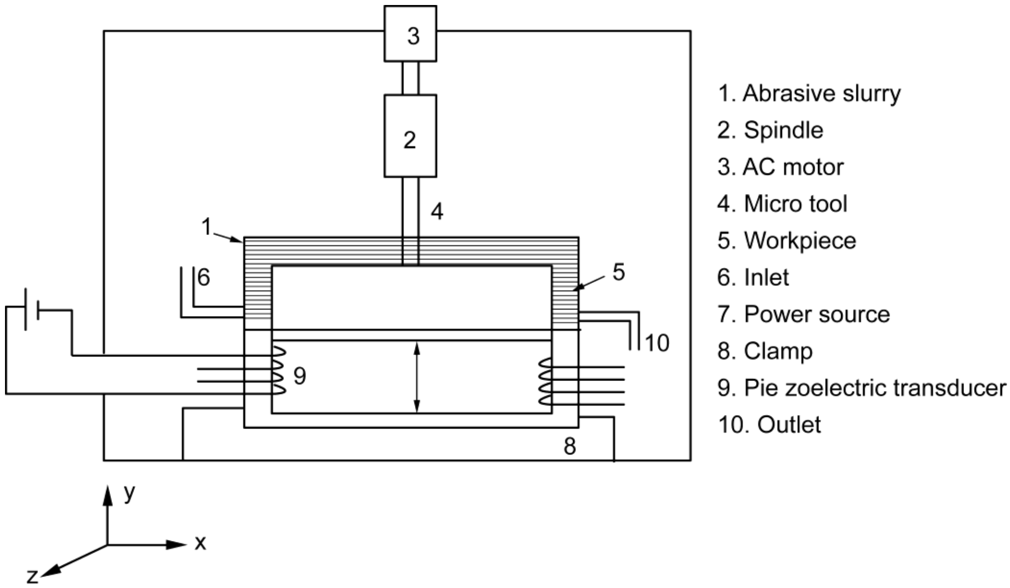


Fig. 5.18. Schematic diagram of ultrasonic micro machining

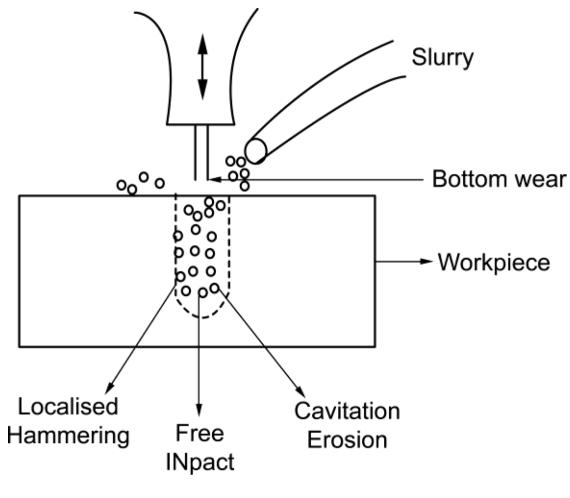


Fig. 5.19. Material removal in ultrasonic micro machining

- Ultrasonic micromachining has 7 basic components.
  1. High frequency oscillating current generator
  2. The acoustic head
  3. Tool spindle mechanism
  4. Controlled axes
  5. The micro tool
  6. Abrasive slurry
  7. Workpiece
- The high frequency oscillating coherent generator consists of resonance circuit, electrically turned, generates high frequency electrical impulses.
- The range of output produced is 5 to 15 kW and controlled range of 19-22 kHz. The main function of this generator is to convert low frequency 50 Hz electrical power to high frequency 220 Hz.
- The high frequency electrical signal is supplied to the transducer for conversion into mechanical motion.
- The acoustic head is important component of ultrasonic micro machine. It has 2 parts (*i*) Transducer (*ii*) horn.
- A transducer is a device that converts electrical energy to mechanical energy through vibration.
- The transducer are two types (*i*) Piezoelectric (*ii*) Magnetostrictive.
- Piezoelectric transducer are used in USMM as it produces high electromechanical conversion efficiency, which can eliminate the need for water cooling of the transducer. The power capabilities upto 900 W.
- Horn is otherwise called as acoustic coupler velocity / mechanical transformer, tool holder, concentrator and shank.
- The horn amplifier and focuses the vibration of the transducer to an intensity that is necessary to drive the tool to perform the particular work.
- The horn material are movel, titanium, SS304, Aluminium, Aluminium bronze.

- The properties of horn are it should possess good acoustic transmission coefficient, high fatigue resistance at high working amplitude, good brazability, high corrosion resistance.
- CNC controller used in USMM for transferring information to the tool spindle from the tool making stage to actual machining stage.
- The USMM controller has four computer numerically controlled axes X, Y, Z and C

❖ Here stepping motor and lead screw driver the X, Y, Z axes.
❖ The ‘C’ axis is driven by DC servometer.

Microtool

❖ The shape and dimension of the final product depends on the tool (i.e) the size and length of holes drilled is diameter and length of the tool.
❖ At a given frequency, the force end of the tool is designed to provide maximum amplitude.
❖ The materials used as micro tool are tungsten carbide (WC) alloy tools used for machining 5 μm diameter.
❖ The properties of microtool material should have
  - High wear resistance
  - Good elasticity and fatigue strength
  - Optimum toughness and hardness
❖ Cemented carbide tools are used for its hardness toughness and thermal conductivity that is used to cut glass.

Abrasive Tools

❖ The abrasive particles are the actual cutting tools
❖ The slurry consists of small abrasives particles mixed with water or oil and abrasive concentration 30 to 60% by weight
❖ The abrasive materials used are boron carbide, silicon carbide, aluminium oxide and diamond dust.

❖ The abrasives are selected based on the hardness, usuable life, grit size and cost.
❖ Each abrasives are used for different applications as boron best suits for cutting tungsten carbides tool steel and precious stones
❖ Alumina is best for cutting glass, germanium and ceramics
❖ Diamond powder for cutting diamond rubies
❖ The size of the abrasives range between 300 to 2000 grit
❖ Coarse grades are used for roughing operation
❖ Fine grades are used for finishing operation.

Function of Slurry

❖ It acts as coolant for the horn, tool and workpiece
❖ Supplies fresh abrasives to cutting zone and removes debris from the cutting area.

The slurry from a good acoustic bond between the tool, abrasives and workpieces allowing efficient energy transfer.

Low viscous slurry are provided for free transport of the medium.

Workpiece

The workpiece used in USMM is suitable for brittle material such as tungsten carbide, titanium carbide, ceramic and diamond.

Material having high hardness, high impact brittleness (example: germanium, ferrite, glass and quartz) can be machined using USMM.

Based on the force of withstanding capacity, the workpiece is classified as three categories.

The categories which is either very hard or very ductile material such as silicon nitride or diamond that has good resistant can be machined using USMM.

Working

- ❖ Material removal by means of USMM is due to combination of four mechanism. They are

  - Mechanical abrasion by direct hammering of the abrasive particles against the workpiece or work surface.
  - Micro chipping by impart of the free moving abrasive particles.
  - Cavitations erosion by abrasive slurry.
  - Chemical action associated with the fluid employed.

- ❖ The material removal takes place due to individual or combine effect of above mechanism (1) shear (2) fracture (3) plastic deformation and others have concluded.

The 1st two mechanism are primarily responsible for major stock removal while cavitation erosion and chemical action are of secondary significance for normal material machined by this process as shown in figure 5.19.

- ❖ For porous material like graphite, cavitation erosion is a significant contribution to material removal.
- ❖ Factors affecting process parameter are
  - machining rate
  - surface finish
  - machining accuracy
  - Toolwear

The process variables of USMM changes for the micro hole drilling process is as follows

1. Amplitude of vibration = 5 μm

2. Workpiece material = silicon
3. Tool material = Tungsten
4. Tool size = 50, 100,150 μm
5. Abrasive grain type = polycrystalline diamond powder
6. size = 1 – 3 μm
7. Total tool feed = 515 μm

5.6.3. EFFECT OF PROCESS PARAMETERS ON QUALITY CHARACTERISTICS OF USMM

- Effect of process parameters on material removal rate
- Effect of process parameter on tool wear
- Effect of process parameter on surface finish
- Effect of process parameter on accuracy

1. Effect of process Parameter on Material Removal Rate

- Material removal rate (MRR) depends upon
  - Machining parameters
  - Abrasive slurry
  - Work material properties
  - Tool material properties and tool geometry
- The machining parameters that affect the material removal rate are
  - amplitude of vibration
  - frequency of vibration
  - static load
- If the amplitude of ultrasonic oscillation increases, then there is a increase in energy input into the machining process.
- When the frequency of vibration is high more number of abrasive particles hits the material surface.
- Static load affects the size of hook impulses coming from the abrasive grains to the work surface.
- This in turn affects the condition of abrasive grains and concentration of abrasive slurry near the tool face.
- The parameters of abrasive slurry that affects the material removal rate are
  - Type, size and shape of grains
  - Slurry concentration
  - Method of feeding slurry medium
  - Slurry temperature

- The type and shape of grains are chosen based on the type of operation and hardness requirement.
- Grit or grain size has a strong influence on MRR. MRR is proportional to the fourth power of grain size '*d*'.
- If the slurry concentration is higher, then higher is the MRR.
- The liquid that is used as carrying medium for the abrasive should have good wetting properties with respect to work material, the tool and the abrasives.
- The liquid should have high density, high thermal conductivity, high specific heat and low viscosity for good MRR.
- When the temperature of the slurry increases vapour pressure of the liquid in the slurry is varied. This increases the incidence of cavitation and thus MRR also increases.

Effect of Work Material Properties

- The machinability of the workpiece surface depend on its mechanical properties and fracture behavior.
- Harder materials are machined by brittle fracture whereas softer ductile material are cut by shearing action.

Effect of Tool Material Properties and Tool Geometry

- The property of the tool material affects the penetration of the abrasive grains into the workpiece and the tool.
- The hardness of the tool material affects the machinery rate.
- Coarer abrasives are used for rough machining
- Finer abrasives are used for fine machining
- The geometry cross sectional area and shape of the tool affects the material removal rate.

2. Effect of Process Parameters on Tool Wear

- Tool wear is another important factor that affects the MRR and hole accuracy in USMM.

- The factors that influences tool wear are
  - Static load
  - Work material
  - Tool size
  - Tool material
  - Type of abrasives and its grain size
  - Machining time
  - Depth of machining
- As a result of tool wear, tool length and weight decreases and it affects the resonance frequency of the machine and reduce the amplitude of vibrations and inturn reduces MRR.

Effect of Abrasive Slurry on Tool Wear

- Tool wear is higher on using harder abrasives like boron carbide and tool wear is less on using softer abrasives like silicon carbide.

Effect of Work Material on Tool Wear

- Tool wear is affect by the hardness and toughness of the workpiece material.

Effect of Tool Material on Tool Wear

- Tungsten carbides and stainless steel tools have less tool wear as compared to milded steel. This is due to high resistance property of tool material that SS tools produces less tool wear.
- This tool wear is controlled by tool hardening. Due to this the penetration of the abrasive grains into the tool is decreased and results in higher MRR.
- Also use of hard metals such as tungsten carbides reduces plastic deformation and the tool surfaces.

3. Effect of Process Parameter on Surface Finish

A good surface finish depends upon

- Abrasive grit size
- Properties of the work material
- Surface finish of the tool
- Amplitude of vibration
- The types of liquid carrier used for abrasive slurry

Effect of Machining Parameter on Surface Finish

- Better surface finish can be obtained when feed rates and depth of cut are low.

- But when the amplitude of tool vibration increase, the penetration of abrasive grains increases and surface finish get reduced.

Effect of Abrasive Slurry on Surface Finish

In USMM process. good surface finish is obtained under the following conditions

- By using fine grains
- Driven by smaller vibrations and amplitude.
- Smaller static force at smaller depth of cut and larger lateral feed.
- Larger grain size of 2 to 120 μm is used for roughing operation.
- Smaller grain size of 0.2 to 10 μm is used for finishing operations.

Effect of Workpiece Properties and Tool Geometry

- The surface roughness depends upon the material to be machined.
- If the material used is a brittle material like graphite and glass. It isobserved that 40 size abrasive grains produces a surface roughness of 1.5 to 2 μm.
- If the material is less brittle material like silicon carbide, boron carbide and sodium nitride the abrasive grains produces a surface roughness of about 0.4 μm.
- Also, the tool geometry has effect on the surface finish of workpiece.
- Any irregularities on the surface of the tool are reproduced on the machined surfaces.
- From this it is clear that the working face of the tool has important effect on the machined surface.

4. Effect of Process Parameter on Accuracy

- The factors affecting accuracy in USMM are
  - accuracy of feed motion
  - accuracy of fixtures used
  - quality of assembly element
  - abrasive grit size
  - tool wear
  - transverse vibration effect
  - depth of cut
- The accuracy of holes produced in USMM must take into account both dimensional accuracy and out of roundness and coincity.
- When static load is increased, it reduces abrasive size and suppress lateral vibration of the tool which in turn improves the surface roughness.
- Coincity is reduced at higher static loads and prolonged operating times also

tool wear is less with fine abrasives.

- ❖ Out of roundness is due to lateral vibration and in accuracy in the feed motion at entry. It can be reduced with increase in static pressure and machining time.
- ❖ Use of WEDG for tool fabrication also produced high accuracy.

5.6.4. ADVANTAGES OF USMM

- ❖ Machining of any materials regardless of their conductivity
- ❖ Machining of semiconductor as silicon germanium
- ❖ Suitable for machining precise brittle materials
- ❖ Can drill circular or non circular holes in hard materials
- ❖ Less stress is produced because of its non thermal characteristics

5.6.5. DISADVANTAGES OF USMM

- ❖ Low material removal rate
- ❖ Tool wear is faster in USMM
- ❖ Machining area and depth is restrained in USMM.

5.6.6. APPLICATIONS OF USMM

- ❖ Used for making press tool dies
- ❖ Drilling small holes in helicopter power transmission shaft
- ❖ Drilling of diamond dies, machining of aluminium oxides Al_2O_3
- ❖ Producing hollow cubes
- ❖ Used in surgical tools manufacturer for better evaculation of chips
- ❖ Plague from the teeth are removed without any damage.

5.7. THERMAL ADVANCED MICRO MACHINING PROCESSES

In thermal advanced micromachining intense heat is produced and localized which increases the workpiece temperature in a zone or beam diameter equal to its melting and vapourization temperature.

The types of thermal advanced micromachining process are

(i) Electric discharge micromachining

(ii) Electron beam micromachining

(iii) Laser beam micromachining

The material removal is at micro-nano level in form of debris.

Electric Discharge Micro Machining

5.7.1. PRINCIPLE

Electric discharge micromachining (EDMM) works in the same principle of electric discharge machining (EDM).

EDM removes material by thermal erosive action of electrical discharge (spark) produced by a pulse DC power supply between anode and cathode. The tool acts as

the cathode and the workpiece acts as the cathode and the workpiece acts as the anode.

- ❖ The high electric field gradient is produced across the electrodes, a plasma channel is formed and a discharge takes place through the dielectric. A part of molten material is removed.
- ❖ The servo system with highest sensitivity and positional accuracy of ± 0.5 μm. It permits a minimum distance gap with 1 μm.

5.7.2. CONSTRUCTION AND WORKING OF EDMM

- ❖ The schematic arrangement of micro EDM or EDMM is as shown in figure 5.20.
- ❖ The main components of EDMM process are the electrode, workpiece and the dielectric fluid.
- ❖ The modification and development of electric discharge micromachining from conventional EDM process is as follows
- ❖ Accurate control over the inter-electrode gap mainly requires high positioning accuracy
- ❖ Accurate control over the discharge energy
- ❖ Compensation of electrode wear
- ❖ Effective removal of debris from small inter electrode gap.
- ❖ Reduction in the overall size of the machine to conserve space and operating resources.
- ❖ It is a single spark process and it is necessary to avoid short circuiting during entire pulse duration.
- ❖ Suitable gap is maintained between two electrodes at high frequency response.
- ❖ The machine has 2 drives, the stepper motor is used for coaser and piezoelectric activation is used for finer works.
- ❖ The stepper motor drive is low response drive and is used for moving workpiece that is fixed on the fixture.
- ❖ The piezoelectric is high response drive used to move the electrode which is fixed in the spindle. The gap distance changes with the electrode wear and machining depth.
- ❖ By changing the electric current through the electromagnets, it is possible to control the position of the electrodes.

- ❖ Eight radial electromagnets are used in the sets of four each to achieve radial direction motion. Thus electrode motion in all X., Y, and Z directioncan be achieved. This module has response frequency of 200 Hz developed for EDM micro dies.
- ❖ Properties of electrode used in EDMM
  - High electrical conductivity
  - High thermal conductivity
  - High melting point
  - Cheap and easy manufacturability
- ❖ The types of electrodes and their materials

S.No	Electrode	Materials
1.	Metallic electrode	Cu, CuW, Br, Al, Alalloy W
2.	Non metallic electrode	Graphite
3.	Combined	Copper graphite
4.	Metallic coating on insulator	Copper on molded plaster and copper on ceramics
5.	Powder material	Powder-sintered or green compact

- ❖ The power supply used in EDMM's
  - Basic RC discharge circuit
  - Transistor control circuit
- ❖ The types of workpiece material used in EDMM are
  - Alumina
  - Cobalt
  - Tantalumj
  - Titanium
  - PCD/CBN
  - Tungsten
  - Vanadium
  - Inconel Hastelloy
  - Wasp alloy
  - Carbide
  - All grades of stainless steel and tool steel
- ❖ The types of dielectric fluids and its properties

S.No	Dielectric Fluid	Viscosity	Application

1.	Mineral oil	5-20 CST	applied for roughing process
2.	White oil or kerosene		For furnishing and super finishing operation and for machining tungsten carbide
3.	Water (deionized)	Nearly zero	Used for micromachining wire draw process
4.	Napaffic oil	specific gravity = 0.8 flash point = 105°C light: odour	High finishing accuracy and surface finish

Working of EDMM

- When the power is supplied the anode and the cathode, the material erosion takes place in EDMM.
- The number of sparks that is formed in each discharge dependent upon the distribution of micropeaks on the surface of both the electrodes as shown in figure 5.21.

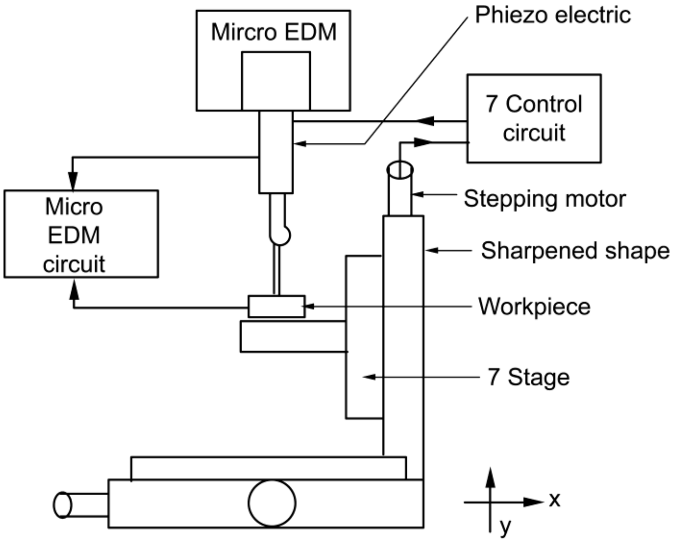


Fig. 5.20. Schematic arrangement of electric discharge micromachining

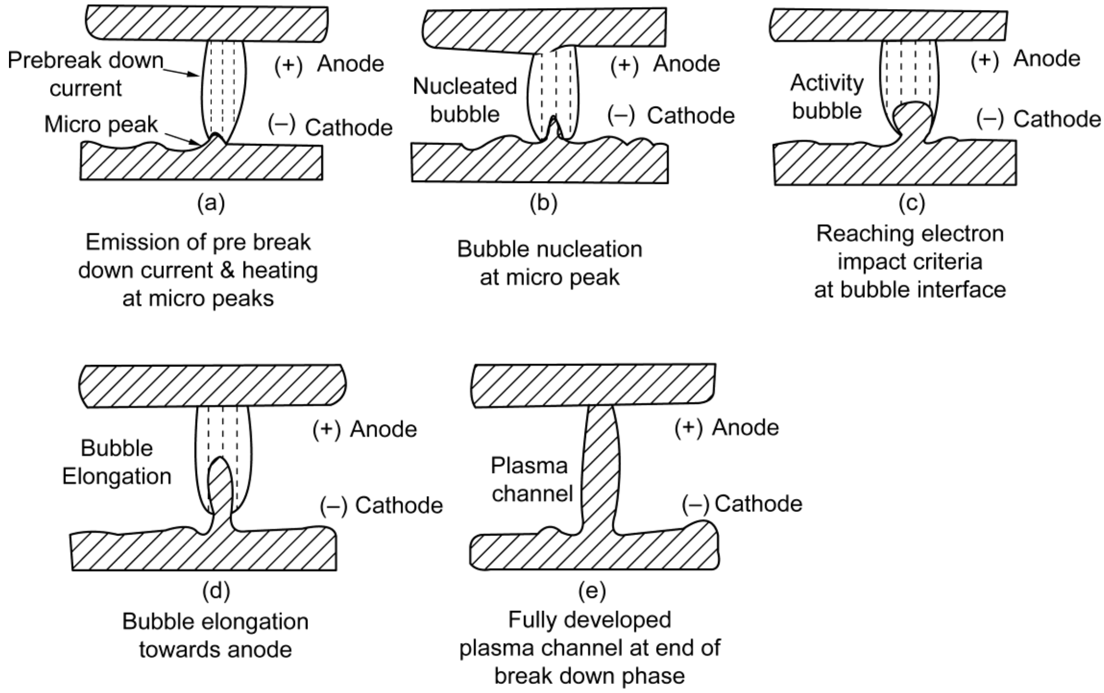


Fig. 5.21. Single Spark erosion in electric discharge micro machining

- There are three stages involved in formation of each spark. They are
  - Ignition stage
  - Heating stage
  - Removal stage

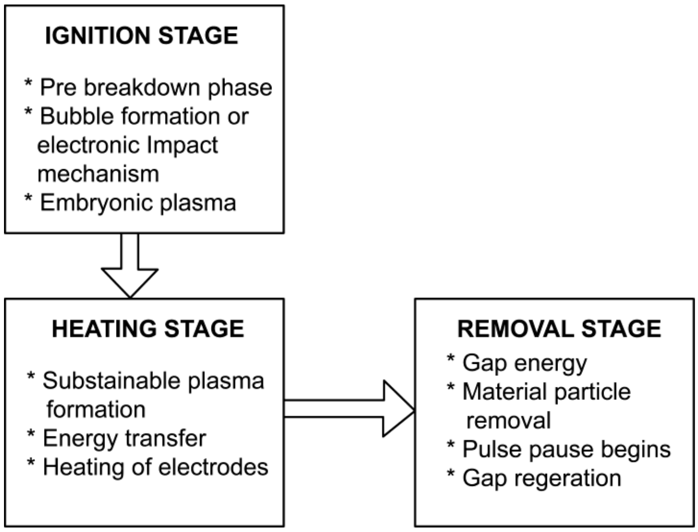


Fig. 5.22.

(i) Ignition Stage

- Prebreakdown phase – The initial stage of the ignition stage is prebreakdown phase.

During this phase two phenomena occurs that breakdown of dielectric between electrodes take place.

(i) Bubble formation

(ii) Electronic impact mechanism

The bubble formation or nucleation takes place by the usual bubble formation mechanism. The inter electrode gap in EDMM are in order of 1 μm and pulse on time is in order of few μs, the breakdown period is in the order of sub-micro seconds.

Further the growth of bubble takes place by electron impact mechanism. The bubble formed at the micropeaks expands when active growth criterion is reached. The temperature of the embroyonic plasma increases and the energy balance equation is given by

$$\rho_{av} = \int_{T_n}^{T_p} C_p(T)\, dT = E_j\, \tau_{growth}$$

Heating Stage

- In heating stage, an embroyonic plasma formed at the end of ignition stage is transformed into a variable mass using the available circuit energy.
- In plasma growth the vapour bubble expands due to pressure difference between plasma bubble and dielectric.
- The mass flow of liquid takes place because of vaporization at the boundary of the bubbles and dielectric.
- The power utilization is given by
  - Work done during expansion of plasma channel
  - Power flux utilized for vaporization and dissociation of dielectric media.
  - Power flux dissipating towards anode and cathode.
- The power fraction utilized by the plasma

$$P_{circuit} = V(t) \times I(t)$$

There is drastic change in thermo physical properties of water vapour at high temperature.

This is caused because of its dissociation to smaller molecules and ionization into charged particles.

The particles play an important role in heat transfer to anode and cathode and such properties used to be evaluated.

Removal Stage

In the removal stage, the heat generated during plasma formation and expansion is transferred to anode and cathode by two ways.

- By radiation heat transfer
- Ion or electron bombardment

The power transfer due to particle bombardment and radiation flux is given by

$$\Delta P_{cathode} = \Delta P_{ions} + \Delta P_{electron} + \Delta P_{radiation}$$

5.7.3. PROCESS PARAMETERS OF EDMM

1. Mechanism of material removal by melting and evaporisation.

2. Material removal rate is between 0.6 to 6 mm^3 /hr
3. Dimensional accuracy is 2 μm (sinking EDM) and 1 μm (wire EDM).
4. Surface finish is 0.4 to 0.5 μm

❖ Power consumption is negligible

❖ The tool material used in EDMM is tungsten electrode upto 20 μm

❖ The gap is maintained at much smaller size.

5.7.4. EFFECT OF PROCESS PARAMETERS ON EDMM

The process parameters that affect the EDMM process are

❖ Dielectric

❖ Tool

❖ Workpiece

1. Effect of Dielectric Fluid on Metal Removal Rate

❖ Water is used as dielectric which provides good discharge repetition rate.

❖ Use of water cause electrochemical reaction between the tool and workpiece which leads to rounding of edges and enlargement of the hole diameter.

❖ Use of water also lowers resistivity value. This problem is sorted out by increasing the resistivity of water to 10^7 Ω cm.

❖ Also addition of oxygen in dielectric works more efficiently at lowerdischarge energies.

❖ It increases the rate of heat generations to about 5.6% which in helpful for melting workpiece and increase material removal rate.

❖ Effect of powder suspension in the dielectric on the thermal influenced zone. Silicon powder is used in dielectric which is able to store four times more energy than usual. This heat energy is stored in silicon during the discharge is given back and it slows down rapid cooling process of molten metal.

2. Effect of Tool and Work Related Parameters

Electrode wear occurs during spark erosion operation in EDMM. As material removal volume is low in EDMM, electrode wear have imported effect on obtaining high finish and high accuracy in the process.

The resistance of tool electrode in EDMM is given by electrode wear resistance index

$$= \rho_c \lambda T_{me} T_{bc}$$

where, ρ - density of tool material

c - specific heat of the tool material

λ - thermal conductivity of the tool

T_{mc} and T_{bc} - melting and boiling point

of tool material The electrode wear resistance index with boiling point gives better correlation. his

given the highest temperature to which the cathode can be heated and ability of electron emission.

Electrode wear can be reduced by using diamond electrode.

5.7.5. ADVANTAGES OF EDMM

- It is used for cutting complex or odd shape materials that are electricallyconductive.
- It is used in machining hardened materials
- It has high machining rate
- It has good dimensional accuracy and surface integrity.

5.7.6. DISADVANTAGE OF EDMM

- It is not suitable for high aspect ratio holes and features.

5.7.7. APPLICATIONS OF EDMM

- Used in drilling 6.5 μ holes in 50 μm plate
- Used in making 1.2 μ slots in 2.5 μm wall.
- Used in shaping microfluids mixer and channel